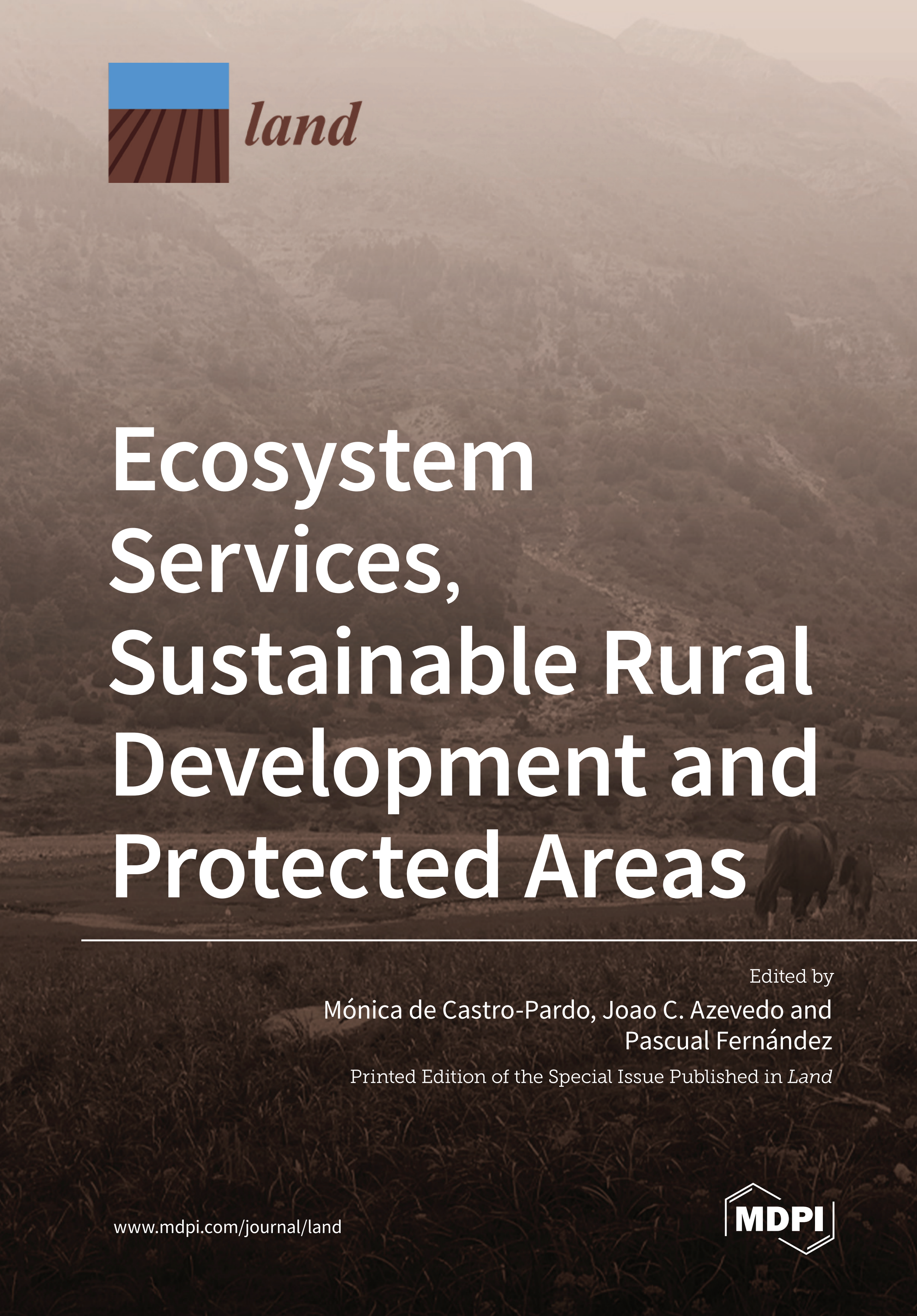


land

Ecosystem Services, Sustainable Rural Development and Protected Areas

Edited by
Mónica de Castro-Pardo, Joao C. Azevedo and Pascual Fernández

Printed Edition of the Special Issue Published in *Land*

www.mdpi.com/journal/land

MDPI

Ecosystem Services, Sustainable Rural Development and Protected Areas

Ecosystem Services, Sustainable Rural Development and Protected Areas

Editors

Mónica de Castro-Pardo
Joao C. Azevedo
Pascual Fernández

MDPI • Basel • Beijing • Wuhan • Barcelona • Belgrade • Manchester • Tokyo • Cluj • Tianjin

MDPI

Editors
Mónica de Castro-Pardo
Complutense University of Madrid
Spain

Joao C. Azevedo
Escola Superior Agrária, Instituto Politécnico de Bragança
Portugal

Pascual Martínez
University Rey Juan Carlos-Spain
Spain

Editorial Office
MDPI
St. Alban-Anlage 66
4052 Basel, Switzerland

This is a reprint of articles from the Special Issue published online in the open access journal *Land* (ISSN 2073-445X) (available at: https://www.mdpi.com/journal/land/special_issues/protected_area).

For citation purposes, cite each article independently as indicated on the article page online and as indicated below:

LastName, A.A.; LastName, B.B.; LastName, C.C. Article Title. *Journal Name* **Year**, *Volume Number*, Page Range.

ISBN 978-3-0365-2293-7 (Hbk)
ISBN 978-3-0365-2294-4 (PDF)

Cover image courtesy of Mónica de Castro-Pardo.

Contents

About the Editors

Mónica de Castro-Pardo is a Professor at the Complutense University of Madrid. She holds a PhD degree from the University of Alicante (Spain) with a thesis on governance in protected areas. Her current research is focused on multi-criteria modeling applied to natural resource management, human–nature conflict management and sustainable rural development. She has been part of the research team of the National Parks Chair and currently she is a member of the team of the UNESCO Water and Peace Chair (UNED-URJC). She actively collaborates with the Mountain Research Center (CIMO) of the Polytechnic Institute of Bragança, Portugal, on projects related to sustainable rural development and wildlife conservation.

Joao C. Azevedo is a Professor at the Polytechnic Institute of Bragança and researcher at the Mountain Research Centre, in Portugal, and member of the research team of the UNESCO Water and Peace Chair (UNED-URJC), in Spain. He is Chair of the IUFRO Landscape Ecology unit and former chair of the Portuguese Landscape Ecology Association (IALE-Portugal). His research interests include forest landscape ecology, sustainability in forested landscapes, ecosystem services in changing landscapes, sustainable forest bioenergy production systems and mountain sustainability. João holds a BS degree in Forest Engineering from UTAD, Portugal, and MSc and PhD degrees in Forestry from Texas A&M University, USA.

Pascual Fernández is a Professor of Economics at the Universidad Rey Juan Carlos (Spain) and Co-Chairholder of the UNESCO Chair for Water and Peace (UNED-URJC). He is former Vice-Chairman of the Spanish Economists Association, former Chairman of the Madrid Economists Association, former director at the Center of Studies "Economy of Madrid" (Universidad Rey Juan Carlos). He was also a European Parliament Adviser (Committee on Regional Development and Temporary Committee on Policy Challenges and Budgetary Means of the Enlarged Union). He has specializations in Econometrics, Environmental Economics, International Economics and Regional Economics.

land

Editorial

Ecosystem Services, Sustainable Rural Development and Protected Areas

Mónica de Castro-Pardo [1,*], João C. Azevedo [2] and Pascual Fernández [3]

[1] Department of Financial Economics and Actuarial and Statistics-Statistics and Operational Research, Campus of Somosaguas, Complutense University of Madrid, Pozuelo de Alarcón, 28223 Madrid, Spain
[2] Centro de Investigação de Montanha, Campus de Santa Apolónia, Instituto Politécnico de Bragança, 5300-253 Bragança, Portugal; jazevedo@ipb.pt
[3] Department of Applied Economics I and History and Economic Institutions, UNESCO UNED-URJC Chair in Water and Peace, URJC, Faculty of Law and Social Sciences, Campus of Vicálvaro, Universidad Rey Juan Carlos, Tulipan, Móstoles, 28933 Madrid, Spain; pascual.fernandez@urjc.es
* Correspondence: monica.decastro@ucm.es

check for updates

Citation: de Castro-Pardo, M.; Azevedo, J.C.; Fernández, P. Ecosystem Services, Sustainable Rural Development and Protected Areas. *Land* **2021**, *10*, 1008. https://doi.org/10.3390/land10101008

Received: 17 September 2021
Accepted: 23 September 2021
Published: 26 September 2021

Enhancing social and economic development while preserving nature is one of the most significant challenges for humankind in the current century. The Millennium Ecosystem Assessment showed an alarming degradation of ecosystems across the world due to unprecedented changes in land use and ecosystem management driven by human societies in the 20th century [1]. At the same time, poverty and extreme poverty persist in many regions of the world, especially in rural areas, despite programs focused on ecosystems or development and reduction of poverty [2]. Problems related to both ecosystem condition and poverty may be aggravated in the near future if ecosystem destruction and degradation are not reverted. The 2019 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) report [3] highlights the deterioration of ecosystems and the reduction in the supply of ecosystem services worldwide due to increasing pressures and drivers of change in the last 50 years, which have rendered conservation (Aichi Biodiversity Targets) and sustainability (2030 UN Sustainable Development Goals) objectives impossible to achieve unless transformative changes take place in society at both local and global scales.

All the initiatives above and their intrinsic sustainable development models rely on the role of nature as a supporter of ecological functions and provider of ecosystem services. As evidence that drivers of change such as climate and demographics are leading to a worrying increase in environmental risks and decrease in the capability of ecosystems to contribute to well-being, communities across the world are looking for balanced and integrated solutions for growing challenges.

Sustainable rural development is the key to maintaining active local communities in rural and semi-natural areas, avoiding depopulation and preserving sites of high ecological value, including protected areas, and the ecosystem functions and services upon which society relies and that contribute to poverty alleviation both locally and globally.

The establishment of Protected Areas is the oldest and the most commonly applied strategy in biodiversity conservation around the world. Protected areas are core components of conservation infrastructures at national and international levels and contribute strongly to the maintenance of genetic, species and ecosystem diversity as well as the supply of a diverse range of fundamental ecosystem services. The interaction of human communities with protected areas, usually located in rural areas, is complex and often conflictive, although this changes with the categorization as protected areas and the level and economic value of available natural resources. Depending on how they affect access to natural resources and economic opportunities, protected areas can either attract or repel human activities, leading to different development paths. The convergence of development and conservation measures requires, therefore, robust and participative decision-making processes that are capable of aligning the needs and expectations of rural communities and the goals of biodiversity conservation. However, the complexity and multi-functionality of rural socioecological systems make decision-making difficult in these areas. It is, therefore, crucial to develop innovative strategies, approaches, methods and models to improve the livelihoods of rural communities and achieve the objectives of nature conservation and sustainable development.

The purpose of this Special Issue was to gather contributions of the scientific community regarding the challenges related to rural development and protected areas, using the concept and application of ecosystem services to support conservation-based development models. It was also a goal of the Special Issue to find directions and guidelines for sustainable rural development, in particular in the context of conservation in natural areas.

This Special Issue includes nine research papers and two review papers. The papers published cover a very wide and diverse geographic area, including studies conducted in national parks in China, in Iceland, a regional park in Spain, a watershed in Costa Rica, the Piedmont Region in Italy, the Taihu Lake in China, the Inner Mongolia region and the Jixi County in China, and the Kapuas Hulu regency in Indonesia. Authors contributing to the Special Issue also come from a wide range of regions and countries, including Chile, China, Costa Rica, Germany, Iceland, Indonesia, Israel, Italy, Portugal, Republic of Korea, Spain, Switzerland and the Netherlands.

The topics covered are very diverse but each brings important contributions to this Special Issue. The concept of ecosystem services and its application have been addressed in the context of land management in national parks and restoration projects [4,5]. He and colleagues [4] analyzed perceptions of ecosystem services and social well-being by residents in the Wuyishan National Park, China, and how these change among groups with different livelihood strategies. Pérez-Rubio et al. [5] developed a micro-scale Payment of Ecosystem Services scheme in southern Costa Rica using primary data generated through spatial modeling and socio-economic and stated preference surveys in the framework of forest ecosystem restoration.

Governance has been addressed in protected areas to test models for expansion of protected areas and in pollinators' conservation policy to support sustainable development [6,7]. In [6], Petursson and Kristofersson analyzed the co-management governance system in the Vatnajökull National Park (VNP), Iceland, providing valuable indications of improvements in a time when there are plans for protected areas to expand in the country. Novelli and co-authors [7] presented and tested a mixed-method tool for use with SWOT analysis to design effective and participative rural development actions in the beekeeping sector in the Piedmont Region, Italy, in the framework of pollinator conservation policy.

The paper by Ibarra-Marinas et al. [8], analyzed an environmental restoration and conservation project in progress in the Regional Park of Las Salinas and Arenales of San Pedro del Pinatar, southeastern Spain, and looked for Natura 2000 network sites for replicating major actions of the project.

Rural areas received attention in this Special Issue from multiple perspectives and in different regions in the world, but one set of papers in particular dealt with sustainability in traditional rural villages and towns, interactions between visitors and rural areas, and economic and ecological effects of agroforestry [9–12]. Kong and colleagues [9] constructed a comprehensive evaluation system for the living protection of traditional villages based on the land-use-integration concept "Production–Living–Ecology", applying it to six traditional villages in Taihu Lake, China. Han and co-authors [10] developed a theoretical framework to explore how cultural contact, natural environment and risk perception affected traveler destination involvement and approach behaviors in the rural tourism sector in Inner Mongolia, China. Additionally, Ren [11] built an indicator system and measurement model for the assessment of rural functions applied to 11 towns in Jixi County, China, to analyze the differentiation characteristics and rules of rural functions (agriculture and nonagricultural production, life and leisure, and ecological functions). Nöldeke and colleagues [12] analyzed the impacts of adopting agroforestry by small farmers on their livelihoods and the environment in rural Indonesia (Kapuas Hulu regency), which was revealed to be positive, particularly in the context of climate change.

The review papers covered two separate topics. De Castro et al. [13] reviewed the application of Multiple-Criteria Decision-Making (MCDM) approaches to the social, economic and ecological planning and management of water ecosystem services over the 2000–2020 period. Stavi and Yizhaq [14] reviewed the hydrological and geomorphic impacts of mountain biking, highlighting the importance of applying geomorphic principles in the design of singletracks.

The need to align the objectives of local human communities with nature conservation policy and practice is increasingly urgent and vital for the sustainable supply of ecosystem services. The articles compiled in this Special Issue make important contributions to this challenge from different approaches, disciplines and regions in the world, although we expect this topic to remain a research priority for years to come.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Editors acknowledge the contribution of all authors of the publications in this Special Issue as well as all editors and staff at the journal *Land* for their collaboration.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being: Current State and Trends*; Findings of the Condition and Trends Working Group, Hassan, R., Scholes, R., Ash, N., Eds.; Island Press: Washington, DC, USA, 2005; 948p.
2. Duraiappah, K.A.; Comim, F.; Oliveira, T.; Gupta, J.; Kumar, P.; Pyoos, M.; Spierenburg, M.; Barkin, D.; Brondizio, E.; Tsutsumi, R. Consequences of Responses on Human Well-being and Poverty Reduction. In *Millennium Ecosystem Assessment, Ecosystems and Human Well-being: Policy Responses*; Findings of the Responses Working Group, Chopra, K., Leemans, R., Kumar, P., Simons, H., Eds.; Island Press: Washington, DC, USA, 2005; pp. 487–526.
3. IPBES. *Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*; Brondizio, E.S., Settele, J., Díaz, S., Ngo, H.T., Eds.; IPBES Secretariat: Bonn, Germany, 2019; 1148p. [CrossRef]
4. He, S.; Gallagher, L.; Min, Q. Examining Linkages among Livelihood Strategies, Ecosystem Services, and Social Well-Being to Improve National Park Management. *Land* **2021**, *10*, 823. [CrossRef]
5. Pérez-Rubio, I.; Flores, D.; Vargas, C.; Jiménez, F.; Etxano, I. To What Extent Are Cattle Ranching Landholders Willing to Restore Ecosystem Services? Constructing a Micro-Scale PES Scheme in Southern Costa Rica. *Land* **2021**, *10*, 709. [CrossRef]
6. Petursson, J.G.; Kristofersson, D.M. Co-Management of Protected Areas: A Governance System Analysis of Vatnajökull National Park, Iceland. *Land* **2021**, *10*, 681. [CrossRef]
7. Novelli, S.; Vercelli, M.; Ferracini, C. An Easy Mixed-Method Analysis Tool to Support Rural Development Strategy Decision-Making for Beekeeping. *Land* **2021**, *10*, 675. [CrossRef]
8. Ibarra-Marinas, D.; Belmonte-Serrato, F.; García-Marín, R.; Ballesteros-Pelegrín, G. Analysis of Replicability of Conservation Actions across Mediterranean Europe. *Land* **2021**, *10*, 598. [CrossRef]
9. Kong, L.; Xu, X.; Wang, W.; Wu, J.; Zhang, M. Comprehensive Evaluation and Quantitative Research on the Living Protection of Traditional Villages from the Perspective of "Production–Living–Ecology". *Land* **2021**, *10*, 570. [CrossRef]
10. Han, H.; Chen, C.; Ariza-Montes, A.; Hernández-Perlines, F.; Araya-Castillo, L.; Yu, J. Impact of Sustainable Cultural Contact, Natural Atmospherics, and Risk Perception on Rural Destination Involvement and Traveler Behavior in Inner Mongolia. *Land* **2021**, *10*, 568. [CrossRef]
11. Ren, K. Following Rural Functions to Classify Rural Sites: An Application in Jixi, Anhui Province, China. *Land* **2021**, *10*, 418. [CrossRef]
12. Nöldeke, B.; Winter, E.; Laumonier, Y.; Simamora, T. Simulating Agroforestry Adoption in Rural Indonesia: The Potential of Trees on Farms for Livelihoods and Environment. *Land* **2021**, *10*, 385. [CrossRef]
13. de Castro-Pardo, M.; Fernández Martínez, P.; Pérez Zabaleta, A.; Azevedo, J.C. Dealing with Water Conflicts: A Comprehensive Review of MCDM Approaches to Manage Freshwater Ecosystem Services. *Land* **2021**, *10*, 469. [CrossRef]
14. Stavi, I.; Yizhaq, H. Applying Geomorphic Principles in the Design of Mountain Biking Singletracks: Conceptual Analysis and Mathematical Modeling. *Land* **2020**, *9*, 442. [CrossRef]

land

MDPI

Review

Applying Geomorphic Principles in the Design of Mountain Biking Singletracks: Conceptual Analysis and Mathematical Modeling

Ilan Stavi [1,2,*] **and Hezi Yizhaq** [3]

[1] Dead Sea and Arava Science Center, Yotvata 88820, Israel
[2] Eilat Campus, Ben-Gurion University of the Negev, Eilat 88100, Israel
[3] Department of Solar Energy and Environmental Physics, Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Sede Boqer Campus 84990, Israel; yiyeh@bgu.ac.il
* Correspondence: istavi@adssc.org

Received: 21 October 2020; Accepted: 10 November 2020; Published: 11 November 2020

Abstract: Mountain biking, also known as singletracking, is an emerging sector in outdoor recreation activities. Experience shows that although bicycling is considered a low-impact activity, singletracking may have adverse environmental footprints. Here, we review and conceptually analyze the forces applied on singletracks, and implement mathematical modeling of these forces, for a range of climatic conditions and geographic settings. Specifically, we focus on the hydrological and geomorphic impacts of singletracking, and highlight the importance of applying geomorphic principles in their design. Also, we demonstrate specific measures for establishing singletracks on hillslopes and in ephemeral stream channels. We discuss how climate, topography, surface roughness, hydrological connectivity, and pedology determine the processes of water runoff and soil erosion on singletrack trails. Further, we demonstrate how riders' behavior determines the rate of shearing, wearing, compaction, deformation, and rutting of the singletrack, as well as the expansion of physical damages to the track's surroundings. These conditions and effects determine the durability of singletracks, with implications for maintenance requirements over time. The specific implications of the emerging sector of electric mountain bikes on singletrack durability are discussed. Insights of this paper will benefit landscape designers and land managers aiming to foster ecotourism and sustainable recreation opportunities.

Keywords: biking velocity and acceleration; e-mountain bikes; environmental planning and sustainability; erodibility; geo-ecosystem functioning; intrrill; rill; and gully erosion; outdoor recreation; shear stress; water overland flow

1. Introduction

Outdoor recreation, characterized as nature-based tourism, provides essential benefits to individuals, communities, and society, and therefore contributes to sustainability [1]. The popularity of outdoor recreation and sports has increased tremendously since the mid-20th century [2,3], encompassing a growing branch in national economies. These activities include a wide range of sectors, such as hiking, climbing, horse-riding, camping, RVing, etc. [2]. These and other types of outdoor recreational activities are known as effective means of increasing nature conservation perceptions and attitudes among their participants [1]. Further, outdoor recreation is included within the framework of cultural ecosystem services, which encompass physical, intellectual, and spiritual interactions with nature. Specifically, since cultural ecosystem services are defined as non-material benefits that are obtained by people from ecosystems–including spiritual enrichment, cognitive development, reflection, and aesthetic experience–they clearly encompass ecotourism and outdoor recreation [4]. At the same time, the growing volume of outdoor recreation activities has increased the pressures imposed on open lands and natural ecosystems, highlighting the need to balance the tradeoff between recreation requirements and nature conservation [3].

Mountain biking, cross-country biking, or singletracking, started evolving in the 1970s and has become increasingly popular since the early 21st century [5], encompassing an emerging sector in outdoor recreational and ecotourism activities [6–8]. This activity is implemented on trails that feature a wide variety of terrains, as well as routes that consist of uphill, downhill, and flat sections. Often it utilizes trails that were originally developed for other intended uses, such as hiking [5]. An abundant bibliography has been published on the impacts of mountain biking on the biophysical environment. For example, mountain biking was reported to impact vegetation [9,10] by dispersing seeds and modifying plant distribution [11,12]. In Ontario, Canada, mountain biking was reported to expose soil and decrease vegetation species richness along singletracks [10]. Specifically, singletracking may cause the replacement of sensitive vegetation species with tolerant ones, and in particular, may increase the risk of invasion by exotic plant species [13]. In terms of impacts on the ground surface, biking increases soil compaction and shearing [14,15]. A study in Montana, the United States, compared the impacts of mountain biking to these of hiking, horse riding, and motorcycling, and reported that sediment yield under hiking and horse riding is greater than that under mountain biking and motorcycling [16].

Protected natural areas, e.g., nature reserves and national parks, often encompass both conservation components and recreational activities. The built-in conflict between these two aspects could lead to managerial tensions, which dictate operational actions and visitor regulations [3,17]. Regarding mountain biking, a specific contradiction may exist between the experiential expectations of the average rider–who prefers challenging technical tracks [5,6]–and the durability of singletracks, necessitating land managers and track designers to simultaneously consider physical, conservational, recreational, and structural aspects [5,18,19]. The recent emergence of the sub-sector of electric mountain bikes (e-mountain bikes: [20,21]) has posed specific challenges in terms of singletrack durability over time.

Despite this rich bibliography, the effects of geophysical conditions, structural and engineering features, and rider characteristics on the durability of singletracks over time have been only scarcely studied. Specifically, the hydrologic and geomorphic implications of these conditions and characteristics have not gained enough attention. Therefore, the objectives of this paper were to review, conceptually analyze, and mathematically model these effects and implications, and to produce a practical tool that can be utilized by landscape designers and land managers in planning, establishing, and maintaining singletracks. Specifically, in Section 2, we discuss topics such as the soil erodibility factor, forces acting on a bicycle, as well as forces applied by a bicycle moving uphill and downhill, including shear stress and skidding, and their relevance to the stability of singletracks. In Section 3, we highlight certain procedures for singletrack construction, such as 'cementing', 'fortification', and 'paving', as well as some specific means for hotspot singletrack sections. Judicious use of this knowledge–under any climatic conditions and geographic region–could increase the durability of singletracks and decrease their maintenance costs over time.

2. Implementing Geomorphic Knowledge in Biking Singletracks

The susceptibility of singletracks to damage is strongly determined by the prevailing geophysical conditions, and particularly, by the characteristic precipitation regime, topography, and soil properties [6,9,22]. Overall, greater precipitations, steeper topography, and higher soil erodibility make singletracks more vulnerable to destruction. Among the soil properties, one of the most relevant is the texture (mechanical composition). Marion and Olive [23] reported that trail substrates classified as sandy are most susceptible to erosion, while loamy and silty soils are more durable. Soil susceptibility to erosion is determined by calculating the erodibility factor (*K factor*), according to Equation (1) [24]:

$$K\,factor = 2.8 \times 10^{-7} M^{1.14} (12 - a) + 4.3 \times 10^{-3} (b - 2) + 3.3 \times 10^{-3} (c - 3) \quad (1)$$

where: M is the particle size parameter (percent silt + percent very fine sand) × (100 − percent clay); a is the percent of soil organic matter; b is the soil-structure code (1 for very fine granular, 2 for fine granular, 3 for medium or coarse granular, and 4 for blocky, platy, or massive); and c is the profile-permeability class (1 for rapid, 2 for moderate to rapid, 3 for moderate, 4 for slow to moderate, 5 for slow, and 6 for very slow: [24]). The units of *K factor* are: (Mg·ha·h)/(ha·MJ·mm) [25]. For ranges of the *K factor*, according to M parameter of different soil textures, and giving characterizing values of a, b, and c, see Figure 1.

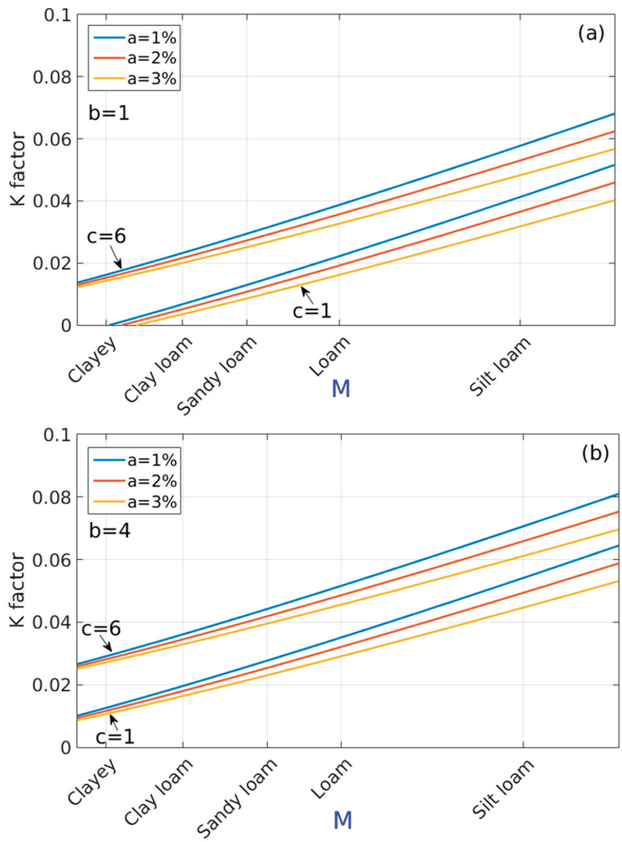


Figure 1. Modeling the erodibility factor (*K factor*) according to percent soil organic matter (a), soil-structure code (b), and profile-permeability class (c), and according to particle size parameter (M) representing soils with different textures. These combinations are demonstrated for b representing very fine granular (**a**) or blocky, platy, or massive (**b**) soil-structure code. The *K factor* units are (Mg·ha·h)/(ha·MJ·mm).

In active singletracks, shearing and wearing of the ground surface by bike tires loosen soil particles, increasing their erodibility by either water or wind. This is in accordance with Chiu and Kriwoken [14], who highlighted the potential damage to singletracks caused by the shearing stress of rotating bike tires. Yet, properly designed and well-constructed singletracks require minimal maintenance and are durable over time [23]. In this regard, knowledge on the forces imposed by bikers on the singletracks' surface is crucial when designing trails. The singletracks' incline is a major factor affecting the shear forces imposed by the moving bike. In uphill track sections, the rear wheel turns and creates the frictional force on the ground, which is directed backwards. According to Newton's third law of motion, the ground exerts an equal but opposite force on the bike, which is the force that actually propels the bike. Figure 2 illustrates the forces acting on a bicycle moving uphill on a straight track. The equation of motion along the slope (Newton's second law) of the moving bike can be described by Equation (2) [26,27]:

$$ma = F_p - (F_A + F_s + F_R) \quad (2)$$

where: m is the combined mass of the rider and bicycle (kg); a is the biking acceleration (m·s^{-2}); F_p is the force pushing the bike (N); F_A is the drag force of air (N); F_s is the opposing force caused by the weight component that is parallel to the slope (N); and F_R is the frictional rolling force caused by the deformation of the tire and the ground (N).

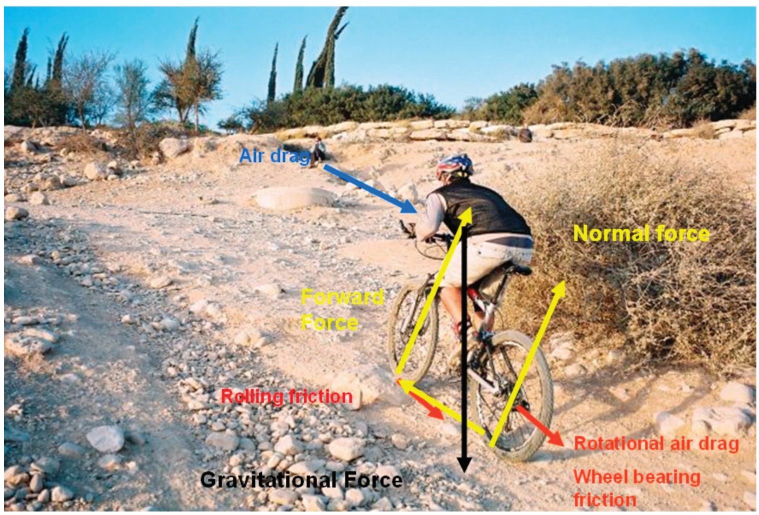


Figure 2. The forces acting on a bicycle ascending a straight track. Note: There are two main frictional forces: the first is the rolling friction that dominates at low speeds, while the air drag dominates at high speeds.

On a relatively smooth track, the most significant forces are F_A and F_R. The drag force, F_A, is caused by the bike's movement pushing air aside, forming a pocket of higher air pressure in front of the rider and a pocket of lower pressure behind the rider, as well as by the friction of the air moving along the front surface of bike and rider. This force is dependent on the biker's velocity squared. At a velocity of 15 km·h^{-1} (4.17 m·s^{-1}) and more, this force dominates [28]. F_A can be calculated by Equation (3):

$$F_A = K_d\,(v + v_w)^2 \quad (3)$$

where: K_d is a coefficient that is dependent on the cross-section of the rider and bike perpendicular to the direction of movement, the bicycle frame design, and the density of air; v is the biking velocity with respect to the ground (m·s^{-1}); and v_w is the wind speed (m·s^{-1}, with $v_w > 0$ for an opposing wind).

The coefficient K_d can be expressed by Equation (4) [29]:

$$K_d = 0.5 c_d A \rho \quad (4)$$

where: c_d is a dimensionless air drag coefficient, which is nearly constant for regular biking velocities, and as a first approximation does not depend on v. The drag coefficient is primarily the result of eddy currents that develop in the air behind the moving bike. For example, for sport bicycles, $c_d = 1$ when the rider sits upright, but drops to 0.9 when the rider bends over; A is the cross-section area of the bike and rider perpendicular to the direction of motion; and ρ is the air density.

The frictional rolling force, F_R, depends on the normal forces acting on the two wheels, and can be calculated by Equation (5):

$$F_R = c_r N \quad (5)$$

where: c_r is a coefficient of the rolling friction, which depends on the tire's air pressure, area, and cross section, the wheel diameter, and the roughness of ground surface. The rolling resistance to motion arises from deformation of both the tire and the ground surface on which it rolls, resulting in the loss of some energy to heat [30]; N is the combined normal force on the two wheels (N). It is important to note that the F_R does not depend on v, while F_A is dependent on the square of v. The mechanical power of a force F, acting on a body that moves in a constant velocity v, is F_v. Since the air resistance is proportional to v^2, the power (invested by the rider) that is required to overcome F_A increases as v^3.

Assuming that a biker rides uphill at constant velocity, then F_p equals F_{ground} that is applied to the ground by the rear wheel. F_{ground} can be calculated by using Equation (6):

$$F_{ground} = mg(sin\alpha + c_r cos\alpha) + K_d v^2 \quad (6)$$

where: m is the combined mass of rider and bike (kg); g is the gravitational force equivalent (9.8 $m \cdot s^{-2}$); α is the uphill track's incline (°); c_r is the coefficient of the rolling friction; K_d is a coefficient that is dependent on the cross-section of the rider and bike perpendicular to the direction of movement, the type of bicycle frame, and the density of the air; and v is the bicycle speed relative to the ground ($m \cdot s^{-1}$).

The shear stress applied by the bike's rear tire on the ground surface (τ_{ground}) can be calculated by Equation (7):

$$\tau_{ground} = F_{ground}/A_{patch} \quad (7)$$

where: F_{ground} is the force applied to the ground by the rear wheel (N); and A_{patch} is the rear tires' contact patch area (m^2).

A_{patch} depends on the tire's structure, the wheel diameter, the tire's inflation, and the load it carries [30]. Usually, the rear wheel carries about twice the load of the front wheel. Figure 3 shows typical values of shear stress applied to the ground by the rear wheel when biking uphill, as a function of incline, and for different masses (combined mass of the rider and bike). The model uses typical values of parameters to estimate the shear stress applied to the ground. Overall, it shows that at a constant uphill velocity, the shear stress applied to the trail increases with increasing incline and combined mass of rider and bike (Figure 3a). Furthermore, spinning tires on uphill sections may accelerate shearing or rutting of the ground surface [6]. We assessed the impact of biking velocity on the imposed shear force for velocities ranging between 0–10 $km \cdot h^{-1}$, and revealed insignificant differences, suggesting that biking velocity has no effect as long as it is constant. Due to physiological constraints, this situation is relevant for regular (non-electric) bikes, in which riding velocity is relatively constant or at deceleration along uphill track sections. At the same time, if the rider accelerates uphill, then F_{ground} increases tremendously, augmenting τ_{ground}. Such an effect is particularly relevant for riders of electric bikes, who can easily accelerate uphill, resulting in a considerable increase in τ_{ground} imposed on the singletrack surface (Figure 3b), potentially causing greater shearing and wearing damages. Indeed, the emerging e-mountain bikes sub-sector [20,21] imposes new challenges for singletrack durability over time, requiring special attention by singletrack planners and land managers.

When biking along downhill track sections, as long as riding velocity is constant, the only force acting on the ground is F_R, which is the rolling friction between the wheel and the ground, as given by Equation (5). Under these conditions, c_r is quite low (~0.01: [31]). Figure 4 shows the shear stress applied to the ground surface by the two wheels as a function of the downhill track's incline, and for riding at a constant velocity. Yet, upon skidding, the force applied to the ground is the kinetic friction between the wheels and the ground, as shown in Equation (8):

$$F_k = \mu_k N = \mu_k mgcos\alpha \quad (8)$$

where: F_k is the kinetic frictional force (N); μ_k is the kinetic friction coefficient; N is the combined normal force on the two wheels (N); m is the combined mass of rider and bike (kg); g is the gravitational acceleration (9.8 m·s^{-2}); and α is the downhill track's incline (°).

While skidding, since μ_k is much larger than c_r, the shear stress applied to the ground surface is much greater, as shown in Figure 5. This accords with other studies, which showed that fast downhill biking with frequent hard braking imposes excess torque on the wheels and causes the skidding ('wheeling impact'), resulting in soil shearing and track surface rutting, and ultimately increasing track destruction [5,9,14,15,22].

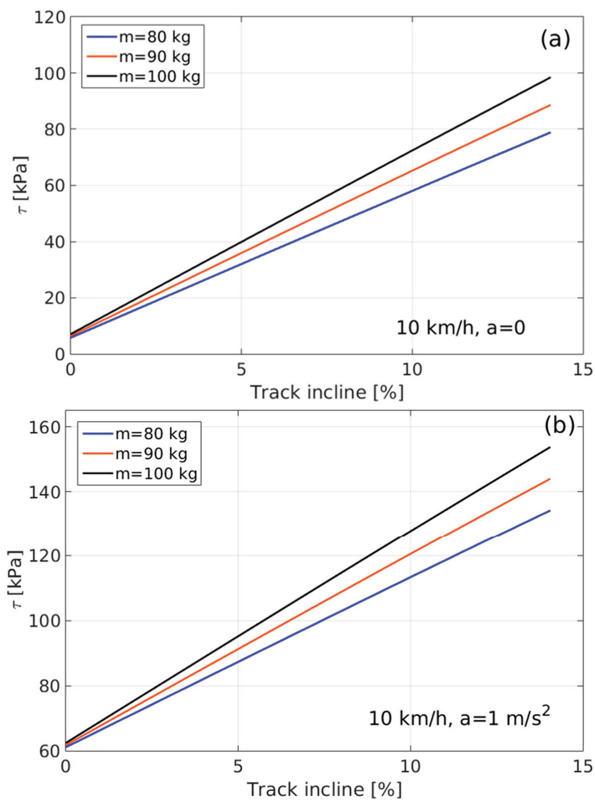


Figure 3. Modeling the shear stress imposed on the singletrack surface, according to longitudinal incline and combined mass of biker and bike, at a constant riding velocity of 10 km·h^{-1} (**a**), and at 10 km·h^{-1}, with an acceleration of 1 m·s^{-2} (**b**). Parameters values: c_d (air drag coefficient) = 0.7; c_r (coefficient of the rolling friction) = 0.01, A (the cross-section area of the bike and rider perpendicular to the direction of motion) = 0.7 m^2; ρ (tire inflation pressure) = 1.2 kg·m^3; A_{patch} = 1×10^{-4} m^2; and m is the combined mass of rider and bike (kg).

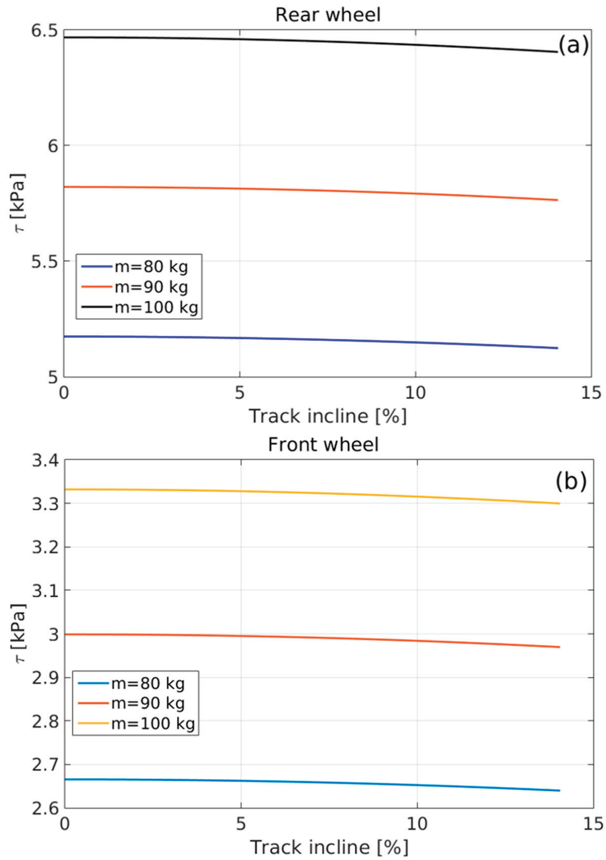


Figure 4. The shear stress applied on the ground surface by the rear (**a**) and front (**b**) wheels, as a function of the downhill track's incline and combined mass of biker and bike, at a constant riding velocity. Note: we assume that $c_r = 0.01$, and that two thirds of total weight of the bike and the rider are on the rear wheel.

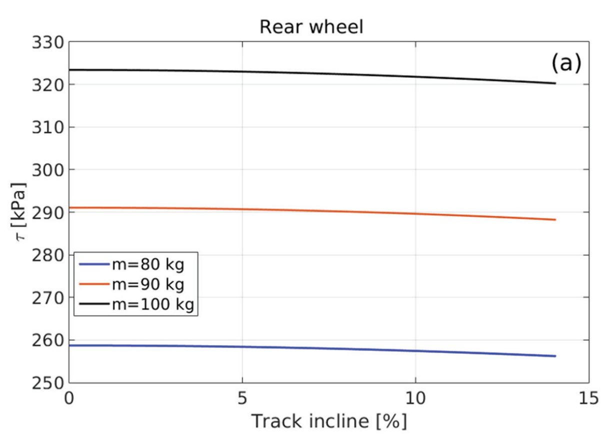


Figure 5. *Cont.*

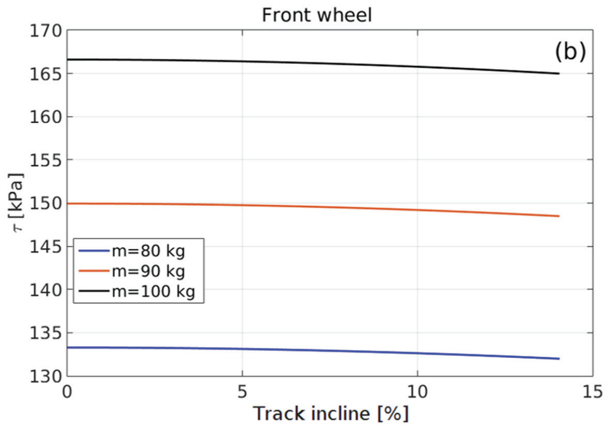


Figure 5. The shear stress applied on the ground surface by the rear (**a**) and front (**b**) wheels as a function of downhill track's incline and combined mass of biker and bike, when the bike skids. Note: we assume that μ_k = 0.5, and that two thirds of total weight are on the rear wheel.

3. Specific Measures for Singletrack Construction

Wherever highly durable track segments are necessary to prevent their shearing or wearing under the bike wheels, 'cementing' of the tracks' surface may be conducted by slightly moistening the target segments and compacting them using a manual ramming machine (Figure 6a). In highly susceptible hotspots, the tracks' surface may need additional fortification. This can be achieved by compacting a mixture of ~5–10 cm rock fragments, clay-rich soil (sustainably obtained from the nearby surroundings), and water, to form a ~10-cm thick durable layer on the track surface (Figure 6b). This consists with Marion and Olive [23], who stressed that trails can be hardened by adding gravel to their soil, resulting in increased singletrack durability over time.

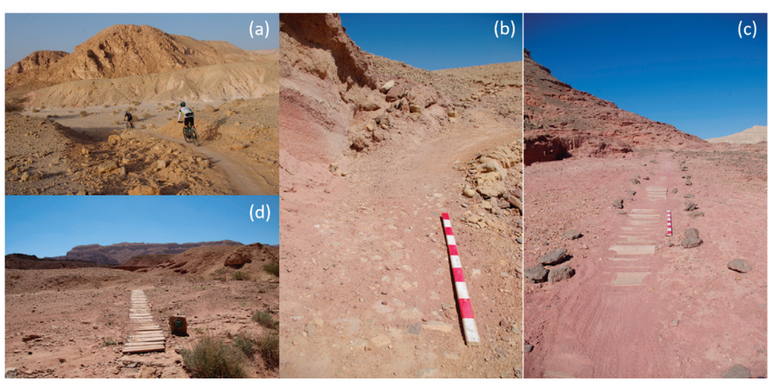


Figure 6. Pictures taken (by the manuscript's first author) in Timna Park, southern Israel, demonstrate: (**a**) a 'cemented' singletrack section. Track 'cementing' was implemented by slightly moistening the track surface and compacting it by a manual ramming machine; (**b**) a 'fortified' singletrack section. Track 'fortification' was implemented by mixing ~5–10 cm rock fragments, clay-rich soil, and water, and compacting the mixture on the track by a manual ramming machine; (**c**) the chain-woven woodblock trail section on a hillslope negates shearing and rutting of singletrack surface in high-instability hotspots; and (**d**) the chain-woven woodblock trail section in ephemeral stream channel facilitates biking and prevents tire trenching in channel beds.

Following rainstorms, when the soil is moist, the singletrack's surface is highly prone to compaction and deformation, exacerbating the risk of rutting by the bike tires [6,32]. This is because friction between soil particles decreases in moist conditions, making the soil more deformable [33]. This accords with previous studies, which highlighted the risk of soil structure disruption in muddy sections along singletracks [6,9]. Further, it is evident that muddy sections force bikers to bypass them and thus widen the trail. Over time, widening of such singletrack sections increases their environmental footprint, adversely affecting geo-ecosystem functioning and the sustainability of mountain biking [5,9,23]. Further, the excess soil compaction by the bike tires decreases water infiltrability, consequently increasing water overland flow [34] along the singletrack. A specific risk is imposed by the longitudinal ruts formed by tires, which may increase concentrated overland water flow along them, accelerating rill erosion [9] and possibly gully incision. At the same time, the compaction of track's ground surface increases soil strength, decreasing its susceptibility to shear by external forces, such as wind, runoff [13,35], and bike tires [22]. Over time, the combined effect of shearing (under dry conditions) and compaction (under moist conditions) of trails' ground surface, give the singletracks surface a concave cross-section, effectively turning them into connective water courses [13], resulting in risk of accelerated soil erosion.

Wherever singletrack construction requires building materials, local materials should be used for both environmental and economic reasons. Specifically, local stones, which are abundant in many landforms, can easily be used to construct singletracks. Yet, in highly erodible or extremely unstable hotspots, artificial materials, such as chain-woven woodblocks, might be needed to construct short singletrack sections in hillslopes (Figure 6c) or ephemeral stream channels (Figure 6d). Being either natural or artificial, the use of these materials in hotspots is expected to decrease the shearing, rutting, and erosion of singletracks, resulting in increased durability.

Highly sheared, rutted, or eroded singletrack sections, which are unsuitable for reclamation schemes, should be closed to bike traffic to negate further degradation of their surroundings. This can be achieved by scattering local stones over the target singletrack sections. This management practice not only prevents singletrack use, it also increases the tracks' surface roughness and negates its hydrological connectivity, augmenting on-site accumulation of water and retention of mineral and organic resources. Over time, it is expected that the materials deposited along the closed track sections will allow self-restoration of pedogenic conditions. This accords with Marion and Olive [23], who stressed the importance of slowing the velocity of runoff water by laying down small stones along trails. Yet, stones must not be extensively cleared from the source area as they act as a protective cover and decrease soil erosion.

To prevent singletracks from becoming runoff channeling courses in hillslopes, the (unintended) formation of downslope berms should be avoided. For the same reason, the tracks should not have a counter-slope side-axis, nor a leveled surface. Rather, upon establishment, a slight downslope side-incline (~5% = ~3°: [23]) should be implemented. Regardless, to prevent aeolian-deposited particles from covering tracks near sand dunes, their side-incline should be steeper than that of sand's critical angle of repose (60–70% or 30–35°: see [36]). To stabilize the track's outer (downslope) berm, its rim should be convexly 'ironed' using a manual ramming machine.

Tracks with steeper longitudinal incline are at higher risk of damage by erosional processes. For example, in southwestern United States it was demonstrated that such damages are minimal in track sections with longitudinal incline of 5%, medium for these of 5–10%, and maximal for these greater than 10% [6]. In events of negligent trail design, mudding and puddling of its surface, as well as breaching of its downslope berm, may occur. To prevent such damages, the tracks' longitudinal axis must be transected. This can be achieved by establishing spillways (runoff outlets) at certain intervals along the track's longitudinal axis, allowing overland flow to drain to the tracks' downslope side (Figure 7a). This accords with other studies [9,14,23], which stressed that drainage points along singletracks act as water outlets and negate soil erosion. Additionally, downtrack of spillways, a shallow bump should be formed to completely halt runoff channeling along it. This accords with Chiu and Kriwoken [14], who studied the physical impacts of mountain biking in Tasmania, Australia, and noted that obstacles and rough track surface slow down runoff and reduce erosion. The longitudinal interval between each two adjacent spillways can be determined according to Equation (9) [37]:

$$LI = (xs + y)(100/s) \tag{9}$$

where: LI is the longitudinal interval (m); x is a geographical zone coefficient (ranging between 0.12 (or less) for mesic conditions and 0.24 (or more) for xeric conditions); s is the singletrack incline (%); and y is a soil erodibility coefficient (ranging between 0.3 for the most erodible soils and 1.2 for the least erodible soils).

Using this equation, we modeled the required longitudinal interval between adjacent spillways according to a wide range of combinations of x, y, and s (Figure 8). Overall, this model shows that the longitudinal interval decreases with the increase in singletrack incline, as more runoff is expected to reach the spillway. Also, the model shows that the longitudinal interval increases for xeric conditions, where less precipitation and runoff are expected.

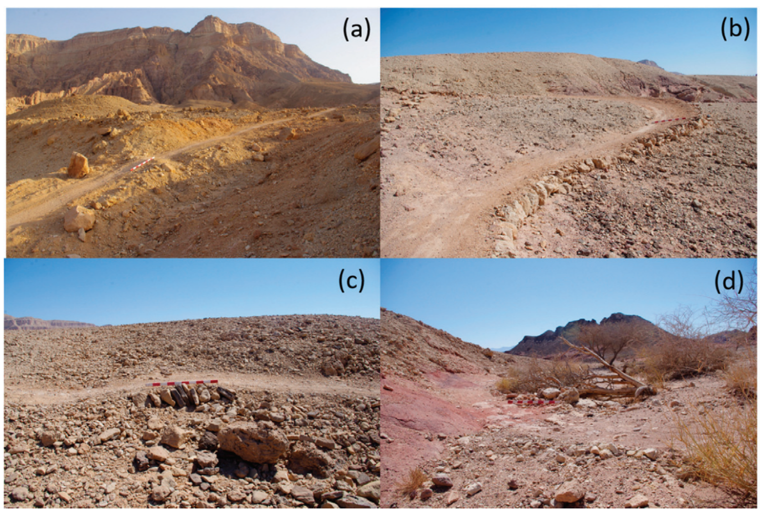


Figure 7. Pictures taken (by the manuscript's first author) in Timna Park, southern Israel, demonstrate: (**a**) a spillway cutting the longitudinal connectivity of a singletrack. Note the shallow bump downtrack of the spillway, aimed at completely halting hydrological connectivity down the track. Also, note the stones spread downhill of spillway, aimed at dissipating flow energy and preventing gully incision; (**b**) downhill curving singletrack. Curve is constructed with a soil-filled berm and strengthened with a stone terrace. Note the 'cemented' track surface, and the berm's counter-slope in the upper curve; (**c**) the 'library' structure, made of vertically-positioned elongated stones, wedged in the soil is effective in forming high and yet stable terraces; and (**d**) an ephemeral stream channel crossing point. Note the large flat rocks 'paving' the channel floor, aimed at preventing the bike tires' from trenching the bed's stone fill. The rocks positioned upstream of the crossing site dissipate flash floods' energy, and the loose rock check dam downstream of the crossing site negates gully incision.

Further, in order to dissipate flow energy and prevent gully headcut retreat downslope of spillways, stones should be spread over the ground. The efforts spent on this practice can be pre-assessed by calculating the potential volume of runoff water that may possibly drain through the spillway. This can be calculated by Equation (10) (modified from [38]):

$$V_w = ((A_b)(C_{rb}R_A) + R_A) + ((A_s)(C_{rs}R_A) + R_A) \tag{10}$$

where: V_w is the volume of water that drains through the spillway during a rainfall event (m^3); A_b is the area of drainage basin (excluding the uphill singletrack area: m^2); C_{rb} is the characterizing runoff coefficient of drainage basin (excluding the uphill singletrack); R_A is the rainfall depth (m); A_s is the area of uphill singletrack interval (m^2); and C_{rs} is the characterizing runoff coefficient of the uphill singletrack interval. For ranges of V_w, according to A_b and A_s, and representative values of C_{rb}, C_{rs}, and R_A, see Figure 9.

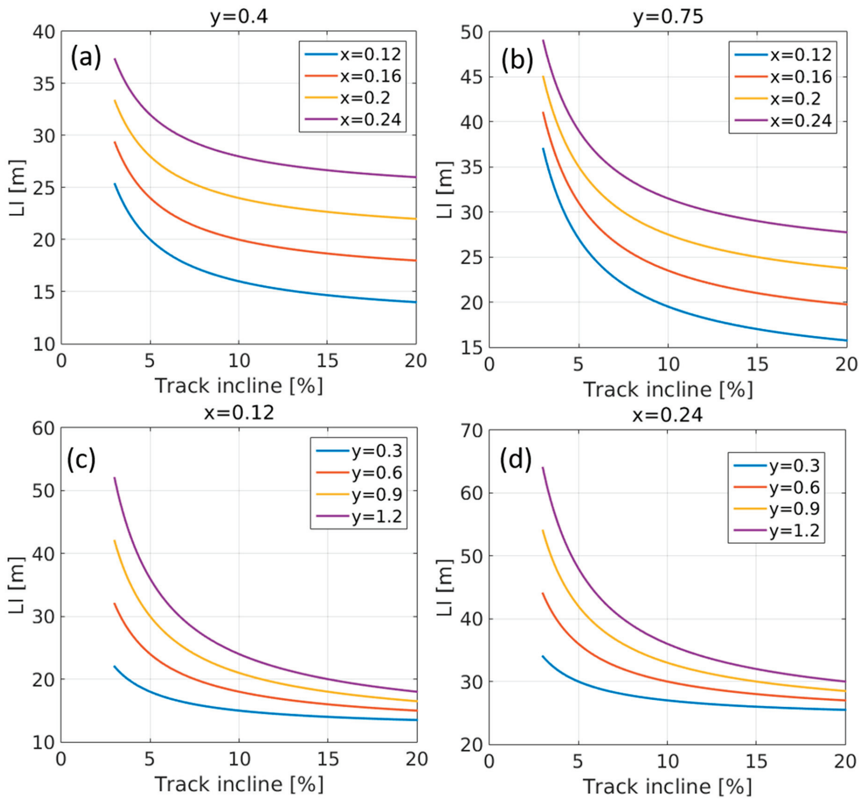


Figure 8. Modeling the length of longitudinal interval between successive spillways (*LI*) as a function of singletrack incline, according to geographical zone coefficient (*x*: ranges between 0.12 (or less) for mesic conditions and 0.24 (or more) for xeric conditions), and soil erodibility coefficient (*y*: ranges between 0.3 for most erodible soils and 1.2 for least erodible soils). *LI* for low-modestly erodible soils (**a**); *LI* for modestly-high erodible soils (**b**); *LI* for relatively mesic conditions (**c**); and *LI* for relatively xeric conditions (**d**).

Regardless, in downhill tracks, hotspot sections should meander. Winding tracks force bikers to limit their speed, preventing frequent braking and the consequent skidding of bike tires, and negating the shearing of ground surface. Because of the centrifugal force imposed on the bikers, counter-slope berm should be established along the curve, reducing the need for hard braking. This counter-slope can be determined according to Equation (11):

$$tan\theta = (v^2 - \mu_s gr)/(\mu_s v^2 + gr) \quad (11)$$

where: θ is the trail counter-slope (°); v is the biking velocity with respect to the ground (m·s^{-1}); μ_s is the static friction coefficient between the tires and the ground (ranging between 0.3 and 0.7); g is the gravitational acceleration (9.8 m·s^{-2}); and r is the radius of curvature (m).

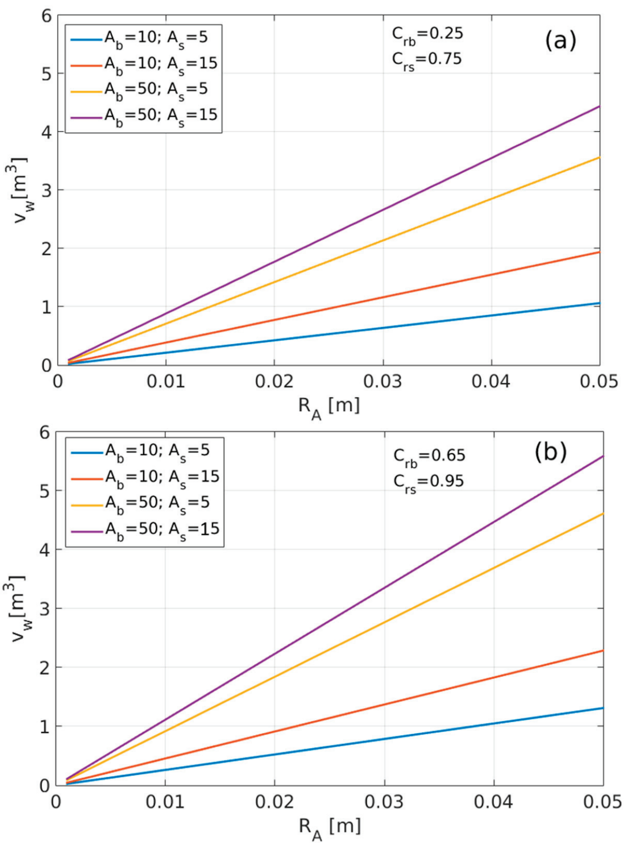


Figure 9. Modeling the volume of runoff water that drains through a spillway (V_w: m^3), according to area of drainage basin (A_b: m^2), area of uphill singletrack interval (A_s: m^2), runoff coefficient of drainage basin (C_{rb}), runoff coefficient of uphill singletrack interval (C_{rs}), and characteristic rainfall depths (R_A: m), for combinations of lowest (**a**) and highest (**b**) values of C_{rb} and C_{rs}.

Forming the counter-slope's berm may require a large volume of soil, which should not be obtained from either intact or erodible landforms. In order to increase the strength and stability of the curve berms, stone terraces may be incorporated in these structures. Where high terraces are needed, multi-layered terraces might be required. In these structures, the particle size should gradually decrease upwards, with relatively large stones at the deeper layers, decreasing stone size in the middle layers, and fine earth material at the surface layer. The terrace's surface soil should be compacted using a manual ramming machine (Figure 7b). In relatively steep sideslopes or in bottleneck sites, extra-stable structures might be needed. In these hotspots, 'library' structures made of vertically-positioned, elongated stones wedged in the soil may form high and yet stable terraces (Figure 7c).

Wherever possible, singletracks should avoid trailing along ephemeral stream channels, where difficult biking in the channel's stone-filled bed increases the likelihood of trenching by bike tires. Where singletracks must cross channel beds, the crossing should be perpendicular to the stream bed and where the channel is narrowest. To stabilize the bed's stone fill and negate trenching by bike tires, 'paving' can be achieved by embedding large flat rocks in the channel floor. Further, to fortify crossing points, large rocks should be positioned upstream of the crossing site, aimed at dissipating flash floods' energy and reducing their erosive power. Downstream of the crossing site, loose rock check dams (see: [39]) should be established, negating gully incision and headcut retreat, and preventing the risk of crossing point collapse (Figure 7d).

Overall, while establishing singletracks, the most important issues are minimizing ground surface disturbance, and maintaining the protective cover of stones [40] and of physical, biological, or biophysical crusts [41]. As a by-product, sustaining ground surface geodiversity negates hydrological connectivity of hillslopes and reduces the erosive power of alluvial processes [42]. In turn, less runoff is expected to reach the downhill stream channels, decreasing the energy of flash floods, and lessening the magnitude of potentially devastating fluvial processes [38].

4. Concluding Remarks

Mountain biking has become a significant sector of outdoor sport, recreation, and ecotourism activities in many countries. Hence, existing singletracks receive increasing pressures, and new singletracks must be established. This conceptual study demonstrates the need to consider hydrologic and geomorphic principles while planning, establishing, and maintaining singletracks. If singletracks are properly designed, their durability is expected to increase, requiring less maintenance over time. At the same time, poorly designed and unmaintained singletracks may have an adverse impact on geo-ecosystem functioning and sustainability. Here, we demonstrate the geophysical conditions and rider characteristics that landscape designers and land managers should consider when planning nature-based, outdoor recreation opportunities.

It should be stressed that even well-designed tracks, established according to hydrologic and geomorphic principles, should be routinely inspected to monitor processes of shearing and rutting, breaching of track's rims, and the emergence of rill and gully erosional processes. Regardless, a crucial management tool should prohibit biking after rainstorms, when soil is moist and singletracks are highly prone to deformation.

Several issues still require intensive research. For example: (i) an empirical study of the long-term durability of tracks established in different lithologies, soil types, and climatic conditions; (ii) formulating visitor impact monitoring programs, and specifically, evaluating the site-specific, optimal seasonal and annual rate, by considering the prevailing biophysical conditions, as well as the 'average' biker's behavior; (iii) investigating long-term effects of singletracks on spatial distribution, productivity, and diversity of downslope/downstream vegetation; and (iv) empirically assessing the impacts of e-mountain bikes on durability of tracks over time.

Author Contributions: Conceptualization, original draft preparation, writing, and funding acquisition, I.S.; modeling, H.Y.; All authors have read and agreed to the published version of the manuscript.

Funding: The study was funded by the Economic Branch of the Hevel Eilot Regional Council. Also, general support was provided by the Ministry of Science and Technology.

Acknowledgments: The authors are grateful to Yaron Deri, Yair Sela, Rahamim Shem-Tov, Yanai Shlomi, Guy Markman, and Hanan Ginat for the assistance in fieldwork and/or the constructive discussions on mountain biking. Also, the authors gratefully acknowledge Michelle Finzi for proofreading of the manuscript. The authors thank three anonymous reviewers, whose comments considerably improved the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Winter, P.L.; Selin, S.; Cerveny, L.; Bricker, K. Outdoor recreation, nature-based tourism, and sustainability. *Sustainability* **2020**, *12*, 81. [CrossRef]
2. Highfill, T.; Franks, C. Measuring the U.S. outdoor recreation economy, 2012–2016. *J. Outdoor Recreat. Tour.* **2019**, *27*, 100223. [CrossRef]

3. Thomas, S.L.; Reed, S.E. Entrenched ties between outdoor recreation and conservation pose challenges for sustainable land management. *Environ. Res. Lett.* **2019**, *14*, 115009. [CrossRef]
4. Paracchini, M.L.; Zulian, G.; Kopperoinen, L.; Maes, J.; Schägner, J.P.; Termansen, M.; Zandersen, M.; Perez-Soba, M.; Scholefield, P.A.; Bidoglio, G. Mapping cultural ecosystem services: A framework to assess the potential for outdoor recreation across the EU. *Ecol. Indic.* **2014**, *45*, 371–385. [CrossRef]
5. Quinn, M.; Chernoff, G. Mountain Biking: A Review of the Ecological Effects. A Literature Review for Parks Canada—National Office (Visitor Experience Branch), Final Report. 2010. Available online: https://www.lib.washington.edu/msd/norestriction/b67566091.pdf (accessed on 10 November 2020).
6. White, D.D.; Waskey, M.T.; Brodehl, G.P.; Foti, P.E. A comparative study of impacts to mountain bike trails in five common ecological regions of the southwestern U.S. *J. Park Recreat. Adm.* **2006**, *24*, 21–41.
7. Pickering, C.M.; Hill, W.; Newsome, D.; Leung, Y.F. Comparing hiking, mountain biking and horse riding impacts on vegetation and soils in Australia and the United States of America. *J. Environ. Manag.* **2010**, *91*, 551–562. [CrossRef] [PubMed]
8. Koemle, D.B.A.; Morawetz, U.B. Improving mountain bike trails in Austria: An assessment of trail preferences and benefits from trail features using choice experiments. *J. Outdoor Recreat. Tour.* **2016**, *15*, 55–65. [CrossRef]
9. Cessford, G.R. *Off-Road Impacts of Mountain Bikes: A Review and Discussion*; Science & Research Series No. 92; New Zealand Department of Conservation: Wellington, New Zealand, 1995. Available online: https://www.imba-europe.org/sites/default/files/Off%20road%20impacts%20of%20mountain%20bikes_review%20and%20discussion.pdf (accessed on 10 November 2020).
10. Thurston, E.; Reader, R.J. Impacts of experimentally applied mountain biking and hiking on vegetation and soil of a deciduous forest. *Environ. Manag.* **2001**, *27*, 397–409. [CrossRef]
11. Pickering, C.; Ansong, M.; Wallace, E. Experimental assessment of weed seed attaching to a mountain bike and horse under dry conditions. *J. Outdoor Recreat. Tour.* **2016**, *15*, 66–70. [CrossRef]
12. Weiss, F.; Brummer, T.J.; Pufal, G. Mountain bikes as seed dispersers and their potential socio-ecological consequences. *J. Environ. Manag.* **2016**, *181*, 326–332. [CrossRef]
13. Marion, J.; Wimpey, J. *Environmental Impacts of Mountain Biking: Science Review and Best Practices*; USGS Patuxent Wildlife Research Center: Laurel, MD, USA, 2007. Available online: https://pubs.er.usgs.gov/publication/5211390 (accessed on 10 November 2020).
14. Chiu, L.; Kriwoken, L. Managing recreational mountain biking in Wellington Park, Tasmania, Australia. *Ann. Leis. Res.* **2003**, *6*, 339–361. [CrossRef]
15. Martin, R.H.; Butler, D.R.; Klier, J. The influence of tire size on bicycle impacts to soil and vegetation. *J. Outdoor Recreat. Tour.* **2018**, *24*, 52–58. [CrossRef]
16. Wilson, J.P.; Seney, J.P. Erosional impact of hikers, horses, motorcycles, and off-road bicycles on mountain trails in Montana. *Mt. Res. Dev.* **1994**, *14*, 77–88. [CrossRef]
17. Tomczyk, A.M.; Ewertowski, M.W.; White, P.C.L.; Kasprzak, L. A new framework for prioritising decisions on recreational trail management. *Landsc. Urban Plan.* **2017**, *167*, 1–13. [CrossRef]
18. Chavez, D.J. *Mountain Biking: Issues and Actions for USDA Forest Service Managers*; Research Paper PSW-RP-226-Web; United States Department of Agriculture, Forest Service, Pacific Southwest Research Station: Albany, CA, USA, 1996.
19. Symmonds, M.C.; Hammitt, W.E.; Quisenberry, V.L. Managing recreational trail environments for mountain bike user preferences. *Environ. Manag.* **2000**, *25*, 549–564. [CrossRef] [PubMed]
20. Pröbstl-Haider, U.; Lund-Durlacher, D.; Antonschmidt, H.; Hödl, C. Mountain bike tourism in Austria and the Alpine region—Towards a sustainable model for multi-stakeholder product development. *J. Sustain. Tour.* **2018**, *26*, 567–582. [CrossRef]
21. Schlemmer, P.; Barth, M.; Schnitzer, M. Comparing motivational patterns of e-mountain bike and common mountain bike tourists. *Curr. Issues Tour.* **2020**, *23*, 1186–1190. [CrossRef]
22. US Forest Service. *User Created Trail Impacts—Literature Review*; USFS Red Rock District, United States Department of Agriculture: Washington, DC, USA, 2014. Available online: https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprd3799134.pdf (accessed on 10 November 2020).
23. Marion, J.L.; Olive, N. *Assessing and Understanding Trail Degradation: Results from Big South Fork National River and Recreational Area*; USGS Patuxent Wildlife Research Center: Laurel, MD, USA, 2006. Available online: https://www.pwrc.usgs.gov/prodabs/pubpdfs/6612_Marion.pdf (accessed on 10 November 2020).

24. Lal, R.; Elliot, W. Erodibility and erosivity. In *Soil Erosion Research Methods*, 2nd ed.; Lal, R., Ed.; Soil and Water Conservation Society: Ankeny, IA, USA, 1994; pp. 181–209.
25. Lal, R. Erodibility and erosivity. In *Soil Erosion Research Methods*, 1st ed.; Lal, R., Ed.; Soil and Water Conservation Society: Ankeny, IA, USA, 1988; pp. 141–160.
26. Kyle, C.R. Selecting cycling equipment. In *High-Tech Cycling*; Burke, E.R., Ed.; Human Kinetics: Urbana-Champaign, IL, USA, 2003; pp. 1–48.
27. Wilson, D.G. *Bicycling Science*, 3rd ed.; The MIT Press: Cambridge, MA, USA, 2004.
28. Kyle, C.R. Mechanical factors affecting the speed of a bicycle. In *High-Tech Cycling*; Burke, E.R., Ed.; Human Kinetics: Urbana-Champaign, IL, USA, 2003; pp. 123–136.
29. Hennekam, W. The speed of a cyclist. *Phys. Educ.* **1990**, *25*, 141–146.
30. Glaskin, M. *Cycling Science*; Ivy Press, Paper Edition: London, UK, 2019; p. 192.
31. Steyn, W.J.v.d.M.; Warnich, J. Comparison of the tyre rolling resistance for different mountain bike tyre diameters and surface conditions. *S. Afr. J. Res. Sport Phys. Educ. Recreat.* **2014**, *36*, 179–193.
32. Hagen, S.; Boyes, M. Affective ride experiences on mountain bike terrain. *J. Outdoor Recreat. Tour.* **2016**, *15*, 89–98. [CrossRef]
33. BD2304 Appendices to SID5. Soil Compaction in England and Wales—Scoping Study to Assess Soil Compaction Affecting Upland and Lowland Grassland in England and Wales. Appendix 2: The causes of Soil Compaction. 2008. Available online: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=14699 (accessed on 10 November 2020).
34. Chong, S.K.; Cowsert, P.T. Infiltration in reclaimed mined land ameliorated with deep tillage treatments. *Soil Till. Res.* **1997**, *44*, 255–264. [CrossRef]
35. Unger, P.W.; Blanco-Canqui, H. Conservation tillage. In *Handbook of Soil Sciences: Resource Management and Environmental Impacts*, 2nd ed.; Huang, P.M., Li, Y., Sumner, M.E., Eds.; CRC Press: Boca Raton, FL, USA, 2011; pp. 25-1–25-23.
36. Al-Hashemi, H.M.B.; Al-Amoudi, O.S.B. A review on the angle of repose of granular materials. *Powder Technol.* **2018**, *330*, 397–417. [CrossRef]
37. NRCS Terrace. Code 600, NHCP. United States Department of Agriculture, Natural Resources Conservation Service. 2002. Available online: File:///D:/adssc/Downloads/600_NHCP_CPS_Terrace_2019.pdf (accessed on 10 November 2020).
38. Stavi, I.; Siad, S.M.; Kyriazopoulos, A.P.; Halbac-Cotoara-Zamfir, R. Water runoff harvesting systems for restoration of degraded rangelands: A review of challenges and opportunities. *J. Environ. Manag.* **2020**, *255*, 109823. [CrossRef] [PubMed]
39. USDA. *Check Dam Erosion Control*; United States Department of Agriculture: Washington, DC, USA, 2000. Available online: https://afghanag.ucdavis.edu/irrigation-natural-resource/files/water-check-dams.pdf (accessed on 10 November 2020).
40. Poesen, J.; Ingelmo-Sanchez, F.; Mucher, H. The hydrological response of soil surfaces to rainfall as affected by cover and position of rock fragments in the top layer. *Earth Surf. Proc. Land* **1990**, *15*, 653–671. [CrossRef]
41. Lu, P.; Xie, X.L.; Wang, L.H.; Wu, F.Q. Effects of different spatial distributions of physical soil crusts on runoff and erosion on the Loess Plateau in China. *Earth Surf. Proc. Land.* **2017**, *42*, 2082–2089. [CrossRef]
42. Stavi, I.; Rachmilevitch, S.; Hjazin, A.; Yizhaq, H. Geodiversity decreases shrub mortality and increases ecosystem tolerance to droughts and climate change. *Earth Surf. Proc. Land* **2018**, *43*, 2808–2817. [CrossRef]

land

Article

Simulating Agroforestry Adoption in Rural Indonesia: The Potential of Trees on Farms for Livelihoods and Environment

Beatrice Nöldeke [1,*], Etti Winter [1], Yves Laumonier [2] and Trifosa Simamora [2]

[1] Institute for Environmental Economics and World Trade, Leibniz University of Hannover, Königsworther Platz 1, 30167 Hannover, Germany; winter@iuw.uni-hannover.de
[2] Centre For International Forestry Research, Jalan CIFOR, Situ Gede, Bogor Barat, Bogor 16115, Jawa Barat, Indonesia; y.laumonier@cgiar.org (Y.L.); t.simamora@cgiar.org (T.S.)
* Correspondence: noeldeke@iuw.uni-hannover.de; Tel.: +49-511-762-4038

Abstract: In recent years, agroforestry has gained increasing attention as an option to simultaneously alleviate poverty, provide ecological benefits, and mitigate climate change. The present study simulates small-scale farmers' agroforestry adoption decisions to investigate the consequences for livelihoods and the environment over time. To explore the interdependencies between agroforestry adoption, livelihoods, and the environment, an agent-based model adjusted to a case study area in rural Indonesia was implemented. Thereby, the model compares different scenarios, including a climate change scenario. The agroforestry system under investigation consists of an illipe (*Shorea stenoptera*) rubber (*Hevea brasiliensis*) mix, which are both locally valued tree species. The simulations reveal that farmers who adopt agroforestry diversify their livelihood portfolio while increasing income. Additionally, the model predicts environmental benefits: enhanced biodiversity and higher carbon sequestration in the landscape. The benefits of agroforestry for livelihoods and nature gain particular importance in the climate change scenario. The results therefore provide policymakers and practitioners with insights into the dynamic economic and environmental advantages of promoting agroforestry.

Keywords: agroforestry adoption; agent-based modelling; socioecological systems; ecosystem services; sustainable rural development; climate change; Indonesia

Citation: Nöldeke, B.; Winter, E.; Laumonier, Y.; Simamora, T. Simulating Agroforestry Adoption in Rural Indonesia: The Potential of Trees on Farms for Livelihoods and Environment. *Land* **2021**, *10*, 385. https://doi.org/10.3390/land10040385

Academic Editors: Mónica de Castro-Pardo, Joao C. Azevedo and Pascual Fernández

Received: 15 March 2021
Accepted: 31 March 2021
Published: 7 April 2021

1. Introduction

Agriculture is an ubiquitous interaction between humans and the environment and affects more natural resources than any other human activity [1,2]. As the world's population grows, the agricultural sector experiences increasing pressure to produce higher quantities of food [3–6]. As a response to the rising demand for food, agriculture is intensified, which can result in soil quality deterioration, and expanded to forest landscapes [7–9]. The consequent deforestation causes loss of biodiversity and regulating ecosystem functions, and thereby aggravates the vulnerability of ecological systems [10,11]. Furthermore, climate change exacerbates this ecological vulnerability and threatens agricultural productivity due to rising temperatures, drought-related stress, and changes in precipitation patterns [12,13]. Hence, producing food for a growing population while combating climate change at the same time poses a major challenge for agriculture and requires sustainable agricultural practices such as organic farming, sustainable intensification, agroecology, and nature-inclusive agriculture [14–17].

Another sustainable agricultural practice is agroforestry [18]. The Food and Agriculture Organization (FAO) defines agroforestry as the "use of trees and shrubs as part of an agricultural system" [19]. Agroforestry presents a promising approach to protect agricultural production and enhance farmers' resilience to climate risks, especially in tropical regions, because it offers numerous economic and environmental benefits [6,12,20–22]. As a mixed tree-crop practice, agroforestry provides ecosystem services such as generation of food and non-food products, regulation of nutrient and hydrological cycles, prevention of soil erosion, and carbon sequestration [23–27]. The emerging benefits of agroforestry affect the small-scale level up to regional and even global scales [28]. As a result, synergies between ecosystem service provision and income opportunities make agroforestry systems a powerful solution to simultaneously counteract deforestation, protect livelihoods, alleviate poverty, and mitigate climate change [28–31]. Yet, despite the diverse benefits highlighted by research, in many regions agroforestry adoption by small-scale farmers remains low [32].

A number of studies have investigated the determinants leading to agroforestry adoption in developing countries. According to the literature, socio-economic household characteristics such as gender, education, household size, wealth, and farm size influence adoption [33–35]. Famers' risk aversion and time preference also impact implementation [36–38]. Further determinants include topography [39], biophysical factors like soil fertility [40], and country-specific effects [41], which indicates the importance of institutions who provide extension services and access to information and materials [42–44]. Subsequent to agroforestry adoption by farmers, further studies have contributed to the literature by investigating tree, soil, and crop interactions either through agroforestry experiments on-farm and on-station [45,46] or via simulations [26,47] showing either competitive, complementary, or balanced interaction between trees and crops. Complementing purely econometric or biophysical studies, a few applications combine behavioral and ecological aspects of agroforestry adoption. Addressing both individual decision making and environmental aspects, Magcale-Macandog et al. (2007) implemented the companion modelling approach to investigate the effects of market information, neighbors, and the establishment of a tree seedling nursery on agroforestry adoption in the Philippines [48]. Villamor et al. (2013) applied the land-use dynamic simulator for spatial-temporal simulations of coupled human-landscape systems to examine the effectiveness of payments for ecosystem services to keep rubber agroforests from conversion into monoculture plantations in Indonesia [49]. In contrast, Smajgl et al. (2015) use agent-based simulations to assess outcomes of payment for ecosystem services to encourage conversion of rubber monoculture to rubber agroforestry in China [50]. Suwarno et al. (2018) developed an agent-based model to explore how different forest moratorium policies impact land-use decisions and resulting area under agroforestry in Indonesia [51]. Overall, many studies point out the high potential for sustainable development related to trees on farms, but the majority of these studies employ econometric approaches or focus on biophysical processes. Research taking the dynamic interplay between individual adoption decisions and their environment or larger temporal and spatial scales into account remains limited. Yet medium- and long-term research integrating ecological and behavioral components to investigate the synergies and trade-offs of agroforestry adoption over time is essential for sustainable land management [18,41,52,53].

To contribute to a better understanding of environmental and economic interrelations of agroforestry systems, this study provides a simulation model of agroforestry adoption that links behavioral and environmental system dynamics under climate change. Specifically, the model investigates: (1) small-scale farmers' agroforestry adoption decisions; (2) their consequences for livelihoods; and (3) their effects on biodiversity and carbon sequestration over time and space. The model aims to support policy-makers and practitioners to assess the potential of agroforestry as an option to strengthen local livelihoods and simultaneously mitigate climate change. As a decision support tool, the model is designed to raise awareness and motivate policy makers to provide supporting measures to increase agroforestry adoption. The research is adjusted to a case study in rural West Kalimantan, Borneo, Indonesia. The study area is located within a corridor between two national parks, which are considered biodiversity-hotspots [54]. In this remote region, traditional jungle rubber systems and rice in shifting cultivation prevails. However, the government promotes the transition to rubber monoculture, creating pressure on the traditional way of life of the indigenous communities. At the same time, the threat of land use change due to encroachment of rubber and oil palm monocultures has been highlighted for years (see for example [55–58]). According to calculations by Barnes et al. (2014), the transition to rubber and oil palm monocultures has serious consequences for biodiversity and ecosystem functioning [56]. In addition to agricultural intensification and expansion, the loss of forest and native species, as well as climate change, aggravate the local farmers' vulnerability [59–61]. Thus, timely interventions are needed to support preferred local livelihoods and increasing income at the same time. Therefore, the present analysis focuses on agroforestry systems combining illipe nut (*Shorea stenoptera* Burk) and rubber (*Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg.) trees [62]. Whereas rubber plants are widely established in the area, cultivation of illipe nut trees in these agroforestry systems poses a noteworthy addition to the local agricultural systems in West Kalimantan [63,64]. The *tengkawang* tree (*Shorea stenoptera*) of the Dipterocarpaceae family, which the International Union for Conservation of Nature has listed as near threatened and which occurs naturally in that area, offers the potential to generate cash income (selling raw nuts or oil extracted from them) and provides various ecosystems services such as biomass accumulation and carbon sequestration [62,65]. Additionally, the high forest canopy cover connects forest habitats and thereby enables movement of local flagship species such as the orangutan [66–68]. Thus, illipe rubber agroforests gain particular appeal in the study area to conserve biological diversity, but also to mitigate and adapt to the mentioned challenges prevailing in the area. To explicitly model the decision-making process of small-scale farming households and connect human and ecological dynamics over larger spatial and temporal scales, we developed an agent-based model (ABM). The implemented ABM compares different scenarios. The first scenario describes the agricultural practices prevalent in the study area, which focus on rice cultivation in swidden agricultural systems and jungle rubber cultivation, without any intervention (business as usual (BAU) scenario). The BAU scenario is compared to a scenario where illipe nut trees and rubber are developed into agroforestry as an innovative alternative that offers potential for additional income and livelihood diversification. Furthermore, a climate change scenario with a rise in temperature of 1.5 °C was simulated consistent with the climate targets according to the Paris Climate Agreement, which is expected under the Representative Concentration Pathway 2.6 [69,70]. The simulations demonstrate that farmers who decide to adopt agroforestry increase their income while diversifying their livelihood portfolio. Additionally, the model predicts higher biodiversity levels and improved carbon sequestration in the landscape as a consequence of agroforestry adoption. The benefits of agroforestry for livelihoods and nature will gain particular importance if temperatures rise.

The remainder of this paper is structured as follows: Section 2 describes the study area and data, followed by the outline of the ABM; Section 3 presents the findings; Section 4 discusses the simulations results; and Section 5 summarizes and concludes the paper.

2. Materials and Methods

2.1. Study Site

The research is based on a case study in Kapuas Hulu regency, West Kalimantan, Indonesia (Figure 1). Batang Lupar district in Kapuas Hulu was selected as a study site because it represents a landscape that is still traditionally managed, and its Leboyan River watershed directly impacts the Danau Sentarum National Park wetlands. Located in close proximity to the equator, the regional climate exhibits equatorial characteristics with high amounts of rainfall throughout the year (average of 4154 mm per year) and a mean temperature of 27.2 °C [71]. Due to the diverse forest types and their roles for the hydrology of the Kapuas River basin, the Danau Sentarum National Park (south) and Betung Kerihun National Park (north of the study area) were established [63,72].

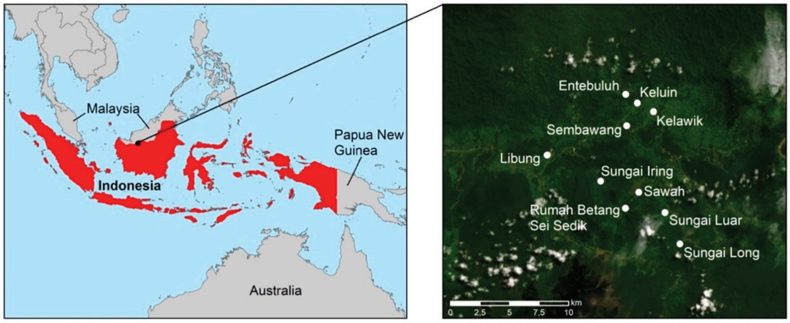


Figure 1. Study area. Source: own illustration based on Geographic Information System (GIS) data.

The inhabitants consist in large part of Dayak ethnic groups in the hilly interior, whose livelihoods are traditionally swidden agriculture systems, and Malay along the rivers and in the wetlands, who live mainly on fisheries [73]. Like elsewhere in Southeast Asia, rice plays a central element for local livelihoods as a subsistence crop, and the Dayak traditionally practice slash and burn cyclic agriculture to grow rice [74]. Rubber was first introduced in Borneo at the beginning of the 20th century and was adopted rapidly by farmers [75]. For generating cash income and as a safety net, rubber remains very popular in the study area [63,76]. Despite a positive trend in recent years, low education levels and poor infrastructure persist in the area, and with a Human Development Index of 67.65 in 2019 the study area belongs to the less developed provinces in Indonesia [63,72,73,77]. Given the traditionally close link to agriculture, the challenged livelihood situation, and the location in the buffer zone between two national parks, agroforestry systems pose a promising approach to create economic development and protect natural resources in Kapuas Hulu [63,78].

2.2. Data

Within Batang Lupar district, ten settlements consisting of at least ten households were randomly chosen for the study. Within each settlement, all households were selected for the survey, comprising a total sample of 139 households interviewed, out of which one had to be excluded from the analysis due to missing data. The socioeconomic survey took place in the period from May until September 2014. The interview contained segments on demographics, assets, financials, food security, agricultural activities, use of natural resources, and social networks, amongst other [72]. Furthermore, remote sensing data for the year 2014 and data describing the landscape collected using an unmanned aerial vehicle (UAV) for the years 2016 and 2017 were collected [72]. Ecological indicators to estimate biodiversity and carbon sequestration include tree species biomass, and species richness and Fisher's alpha, which is a logarithmic series model to describe the number of species and the number of individuals within those species independent of sample size, for trees and bird species richness [72,79]. The data collection was based on equally-stratified sampling of the vegetation units in the study area. To investigate tree biodiversity, plots (20 m $\times$ 20 m) were laid out, recording trees with Ø $\geq$ 5 cm for each vegetation type. The bird survey, which took place in November and December 2016, included point count recordings and mist net monitoring [72]. Further details regarding data collection and calculation of the biodiversity and carbon indicators can be found in Laumonier et al. (2020).

2.3. Agent-Based Model

An agent-based model was adjusted to the case study area. The following section, which describes the model, follows the Overview, Design concepts, Details (ODD) protocol [80–82]. The model was implemented using NetLogo 6.1.1 [83].

Purpose

The Simulating Agroforestry Adoption in Rural Indonesia (SAFARI) model is used to explore the adoption of illipe rubber agroforestry systems by farming households in a case study region in rural Indonesia. Thereby, the ABM simulates the interdependencies of agroforestry systems and local livelihoods, income, land use, biodiversity, and carbon sequestration. The model contrasts development paths without agroforestry (BAU), corresponding to prevalent practices in the study area, to a scenario that introduces an illipe nut tree (*Shorea* spp.) mix with rubber in an agroforestry system (IRA scenario) as an alternative. It aims to support policymakers to assess the potential of IRA over larger temporal and spatial scales.

State variables and scales

The SAFARI model comprises two agent types: farming households and landscape patches. The farming households are the primary decision-making units in the model. They are characterized by state variables indicating their location, household size and resulting energy requirement, labor force, and further variables related to their agricultural activities as displayed in Table 1. Livelihood indicators show whether the households engaged in rice or jungle rubber farming, agroforestry cultivation, and illipe processing. The variable food-insecure indicates whether a household has failed to meet its minimal energy requirement. Income indicates household wealth. Decision making follows a bounded rationality approach including a satisficing heuristic based on if-then-else statements.

Table 1. Model description: farmer agent variables.

Variable	Description
HHID	Identifier of household
Initial-laborforce	Initial labor force, based on household size
Available-laborforce	Available labor force after livelihood decision, considers labor input for livelihoods chosen
Farmsize	Total farm size
NumberPlots	Number of plots
My-plots	Set of plots claimed by household
Plots_cultivated	Plots cultivated by household
Fallow_plots	Fallow plots claimed by household
Plots_rice	Number of plots with rice
Plots_rubber	Number of plots with jungle rubber
Plots_AF	Number of plots with agroforestry
RiceFarmer	1 if household cultivates rice, 0 otherwise
RubberFarmer	1 if household cultivates jungle rubber, 0 otherwise
IllipeFarmer	1 if household cultivates agroforestry, 0 otherwise
Illipeprocessor	1 if household processes illipe nuts, 0 otherwise
Illipeharvest	Illipe nuts harvested (in kg)
iEnergyRequirement	Auxiliary variable to calculate initial energy requirement of household
EnergyRequirement	Energy requirement of household
EnergyConsumption	Expected energy consumption resulting from agriculture cultivated in previous and current period
RiceConsumption	Expected energy consumption from rice
RubberIncome	Expected income from jungle rubber
IllipeAFIncome	Expected income from illipe nuts in agroforestry systems
RubberAFIncome	Expected income from rubber in agroforestry systems
AFincome	Expected total income from agroforestry
IllipeIncomeProcessed	Expected income from illipe nuts processed
aEnergyConsumption	Actual total energy consumption (total)
aRiceConsumption	Actual energy consumption from rice
aRubberIncome	Actual income from jungle rubber
aIllipeAFIncome	Actual income from illipe in agroforestry systems
aRubberAFIncome	Actual income from rubber in agroforestry systems
aAFIncome	Actual total income from agroforestry
aIllipeIncomeProcessed	Actual income from processed illipe
Income	Total income in Mio Indonesian rupiah (IDR)
Food-insecure	1 if household did not meet energy requirements, 0 otherwise
Deficit	Caloric deficit

Landscape patches, the other agent type, represent the spatial environment of the model. They describe the land use and resulting vegetation cover as Table 2 presents. Based on patch class, vegetation, fallow age, and the resulting fertility are derived. Fertility is used as an input to calculate yields. Associated to the specific uses, patch variables indicate carbon sequestration and biodiversity indicators, namely tree species richness, tree Fisher's alpha, tree density and basal area, as well as bird richness. The agents are parameterized according to survey and GIS data as well as ecological indicators. One patch agent represents an area of 100 × 100 m resulting in a total area of about 28 × 44 km covered.

Table 2. Model description: landscape agent variables.

Variable	Description
Owner	Household claiming ownership
Plotid	Plot identifier according to survey
Class	Land use class (natural forest, secondary forest, old fallow, young fallow, rice and weeds, rice, jungle rubber, illipe nut trees (*Shorea* spp.) mix with rubber in an agroforestry system (IRA)
Vegetation	Plot vegetation
Fallowlength	Indicates age of fallow
Fertility	Auxiliary variable to calculate yield
Yield	Rice yield, depends on fertility
Rubber	Indicates if rubber trees are planted on patch and age of trees
Illipe	Indicates if illipe nut trees are planted on patch and age of trees
Patch_alpha	Tree Fisher's alpha
Patch_basal	Basal area
Patch_tree_richness	Tree richness
Patch_density	Tree density
Bird_richness	Species richness of birds
Biomass	Above-ground biomass in C Mg/patch
Vegetastipatch	Land cover according to GIS data
River	Indicates location of rivers
River-prox	Indicates patch proximity to a river
Nationalpark	Indicates location of national parks

Process overview and scheduling

The model proceeds in annual time steps, and simulations were run for 60 years, with 40 repetitions for each scenario. Within each time step, six modules are processed in the order corresponding to Figure 2. Within each module, the agents conduct the respective processes in a random order.

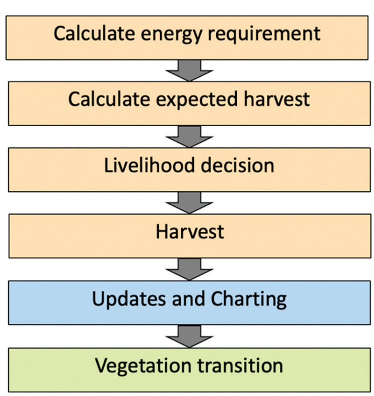


Figure 2. Model description: process overview. Orange: household agent procedures, green: landscape agent procedures, blue: general procedures.

Design concepts

Basic principles: Given the limited cognitive abilities of humans, farming households are assumed to follow a satisficing approach based on the concept of bounded rationality [84,85]. The landscape patches follow transition rules and are impacted by the farmers' land use decisions.

Emergence: Livelihood decisions determine land use, which in turn influences the development of land cover and future livelihood decisions. Thus, landscape dynamics emerge from the interaction between patches and farming households.

Adaptation: Farming households adapt by taking past agricultural decisions and their subsequent situation in the present into account when deciding about livelihoods to fulfill caloric requirements.

Fitness: Fitness-seeking is modelled as the objective to fulfil caloric needs as part of a satisficing procedure. As a secondary objective, households invest the excess labor to generate cash income.

Sensing: Farming households know their own characteristics such as household labor, agricultural activities, and so on. Furthermore, they are aware of the land use and which patch has been claimed by a household. Households also know about the labor requirements of each agricultural activity and market prices of the outputs.

Interaction: Interaction between households takes place indirectly through competition for land.

Stochasticity: Agents perform the procedures in random order. The location of claimed plots contains stochastic elements. The initialization procedure comprises random elements with respect to the location of farms, initial cultivation of rice and rubber, vegetation, fallow length, and hence fertility, whose initialization values are drawn from random distributions.

Observation: The main simulation outcomes computed every time step include livelihood choices, income generation, land cover, carbon sequestration, and biodiversity indicators. Regarding the latter, bird species richness and Fisher's alpha for trees signify the respective biodiversity levels. Additional biodiversity indicators reflecting further aspects of biodiversity include tree density, basal area, and tree species richness.

Initialization

The farming households are initialized according to a household survey. Specifically, their original farm size, number of (cultivated and fallow) plots, labor force, and location are directly derived from the survey data and are thus household-specific. Locations of plots are assigned randomly, but within a certain radius that corresponds to maximum distances between households and plots derived from the survey. Cultivation of rice and jungle rubber is probabilistic with likelihoods corresponding to the share of households engaging as indicated in the survey (23% and 76%, respectively). Other land uses originate from GIS data. The setup of the biodiversity and carbon indicators is based on local data collection [86] as presented in Table 3. Fallow age is random and corresponds with vegetation. Fertility equals the fallow age.

Input

Data input is used for the initialization of the model; household survey data indicates household composition and energy requirements as described in Table 1. GIS data provide information to setup the landscape agents [86]. The input for the biodiversity indicators and carbon sequestration origins from data collection on site [72]. Further inputs used include costs and benefits of the livelihood activities. The labor inputs originate from Suyanto et al. (2009). Labor inputs for trees are adjusted to account for the duration until trees reach maturity; accordingly, rubber is assumed to require 52 labor days per person per hectare in the first year, 26 in the years 2–5, and 99 afterwards as input [87]. Illipe nut trees are assumed to require the same amount of labor input as rubber trees. However, after illipe nut trees mature at the age of eight, 99 labor days per person per hectare are only required every four years, when the illipe nut trees can be harvested. In the other years, 26 labor days per person per hectare are assumed to be required for maintenance. 20 labor days per person are assumed as input for illipe nuts processing. Whereas for rice a yield function following Jepsen et al. (2006) is used, annual outputs for rubber and illipe rubber system follow Winarni et al. (2017) and Wulan et al. (2006) [62,88,89]. Furthermore, rice is assumed to provide 1650 kcal per kg. The cost of 1 kg of rice is 10,000 IDR, and the price for rubber is 6500 IDR per kg according to the survey and Winarni et al. (2017) [62]. Illipe nuts cost 7000 IDR per kg [62,90]. Regarding processing, about 5 kg of raw illipe nuts yield up to 1 kg fat, which can be sold for about 100,000 IDR [91].

Table 3. Model description: landscape agents' setup.

Vegetation Class	Setup
Natural forest	Vegetation: uniformly distributed between 20 and 40 Basal area: 3.75 Tree Fisher's alpha: 50.487 Tree density: 81 Tree richness: 91 Biomass: 36.7 Bird richness: 81a
Secondary forest	Vegetation: uniformly distributed between 20 and 40 Basal area: 3.53 Tree Fisher's alpha: 35.3 Tree density: 96 Tree richness: 85 Biomass: 7.4335 Bird richness: 68
Old fallow	Vegetation: uniformly distributed between 10 and 20 Basal area: 0.75 Tree Fisher's alpha: 18.38 Tree density: 67.5 Tree richness: 39 Biomass: 0.8119 Bird richness: 69
Young fallow	Vegetation: uniformly distributed between 2 and 10 Basal area: 0.25 Tree Fisher's alpha: 10.91 Tree density: 48.5 Tree richness: 25 Biomass: 0.2 Bird richness: 57
Rice + weeds	Vegetation: 1 Basal area: 0 Tree Fisher's alpha: 0 Tree density: 0 Tree richness: 0 Biomass: 0 Bird richness: 1
Rice	Vegetation: 0 Basal area: 0 Tree Fisher's alpha: 0 Tree density: 0 Tree richness: 0 Biomass: 0 Bird richness: 1

Table 3. *Cont.*

Vegetation Class	Setup
Jungle rubber	Basal area: 2 Tree Fisher's alpha: 25.48 Tree density: 54.7 Tree richness: 69 Biomass: 9.8 Bird richness: 49
Illipe rubber agroforestry	Basal area: 2.7 Tree Fisher's alpha: 39.74 Tree density: 132 Tree richness 60 Biomass: 13 Bird richness: 60

Submodels

Calculate energy requirements

As the first step of each simulation run, the households calculate their energy requirements based on the household size in adult equivalents [92]. For every adult equivalent, a minimum consumption corresponding to the average caloric consumption (1935 kcal per person per day) from Kalimantan in 2015 [93] as the aspired consumption threshold is assumed. During the same step, variables such as energy consumption are reset to zero.

Calculate expected harvest

Then, households estimate their expected harvest. Households may have engaged in agricultural cultivation in previous seasons and take the expected yields into consideration for their livelihood decisions in the current year. This includes rice from swidden fields in the second year as well as rubber and illipe nut yields. Thereby, mature illipe nut trees can be harvested only every four years, whereas rubber in the agroforestry systems can be harvested every year once the trees mature. Rice yields are calculated following a yield function of Jepsen et al. (2006) calibrated to the study region

$$y = \frac{a}{1 + b * \exp(-c * x)} \tag{1}$$

with $a = 783.7$, $b = 8.07$, $c = 0.52$, and $x = \mathit{fertility}$ [88]. During the second year of swidden agriculture, the rice yield is assumed to be 50% of first-year-yields. Because the farmers anticipate these yields, they plan accordingly and allocate labor to the respective harvesting activities, which is thus subtracted from the available labor force.

Livelihood decisions

Based on expected harvest, households make decisions about additional livelihood activities in the current period. Given the cost of searching and comparing alternative actions combined with limited cognitive and computational abilities of humans, a bounded rationality approach including a satisficing heuristic was applied to simulate farmer decision making [84,94]. A decision tree represents decision making as a series of if-then-else statements, as illustrated in Figure 3. The baseline scenario considers rice and jungle rubber, which are the main livelihood activities in the study area. The respective decisions depend on caloric needs and resource availability. Farming households prioritize to fulfill their caloric needs, which represents the aspiration threshold, through rice planting before engaging in market production of rubber [95,96]. If the households have claimed available plots, they choose to plant rice on the plot with the longest fallow age, which represents a preference for clearing secondary fallow over primary forest [97]. Only if no such plot exists, then the household decides to clear an unclaimed plot through slash and burn, located within a radius of six kilometers, to plant rice there. The household continues planting rice until the caloric needs are expected to be satisfied. The maximum area for clearing unclaimed areas is set to four hectares per period. Once the harvest meets the caloric requirements, the households check whether they have more labor available. If that is the case, they engage in rubber tapping and maintenance. If still more labor is available, they decide to plant additional jungle rubber as a cash crop. The maximum amount of rubber is restricted to 1.2 ha, in line with survey results.

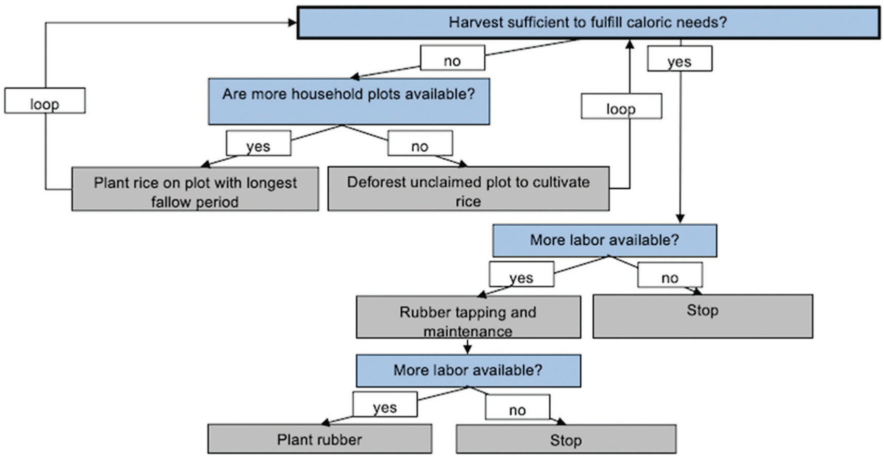


Figure 3. Model description: livelihood decision tree (business as usual (BAU) scenario).

Extending the baseline scenario, farmers have the option to additionally plant illipe trees mixed with rubber agroforestry on their plots on riverbanks as an option to generate cash income (Figure 4). First, they harvest illipe nuts if it is possible in that season. Then, consistent with the baseline scenario, households aim to fulfill caloric requirements through swidden agriculture on already claimed or newly cleared plots. When the expected yields suffice to ensure food security, rubber has been tapped, and more labor is available, the households check whether they have fallow plots in proximity to a river available. If they do not, they plant jungle rubber on another plot. If they do, they cultivate IRA on that plot. If still more labor is available to the household during an illipe nut harvesting season, they process the illipe nuts into fat.

Harvest

After household decisions are made, the households harvest their plots. As the illipe nut tree produces yield approximately every four years depending on weather conditions, illipe nut harvest is assumed to occur every four years for all trees simultaneously [98]. In contrast, rubber (jungle rubber or as part of IRA) can be harvested every year. The households accumulate the calories and cash income generated from their livelihood activities. If a household is not able to produce the required calories, it is marked as food insecure.

Update of variables and charting

Update of the farmers includes the number of farmers who chose the respective livelihoods, mean caloric consumptions, and income. Furthermore, number of plots claimed, fallow plots and plots cultivated, total farm size, and the share of plots with agroforestry are updated. Besides, the number of landscape agents with the various vegetation classes, mean biodiversity indicators of the patches, and carbon sequestered according to the land use are calculated.

Vegetation transition

As the last step of the modelling cycle, the vegetation classes undergo transition dependent on their fallow age and use according to the swidden agriculture cycle (Figure 5).

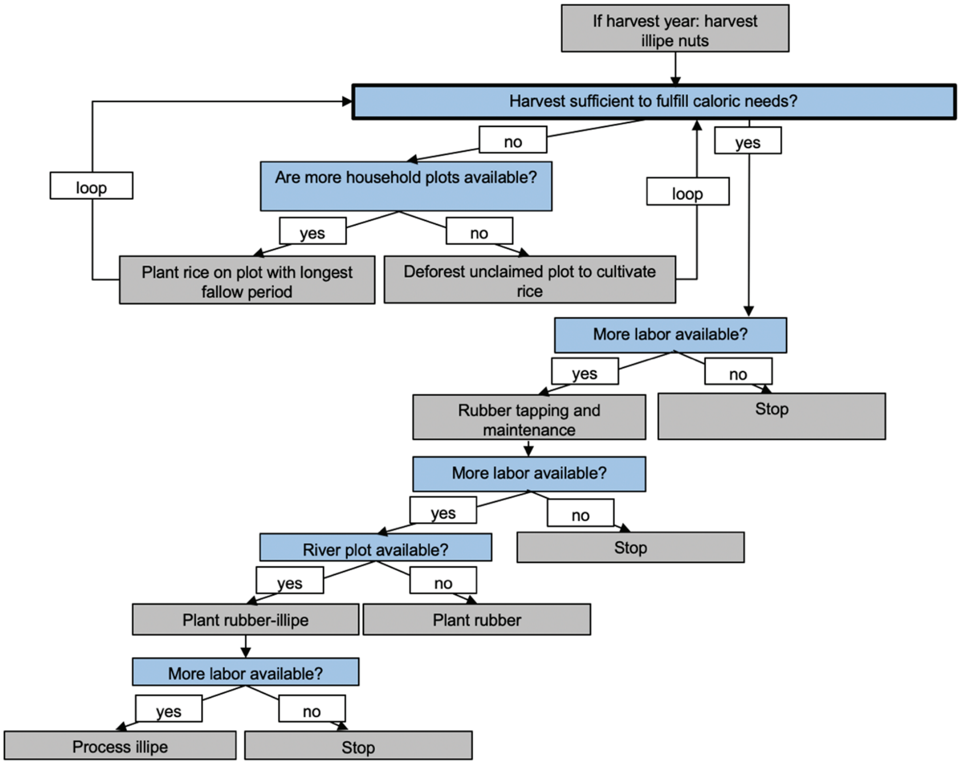


Figure 4. Model description: livelihood decision tree (IRA scenario).

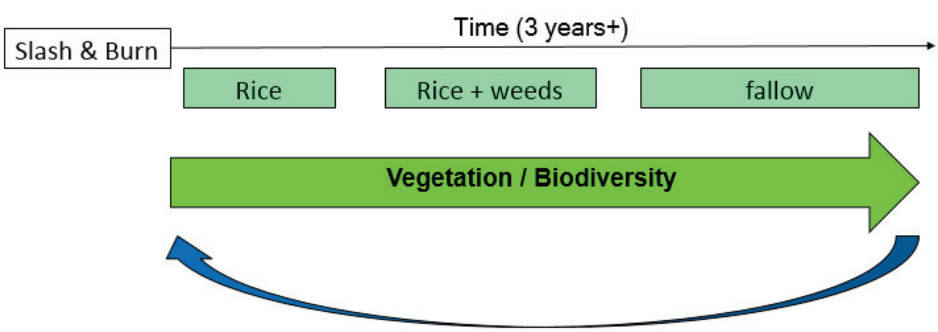


Figure 5. Model description: landscape patches' cycle of swidden agriculture.

Before farmers can cultivate plots, they need to clear them through slash and burn activities. Rice planted on cleared (swidden) fields also provides yield in the second year after planting, when weeds grow on the fields as well. In the consecutive periods, the fields lay fallow to regenerate their fertility until the farmers decide to clear and cultivate them again. During that fallow period, plots transition from young fallow to old fallow to secondary forest unless they are cleared (Table 4). Also patches with forest vegetation can be cleared for rice cultivation through slash-and-burning.

Table 4. Model description: vegetation class transition of landscape agents.

Vegetation Class	Transition into
Rice	Rice + weeds
Rice + weeds	Young fallow (up to 10 years)
Young fallow	Old fallow (11–20 years)
Old fallow	Secondary forest (>20 years)

To represent the fertility and vegetation on the swidden fields, fallow age, vegetation, and fertility increase by one during every time step except when the plot is cleared. In that case, fallow age and vegetation are reset to zero. Only fertility, whose maximum value is restricted to 12, is not reset until the harvest is completed because it is needed to calculate the yield since fertility improves output. For vegetation, a maximum of 30 is assumed. With increasing fallow length and change in vegetation, the biodiversity indicators are also modified, corresponding to the respective land use as indicated in Table 3. Lastly, rubber trees exceeding the age of 25 are assumed to die and be replaced. Illipe trees can reach the age of 99 years, which is longer than the simulated time span and thus is not considered in this context.

Climate change scenario

Extending the model, a climate change scenario (CCS) was introduced. This scenario simulates a pathway consistent with the climate goals of the Paris Climate Agreement to restrict temperature rise to 1.5 °C above preindustrial levels [70]. This stringent mitigation scenario corresponds to the temperature change expected under Projected Concentration Pathway 2.6 [69]. In the model, the resulting change in temperatures is assumed to lead to decreases in rice yields of 12.6% [99].

Calibration

Regarding livelihood choices, the model parameters were adjusted according to the survey data. The spatial landscape is based on GIS data and ecological indicators collected in the study area. The calibration of the yield function is based on UAV data. As the UAV data comprises information for the several years, the first year was used for calibration, whereas the validation used the following period.

Verification and validation

Verification to assess the accuracy of the programmed model was carried out through a careful scan of the model code. Verification further included the testing of certain cases such as extreme points [100]. Validation to demonstrate the model's consistency with the intended application was based on the indirect calibration approach [101]. First, patterns regarding the livelihood portfolio, e.g., rice and rubber cultivation, which the model aimed to reproduce, were defined. Then, the model modules including the decision-making processes and vegetation transition were developed according to stakeholder and expert opinions. Third, the empirical evidence on the livelihood patterns provided through the survey and UAV data was used to restrict the parameter space and initial conditions (see calibration). Besides, the decision rules were evaluated. Comparing the model outputs with collected land cover data demonstrates only minor deviations between simulated and observed data (land cover with rice and rubber patches around 1% and 5% deviation, respectively). The adjusted model was then used to derive further insights [101].

Data analysis

The analysis of simulation results includes the comparison of scenarios with and without IRA. Additionally, a climate change scenario is contrasted to a scenario without temperature rises. The scenarios were compared by applying *t*-tests using Stata 14.2 [102]. To check for robustness, Wilcoxon-Mann-Whitney-tests were also performed.

3. Results

The following chapter presents the descriptive findings of the survey and simulation results related to farmers' adoption and income, land use change, and ecological indicators.

3.1. Descriptive Results

The subsequent section presents selected descriptive findings of the study area. In line with official statistics [103], the survey results show that high poverty, low education levels, subsistence farming (mainly rice), and rubber cultivation for cash income prevail in the study area.

About 36% of the household heads, who are predominantly male, are unable to read and write, and about 75% of household heads did not receive education after primary school. Most of the households have an acceptable food consumption score, about 24% fall into the category of borderline food security, and 1% suffer from poor food security. Regarding the household dietary diversity score, households on average reported a score of 13.40. The yearly household income of 9,503,805 IDR corresponds to approximately 690 US Dollars per year. The Progress out of Poverty Index of 82.73 denotes the likelihood of a household living on less than 2.50 US-Dollars per day. Income diversification is rather low, as the average Simpson index of income diversification of 0.25 shows with about 70% of the households relying on one income source exclusively. In that area, all households heavily depend on agriculture for their livelihood, as the high proportion of income from farming shows (Table 5).

Table 5. Descriptive results: general household characteristics.

Variable	Description
Household size	4.55 (2.26)
Labor capacity	3.66 (1.80)
Share of farm income (in %)	74.59 (28.98)
Years of schooling of household head	4.38 (4.10)
Age of household head	46.85 (14.09)

Note: Standard deviation in parentheses. $n = 138$.

On average, farmers claim 14.45 hectare of land distributed over approximately seven plots, out of which about one third are cultivated (Table 6). Nearly all of the plots are owned without an official title (98%). The majority of households (76%) engage in rubber cultivation. Livestock is not common in the area, as over 70% of the households report no livestock, and the average ownership amounts to 0.07 tropical livestock units.

Table 6. Descriptive results: agricultural characteristics.

Variable	Description
Average claimed land size (in hectare)	14.45 (16.18)
Average number of plots claimed	7.19 (4.82)
Average plot size (in hectare)	1.93 (2.27)
Average distance to the house (in meters)	2871.80 (3058.82)
Average number of plots cultivated	2.41 (1.94)
Share of households cultivating rubber (in %)	75.64

Note: Standard deviation in parentheses.

3.2. Simulation Results

The following section presents the simulation results of the SAFARI model, which compares the business as usual and illipe rubber agroforestry scenario as well as the climate change scenario.

3.2.1. Agroforestry Adoption and Income Effects

One main simulation outcome is the farmers' livelihood choice. The simulations demonstrate that hill rice farming plays an essential role for the population, as illustrated in Figure 6. Conforming with the decision-making heuristic, all farmers cultivate rice on fallow plots in the BAU scenario. However, if the opportunity to adopt IRA exists, only 88% of the farmers engage in rice cultivation as part of a swidden agricultural system, which poses a significant difference between the IRA and the BAU scenarios ($p = 0.000$). In addition to rice, rubber as a cash crop is an integral part of the rural farming livelihoods. Again, in line with the decision heuristic, all farmers engage in jungle rubber farming in the BAU scenario, but significantly fewer farmers (69%) plant jungle rubber in the IRA scenario ($p = 0.000$). With respect to agroforestry, the IRA scenario exhibits high adoption rates with 99.6% of the farmers implementing IRA to generate additional cash. Thereby, the majority of farmers reduce their labor input for rice and jungle rubber cultivation in favor of the illipe tree mixed with rubber type of agroforestry implementation. They still engage in swidden agriculture and agroforestry simultaneously to create diversified livelihood portfolios. Particularly, in the years before the first agroforestry harvest and in the periods when illipe nuts cannot be harvested, farmers increase their labor input for rice cultivation. According to the simulations, 27% of farmers who cultivate IRA process illipe nuts into fat in the years of harvest.

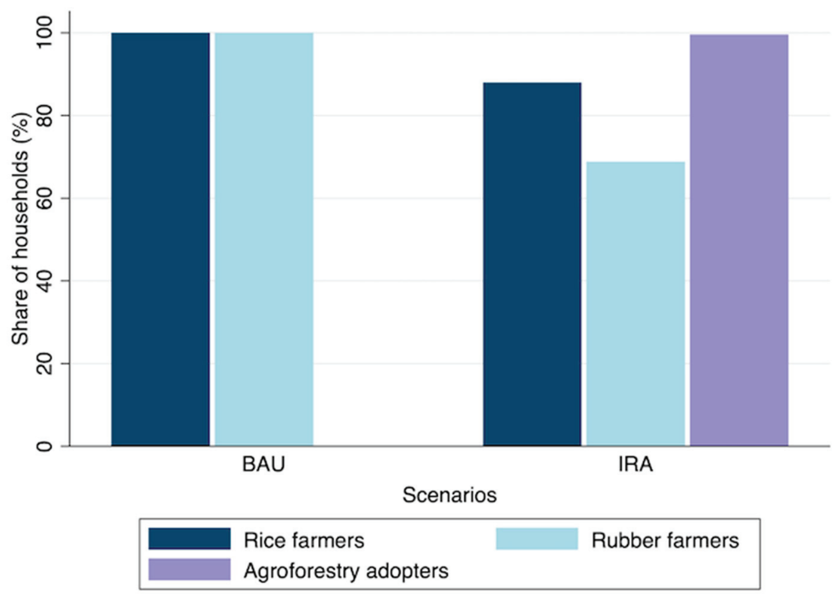


Figure 6. Simulation results: farmers' livelihood choices.

Based on the farmers' livelihood decisions, the simulations reveal changes in rice consumption and cash income (Figures 7 and 8). As IRA adopters reduce their labor input for rice cultivation, the calories available through rice cultivation decrease significantly from 2121 kcal available per person per day on average in the BAU scenario to 1009 kcal in the IRA scenario ($p = 0.000$). In contrast, cash income greatly increases in the IRA scenario compared with the BAU scenario ($p = 0.000$), enabling farmers to buy rice for example. Thereby, illipe nuts from agroforestry contribute to income to the largest extent with 84% and with a positive trend over time, as Figure 8 shows the development for the years 1–20, 21–40, and 41–60. The notable difference in incomes gives an indication about the potential of agroforestry to increase wealth and alleviate poverty. Generally, food insecurity is not a severe problem.

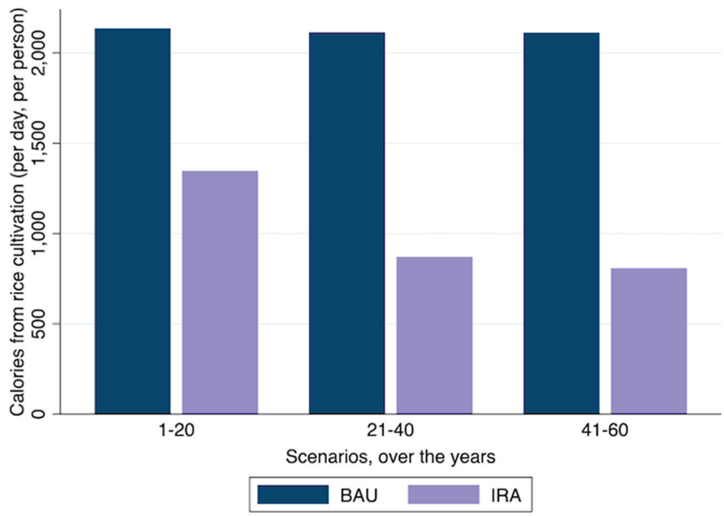


Figure 7. Simulation results: calories generated from rice cultivation over time.

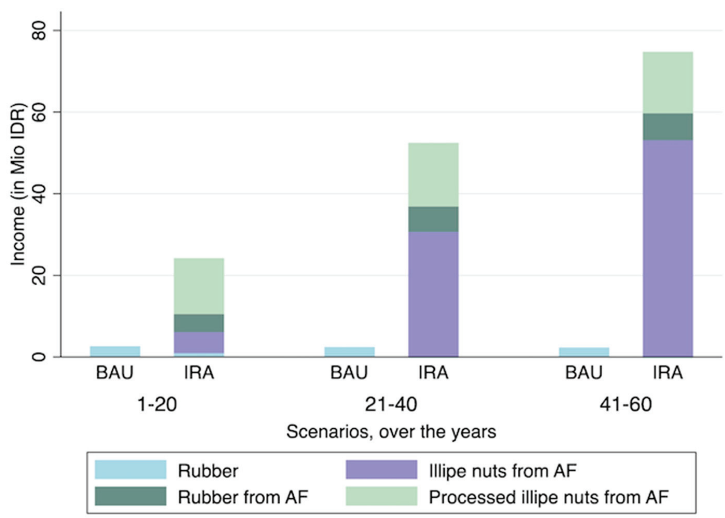


Figure 8. Simulation results: generated cash income over time.

3.2.2. Land Use Changes

In accordance with the farmers' livelihood choices, the land use and land cover shift. Subsequently, the area under illipe rubber agroforestry rises strongly in the IRA scenario up to 27.8% of the whole area ($p = 0.000$). In contrast, the area under jungle rubber cultivation is replaced and decreases from 5.5% in the BAU to less than 1% in the IRA scenario ($p = 0.000$). Also, the area under rice decreases significantly from 7.9% in the BAU scenario by more than half in the IRA scenario ($p = 0.000$). The changed land use in the IRA scenario allows the farmers to increase the fallow age of their swidden agriculture plots, which is reflected by the proportionally lower number of young fallow plots ($p = 0.000$) in the IRA scenario, but relatively higher number of old fallow plots ($p = 0.000$). The longer fallow periods in the agroforestry scenario affect plot fertility positively ($p = 0.000$), which in turn enhances rice yields. Secondary forest covers about 58.3% of the land in the BAU scenario and significantly decreases to 48.9% if agroforestry is introduced (p = 0.000). The area under natural forest cover amounts up to about 12.2% and does not differ significantly between the BAU and IRA scenarios (p = 0.9948). Figure 9 illustrates that the strongest change takes place shortly after introducing agroforestry, but also long-term effects can be expected.

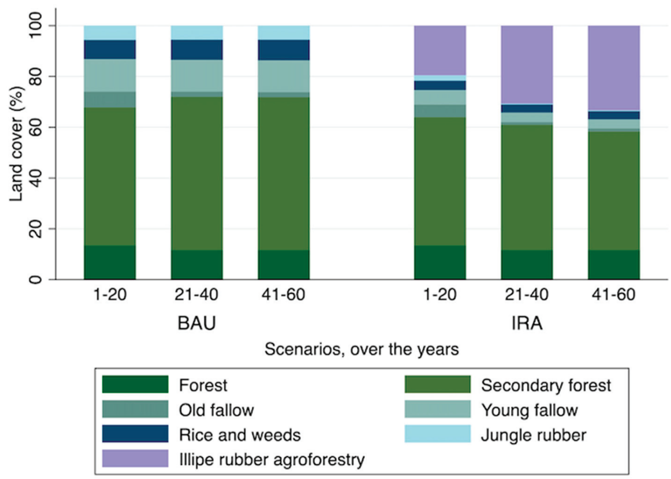


Figure 9. Simulation results: land cover trends over time.

3.2.3. Effects on Biodiversity Conservation and Carbon Sequestration

In addition to livelihood choices and land cover, the model simulates ecosystem changes. The simulations indicate that agroforestry provides a range of environmental benefits. Agroforestry adoption and the related changes of land use significantly improve biodiversity. Specifically, Fisher's alpha increases by 18% (p = 0.000) in the IRA scenario, and bird richness rises by 4% (p = 0.000), as illustrated in Figure 10. Biodiversity is particularly high in native and secondary forests, but also agroforests maintain a comparatively high level of biological diversity. In contrast, biodiversity is rather low in rice plots. The results of tree species richness, tree density, and basal area confirm the results and are presented in the Appendix A.

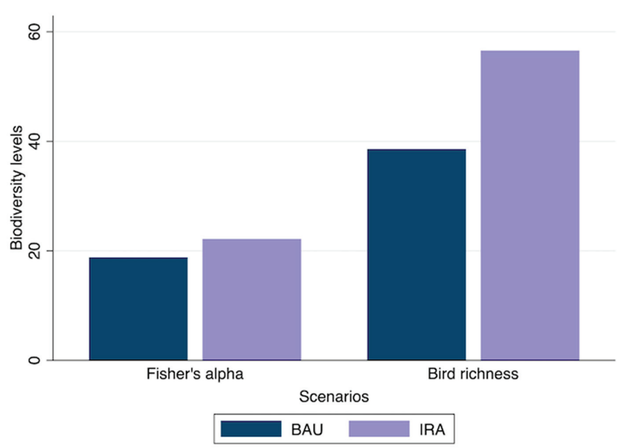


Figure 10. Simulation results: biodiversity levels of tree Fisher's alpha and bird species richness.

In addition to biodiversity, the SAFARI model also simulates changes in aboveground biomass and hence carbon sequestered in the landscape. The results reveal that carbon fixed in the IRA scenario significantly exceeds the amount sequestered in the BAU scenario by 25% ($p = 0.000$) with a positive trend over the years as displayed in Figure 11. Land uses with high biomass and thus carbon sequestration potential include natural and secondary forests as well as agroforests, but jungle rubber plots also store a certain amount of carbon.

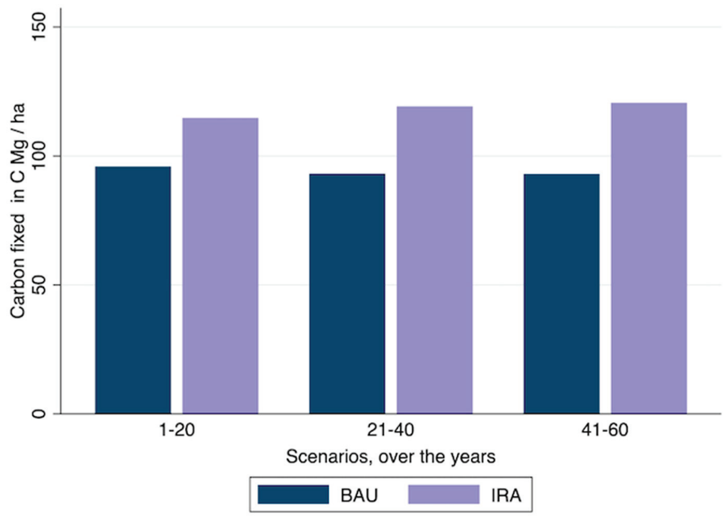


Figure 11. Simulation results: carbon sequestration in the landscape over time.

3.2.4. Climate Change Scenario

Complementing the baseline scenario with constant temperatures, the model further simulates a climate change scenario with a temperature rise of 1.5 °C. As a result of the increased temperatures and consequently reduced rice yields in the CCS, farmers adapt their livelihood choices. Whereas the total number of rice and jungle rubber farmers remains constant in the BAU scenario, farmers react by adjusting the extent to which they engage in these livelihoods. In the BAU scenario, farmers expand their rice production ($p = 0.000$) at the cost of jungle rubber cultivation, which consequently declines ($p = 0.000$), thus shifting their focus away from cash crops to subsistence agriculture as a response to climate change. Yet, the expansion of rice cultivation does not compensate for the yield reduction, and overall climate change results in less calories provided through rice cultivation in the BAU scenario ($p = 0.000$). When the option of agroforestry exists, the simulations indicate that farmers react to climate change by also increasing their rice production ($p = 0.000$), but do not fully compensate yield reduction lowering overall calorie availability from rice cultivation as well ($p = 0.0013$). Simultaneously, farmers expand the share of land under agroforestry ($p = 0.0121$) and slightly more farmers establish agroforestry systems ($p = 0.7825$). Consequently, income from cash crops is significantly higher in the IRA scenario compared with the BAU scenario under climate change ($p = 0.000$), implying that agroforest expansion poses a coping strategy towards climate change.

Rising temperatures and the resulting changes in livelihoods and land use also have environmental consequences. Biodiversity declines due to climate change and resulting livelihood decisions as shown by significant reductions in Fisher's alpha for trees (BAU: $p = 0.000$; IRA: $p = 0.0050$) and bird richness (BAU: $p = 0.0000$; IRA $p = 0.000$). Although climate change affects biodiversity negatively, the simulations predict significantly higher biodiversity levels in the IRA scenario than in the BAU scenario ($p = 0.000$ for Fisher's alpha, $p = 0.000$ for bird richness). Hence, adjusted livelihood choices due to climate change cause lower biodiversity, but agroforests play an important role in conserving biological diversity, especially under climate change. The other biodiversity indicators basal area, tree density, and tree species richness confirm the results that climate change reduces biodiversity due to land use changes in both scenarios, but less so in the agroforestry scenario. Carbon sequestration remains constant in the IRA scenario compared to the BAU scenario, despite rising temperatures ($p = 0.9330$). Appendix A contains illustrations of these results.

4. Discussion

The following section discusses the simulation results regarding adoption rates and income development, land use change, biodiversity conservation, and carbon sequestration.

4.1. Agroforestry Adopters Diversify and Increase Their Income

The simulation results demonstrate high IRA adoption rates amongst farmers. While combining it with jungle rubber and rice cultivation, farmers integrate illipe nut and rubber agroforestry into their livelihood portfolios. Although agroforestry has a higher net present value and cost benefit ratio than swidden agriculture [104], preserving shifting cultivation as an additional livelihood option offers certain advantages; traditional subsistence farming ensures access to the respective commodities and poses a strategy for protecting livelihoods from price fluctuations [87,105]. Besides, combining annual food crops such as rice with agroforestry can bridge the relatively long investment period associated with trees [96,106]. The simulations show that farmers rely on rice cultivation for consumption in the time before the first agroforestry harvest and, to some extent, in the periods when illipe nuts cannot be harvested. Furthermore, subsistence farmers who engage in agroforestry diversify their risk and thus enhance their resilience, as the climate change scenario also demonstrates [96].

The simulation results of the IRA scenario further indicate strong increases in cash income as a result of agroforestry adoption. Several studies highlight that financial outcomes are major benefits of agroforestry, motivating farmers to plant trees on their farms [41,43,107,108]. Agroforestry may even lift poor households out of the poverty cycle [43]. Other studies point out that agroforestry further impacts food security, either indirectly through increased income or directly through self-consumption [3,4,109]. As illipe nuts and rubber are cash crops, they provide additional income sources for rural farmers that can be utilized to improve food security, for example to overcome rice shortages [18,110]. However, illipe nut trees do not flower every year, which limits their income generation potential [98]. Yet, during harvest season, yields are abundant, and in non-harvest years, farmers can profit from the rubber planted in the agroforestry systems [62,98]. According to the simulation results, the positive income effect of agroforestry prevails over several decades and even increases in the long-term. Overall, synergies between rice farming and agroforestry in a diversified portfolio contribute to long-term livelihood improvement and poverty alleviation.

4.2. Illipe Rubber Agroforestry Replaces Jungle Rubber and Rice Cultivation and Thereby Impacts Deforestation

The simulation results regarding land use give an indication of how farmers' agroforestry adoption transforms the landscape. According to the results, the area covered by agroforests significantly increases. In contrast, jungle rubber and rice farming become less popular as land uses in the IRA scenario. While agricultural activities and rice cultivation are significant drivers of tropical deforestation [9,61,111], agroforestry can offer high potential to reduce forest loss [3,23]. If agroforests are established on fallow land, as in our site, they rehabilitate formerly forested open land [112]. Furthermore, agroforestry adoption indirectly impacts deforestation because agroforestry adopters clear less land than purely swidden farmers [104]. Thus, although agroforests cover a relatively large share of the landscape, the simulations show that the native forest area remains constant under the IRA and BAU scenarios. Thereby, the results highlight the potential of agroforestry to significantly enhance livelihoods without causing forest loss.

4.3. Agroforestry Supports Biodiversity Conservation and Carbon Sequestration

With respect to biodiversity conservation, the model shows that agroforestry adoption improves tree and bird biodiversity levels. Our results confirm several studies which show that agroforestry protects biodiversity, as demonstrated by increased species richness [67,113], species diversity [2,27,108,114], or species density [20,115]. Thereby, biodiversity-supporting agroforests provide a high-quality habitat with stable conditions outside formally protected areas [96,116]. Some authors argue that biodiversity levels in tropical agroforests are comparable to native forest, although species composition differs [114,117]. However, our model suggests that the potential of agroforests to conserve biodiversity is limited as they cannot fully replace native forests and habitats [20]. The extent to which agroforestry systems conserve biodiversity possibly depends on their structural and floristic characteristics and connectivity to natural forests. Consequently, incorporating native forest trees with high canopy cover, such as the illipe nut tree, are favorable to maintain high bird species richness for example [67,114]. Although agroforests might not achieve the same level of species richness as forests and comprise distinguished species compositions, these systems nevertheless result in greater biodiversity compared with otherwise open land [67,116]. Accordingly, agroforestry implemented on former fallow land as in our site affects biodiversity positively. Agroforests also indirectly benefit biodiversity by reducing the need for conversion of forests into cropland [11,20,118]. Furthermore, by connecting areas of natural habitats, agroforestry plays a key role for biodiversity conservation in human-dominated landscapes [20,67,119]. In this way, agroforests ensure persistence and movement of wild species across landscapes, and hence gain special appeal in buffer zones or biological corridors such as the study area [20,67,116,117]. For example, agroforests in Batang Lupar district can contribute to biodiversity conservation through their canopy cover, which supports local orangutan species to move between the adjacent national parks [66–68].

Additional to biodiversity, agroforestry adoption enhances long-term carbon sequestration in the landscape according to the model findings. The simulation results comply with many studies which point out the high potential of agroforests to increase biomass and thereby accumulate carbon leading to long-term climate mitigation [24,27]. Whereas Abbas et al. (2017) find agroforestry to reach carbon levels comparable to natural forests, Matocha et al. (2012) conclude that agroforests fix less carbon than primary forests. However, compared with crop and grazing land use, whose carbon stocks are low, agroforestry systems retain much higher quantities of carbon in above and belowground biomass [24,112]. Consequently, similar to biodiversity conservation, net benefits of agroforestry may depend on the location [112]. Agroforests implemented within forests may cause degradation, but realize net benefits if cultivated on open land as an alternative to cropland, pasture, or fallow [112,120]. In addition to direct carbon sequestration, agroforestry poses an alternative to agriculture, which is the second largest source of anthropogenic greenhouse gas emissions [9,61,111]. Therefore, as agroforestry reduces the need for deforestation, shown by the changed land use and cover according to the simulations, it also indirectly contributes to carbon sequestration [24,120]. In sum, agroforestry poses a powerful pathway to conserve biodiversity and mitigate climate change through carbon accumulation [3,23,24].

4.4. Agroforestry as a Means to Adapt to and Mitigate Climate Change

The simulations of the climate change scenario indicate that rising temperatures endanger agricultural production and farmers' wealth with negative impacts on ecosystem services. Several studies confirm that climate change is a significant and growing threat to livelihoods and particularly food security [13,121,122]. The simulation results further show that significantly higher incomes can be expected in the IRA scenario compared with the BAU scenario under climate change. These results conform with other studies' findings that agroforests enhance the ability to adapt to market and climate shocks as diversification through trees helps to spread risk [18,96]. This result gains special importance for subsistence farmers in developing countries. These farmers are particularly vulnerable as they frequently lack assets and flexibility to cope with the impacts that climate change has on agricultural productivity [121–123]. Hence the findings stress the importance of agroforests like the illipe rubber mix as a safety net in the light of the ongoing climate change as they contribute to increased income, risk diversification, and resilience for small-scale farmers [18,96,106]

The simulations further demonstrate that climate change negatively affects biodiversity, but higher levels can be expected in the IRA scenario, which again underlines the role of agroforests in conserving biological diversity [67,113,115]. Besides, the positive effects agroforestry has on carbon sequestration make this agricultural practice an attractive tool for climate change mitigation [29,119,124]. Overall, by combining adaptation and mitigation measures, agroforestry poses a win-win-strategy for farmers and nature to address major local and global environmental challenges including climate change mitigation and poverty alleviation [6,23,29,120].

Although the model refers not only to the farm level, but also to the landscape level, the application is adjusted to a specific case study. However, in many regions of the world, context-specific agroforestry systems are being practiced or tested as a strategy for achieving the UN-Sustainable Development Goals across the world's production landscapes [125]. Case studies show, for example, the positive impacts of agroforestry serving as safety nets for poor households [126], improving food security and income [127], providing habitat for endangered species in corridors between protected areas [128], guaranteeing ecosystem services such as erosion control [129], and conserving biodiversity [130]. Our case study adds to the literature by confirming these positive effects on humans and the environment in the long-run and under rising temperatures. In different contexts and eco-regions, trees on farms have different functions, and tree composition therefore has to be adapted to the specific problems to be addressed through integrating trees. Although the illipe rubber agroforestry system is specifically adjusted to the context of the case study and its promotion requires context-specific considerations, the general socio-economic implications for policy-makers apply to other comparable regions and countries as well.

4.5. ABM as a Tool for Combining Human Decision Making and Environmental Dynamics

The present application demonstrates that agent-based models are eligible tools to explore the complex and interlinked dynamics between environmental and human system components over larger spatial and temporal scales. Hereby, a main advantage of ABMs over other modelling techniques lies in the opportunity to explicitly model individual decision making [131]. In the SAFARI model, farmers make livelihood decisions, which impacts land cover and use. In turn, land use influences farmers' decisions whether to engage in additional agricultural activities. By coupling human behavior with natural processes, ABMs can account for feedback and interdependencies between farmers and their environment in social-ecological systems [132]. Furthermore, the ABM connects characteristics and behaviors of individual agents to the system's dynamics and structure [133]. For example, farmers' decisions and interactions with the environment on the micro-level shape environmental process such as biodiversity changes as well as the emerging land use patterns on larger scales. Since ABMs do not impose assumptions on stationarity, linearity, and homogeneity, they can cover a range of potential system states, including unlikely, path-dependent, or emergent outcomes [134,135].

The present simulation, as well as the growing use of ABMs in policy in general, illustrate that ABMs can be advantageous instruments to assist intervention design. By creating a virtual setting to conduct experiments, ABMs can investigate and compare policy options, such as introducing and promoting IRA systems as an alternative to jungle rubber, and explore possible future development paths that can be anticipated under different states of the world, such as climate change scenarios, in a relatively cost-efficient way [133,136]. Accordingly, the SAFARI ABM allows the user to compare how agroforestry affects farmers' livelihoods and the environment with and without climate change before actually commencing to promote the innovation. Additionally, the SAFARI simulates developments over the long-term (sixty years) and considers effects across the landscape. However, ABMs are not suitable to predict the future. Instead, they aim to identify possible and probable development paths and unwanted or unintended consequences [133,135]. The present analysis shows that introducing IRA likely leads to a favorable development path that enhances livelihoods and environmental outcomes. In this way, the present study demonstrates how ABMs complement existing research and contribute to understanding the potential of agroforestry to alleviate poverty, strengthen resilience, and mitigate climate change in order to support development practitioners in designing innovation interventions.

4.6. Limitations and Future Research

The analysis presented here has several limitations. Our study incorporates a decision heuristic accounting for food security, income generation, and resource availability, but further factors may play a role in farmers' adoption decisions. Investment considerations and information availability can influence adoption [137,138]. Further determinants include socio-economic characteristics as well as behavioral and psychological factors such as risk attitude and time preference [139,140]. Because the present analysis only considers land and labor constraints, other potential barriers such as unavailability of further inputs such as seedlings are not taken into account. Required training to improve technical skills and inputs for agroforestry implementation are assumed to be provided and hence do not restrict adoption in our model. Furthermore, the support of stakeholder engagement to encourage change and correspondingly a preference of IRA systems over jungle rubber are assumed, but in reality, possible aversion to change and innovation might impose a barrier to adoption. As a consequence, the simulations might overestimate implementation until incentives are introduced to address the inhibiting factors, such as lack of credit and markets for inputs, and behavioral preferences such as risk aversion or a lack of willingness to innovate. The use of timber from the illipe nut trees is not considered in this application, but may play a role as a motivating factor to adopt agroforestry [141]. Additionally, functioning markets for illipe nuts and products are assumed to exist, but in practice marketing opportunities in the area are restricted through the remote location of the villages. For simplification, the baseline decision heuristic was restricted to the main livelihoods prevalent in the study area (rice and jungle rubber cultivation). Additionally, illipe nut harvest season is assumed to occur every four years, but may depend on weather conditions [142]. Due to a lack of data, it was not possible to include belowground biomass and further ecosystem services such as soil enrichment, water cycling, or air quality.

These limitations can stimulate further research. Different decision-making processes with additional livelihood options and accounting for behavioral aspects may be considered for further analysis. Future research should assess further ecosystem services and the interaction between them, and how biodiversity impacts ecosystem services. Assessing other aspects of climate change such as droughts and changing rainfall patterns applying empirically based simulation approaches will increase the understanding of the potential of agroforestry for climate change mitigation. Besides, the SAFARI model could be extended to explore additional policy options. In this context, demand for illipe nuts could be included in the model to explore different marketing strategies aiming at supporting local communities to realize economic profits while conserving biodiversity through agroforestry.

5. Conclusions

The present paper explores how agroforestry adoption affects famers' livelihoods, land use, biodiversity, and carbon sequestration over time. To link behavioral and environmental dynamics and compare different scenarios, an empirical agent-based model was implemented and adjusted to a case study in rural Indonesia. By connecting individual farmer decisions with ecological processes, the ABM demonstrates that agroforestry maintains native forests while significantly improving livelihoods, hence realizing advantages on the household and landscape levels. The simulations show that when farmers decide to include illipe rubber agroforestry into their livelihood portfolios, they benefit from such adoption through diversified and increased incomes. These valuable livelihood improvements even intensify in the long-term. Moreover, the simulations confirm that agroforests significantly contribute to biodiversity conservation and carbon sequestration. Especially in the climate change scenario, agroforests gain importance due to strengthened farmers' resilience as well as direct and indirect environmental benefits. Thus, the findings clearly indicate that, compared with the existing agricultural practices, adopting such agroforestry systems is advantageous for the small-scale farmers as well as the environment, and poses a valuable alternative to rubber and oil palm monoculture. The findings provide policy makers and development practitioners with insights into how the promotion of these agroforestry systems can support climate change mitigation and adaptation, biodiversity conservation, and poverty alleviation in developing countries in the long term. The simulation results also imply that policy-makers should consider several aspects when introducing IRA. Firstly, possible adoption barriers need to be removed, for example by providing inputs and trainings through extension services. Secondly, policy-makers should raise awareness of the economic and environmental benefits to stimulate demand for this agricultural practice. Another option to increase investment into agroforestry could be the financial compensation for environmentally friendly practices. Thirdly, attractive marketing opportunities are needed, possibly drawing upon international demand for illipe nuts for cosmetics or as substitutes to palm oil. Although the illipe rubber agroforestry system is adjusted to the Indonesian case study, the findings provide general socio-economic implications that are of interest for other comparable regions and countries, and indicate relevant upscaling possibilities.

Author Contributions: Conceptualization, B.N., E.W. and Y.L.; methodology, B.N.; software, B.N.; validation, B.N.; formal analysis, B.N.; investigation, B.N., Y.L. and T.S.; resources, Y.L., T.S.; data curation, B.N.; writing—original draft preparation, B.N.; writing—review and editing, E.W., Y.L. and T.S.; visualization, B.N.; supervision, E.W. and Y.L.; project administration, E.W. and Y.L.; funding acquisition, E.W. and Y.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the International Climate Initiative (IKI) of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), grant number 18_IV_064_Global_A_Trees on Farms; the Center for International Forestry Research (CIFOR); the World Agroforestry (ICRAF) and the Consortium Research Program on Forests, Trees, and Agroforestry (CRP-FTA).

Acknowledgments: The publication of this article was funded by the Open Access Fund of the Leibniz University of Hannover.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Model Documentation: The model has been implemented in NetLogo [83]. The model is available at: https://www.comses.net/codebase-release/1fb6c49f-a4b3-4135-b25a-1d5534c1a7cf/.

Appendix A

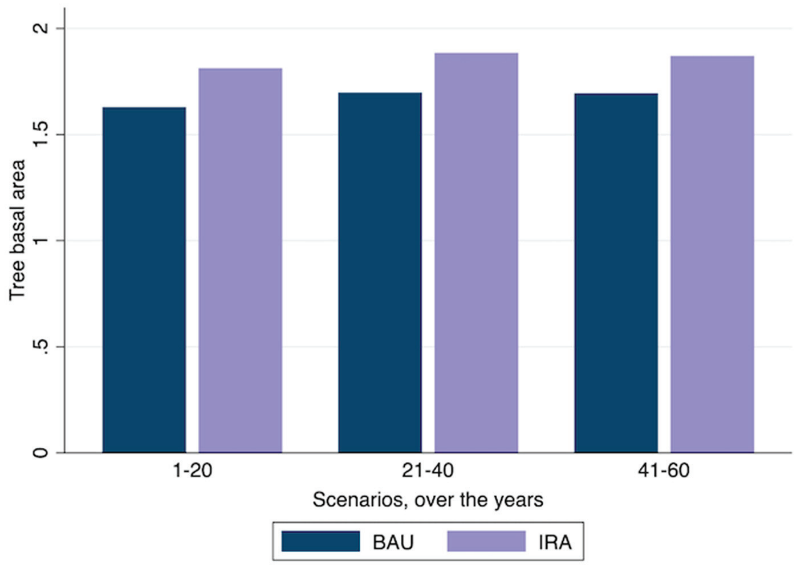


Figure A1. Simulation results: tree basal area over time.

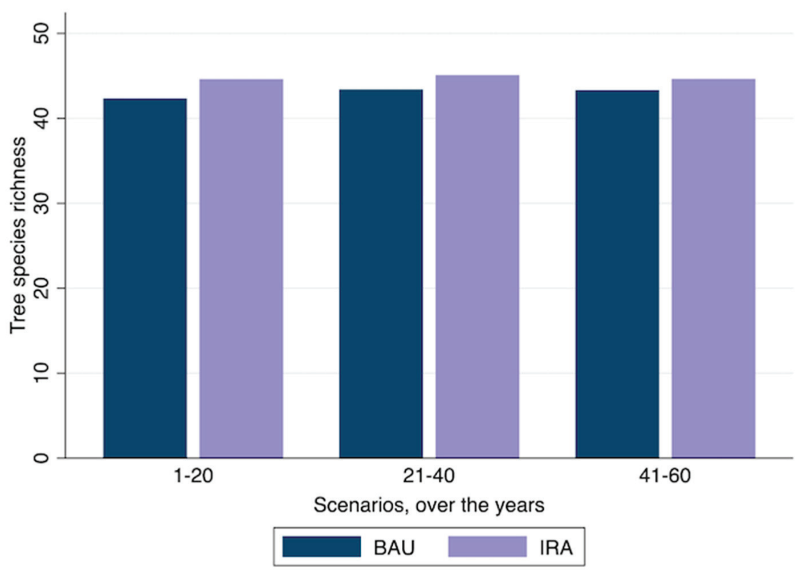


Figure A2. Simulation results: tree species richness over time.

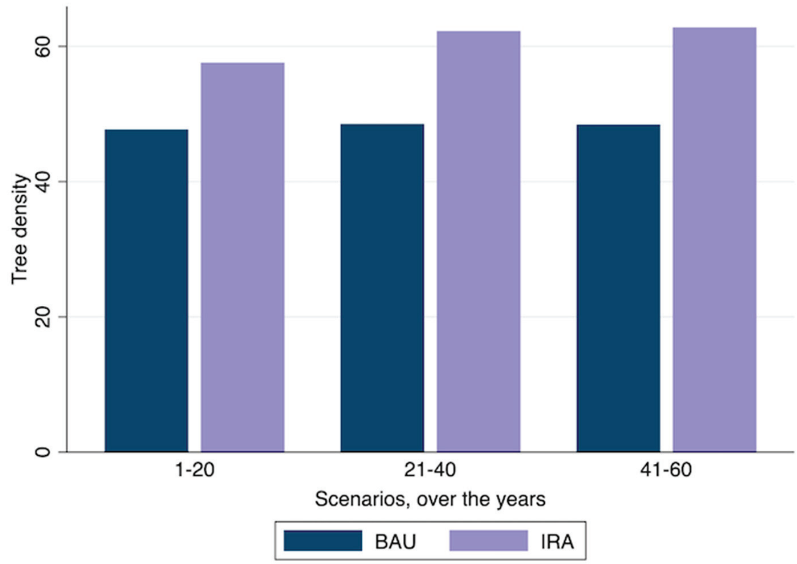


Figure A3. Simulation results: tree density over time.

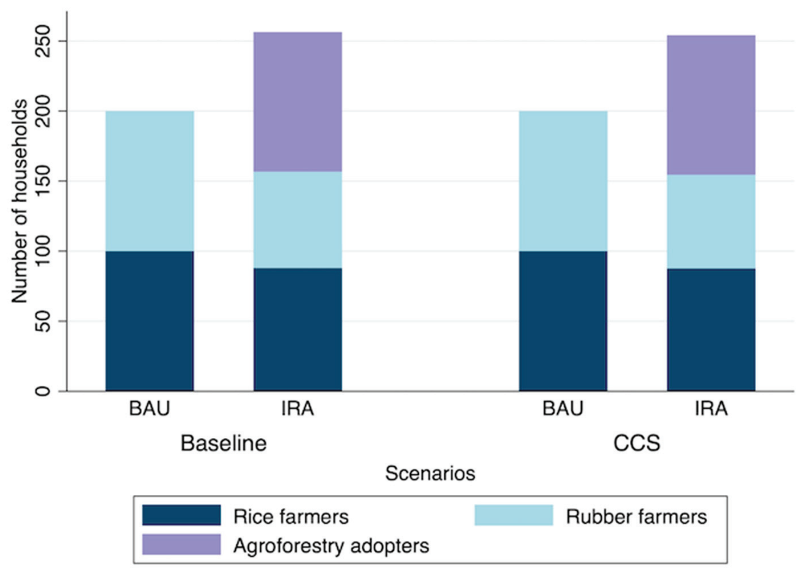


Figure A4. Simulation results: farmers' livelihood choices in the baseline and climate change scenario.

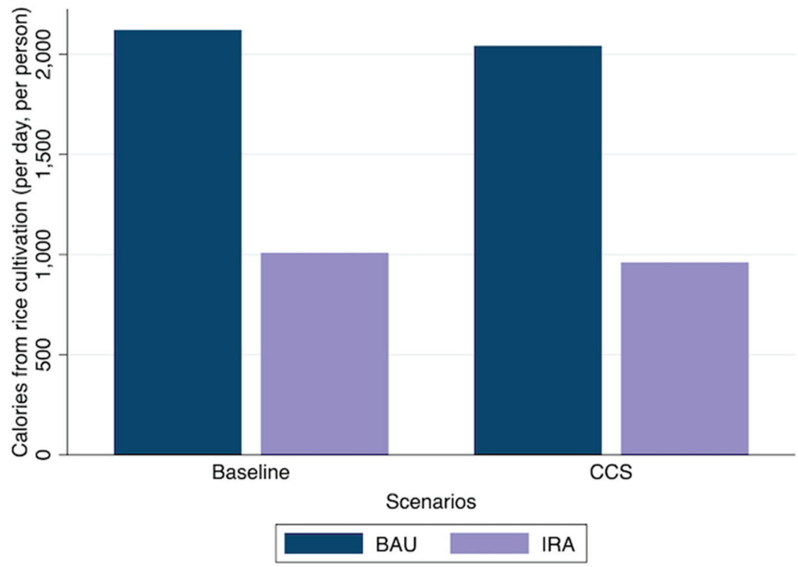


Figure A5. Simulation results: generated calories from rice cultivation in the baseline and climate change scenario.

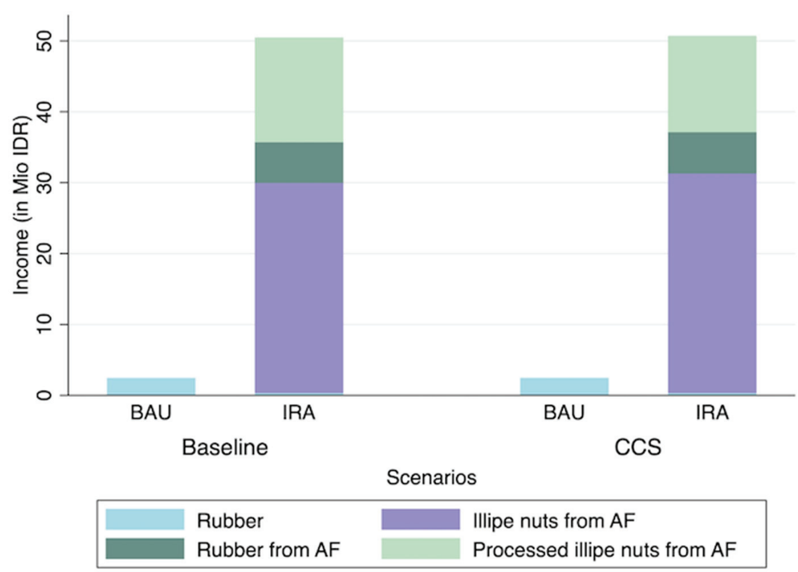


Figure A6. Simulation results: generated cash income in the baseline and climate change scenario.

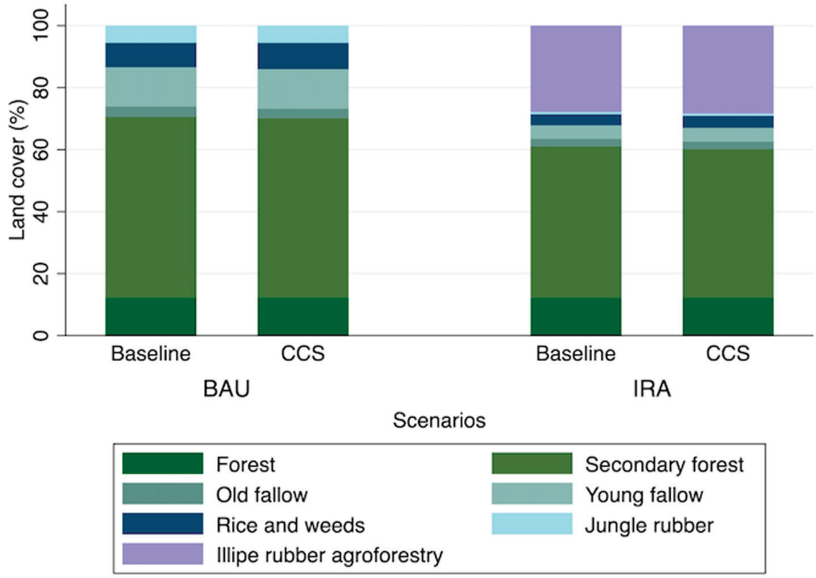


Figure A7. Simulation results: land cover in the baseline and climate change scenario.

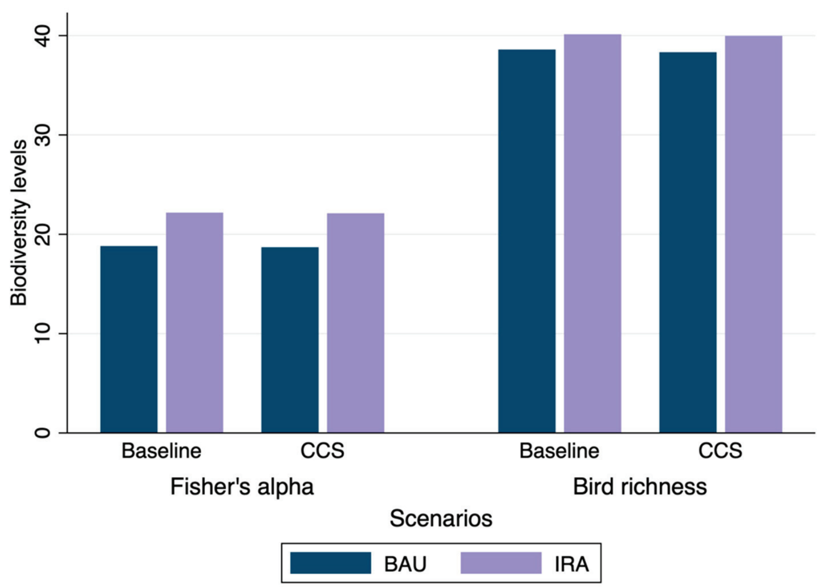


Figure A8. Simulation results: biodiversity levels of tree Fisher's alpha and bird species richness in the baseline and climate change scenario.

References

1. FAO. *The State of the Food and Agriculture*; FAO Agriculture Series No. 38; FAO: Rome, Italy, 2007.
2. Barrios, E.; Valencia, V.; Jonsson, M.; Brauman, A.; Hairiah, K.; Mortimer, P.E.; Okubo, S. Contribution of trees to the conservation of biodiversity and ecosystem services in agricultural landscapes. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* **2018**, *14*, 1–16. [CrossRef]

3. Garrity, D.P.; Akinnifesi, F.K.; Ajayi, O.C.; Weldesemayat, S.G.; Mowo, J.G.; Kalinganire, A.; Larwanou, M.; Bayala, J. Evergreen Agriculture: A robust approach to sustainable food security in Africa. *Food Secur.* **2010**, *2*, 197–214. [CrossRef]
4. Waldron, A.; Garrity, D.; Malhi, Y.; Girardin, C.; Miller, D.C.; Seddon, N. Agroforestry Can Enhance Food Security While Meeting Other Sustainable Development Goals. *Trop. Conserv. Sci.* **2017**, *10*, 1–6. [CrossRef]
5. FAO. *The State of the World's Forests 2018—Forest Pathways to Sustainable Development*; FAO: Rome, Italy, 2018.
6. Tschora, H.; Cherubini, F. Co-benefits and trade-offs of agroforestry for climate change mitigation and other sustainability goals in West Africa. *Glob. Ecol. Conserv.* **2020**, *22*. [CrossRef]
7. Henders, S.; Ostwald, M.; Verendel, V.; Ibisch, P. Do national strategies under the UN biodiversity and climate conventions address agricultural commodity consumption as deforestation driver? *Land Use Policy* **2018**, *70*, 580–590. [CrossRef]
8. Kopittke, P.M.; Menzies, N.W.; Wang, P.; McKenna, B.A.; Lombi, E. Soil and the intensification of agriculture for global food security. *Environ. Int.* **2019**, *132*. [CrossRef] [PubMed]
9. Jayathilake, H.M.; Prescott, G.W.; Carrasco, L.R.; Rao, M.; Symes, W.S. Drivers of deforestation and degradation for 28 tropical conservation landscapes. *Ambio* **2020**. [CrossRef] [PubMed]
10. Ndayambaje, J.D.; Heijman, W.J.M.; Mohren, G.M.J. Household Determinants of Tree Planting on Farms in Rural Rwanda. *Small-Scale For.* **2012**, *11*, 477–508. [CrossRef]
11. Paiva, P.F.P.R.; de Lourdes Pinheiro Ruivo, M.; da Silva Júnior, O.M.; de Nazaré Martins Maciel, M.; Braga, T.G.M.; de Andrade, M.M.N.; dos Santos Junior, P.C.; da Rocha, E.S.; de Freitas, T.P.M.; da Silva Leite, T.V.; et al. Deforestation in protect areas in the Amazon: A threat to biodiversity. *Biodivers. Conserv.* **2020**, *29*, 19–38. [CrossRef]
12. Altieri, M.A.; Nicholls, C.I.; Henao, A.; Lana, M.A. Agroecology and the design of climate change-resilient farming systems. *Agron. Sustain. Dev.* **2015**, *35*, 869–890. [CrossRef]
13. Wiebe, K.; Robinson, S.; Cattaneo, A. Climate Change, Agriculture and Food Security. *Sustain. Food Agric.* **2019**, 55–74. [CrossRef]
14. Salvini, G.; Ligtenberg, A.; van Paassen, A.; Bregt, A.K.; Avitabile, V.; Herold, M. REDD+ and climate smart agriculture in landscapes: A case study in Vietnam using companion modelling. *J. Environ. Manag.* **2016**, *172*, 58–70. [CrossRef] [PubMed]
15. Feleke, S.; Cole, S.M.; Sekabira, H.; Djouaka, R.; Manyong, V. Circular Bioeconomy Research for Development in Sub-Saharan Africa: Innovations, Gaps, and Actions. *Sustainability* **2021**, *13*, 1926. [CrossRef]
16. FAO. *Agroecological and Other Innovative Approaches for Sustainable Agriculture and Food Systems that Enhance Food Security and Nutrition—A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*; FAO: Rome, Italy, 2019.
17. Runhaar, H. Governing the transformation towards 'nature-inclusive' agriculture: Insights from the Netherlands. *Int. J. Agric. Sustain.* **2017**, *15*, 340–349. [CrossRef]
18. Reed, J.; van Vianen, J.; Foli, S.; Clendenning, J.; Yang, K.; MacDonald, M.; Petrokofsky, G.; Padoch, C.; Sunderland, T. Trees for life: The ecosystem service contribution of trees to food production and livelihoods in the tropics. *For. Policy Econ.* **2017**, *84*, 62–71. [CrossRef]
19. FAO. *Advancing Agroforestry on the Policy Agenda: A Guide for Decision-Makers, by G. Buttoud, in Collaboration with O. Ajayi, G. Detlefsen, F. Place & E. Torquebiau*; Agroforestry Working Paper No. 1; FAO: Rome, Italy, 2013.
20. Schroth, G.; da Mota, M.d.S.S. Tropical Agroforestry. In *Farming with Nature: The Science and Practice of Ecoagriculture*; Scherr, S.J., McNeely, J.A., Eds.; Island Press: Washington, DC, USA; London, UK, 2007; pp. 101–118.
21. Lasco, R.D.; Espaldon, M.L.O.; Habito, C.M.D. Smallholder farmers' perceptions of climate change and the roles of trees and agroforestry in climate risk adaptation: Evidence from Bohol, Philippines. *Agrofor. Syst.* **2016**, *90*, 521–540. [CrossRef]
22. FAO; ICRAF. *Agroforestry and tenure*; Forestry Working Paper No. 8; FAO: Rome, Italy, 2019.
23. Casanova-Lugo, F.; Ramírez-Avilés, L.; Parsons, D.; Caamal-Maldonado, A.; Pineiro-Vázquez, A.; Díaz-Echeverría, V. Environmental services from tropical agroforestry systems. *Ser. Ciencias For. Ambient.* **2016**, *XXII*, 269–284. [CrossRef]
24. Abbas, F.; Hammad, H.M.; Fahad, S.; Cerdà, A.; Rizwan, M.; Farhad, W.; Ehsan, S.; Bakhat, H.F. Agroforestry: A sustainable environmental practice for carbon sequestration under the climate change scenarios—A review. *Environ. Sci. Pollut. Res.* **2017**, *24*, 11177–11191. [CrossRef]
25. Hilbrand, A.; Borelli, S.; Conigliaro, M.; Olivier, A. *Agroforestry for Landscape Restoration*; FAO: Rome, Italy, 2017.
26. Van Noordwijk, M.; Lusiana, B. WaNuLCAS, a model of water, nutrient and light capture in agroforestry systems. *Agrofor. Syst.* **1999**, *43*, 217–242. [CrossRef]
27. Sari, R.R.; Saputra, D.D.; Hairiah, K.; Rozendaal, D.M.A.; Roshetko, J.M.; Noordwijk, M. Van Gendered species preferences link tree diversity and carbon stocks in Cacao agroforest in Southeast Sulawesi, Indonesia. *Land* **2020**, *9*, 108. [CrossRef]
28. Newaj, R.; Chaturvedi, O.P.; Handa, A.K. Recent development in agroforestry research and its role in climate change adaptation and mitigation. *Indian J. Agrofor.* **2016**, *18*, 1–9.
29. Verchot, L.V.; Van Noordwijk, M.; Kandji, S.; Tomich, T.; Ong, C.; Albrecht, A.; Mackensen, J.; Bantilan, C.; Anupama, K.V.; Palm, C. Climate change: Linking adaptation and mitigation through agroforestry. *Mitig. Adapt. Strateg. Glob. Chang.* **2007**, *12*, 901–918. [CrossRef]
30. Lasco, R.D.; Delfino, R.J.P.; Catacutan, D.C.; Simelton, E.S.; Wilson, D.M. Climate risk adaptation by smallholder farmers: The roles of trees and agroforestry. *Curr. Opin. Environ. Sustain.* **2014**, *6*, 83–88. [CrossRef]
31. Umar, S.; Yodo, S.; Alam, A.S.; Aslam, D.; Livawanti, L. Post-adoption of the candlenut agroforestry in Central Sulawesi, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* **2018**, *196*. [CrossRef]

32. Do, H.; Luedeling, E.; Whitney, C. Decision analysis of agroforestry options reveals adoption risks for resource-poor farmers. *Agron. Sustain. Dev.* **2020**, *40*. [CrossRef]
33. Ashraf, J.; Pandey, R.; de Jong, W.; Nagar, B. Factors Influencing Farmers' Decisions to Plant Trees on Their Farms in Uttar Pradesh, India. *Small-Scale For.* **2015**, *14*, 301–313. [CrossRef]
34. Gebru, B.M.; Wang, S.W.; Kim, S.J.; Lee, W.K. Socio-ecological niche and factors affecting agroforestry practice adoption in different agroecologies of southern Tigray, Ethiopia. *Sustainability* **2019**, *11*, 3729. [CrossRef]
35. Sabastian, G.E.; Yumn, A.; Roshetko, J.M.; Manalu, P.; Martini, E.; Perdana, A. Adoption of silvicultural practices in smallholder timber and NTFPs production systems in Indonesia. *Agrofor. Syst.* **2019**, *93*, 607–620. [CrossRef]
36. Mekonnen, A.; Damte, A. *Private Trees as Household Assets and Determinants of Tree-Growing Behavior in Rural Ethiopia*; EfD DP 11-14; JSTOR: New York, NY, USA, 2011.
37. Amare, D.; Wondie, M.; Mekuria, W.; Darr, D. Agroforestry of Smallholder Farmers in Ethiopia: Practices and Benefits. *Small-Scale For.* **2019**, *18*, 39–56. [CrossRef]
38. Zerihun, M.F.; Muchie, M.; Worku, Z. Determinants of agroforestry technology adoption in Eastern Cape Province, South Africa. *Dev. Stud. Res.* **2014**, *1*, 382–394. [CrossRef]
39. Vallejo, M.; Ramírez, M.I.; Reyes-González, A.; López-Sánchez, J.G.; Casas, A. Agroforestry systems of the tehuacan-cuicatlan valley: Land use for biocultural diversity conservation. *Land* **2019**, *8*, 24. [CrossRef]
40. Sood, K.K.; Mitchell, C.P. Identifying important biophysical and social determinants of on-farm tree growing in subsistence-based traditional agroforestry systems. *Agrofor. Syst.* **2009**, *75*, 175–187. [CrossRef]
41. Miller, D.C.; Muñoz-Mora, J.C.; Christiaensen, L. Prevalence, economic contribution, and determinants of trees on farms across Sub-Saharan Africa. *For. Policy Econ.* **2017**, *84*, 47–61. [CrossRef]
42. David, M.; Bernard, B.; Aringaniza, I. Determinants of agroforestry adoption as an adaptation means to drought among smallholder farmers in Nakasongola District, Central Uganda. *African J. Agric. Res.* **2017**, *12*, 2024–2035. [CrossRef]
43. Pandit, B.H.; Nuberg, I.; Shrestha, K.K.; Cedamon, E.; Amatya, S.M.; Dhakal, B.; Neupane, R.P. Impacts of market-oriented agroforestry on farm income and food security: Insights from Kavre and Lamjung districts of Nepal. *Agrofor. Syst.* **2019**, *93*, 1593–1604. [CrossRef]
44. Dinh, H.H.; Nguyen, T.T.; Hoang, V.N.; Wilson, C. Economic incentive and factors affecting tree planting of rural households: Evidence from the Central Highlands of Vietnam. *J. For. Econ.* **2017**, *29*, 14–24. [CrossRef]
45. Nyaga, J.; Muthuri, C.W.; Barrios, E.; Öborn, I.; Sinclair, F.L. Enhancing maize productivity in agroforestry systems through managing competition: Lessons from smallholders' farms, Rift valley, Kenya. *Agrofor. Syst.* **2019**, *93*, 715–730. [CrossRef]
46. Do, V.H.; La, N.; Mulia, R.; Bergkvist, G.; Sigrun Dahlin, A.; Nguyen, V.T.; Pham, H.T.; Öborn, I. Fruit tree-based agroforestry systems for smallholder farmers in northwest vietnam—A quantitative and qualitative assessment. *Land* **2020**, *9*, 451. [CrossRef]
47. Van der Werf, W.; Keesman, K.; Burgess, P.; Graves, A.; Pilbeam, D.; Incoll, L.D.; Metselaar, K.; Mayus, M.; Stappers, R.; van Keulen, H.; et al. Yield-SAFE: A parameter-sparse, process-based dynamic model for predicting resource capture, growth, and production in agroforestry systems. *Ecol. Eng.* **2007**, *29*, 419–433. [CrossRef]
48. Magcale-Macandog, D.B.; Ani, P.A.B.; Delgado, M.M.; Campo, P. Modelling the Dynamics of Agroforestry Adoption in the Uplands of Southern Philippines Using Companion Modelling Approach. In Proceedings of the Improving the Triple Bottom Line Returns from Small-scale Forestry, Proceedings from an International Conference, Gatton, Australia, 18–21 June 2007; pp. 347–356.
49. Villamor, G.B.; Djanibekov, U.; Le, Q.B.; Vlek, P.L.G. Modelling the socio-ecological system dynamics of rubber agroforests to design reward mechanisms for agro-biodiversity conservation. In Proceedings of the 20th International Congress on Modelling and Simulation, MODSIM 2013, Adelaide, Australia, 1–6 December 2013; pp. 1861–1867.
50. Smajgl, A.; Xu, J.; Egan, S.; Yi, Z.F.; Ward, J.; Su, Y. Assessing the effectiveness of payments for ecosystem services fordiversifying rubber in Yunnan, China. *Environ. Model. Softw.* **2015**, *69*, 187–195. [CrossRef]
51. Suwarno, A.; van Noordwijk, M.; Weikard, H.P.; Suyamto, D. Indonesia's forest conversion moratorium assessed with an agent-based model of Land-Use Change and Ecosystem Services (LUCES). *Mitig. Adapt. Strateg. Glob. Chang.* **2018**, *23*, 211–229. [CrossRef]
52. Rounsevell, M.D.A.; Robinson, D.T.; Murray-Rust, D. From actors to agents in socio-ecological systems models. *Philos. Trans. R. Soc. B Biol. Sci.* **2012**, *367*, 259–269. [CrossRef]
53. Miller, D.C.; Ordoñez, P.J.; Brown, S.E.; Forrest, S.; Nava, N.J.; Hughes, K.; Baylis, K. The impacts of agroforestry on agricultural productivity, ecosystem services, and human well-being in low-and middle-income countries: An evidence and gap map. *Campbell Syst. Rev.* **2019**, *16*. [CrossRef]
54. Widmann, P.; Tjiu, A.; Putera, M.H.; Wulffraat, S. *Connecting Diversity. People and Nature of Labian-Leboyan Corridor in the Indonesian Heart of Borneo*; WWF: Jakarta, Indonesia, 2012.
55. Ocampo-Peñuela, N.; Garcia-Ulloa, J.; Kornecki, I.; Philipson, C.D.; Ghazoul, J. Impacts of Four Decades of Forest Loss on Vertebrate Functional Habitat on Borneo. *Front. For. Glob. Chang.* **2020**, *3*, 1–13. [CrossRef]
56. Barnes, A.D.; Jochum, M.; Mumme, S.; Haneda, N.F.; Farajallah, A.; Widarto, T.H.; Brose, U. Consequences of tropical land use for multitrophic biodiversity and ecosystem functioning. *Nat. Commun.* **2014**, *5*, 1–7. [CrossRef]
57. Purwanto, E.; Santoso, H.; Jelsma, I.; Widayati, A.; Nugroho, H.Y.S.H.; van Noordwijk, M. Agroforestry as policy option for forest-zone oil palm production in indonesia. *Land* **2020**, *9*, 531. [CrossRef]

58. Jonas, H.; Abram, N.K.; Ancrenaz, M. *Addressing the Impact of Large-Scale Oil Palm Plantations on Orangutan Conservation in Borneo*; IIED: London, UK, 2017.
59. Budiharta, S.; Meijaard, E. State of Kalimantan 's biodiversity. In *Development, Environment and the People of Kalimantan*; Resosudarmo, B.P., Imansyah, M.H., Napitupulu, L., Eds.; Indonesian Regional Science Association (IRSA): Jakarta, Indonesia, 2017.
60. WWF. *Climate Change Scenarios and Risks*; Heart of Borneo Programme WWF-Indonesia: Jakarta, Indonesia, 2016.
61. Austin, K.G.; Schwantes, A.; Gu, Y.; Kasibhatla, P.S. What causes deforestation in Indonesia? *Environ. Res. Lett.* **2019**, *14*, 24007. [CrossRef]
62. Winarni, B.; Lahjie, A.M.; Simarangkir, B.D.A.S.; Yusuf, S.; Ruslim, Y. Tengkawang cultivation model in community forest using agroforestry systems in West Kalimantan, Indonesia. *Biodiversitas* **2017**, *18*, 765–772. [CrossRef]
63. Shantiko, B.; Fripp, E.; Taufiqoh, T.; Heri, T.; Laumonier, Y. *Socio-Economic Considerations for Land-Use Planning; The Case of Kapuas Hulu, West Kalimantan*; Center for International Forestry Research (CIFOR): Bogor, Indonesia, 2013.
64. Dudot, C. Strengthening Community Based Forestry and Watershed Management: Socio-Economic Study of Tengkawang Value Chain, North of Danau Sentarum National Park, West Kalimantan. Master's Thesis, Agroparistech, Montpellier, France, 2014. Unpublished.
65. Randi, A.; Barstow, M.S.J.; Kusumadewi, Y. Shorea Stenoptera. The IUCN Red List of Threatened Species. e.T33623A125629727. Available online: https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T33623A125629727.en (accessed on 25 March 2021).
66. Prayogo, H.; Thohari, A.M.; Solihin, D.D.; Prasetyo, L.B.; Sugardjito, J. Habitat Suitability Modeling of Bornean Orangutan (Pongo pygmaeus pygmaeus) in Betung Kerihun National Park, Danau Sentarum and Corridor, West Kalimantan. *JMHT* **2014**. [CrossRef]
67. Haggar, J.; Pons, D.; Saenz, L.; Vides, M. Contribution of agroforestry systems to sustaining biodiversity in fragmented forest landscapes. *Agric. Ecosyst. Environ.* **2019**, *283*, 1–41. [CrossRef]
68. Adriyanti, D.T.; Hardiwinoto, S.; Giesen, W.; van der Meer, P.; Coolen, Q.; Karyanto, O. *Illipe Nut Plantation on Undrained Peatland*; Mitigation of Climate Change in Agriculture Series 9; FAO: Rome, Italy, 2014.
69. IPCC. Summary for Policymakers. In *Global Warming of 1.5 °C. An IPCC Special Report on the Impacts of Global Warming of 1.5 °C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change*; Masson-Delmotte, V., Zhai, P., Pörtner, H.O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., et al., Eds.; World Meteorological Organization: Geneva, Switzerland, 2018; p. 32.
70. Lehner, F.; Coats, S.; Stocker, T.F.; Pendergrass, A.G.; Sanderson, B.M.; Raible, C.C.; Smerdon, J.E. Projected drought risk in 1.5 °C and 2 °C warmer climates. *Geophys. Res. Lett.* **2017**, *44*, 7419–7428. [CrossRef]
71. Worldclim Global Climate Data. Available online: https://www.worldclim.org (accessed on 13 November 2019).
72. Laumonier, Y.; Simamora, T.; Manurung, A.; Narulita, S.; Pribadi, U.; Simorangkir, A.; Kharisma, S.; Shantiko, B. Sentinel Landscapes initiative. *FTA Work. Pap.* **2020**, *5*, 1–74.
73. Anandi, A.M.; Yuliani, E.L.; Moeliono, M.; Laumonier, Y.; Narulita, S. Kapuas Hulu: A background analysis to implementing integrated landscape approaches in Indonesia. In *Operationalizing Integrated Landscape Approaches in the Tropics*; Center for International Forestry Research (CIFOR): Bogor, Indonesia, 2020; pp. 176–204.
74. Crevello, S. Dayak Land Use Systems and Indigenous Knowledge. *J. Hum. Ecol.* **2004**, *16*, 69–73. [CrossRef]
75. De Jong, W. The Impact of Rubber on the Forest Landscape in Borneo. In *Agricultural Technologies and Tropical Deforestation*; Angelsen, A., Kaimowitz, D., Eds.; CABI Publishing: Wallingford/Oxford, UK, 2001; pp. 367–382.
76. Leonald, L.; Rowland, D. Drivers and effects of agrarian change in Kapuas Hulu Regency, West Kalimantan, Indonesia. In *Agrarian Change in Tropical Landscapes*; Deakin, E.L., Kshatriya, M., Sunderland, T.C.H., Eds.; Center for International Forestry Research (CIFOR): Bogor, Indonesia, 2016; pp. 91–138.
77. BPS Human Development Index by Province [New Method], 2010–2019. Available online: https://www.bps.go.id/dynamictable/2020/02/18/1772/indeks-pembangunan-manusia-menurut-provinsi-metode-baru-2010-2019.html (accessed on 25 January 2021).
78. Murniati; Garrity, D.P.; Gintings, A.N. The contribution of agroforestry systems to reducing farmers' dependence on the resources of adjacent national parks: A case study from Sumatra, Indonesia. *Agrofor. Syst.* **2001**, *52*, 171–184. [CrossRef]
79. Fisher, R.; Corbet, A.; Williams, C. The relation between the number of species and the number of individuals in a random sample of an animal population. *J. Anim. Ecol.* **1943**, *12*, 42–58. [CrossRef]
80. Grimm, V.; Railsback, S.F.; Vincenot, C.E.; Berger, U.; Gallagher, C.; Deangelis, D.L.; Edmonds, B.; Ge, J.; Giske, J.; Groeneveld, J.; et al. The ODD protocol for describing agent-based and other simulation models: A second update to improve clarity, replication, and structural realism. *Jasss* **2020**, *23*. [CrossRef]
81. Grimm, V.; Berger, U.; DeAngelis, D.L.; Polhill, J.G.; Giske, J.; Railsback, S.F. The ODD protocol: A review and first update. *Ecol. Modell.* **2010**, *221*, 2760–2768. [CrossRef]
82. Grimm, V.; Berger, U.; Bastiansen, F.; Eliassen, S.; Ginot, V.; Giske, J.; Goss-Custard, J.; Grand, T.; Heinz, S.K.; Huse, G.; et al. A standard protocol for describing individual-based and agent-based models. *Ecol. Modell.* **2006**, *198*, 115–126. [CrossRef]
83. Wilensky, U. *NetLogo*; Center for Connected Learning and Computer-Based Modeling, Northwestern University: Evanston, IL, USA, 1999; Available online: http://ccl.northwestern.edu/netlogo/ (accessed on 15 March 2021).
84. Gigerenzer, G.; Goldstein, D.G. Reasoning the Fast and Frugal Way: Models of Bounded Rationality. *Psychol. Rev.* **1996**, *103*, 650–669. [CrossRef]

85. Schreinemachers, P.; Berger, T. Land use decisions in developing countries and their representation in multi-agent systems. *J. Land Use Sci.* **2006**, *1*, 29–44. [CrossRef]
86. Laumonier, Y.; Hadi, D.P.; Pribadi, U.A.; Narulita, S. *Kapuas Hulu Ecological Vegetation Map 1:50000*; CIFOR: Bogor, Indonesia, 2020.
87. Suyanto, N.K.; Sardi, I.; Buana, R.Y.; van Noordwijk, M. *Analysis of Local Livelihoods From Past to Present in the Central Kalimantan Ex-Mega Rice Project Area*; World Agroforestry Centre: Bogor, Indonesia, 2009.
88. Jepsen, M.R.; Leisz, S.; Rasmussen, K.; Jakobsen, J.; Møller-Jensen, L.; Christiansen, L. Agent-based modelling of shifting cultivation field patterns, Vietnam. *Int. J. Geogr. Inf. Sci.* **2006**, *20*, 1067–1085. [CrossRef]
89. Wulan, Y.C.; Budidarsono, S.; Joshi, L. Economic analysis of improved smallholder rubber agroforestry systems in West Kalimantan, Indonesia—Implications for rubber development. *Sustain. Sloping Lands Watershed Manag. Conf.* **2006**, 431–444.
90. Ko, R.; Lumangkun, A.; Wardenaar, E. Nilai Manfaat Tengkawang (*Shorea* spp.) Bagi Masyarakat Di Kecamatan Embaloh Hilir Kabupaten Kapuas Hulu Kalimantan Barat Value Benefits Tengkawang (*Shorea* spp.) For The Downstream In The District Embaloh Kapuas Hulu West Kalimantan. *J. Hutan Lestari* **2013**, *1*, 83–91.
91. Maharani, R.; Fernandes, A.; Pujiarti, R. Comparison of Tengkawang fat processing and its effect on Tengkawang fat quality from Sahan and Nanga Yen villages, West Kalimantan, Indonesia. *AIP Conf. Proc.* **2016**, *1744*. [CrossRef]
92. Chiputwa, B.; Spielman, D.J.; Qaim, M. Food standards, certification, and poverty among coffee farmers in Uganda. *World Dev.* **2015**, *66*, 400–412. [CrossRef]
93. Indonesian Statistics Publications Daily Average Consumption of Calorie and Protein per Capita by Province, 2007–2019. Available online: https://www.bps.go.id/statictable/2014/09/08/951/rata-rata-konsumsi-kalori-dan-protein-per-kapita-per-hari-menurut-provinsi-2007-2019.html (accessed on 22 December 2020).
94. Simon, H.A. Theories of Bounded Rationality. In *Decision and Organization*; McGuire, C.B., Radner, R., Eds.; Elsevier: Amsterdam, The Netherlands, 1972; pp. 161–176.
95. Magliocca, N.R.; Brown, D.G.; Ellis, E.C. Exploring Agricultural Livelihood Transitions with an Agent-Based Virtual Laboratory: Global Forces to Local Decision-Making. *PLoS ONE* **2013**, *8*. [CrossRef] [PubMed]
96. Wangpakapattanawong, P.; Finlayson, R.; Öborn, I. *Agroforestry in Rice-Production Landscapes in Southeast Asia a Practical Manual*; Wangpakapattanawong, P., Finlayson, R., Öborn, I., Roshetko, J.M., Sinclair, F., Shono, K., Borelli, S., Hillbrand, A., Conigliaro, M., Eds.; Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok, Thailand & World Agroforestry Centre (ICRAF) Southeast Asia Regional Program: Bogor, Indonesia, 2017.
97. Sorensen, K.W. Traditional Management of Dipterocarp Forests: Examples of Community Forestry By Indigenous Communities. In *Dipterocarp Forest Ecosystems: Towards Sustainable Management*; World Scientific: Singapore, 1996; pp. 335–353.
98. Heri, V.; Bakara, D.O.; Hermanto; Mulyana, A.; Moeliono, M.; Yuliani, E.-L. Illipe nut as the glue for integrated watershed management: Experiences from the Labian-Leboyan watershed. *CIFOR Info Br.* **2020**. [CrossRef]
99. Yuliawan, T.; Handoko, I. The Effect of Temperature Rise to Rice Crop Yield in Indonesia uses Shierary Rice Model with Geographical Information System (GIS) Feature. *Procedia Environ. Sci.* **2016**, *33*, 214–220. [CrossRef]
100. Cooley, P.; Solano, E. Agent-Based Model (ABM) Validation Considerations. In Proceedings of the SIMUL 2011, The Third International Conference on Advances in System Simulation, Barcelona, Spain, 23–29 October 2011; pp. 134–139.
101. Windrum, P.; Fagiolo, G.; Moneta, A. Empirical validation of agent-based models: Alternatives and prospects. *Jasss* **2007**, *10*, 8.
102. *StataCorp Stata Statistical Software: Release 15 2015*; StataCorp LLC: College Station, TX, USA, 2015.
103. BPS-Statistics of Kapuas Hulu Regency. *Kapuas Hulu Regional Statistic 2019*; BPS-Statistics of Kapuas Hulu Regency: Putussibau, Indonesia, 2019.
104. Rahman, S.A.; Jacobsen, J.B.; Healey, J.R.; Roshetko, J.M.; Sunderland, T. Finding alternatives to swidden agriculture: Does agroforestry improve livelihood options and reduce pressure on existing forest? *Agrofor. Syst.* **2017**, *91*, 185–199. [CrossRef]
105. Sulistyawati, E.; Noble, I.R.; Roderick, M.L. A simulation model to study land use strategies in swidden agriculture systems. *Agric. Syst.* **2005**, *85*, 271–288. [CrossRef]
106. Belsky, J. Household Food Security, Farm Trees, and Agroforestry: A Comparative Study in Indonesia and the Philippines. *Hum. Organ.* **1993**, *52*, 130–141. [CrossRef]
107. Nguyen, M.P.; Vaast, P.; Pagella, T.; Sinclair, F. Local knowledge about ecosystem services provided by trees in coffee agroforestry practices in northwest Vietnam. *Land* **2020**, *9*, 1–27. [CrossRef]
108. Córdova, R.; Hogarth, N.J.; Kanninen, M. Sustainability of smallholder livelihoods in the Ecuadorian highlands: A comparison of agroforestry and conventional agriculture systems in the indigenous territory of Kayambi People. *Land* **2018**, *7*, 45. [CrossRef]
109. Rohadi, D.; Herawati, T. Agroforestry Research in Indonesia: Where To Go for the Next. *World Congr. Agrofor.* **2014**. [CrossRef]
110. Hemida, M.A.A.; Adam, Y.O. The Importance of Farm Trees in Rural Livelihoods in Eastern Galabat The Importance of Farm Trees in Rural Livelihoods in Eastern Galabat Locality, Sudan. *Agric. For. J.* **2019**, *3*, 81–88.
111. Pendrill, F.; Persson, U.M.; Godar, J.; Kastner, T.; Moran, D.; Schmidt, S.; Wood, R. Agricultural and forestry trade drives large share of tropical deforestation emissions. *Glob. Environ. Chang.* **2019**, *56*, 1–10. [CrossRef]
112. Martin, D.A.; Osen, K.; Grass, I.; Hölscher, D.; Tscharntke, T.; Wurz, A.; Kreft, H. Land-use history determines ecosystem services and conservation value in tropical agroforestry. *Conserv. Lett.* **2020**, *13*. [CrossRef]
113. Warren-Thomas, E.; Nelson, L.; Juthong, W.; Bumrungsri, S.; Brattström, O.; Stroesser, L.; Chambon, B.; Penot, É.; Tongkaemkaew, U.; Edwards, D.P.; et al. Rubber agroforestry in Thailand provides some biodiversity benefits without reducing yields. *J. Appl. Ecol.* **2020**, *57*, 17–30. [CrossRef]

114. Harvey, C.A.; González Villalobos, J.A. Agroforestry systems conserve species-rich but modified assemblages of tropical birds and bats. *Biodivers. Conserv.* **2007**, *16*, 2257–2292. [CrossRef]
115. Udawatta, R.P.; Rankoth, L.M.; Jose, S. Agroforestry and biodiversity. *Sustainability* **2019**, *11*, 2879. [CrossRef]
116. Bhagwat, S.A.; Willis, K.J.; Birks, H.J.B.; Whittaker, R.J. Agroforestry: A refuge for tropical biodiversity? *Trends Ecol. Evol.* **2008**, *23*, 261–267. [CrossRef]
117. Tscharntke, T.; Clough, Y.; Bhagwat, S.A.; Buchori, D.; Faust, H.; Hertel, D.; Hölscher, D.; Juhrbandt, J.; Kessler, M.; Perfecto, I.; et al. Multifunctional shade-tree management in tropical agroforestry landscapes—A review. *J. Appl. Ecol.* **2011**, *48*, 619–629. [CrossRef]
118. Verstegen, J.A.; van der Laan, C.; Dekker, S.C.; Faaij, A.P.C.; Santos, M.J. Recent and projected impacts of land use and land cover changes on carbon stocks and biodiversity in East Kalimantan, Indonesia. *Ecol. Indic.* **2019**, *103*, 563–575. [CrossRef]
119. Middendorp, R.S.; Vanacker, V.; Lambin, E.F. Impacts of shaded agroforestry management on carbon sequestration, biodiversity and farmers income in cocoa production landscapes. *Landsc. Ecol.* **2018**, *33*, 1953–1974. [CrossRef]
120. Matocha, J.; Schroth, G.; Hills, T.; Hole, D. Integrating Climate Change Adaptation and Mitigation Through Agroforestry and Ecosystem Conservation. In *Agroforestry—The Future of Global Land Use, Advances in Agroforestry 9*; Nair, P.K.R., Garrity, D., Eds.; Springer: Amsterdam, The Netherlands, 2012; pp. 105–126. ISBN 9789400746763.
121. Takama, T.; Aldrian, E.; Kusumaningtyas, S.D.A.; Sulistya, W. Identified vulnerability contexts for a paddy production assessment with climate change in Bali, Indonesia. *Clim. Dev.* **2017**, *9*, 110–123. [CrossRef]
122. Murniati, K.; Mutolib, A. The impact of climate change on the household food security of upland rice farmers in sidomulyo, lampung province, Indonesia. *Biodiversitas* **2020**, *21*, 3487–3493. [CrossRef]
123. Measey, M. Indonesia: A Vulnerable Country in the Face of Climate Change. *Glob. Major. E-J.* **2010**, *1*, 31–45.
124. Mulia, R.; Nguyen, D.D.; Nguyen, M.P.; Steward, P.; Pham, V.T.; Le, H.A.; Rosenstock, T.; Simelton, E. Enhancing Vietnam's nationally determined contribution with mitigation targets for agroforestry: A technical and economic estimate. *Land* **2020**, *9*, 528. [CrossRef]
125. Plieninger, T.; Muñoz-Rojas, J.; Buck, L.E.; Scherr, S.J. Agroforestry for sustainable landscape management. *Sustain. Sci.* **2020**, *15*, 1255–1266. [CrossRef]
126. Ndoli, A.; Mukuralinda, A.; Schut, A.G.T.; Iiyama, M.; Ndayambaje, J.D.; Mowo, J.G.; Giller, K.E.; Baudron, F. On-farm trees are a safety net for the poorest households rather than a major contributor to food security in Rwanda. *Food Secur.* **2021**. [CrossRef]
127. Mekonnen, M.; Worku, T.; Yitaferu, B.; Cerdà, A.; Keesstra, S. Economics of agroforestry land use system, Upper Blue Nile Basin, northwest Ethiopia. *Agrofor. Syst.* **2021**. [CrossRef]
128. Yashmita, U.; Singh, M.; Kumar, A.; Sharma, M. Conservation of Wildlife Diversity in Agroforestry Systems in Eastern Himalayan Biodiversity Hotspot. *Proc. Zool. Soc.* **2021**. [CrossRef]
129. De Leijster, V.; Santos, M.J.; Wassen, M.W.; Camargo García, J.C.; Llorca Fernandez, I.; Verkuil, L.; Scheper, A.; Steenhuis, M.; Verweij, P.A. Ecosystem services trajectories in coffee agroforestry in Colombia over 40 years. *Ecosyst. Serv.* **2021**, *48*, 101246. [CrossRef]
130. Dawson, I.K.; Guariguata, M.R.; Loo, J.; Weber, J.C.; Lengkeek, A.; Bush, D.; Cornelius, J.; Guarino, L.; Kindt, R.; Orwa, C.; et al. What is the relevance of smallholders' agroforestry systems for conserving tropical tree species and genetic diversity in circa situm, in situ and ex situ settings? A review. *Biodivers. Conserv.* **2013**, *22*, 301–324. [CrossRef]
131. Wilensky, U.; Rand, W. *An Introduction to Agent-Based Modeling. Modeling Natural, Social, and Engineered Complex Systems with Netlogo*; The MIT Press: Cambridge, UK, 2015.
132. Villamor, G.B.; Van Noordwijk, M.; Troitzsch, K.G.; Vlek, P.L.G. Human decision making for empirical agent-based models: Construction and validation. *Int. Congr. Environ. Model. Software.* **2012**, *1*, 2529–2536.
133. Ahrweiler, P. Agent-based simulation for science, technology, and innovation policy. *Scientometrics* **2017**, *110*, 391–415. [CrossRef]
134. Dechesne, F.; Ghorbani, A.; Yorke-Smith, N. Introduction to the special issue on agent-based modelling for policy engineering. *AI Soc.* **2015**, *30*, 311–313. [CrossRef]
135. Polhill, J.G.; Ge, J.; Hare, M.P.; Matthews, K.B.; Gimona, A.; Salt, D.; Yeluripati, J. Crossing the chasm: A 'tube-map' for agent-based social simulation of policy scenarios in spatially-distributed systems. *Geoinformatica* **2019**, *23*, 169–199. [CrossRef]
136. Gilbert, N.; Ahrweiler, P.; Barbrook-Johnson, P.; Narasimhan, K.P.; Wilkinson, H. Computational modelling of public policy: Reflections on practice. *Jasss* **2018**, *21*. [CrossRef]
137. Deressa, T.T.; Hassan, R.M.; Ringler, C.; Alemu, T.; Yesuf, M. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Glob. Environ. Chang.* **2009**, *19*, 248–255. [CrossRef]
138. Rogers, E.M. *Diffusion of innovations*, 3rd ed.; Free Press; Collier Macmillan: New York, NY, USA, 1983.
139. Kahneman, D.; Tversky, A. Prospect Theory: An Analysis of Decision under Risk. *Econoemtrica* **1979**, *47*, 263–291. [CrossRef]
140. Llewellyn, R.S.; Brown, B. Predicting Adoption of Innovations by Farmers: What is Different in Smallholder Agriculture? *Appl. Econ. Perspect. Policy* **2020**, *42*, 100–112. [CrossRef]
141. Dessie, A.B.; Abtew, A.A.; Koye, A.D. Determinants of the production and commercial values of Eucalyptus woodlot products in Wogera District, Northern Ethiopia. *Environ. Syst. Res.* **2019**, *8*. [CrossRef]
142. *Project Completion Report PD 586/10 Rev.1 (F) Operational Strategies for the Conservation of Tengkawang Genetic Diversity and for Sustainable Livelihood of Indigenous People in Kalimantan*; Dipterocarps Research Center-Forda, Ministry of Forestry: Samarinda, Indonesia, 2014.

land

Article

Following Rural Functions to Classify Rural Sites: An Application in Jixi, Anhui Province, China

Kai Ren

Department of Urban and Rural Planning, School of Architecture, Southeast University, Nanjing 210096, China; 230189012@seu.edu.cn

Abstract: Rural areas are a type of self-organized regional living environment, with multi-functional symbiosis between humans and land; their functional attributes are function superposition, function difference, and dominant function. The evolution of rural functions is a gradual process and follows the general law of the development of self-organizing systems, which evolutes from the state of general development, competition without rules, and, finally, to an order controlled by the dominant function. By constructing an indicator system and measurement model of rural function evaluation, this study took 11 towns in a hilly area of Jixi County as regional units to analyze the differentiation characteristics and rules of rural functions; the functions include agricultural production functions, nonagricultural production functions, life and leisure functions, and ecological functions. The results show the following: (1) The index of agricultural production functions, life and leisure functions, and ecological functions in Jixi County is higher, while the index of nonagricultural production functions is lower; (2) all towns have at least one function belongings to the "high state strong potential zone", and some towns show a weak comprehensiveness; (3) the interaction between different functions should be considered when determining the dominant functions of the towns; (4) the formation mechanism of a dominant function has a high correlation with its main influencing factors; and (5) nine types of characteristic village are determined, according to the coupling of village characteristic resources and town dominant functions.

Keywords: dominant function; regional differences; rural geography; rural territorial functions; type identification

check for updates

Citation: Ren, K. Following Rural Functions to Classify Rural Sites: An Application in Jixi, Anhui Province, China. *Land* **2021**, *10*, 418. https://doi.org/10.3390/land10040418

Academic Editors: Joao C. Azevedo and Fernández Pascual

Received: 29 March 2021
Accepted: 13 April 2021
Published: 15 April 2021

1. Introduction

Rural areas refer to areas outside urban built-up areas, but they are not an independent analysis category. Combined with research on existing human settlement practices in China, the definition of rural areas in China mainly refers to towns and villages that are not under urban jurisdictions (including urban suburbs and county towns). Rural function refers to the sum of all kinds of services provided to meet the needs of rural self-development and villagers' production and livelihoods, involving economy, society, culture, life, ecology, and other aspects. The evaluation of rural functions can clarify rural development status and its future development path. At present, China's rural areas are still facing the problem of regional value collapse under the long-term "urban–rural dual system" strategy [1–3]. In addition, in recent years, the urbanization tendency of villages has led to the shrinking of rural development space, as the development path of prioritizing economic efficiency has ignored the protection of rural ecological, social, cultural, and other resilient functions, leading to the degradation of traditional functions and the development of new functions that are incompatible with the environment. In 2018, the CPC Central Committee and the State Council issued the Rural Revitalization Strategic Plan (2018–2020) (Strategic Planning for Rural Revitalization (2018–2022). Available online: http://www.gov.cn/zhengce/2018-09/26/content_5325534.htm (accessed on 26 September 2018)). Since then, rural–urban integration had been in the practice stage [4]. In this paper, we propose an important topic of rural geography: how to evaluate regional value and formulate the differentiation law of China's rural functions in the new era; for only on the basis of full analysis of rural functions can rural areas carry out land use, policy making, and financial input according to the function division, and, finally, realize rural–urban integration in industry, ecology, industry, and other aspects.

Research on the multifunctionality of the agricultural sector, rural landscape, and rural space has become a core theoretical tool in the West with which to describe the characteristics of rural differences, explain the process of rural change and development, and support or refute government policies and actions [5]. Scholars have carried out a great deal of research on the spatial characteristics of rural landscape functions [6–8] and rural types [9], the impact of policies on rural landscape functions [10,11], and the interactions among rural functions [12]. Some of the research has been used in relation to evolutionary theory and scenario analysis, and other methods have been used to analyze the complexity and uncertainty of rural development from a functional perspective [13]. However, the current research primarily focuses on agricultural policies and rural revitalization in post-industrial society and the de-urbanization stage [14,15].

Due to historical and geographical reasons, there are abundant natural, ecological, and human resources in the south part of Anhui province, China. However, because the economic environment is relatively backward and the social ecology is fragile, the protection and utilization of the province's cultural and social resources could cause extreme change, leading to social crisis [16,17]. At the same time, the ecological environment in hilly areas is generally fragile, and it would be easy for the outbreak of various geological disasters to destroy natural resources. In addition, hilly areas are mostly underdeveloped and cannot enjoy equal rights in the urban–rural system, so, the development of these areas is constrained by the environment of policy and economy [18,19]. Rural areas are the most basic regional organism in China, and play a fundamental role in the social and economic development of the whole country. As such, they are important for implementing the strategy of 'Main Functional Area' and realizing the integration of urban–rural development. Therefore, at the theoretical level, a comprehensive analysis of rural functions, including function measurement, high-value function interaction analysis, and dominant function formation mechanism, will be key to realizing sustainable development and constructing the structure of urban–rural integration in hilly areas [20]. Moreover, rural areas can realize dislocation competition with urban areas [21]. In addition, comparing the differences among rural functions could improve the current rural regional function evaluation theory. On a practical level, the ultimate carrier of rural revitalization is the village organism, and the village is a rural growth pole based on the dominant function of the town and the accumulation of characteristic resource elements of the village. On the basis of understanding of the functional spatial differentiation characteristics of towns, an analysis of the characteristic types of village is helpful to accurately determine the development path of rural areas, and then improve the current support theory of rural revitalization practice.

2. Analytical Framework

2.1. Rural Regional Organism

The rural regional system is part of urban–rural integration. It is a regional open system with a certain functional structure which is formed by the interaction and connection of its subsystems. The subsystems include location conditions, natural environment, cultural heritage, policy conditions, and economic basis. The function of a rural regional system reflects its development stage, as the rural regional organism is an important carrier for factor allocation and function organization. According to the spatial production theory of Henri Lefebvre [22], the rural regional organism is space system constructed by resources, rights, society, and capital. So, based on the three-dimensional rural space system of culture, society and material proposed by Halfacree [23], from the human–land interaction perspective, this study analyzed the space system of the rural organism from the two dimensions of the inner core system and the outer periphery system [24] (Figure 1).

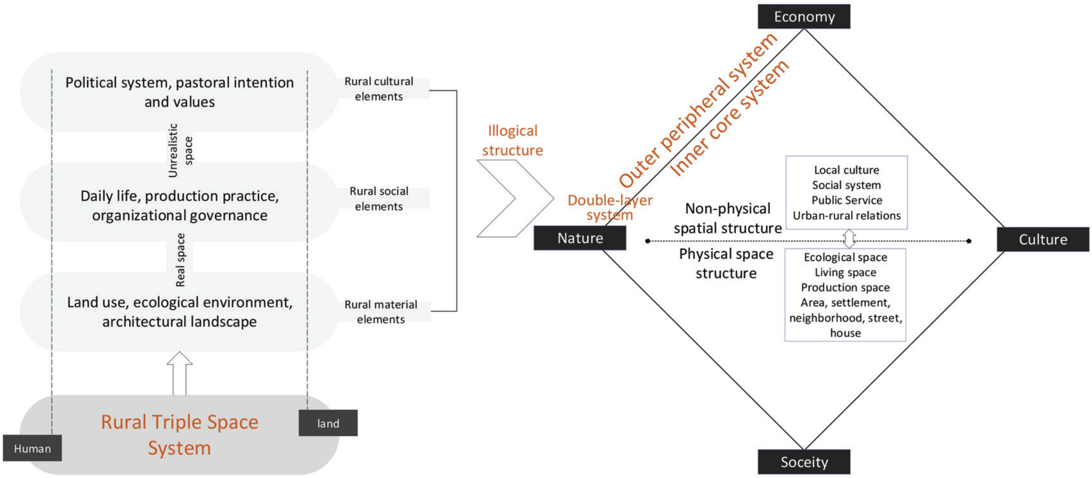


Figure 1. From three-dimensional rural space system to double-layer characteristic rural space system.

Halfacree's three-dimensional rural space system (Figure 1 left) breaks away from the limitation of material space, emphasizes the wide existence of abstract cultural and social space, and argues that there is a strict logical order among the three levels: the material space is the foundation, the social space is the practical behavior, and the system is finally manifested as cultural space. The three-dimensional space system is the evolutionary basis of the internal–external dual-core space system. In a specific period and environment, the rural organism presents the characteristics of non-general order, so its spatial structure may not be limited to the previous progressive relationship. At present, under the strong influence of material flow and information flow, the rural organism presents a spatial structure of "element–structure–function" cross-combination. The main driving factors and expression vectors of this structure are divided into two layers: the inner core system and the outer peripheral system. The main actors are divided into subject and object. The inner core system is composed of the natural, economic, social, cultural, and ecological elements of the rural organism self; the outer peripheral system is composed of national and regional environments, urban–rural relations, etc. The subject are long-resident farmers, governments at all levels, investment bodies, elites returning home, rural enterprises, etc. The objects are natural environmental elements, ecological function carriers, objective foundations for economic development, policy environment, existing social relations (network), cultural customs and heritage (Figure 2). By integrating the relevant elements into an inner core system and outer peripheral system, based on the openness of the rural regional organism, the behavioral subject promotes interactions among various subsystems in the core system and generates energy collisions with the outer peripheral system through material and information exchange. Finally, different rural organisms show developmental differences in terms of scale, industry, landscape, density, etc.; thereby, they each form an open system with specific functional structures [25].

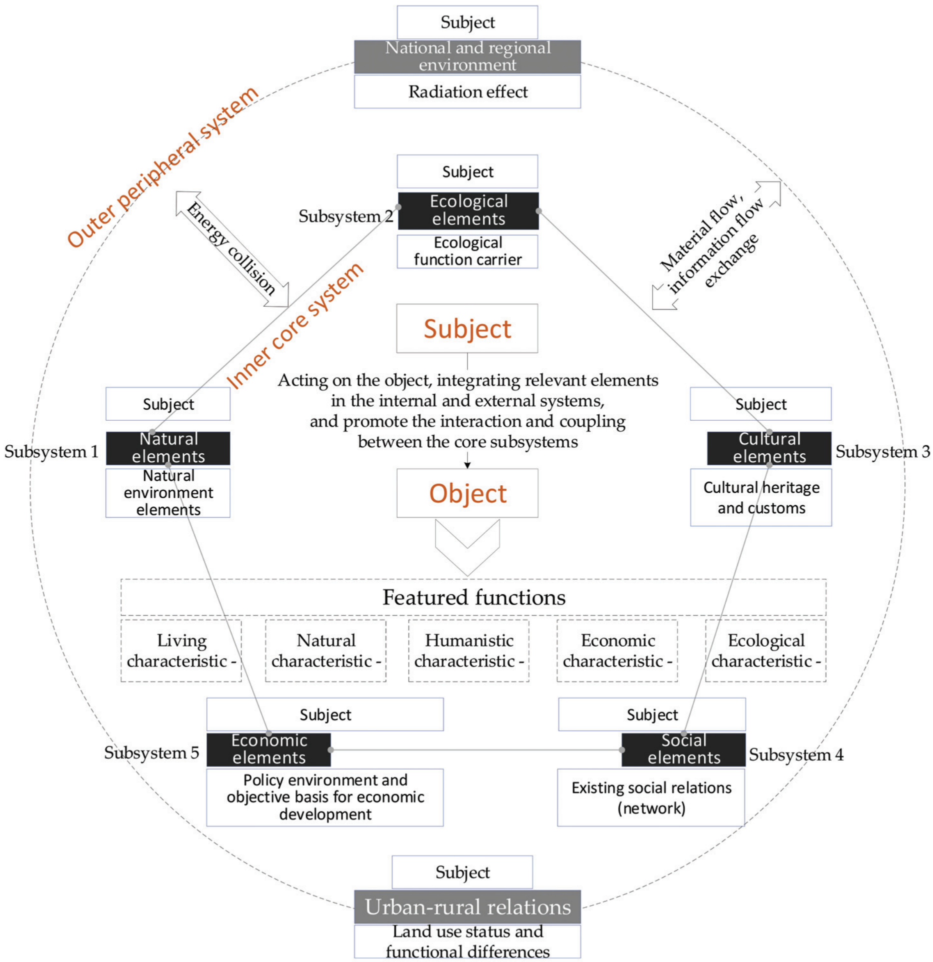


Figure 2. Elements and interactions of characteristic villages and towns.

2.2. Rural Regional Function

The complex nature of the rural organism is expressed through its multifunctional net order [26]. The multifunctional net includes multiple functions, such as production, life, economy, culture, and ecology. For Chinese rural areas in the transitional period, there is a significant coordination relationship among multiple functions, so the relative pattern of different functions is always in a dynamic process of change [27]. Rural functions are a complex of natural local functions provided by the natural ecosystem and the utilized functions given by humans due to the needs of production and life [28]. With the advancement of China's urban–rural integration, urban culture and economy continue to infiltrate the countryside. Under the influence of the external system, rural areas are in the process of industrial transformation and spatial reconstruction. At present, the goal in rural areas is to protect the ecological environment, improve economic benefits, improve quality of living, and realize the sustainable utilization of resources. Therefore, this paper evaluates the rural function from four aspects: agricultural production function, nonagricultural production function, life and leisure function, and ecological function [29]. Rural areas participate in the function division of the urban–rural integration system, as they can provide superior functional services in some aspects, such as agriculture, ecology and tourism. Superior function is the dominant function, and the benefits driven by it accumulate year by year; so, rural areas have the advantage functional niche. A niche is the position and role taken by the biological unit in the process of interaction with the environment in a specific ecosystem; it represents the physical space occupied by the biological unit and the functional role it plays [30]. A function with an advantage niche will be the direction of future development.

3. Data and Functional Measure Methods

3.1. Research Area Overview

Jixi County is a county under the jurisdiction of Xuancheng City, Anhui Province, which is in the east of China, and Jixi is located in the mountainous area of southern Anhui. Jixi has a total area of 1126 square kilometers, and governs 11 towns, 5 communities, and 76 villages, with a permanent population of 159,000 in 2019 (Figure 3). Jixi belonged to the "one prefecture and six counties" in ancient Huizhou and has profound cultural heritage. Jixi was rated as a national historical and cultural city by the State Council in 2007, and won the title of the first batch of national ecological civilization demonstration counties in September 2017. Jixi has an annual average temperature of 15.9 degrees. It belongs to the subtropical humid monsoon climate zone, with annual rainfall of 1519.3 mm. The soil is mainly yellow-red and fertile. The frost-free period is 250 days and the crop growth period is 240 days, with 2–3 crops a year. Jixi is one of the three major characteristic agricultural and forestry industry demonstration bases in Xuancheng. Jixi is part of the Wanjiang Urban Belt Demonstration Zone, which aims to undertake industrial transfer. The construction and healthy development of Jixi's rural areas not only determine the degree of urban–rural integration in the region, but also have an impact on the revitalization of Anhui's villages.

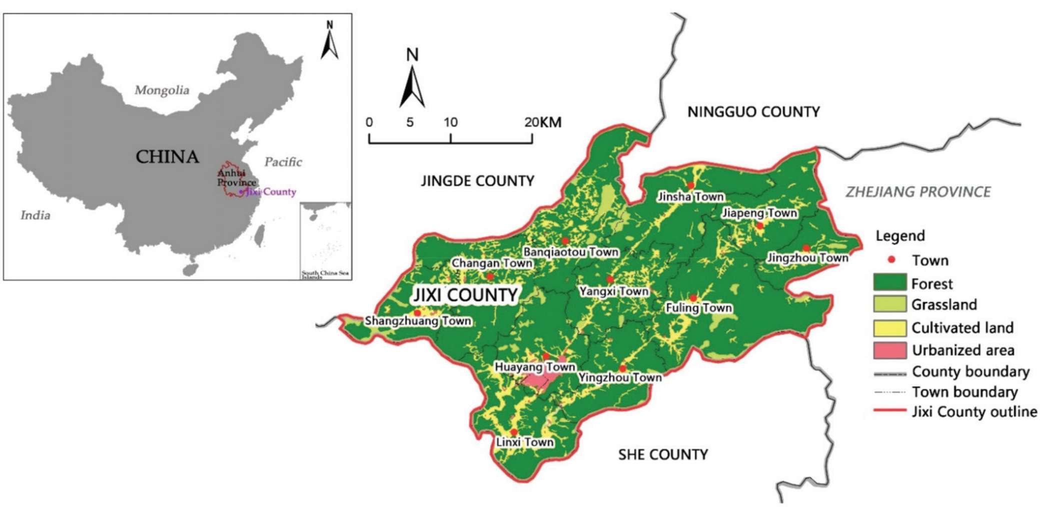


Figure 3. Divisions of administrative areas and land use in Jixi County.

The basic data used include: the sixth population census data (2010) and the second national land survey data. The yearbooks used are: *China Statistical Yearbook*, *China Regional Economic Statistical Yearbook*, *Anhui Statistical Yearbook*, and *Jixi County Statistical Yearbook*. The vector data of administrative divisions come from China's basic geographic information data. The vector data for railways and highways come from *China Railway Highway Traffic Map 2018*, and the vector data are drawn using ArcGIS 10.7 (Figure 3). Planning information comes from: *Jixi County Urban Master Plan (2005–2020)*, *Jixi Historic and Cultural City Protection Plan*, *Jixi County Land Use Master Plan (2006–2020)*, *Jixi County National Ecological*

Civilization Demonstration County Planning Revision (2020–2025), *Jixi County Rural Planning and Construction (2017–2030)*. In addition, there are survey data of 76 villages and 11 towns in Jixi County, as well as data on farmers' economic income, the types of crops planted, and the proportion of migrant workers.

3.2. Construction of Function Measurement Indicator System

(1) Function measurement indicator system

From the perspective of human–land interaction and the generation path for functions, the functions of towns are divided into production functions, life functions and ecological functions. Based on the geographical environment and human characteristics of Jixi, the production function is divided into agricultural production and nonagricultural production; the life function mainly includes cultural inheritance and residential bearing; and the ecological function is mainly based on ecological protection and landscape provision. The indicator selection adopts a combination of qualitative and quantitative methods [31]. Indicators of each function are divided into "state" indicators and "potential" indicators. Therefore, the functional evaluation value of each function is the sum of its "state" intensity index and "potential" development index. "State" is the basis for the formation of functions. Under the current policy background of urban–rural integration, "potential" constitutes the main driving force for the future development of rural areas [32].

Drawing on existing research on the classification of functions in rural area [7,33–39], and taking data availability into account, this paper constructs a function measurement system composed of four standard indicators (agricultural production, nonagricultural production, life and leisure, ecosystem services) and several descriptive indicators. Table 1 is an incomplete list for the function evaluation of a town.

Table 1. Function measurement indicator system.

Target Layer (Functional Form)	Indicator Attributes	Indicator	Indicator Explanation
Agricultural production function	State	The total agricultural output value and proportion	The total output value of agriculture, forestry, animal husbandry, and fishery reflects the level of agricultural production.
		The total area and proportion of agricultural land	Including cultivated land, garden land, forest land, and grazing land, reflecting the total resources of agricultural production space.
		The proportion of agricultural labor force	Number of people of working age and capable of agricultural work, reflecting the degree of agriculturalization of employees.
	Potential	Agricultural product original resources	Calculation of it is according to the value assignment of local agricultural production resources in the area, and it reflects the advantages of endemic varieties.
		The growth rate of agricultural total output value (average value in the past 5 years)	Reflects the development trend of agriculture.
Nonagricultural production function	State	Total industrial output value and proportion	Reflects the development level of the secondary industry.
		Total service industry output value and proportion	Reflects the development level of the tertiary industry.
		Nonagricultural employment proportion of rural employees	Reflects the degree of the nonagriculturalization of employed persons.

Table 1. *Cont.*

Target Layer (Functional Form)	Indicator Attributes	Indicator	Indicator Explanation
Nonagricultural production function	Potential	Original resources of industrial product	Calculation of it is according to the value assignment of the local nonagricultural production resources in the area, and it reflects the advantages of endemic varieties.
		Growth rate of total industrial output value (average value in the past 5 years)	Reflects the industrial development potential.
		Growth rate of total output value of the service industry (average value in the past 5 years)	Reflects the development potential of the tertiary industry.
Life and leisure function	State	Historical and cultural heritage index	Historical and cultural heritage index: $\sum H_i = N_i C_j$. N is the number of the cultural heritage of a certain level, C is the level coefficient. (level coefficients are respectively world level 0.35, national level 0.1, provincial level 0.02, city and county level 0.01, no level 0.005), reflecting the stock of historical and cultural resources.
		Landscape attractiveness index	Calculation of it is according to the value assignment of local natural landscape resources in the area, an it reflects the stock of characteristic natural and cultural resources.
		Regional population density	Population/area (square kilometers), reflecting the scale and consumption power of the town.
		Traffic advantage index	It can be found by adding both the traffic network density and the proximity of traffic facilities (refers to formula (9)).
	Potential	Tourism investment average growth rate in the past 5 years	Reflects the vitality and investment potential of the town.
		Characteristic cultural resources index	Calculation of it is according to the value assignment of the local cultural resources in the area, and it reflects the advantages of characteristic resources.
Ecological function	State	Forest cover rate	Mainly considers land types such as cultivated land, garden land, forest land, grassland, water bodies, etc., reflecting the basic level of ecological security.
		Agricultural development volume	The weight of grain output per square kilometer of land (kg/hm^2), reflecting the level of ecological occupation
	Potential	Characteristic natural resources index	Calculation of it is according to the value assignment of the local ecological resources in the area, and it reflects the advantages of regional resources.
		Characteristic ecological agriculture index	Calculation of it is according to the value assignment of the local ecological agricultural production resources in the area, and it reflects the advantages of ecological economy (refers to formula (8)).

1. Agricultural Production Function

Agricultural production is the original foundation for the existence of rural areas, and has the functions of ensuring food security, ensuring employment, ecological leisure, and generating environmental effects. The "state" indicators are the total agricultural output value and proportion, the total area and proportion of agricultural land, and the proportion of agricultural labor force. The "potential" indicators are agricultural product original resources and the growth rate of the agricultural total output value (average value in the past 5 years).

2. Nonagricultural Production Function

Nonagricultural production focuses more on production than agriculture. Especially in the stage of urban–rural integration and rural transformation, the vitality of nonagricultural production can better represent the development potential of a town. According to rural land-use data and field surveys, "state" indicators are the total industrial output value and proportion, the total service industry output value and proportion, and the nonagricultural employment proportion of rural employees. "State" indicators are original resources of industrial product, the growth rate of the total industrial output value (average value in the past five years), and the growth rate of the total output value of the service industry (average value in the past five years).

3. Life and Leisure Function

Life and leisure services are the ancient functions of rural areas and still play an important role in stabilizing rural vitality. In particular, the integration of urban and rural areas has made the realization of the coordinated development of producing and living an important direction in rural areas. Based on unique and profound cultural resources, life and leisure services mainly consider the suitability of living, residents' income, and the level of service industry. The "state" indicators are the historical and cultural heritage index, the landscape attractiveness index, regional population density, transportation network density, and facility proximity. "Potential" indicators are the tourism investment average growth rate in the past five years and the characteristic natural–cultural resources index.

4. Ecological Function

Ecological function is determined according to the ecological importance of towns. The "state" indicator is the total value of ecosystem services. The "potential" indicator is the characteristic indices of natural resource and ecological agriculture. Ecological functions should reflect biodiversity, landscape cultural services, agricultural organicity, and conservation agriculture.

(2) Standardization of Function Measurement Index

Due to the different dimensions of functional measurement indices, and the numerical differences among the indices, to enable direct comparison among the indices, various indices must be standardized. The extreme value method is used to standardize the index data to eliminate the difference in dimensions [40], and finally the values are within a range of (0, 1) with consistent polarity. For single-factor qualitative indices, discrete algebraic values are assigned according to the quality level. The indicators used in this article are all single-factor indices, so this study used min max standardization to process the data $x_1, x_2, x_3, \ldots, x_n$.

$$y_i = \frac{x_i - \underset{1 \le j \le n}{min} \{x_j\}}{\underset{1 \le j \le n}{max} \{x_j\} - \underset{1 \le j \le n}{min} \{x_j\}} \quad (1)$$

The new sequence $y_1, y_2, y_3, \ldots, y_n \in [0, 1]$ is dimensionless; max is the maximum value of the sample data, and min is the minimum value. One drawback of this method is that adding new data may lead to changes in the max and min; thus, they need to be redefined.

(3) Weight of Function Evaluation Index In this paper, the index weight adopts a combination of subjective and objective weighting methods. For each function, its total

weight is 1, with "state" and "potential" each accounting for 0.5. The weight of each specific index was determined by the entropy method. The determination of the entropy method was divided into four steps:

1. First, calculate the initial standardized value a'_{ij} of the data, mainly to eliminate the dimensional influence, and make the standardized value greater than or equal to 0. The indicators in this study are all positive indicators, so the calculation formula is:

$$a'_{ij} = \frac{a_{ij} - mina_{ij}}{maxa_{ij} - mina_{ij}} \quad (2)$$

In this formula, a'_{ij}, a_{ij}, $mina_{ij}$ and $maxa_{ij}$, respectively, represent the initial standard value, actual value, minimum value, and maximum value of the $j-$th index in the $i-$th function of the town.

2. Second, calculate the integrated standardized value P_{ij}, so that the standardized value is between 0 and 1.
3. Third, calculate the information entropy value E_j of the j index.

$$E_j = -(\ln m)^{-1} \sum_{i=1}^{m} p_{ij} \ln p_{ij} \quad (3)$$

In this formula, m is the number of research samples. In the calculation, if $p_{ij} = 0$, in order to make $\ln p_{ij}$ meaningful, attach a minimum value to it (the article takes 0.0000001).

4. Fourth, calculate the objective weight w_j of the indicator.

$$w_j = \frac{1 - E_j}{n - \sum_{j=1}^{n} E_j} \quad (4)$$

In this formula, w_j is the weight of index j, and n is the number of indicators of the function. The weight of each functional indicator in this study area refers to Table 2.

Table 2. Function measurement indicator system.

Target Layer (Functional Form)	Indicator Attributes	Indicator	Weight
Agricultural production function (AF)	State	The total agricultural output value and proportion	0.1821
		The total area and proportion of agricultural land	0.1698
		The proportion of agricultural labor force	0.1481
	Potential	Agricultural product original resources	0.3642
		The growth rate of agricultural total output value	0.1358
Nonagricultural production function (NF)	State	Total industrial output value and proportion	0.1297
		Total service industry output value and proportion	0.2234
		Nonagricultural employment proportion of rural employees	0.1469
	Potential	Original resources of industrial product	0.3471
		Growth rate of total industrial output value	0.1209
		Growth rate of total output value of the service industry	0.0320

Table 2. *Cont.*

Target Layer (Functional Form)	Indicator Attributes	Indicator	Weight
Life and leisure function (LF)	State	Historical and cultural heritage index	0.2041
		Landscape attractiveness index	0.1412
		Regional population density	0.1136
		Traffic advantage index	0.0411
	Potential	Tourism investment average growth rate	0.1105
		Characteristic cultural resources index	0.3895
Ecological function (EF)	State	Forest cover rate	0.3000
		Agricultural development volume	0.2000
	Potential	Characteristic natural resources index	0.2500
		Characteristic ecological agriculture index	0.2500

3.3. Functional Calculation and Analysis Model

(1) Single Function Calculation

The calculation formula for each function is as follows. The sum value of the "state" indicators is as follows:

$$I_{IFS} = \sum_{j=1}^{n} X'_{ij} w_j \tag{5}$$

The sum value of the "potential" indicators is as follows:

$$I_{DFP} = \sum_{f=1}^{k} Y'_{if} w_f \tag{6}$$

So,

$$S_i = I_{IFS} + I_{DFP} = \sum_{j=1}^{n} X'_{ij} w_j + \sum_{f=1}^{k} Y'_{if} w_f \tag{7}$$

Among them, I_{IFS} represents the "state" intensity index of a certain single function in a town, and I_{DFP} represents the "potential" development index. S_i represents the value of the $i-$ th function in a town; X'_{ij} denotes the j indicator in "state" of the $i-$ th function; w_j represents the weight of j indicator; and n is the number of "state" indicators. Y'_{if} denotes the f indicator in the "potential" of the $i-$ th function; w_f represents the weight of f indicator; and k is the number of "potential" indicators.

Each function can be represented by several indicators, and the value of each indicator can be solved by the function corresponding to the indicator. A certain indicator function of a certain town can be expressed either by material quantity or value quantity. For example:

1. The index function of characteristic ecological agriculture in a town can be expressed as:

$$A_f = \sum_{i=1}^{n} S_i V_i P_{wi} \tag{8}$$

In the formula, A_f is the value of characteristic ecological agriculture; S_i is the area of the i-th type of ecological agriculture; V_i is the unit average increase in the $i-$ th ecological agriculture in the past 5 years (m^2 or kg); and P_{wi} is the unit value of the $i-$ th ecological agriculture (Yuan/m^2 or Yuan/kg)

2. The traffic network density and transportation facility proximity can be expressed as:

$$T_f = D_i + E_i = \sum_{i=1}^{4} \frac{L_i}{R_i} + \sum_{i=1}^{3} E'_{ij} \omega_j \tag{9}$$

In the formula, T_f is the degree of traffic advantage; D_i is the density of a town's traffic network; and E_i is the proximity of traffic facilities. L_i is the total length of a certain traffic network; R_i is the land area of the town administrative area; and there are four types of traffic networks: railway, national road, provincial road, and county road. E'_{ij} is the proximity value of a town with a certain traffic facility j, and ω_j is the weight. There are three types of transportation facilities: ordinary railway station, high-speed railway station, and highway station. Similarly, for any function indicator of a town, the corresponding measurement can be constructed and fitted. All the identified functions constitute the town functions group, which is used to measure the functions of the town.

(2) Determination of High-Value Function

Among the four types of rural functions, high-value function is the one with a high evaluation value, and it reflects regional characteristics and development needs, so it plays a decisive role in the development of towns. Therefore, high-value function has a higher "state" intensity index and "potential" development index. In the identification of high-value function, a 4-quadrant analysis model was used. The horizontal axis was the "state" intensity index, and the vertical axis was the "potential" development index, with 0.25 as the midpoint for distinguishing whether the index was high or low. The plane coordinate system was divided into four areas: "high-state strong-potential area", "low-state strong-potential area", "low-state inferior-potential area", and "high-state inferior potential area". This article proposes that the function entering the "high-state strong-potential area" has the possibility to be a high-value function, and whether the function is high-valued is an important basis for judging whether it is the dominant function (Figure 4).

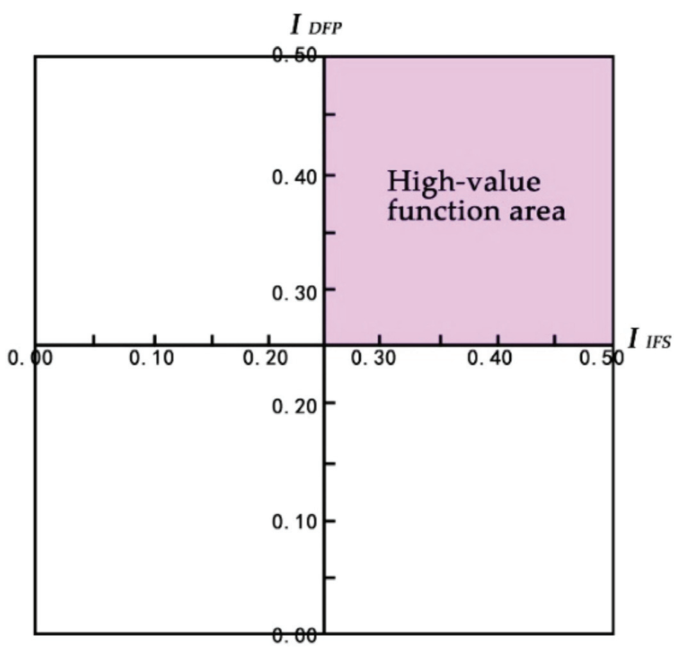


Figure 4. A 4-quadrant analysis model for high-value function.

(3) Analysis of the Interaction between High-Value Functions

As an organism, there are considerable interactions among different functions in a town. For towns with two or more high-value functions, the final dominant function will be determined by the analysis of the interaction among/between different high-value functions [41].

Using Arcgis10.2 to visualize the functions of towns [42], in the spatial visualization result of the four functions, it could be seen that there was a certain interaction between the functions. The interaction between functions referred to the impact of one function on others, including conflict, collaboration and compatibility [43]. Conflict refers to a competitive relationship between two functions, where one is reduced and another grows; collaboration refers to mutual enhancement between two functions; compatibility refers to the existence of two functions at the same time that do not weaken or enhance each other. This paper used Spearman's rank correlation coefficient to quantitatively describe the interaction between rural functions. According to the interaction between high-value functions, the dominant function of a town was determined.

(4) Identification of Main Factors Affecting Dominant Functions The classification of characteristic villages needed further identification of the factors influencing the dominant functions of the town, and to quantitatively analyze the influence degree and intensity of different influencing factors on different dominant functions. This paper comprehensively coordinated the impact factors on various functions, and finally selected several impact factors to analyze the dominant functional mechanism of the regional unit.

1. Moran's I index was used to analyze the local spatial correlation, aiming to reveal the spatial dependence, spatial correlation or spatial autocorrelation between the data related to geographic location, and, finally, to establish the statistical relationship between the data through the spatial location [44]. The local Moran's I index was defined as:

$$I_i = \frac{\mathrm{n}(x_i - \overline{x}) \sum_j w_{ij}(x_j - \overline{x})}{\sum_i (x_i - \overline{x})^2} = \frac{\mathrm{n}z_i \sum_j w_{ij} z_j}{z^T z} = z_i' \sum_j w_{ij} z_j' \tag{10}$$

In the above formula, I is the Moran index, which is often used to measure the degree of spatial difference between the regional unit i and other surrounding units. The value of I is usually between -1 and 1. When the value is less than 0, the two units are negatively correlated, and the smaller the value is, the higher the correlation is. When the value is 0, the two units are not correlated. When the value is more than 0, the two units are positive correlated and, the larger the value is, the greater the correlation is. Moran index calculation can analyze the correlation between specific functions and impact factors in regional units. x_i is the value of a certain function of the $i -$ th unit, and x_j is the value of a certain function of the $j -$ th. z_i is the function value deviation of i from its average value $(x_i - \overline{x})$, and w_{ij} is the spatial weight between elements i and j. n is the number of units. $Z(I_i)$ was calculated in the following way:

$$Z(I_i) = \frac{I_i - E(I_i)}{\sqrt{V(I_i)}} \tag{11}$$

$$E(I_i) = -1/(n-1) \tag{12}$$

$$V(I_i) = E\left(I_i^2\right) - E(I_i)^2 \tag{13}$$

2. From the spatial visualization level, the Moran scatter diagram can further distinguish the functional correlation between a specific research unit and its neighboring units. The Moran scatter plot is generally used to study the instability of local space, and its four quadrants correspond to the four functional connection forms between the research unit and its adjacent units. The first quadrant represents the spatial connection form that the unit with a high observed value is surrounded by the same high-value units. The second quadrant

represents the spatial connection form that the unit with a low observed value is surrounded by high-value units. The third quadrant represents the spatial connection form that the unit with a low observed value is surrounded by the same units. The fourth quadrant represents the spatial connection form that the unit with a high observed value is surrounded by low-value units.

3. In addition to the Moran scatter diagram, the Local Indicators of Spatial Association (LISA) index clearly shows the correlation of each spatial unit through images. If the Moran scatter diagram is a qualitative description of the correlation between the spatial units, the LISA cluster diagram is a quantitative understanding of the relationship degree between the spatial units. For scattered points in the same quadrant, the difference between them may be very large, and Moran cannot reveal this difference—that is, the significance of spatial autocorrelation. Therefore, it is necessary to use LISA to further analyze the degree of correlation between the research units. By combining Moran's four-quadrant scatter diagram with the LISA significance level, we can obtain a Moran significance level map.
4. Next, we dealt with local autocorrelation and factors. By taking a specific value, the Moran's I index between the function type and the influencing factors can be obtained, and the influencing factors with the largest positive correlation and the largest negative correlation can be judged. Combined with the dominant function and the influencing factor LISA cluster diagram, the main factors that affect the corresponding function can be determined.

3.4. Decision Tree of Village Type Identification

The decision tree judgment method is as follows: (1) Towns have multiple functions for the measurement of multiple functions and the judgment of dominant functions; the function group method must be obtained. (2) The decision tree method can be used to express the process of how to zone the dominant function, and the high-value function must be determined in the zoning process. (3) After determining the dominant function, the main factors affecting the dominant function need to be further identified. (4) Finally, for the characteristic type of a specific village, the dominant function of the town should be coupled with the characteristic resources of the specific village [45]. The following four factors need to be considered in the coupling process: (1) the "state" value and "potential" value of the dominant function; (2) the LISA cluster map of function and influencing factors; (3) the effect of the positioning of the county/city relative to the town on social, natural and economic functions; and (4) the sensitivity of the village to resources, policies, and the environment. The above four factors are included in the evaluation of the characteristic type of any village. A complete decision tree method involves three parts: selecting the dominant function according to the function calculation value, forming several different functional advantage areas in space, and then determining the characteristic village type according to the total characteristic resources of the village and other production capacity performances (Figure 5).

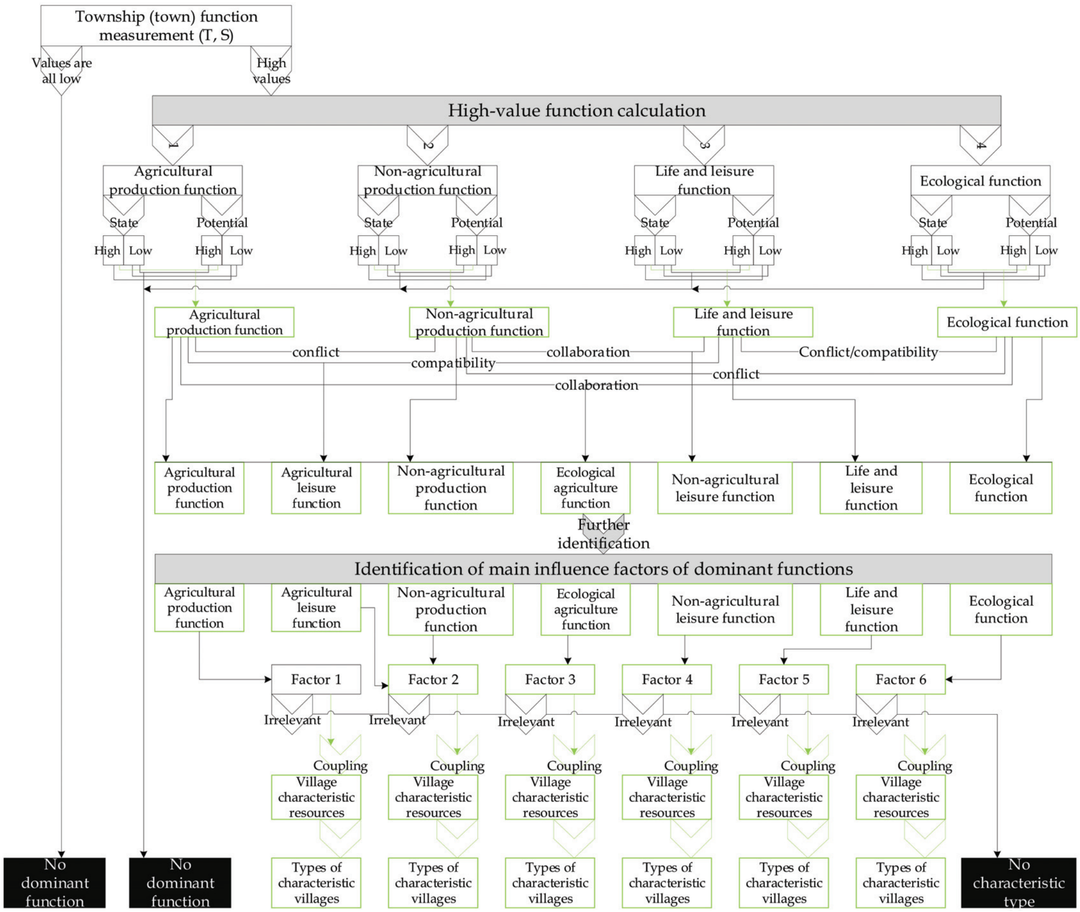


Figure 5. Decision tree for the identification of the village type.

4. Results

4.1. Single Function Calculation

(1) Calculation Result

According to the aforementioned data processing method, the weight of each functional index based on the study area is listed in Table 2.

The value of individual functions and ranking of 11 towns in Jixi County are as follows (Table 3):

A single function with value greater than 0.5 will be the comparative advantage function. So, according to Table 2, it can be seen that each function has a comparative advantage in several towns. There are four towns with a comparative advantage in agricultural production functions, six for life and leisure, five for ecosystem services, and four for nonagricultural production. This result is consistent with the main function positioning of Jixi in the Wanjiang Economic Belt. Each town basically has one or two high-value functions; it shows the diversified development pattern of the Jixi rural area.

Table 3. Calculation results of individual functions.

Function	Agricultural Production Function (AF)		Nonagricultural Production Function (NF)		Life and Leisure Function (LF)		Ecological Function (EF)	
	S1	Order	S2	Order	S3	Order	S4	Order
Huayang Town	0.0970 State Potential	11 0.0509 0.0461	0.6842 State Potential	1 0.2904 0.3938	0.5219 State Potential	6 0.2993 0.2226	0.1033 State Potential	11 0.0709 0.0324
Chang'an Town	0.5435 State Potential	4 0.2515 0.2910	0.3884 State Potential	6 0.2013 0.1871	0.5659 State Potential	5 0.3082 0.2577	0.2883 State Potential	9 0.2239 0.0644
Fuling Town	0.1978 State Potential	10 0.1357 0.0621	0.4412 State Potential	5 0.2309 0.2103	0.7018 State Potential	2 0.4092 0.2926	0.6733 State Potential	3 0.3771 0.2692
Shangzhuang Town	0.2880 State Potential	9 0.1802 0.1078	0.2843 State Potential	8 0.1603 0.1240	0.6814 State Potential	3 0.3977 0.3837	0.3091 State Potential	8 0.2031 0.1060
Yangxi Town	0.6821 State Potential	1 0.3093 0.3728	0.5407 State Potential	3 0.2772 0.2635	0.4108 State Potential	8 0.2471 0.1637	0.3621 State Potential	7 0.1987 0.1634
Linxi Town	0.3799 State Potential	7 0.2307 0.1492	0.6509 State Potential	2 0.2887 0.3622	0.6413 State Potential	4 0.3349 0.3064	0.2224 State Potential	10 0.1405 0.0819
Yingzhou Town	0.3299 State Potential	8 0.2167 0.1132	0.1663 State Potential	11 0.1034 0.0629	0.7885 State Potential	1 0.4577 0.3308	0.4278 State Potential	6 0.1893 0.1385
Jinsha Town	0.3940 State Potential	6 0.2279 0.1661	0.5012 State Potential	4 0.2709 0.2203	0.3261 State Potential	9 0.1805 0.1456	0.5699 State Potential	4 0.2509 0.3190
Banqiaotou Town	0.6206 State Potential	2 0.2992 0.3214	0.3307 State Potential	7 0.1892 0.1415	0.1991 State Potential	10 0.1167 0.0824	0.5494 State Potential	5 0.2781 0.2613
Jiapeng Town	0.5809 State Potential	3 0.3236 0.2583	0.2092 State Potential	9 0.1293 0.0799	0.4686 State Potential	7 0.2784 0.1902	0.7859 State Potential	2 0.4256 0.3603
Jingzhou Town	0.4603 State Potential	5 0.2496 0.2107	0.1865 State Potential	10 0.1108 0.0757	0.1894 State Potential	11 0.1109 0.0885	0.8437 State Potential	1 0.4738 0.3699

(2) Spatial Pattern and Evaluation of Single Function

Through ArcGIS 10.2, the four functions are visualized in space. Relying on the differentiation of natural units, by using the Natural Breakpoint Classification (NBC) method, the four functions of agricultural production, nonagricultural production, life and leisure, and ecosystem services are defined from low to high, as low, medium, higher, and highest (Figures 6–9). A function with an index of more than 0.5 is the highest, while that with less than 0.2 is low.

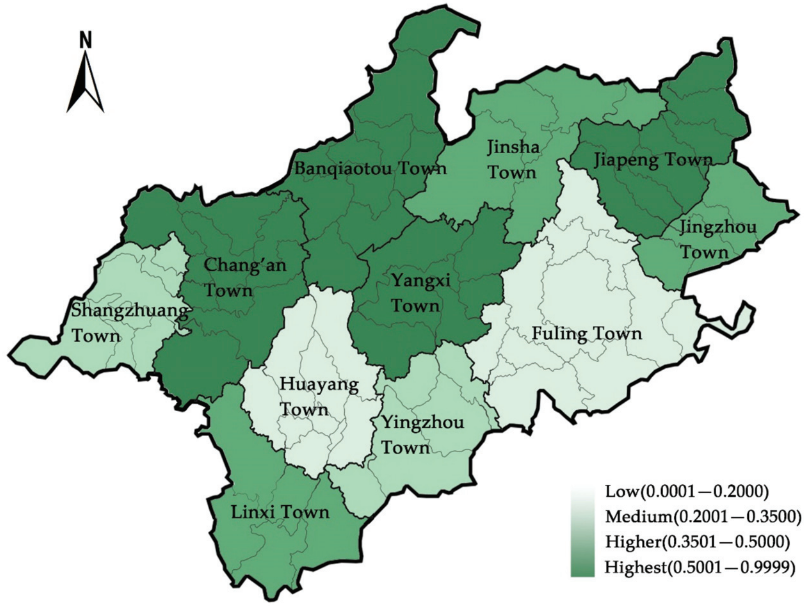


Figure 6. Spatial pattern of the agricultural production function in 11 towns in Jixi.

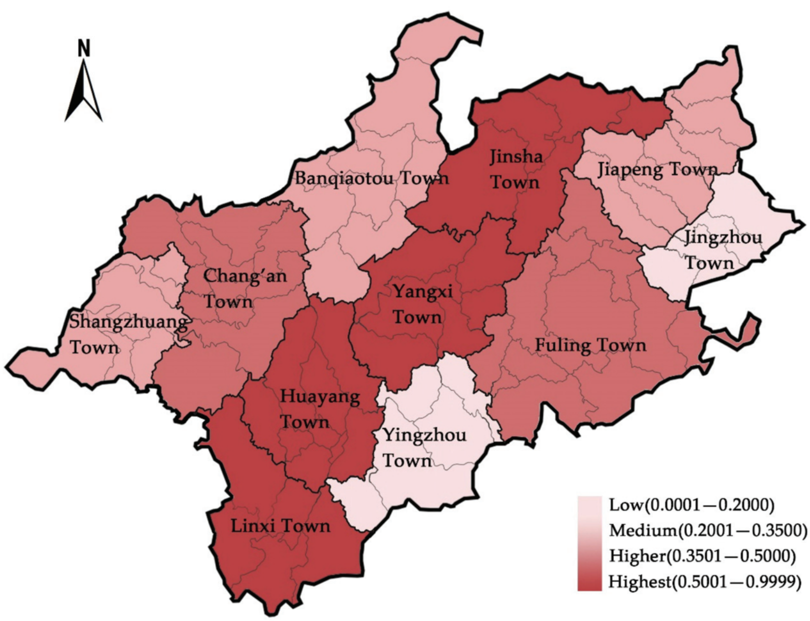


Figure 7. Spatial pattern of the nonagricultural production function in 11 towns in Jixi.

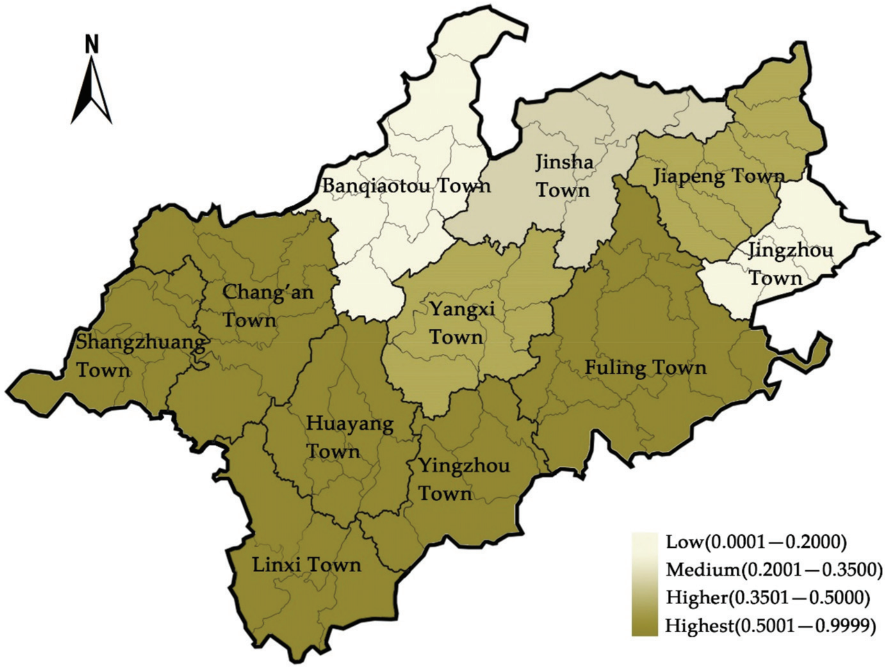


Figure 8. Spatial pattern of the life and leisure function in 11 towns in Jixi.

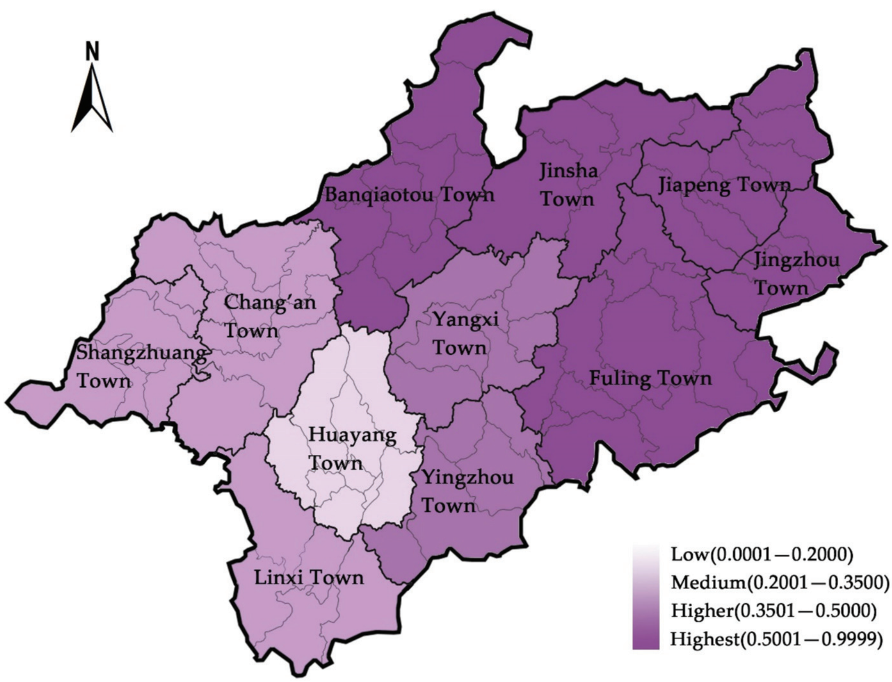


Figure 9. Spatial pattern of the ecological function in 11 towns in Jixi.

From functions visualized in space, it can be seen that the comparative advantage function presents an obvious concentrated distribution in space. Comparative advantage areas for agricultural production functions are located in the northern part of the county; comparative advantage areas for nonagricultural production functions are located in the southwest of the county; comparative advantage areas for life and leisure functions are located in the northwest and southeast of the county; and comparative advantage areas for ecological function are located in the northeast of the county.

4.2. Identification of Dominant Function

(1) Assessment of high-value function

According to the aforementioned four-quadrant function assessment method, if both the "state" and "potential" values are more than 0.25, the function will have a high value. For the four-quadrant evaluation results of 11 towns, refer to Figure 10.

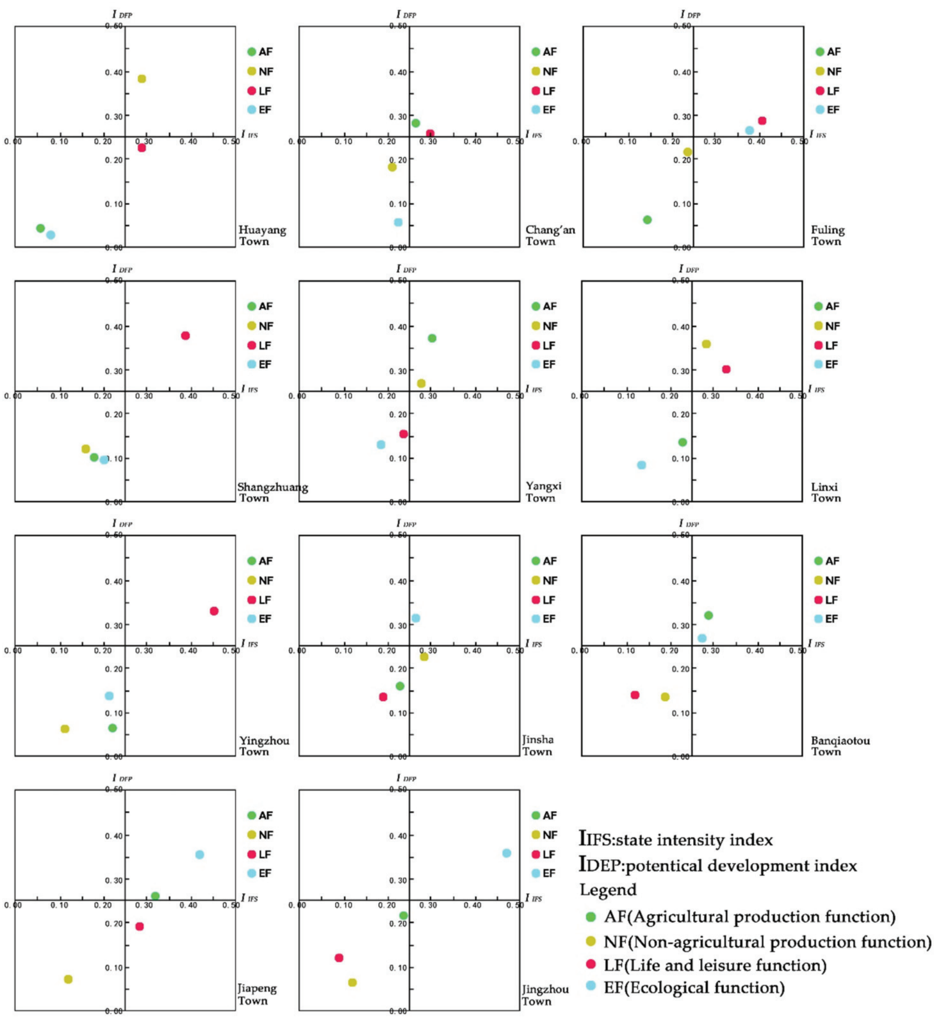


Figure 10. Four-quadrant evaluation results of 11 towns.

The high-value functions of the 11 towns in Jixi are shown in Table 4:

Table 4. Towns with high-value functions.

Types of High-Value Functions Type	Towns
Agricultural production function	Yangxi Town, Banqiaotou Town, Jiapeng Town, Chang'an Town
Nonagricultural production function	Huayang Town, Linxi Town, Yangxi Town
Life and leisure function	Yingzhou Town, Fuling Town, Shangzhuang Town, Linxi Town, Chang'an Town
Ecological function	Jingzhou Town, Jiapeng Town, Fuling Town, Jinsha Town, Banqiaotou Town

There are five towns with two or more high-value functions; they are relatively comprehensive towns, accounting for 45.45% of the total spatial units in the demonstration area. Comprehensiveness is reflected in the balanced development of agricultural production and ecological functions, balanced leisure and ecological functions, and balanced nonagricultural production and leisure functions. Comprehensive towns include Jinsha Town, Banqiaotou Town, Chang'an Town, Linxi Town, and Shangzhuang Town. These five research units all have two high-value functions. Jinsha Town and Banqiaotou Town are densely wooded, rich in ecological resources, and have a high level of development of under-forest industries. They belong to ecological function areas, so their ecological levels and agricultural production levels have high-value. The two regional units of Linxi Town and Shangzhuang Town are rich in cultural resources and have a relatively high level of development in leisure tourism, so their nonagricultural production and leisure are high-valued. Chang'an Town is rich in cultural resources, has a high level of development in terms of tourism and leisure agriculture, and its agricultural production and leisure are high-valued.

There are six towns with only one high-value function, accounting for 54.55% of the regional units in the demonstration area. These regional units have a clear functional orientation, and include Yangxi Town, Huayang Town, Yingzhou Town, Fuling Town, Jingzhou Town, and Jiapeng Town. They are mainly distributed on both sides of Dahui Mountain and Dazhang Mountain Gorge, forming a modern industrial gathering area, a characteristic agricultural production gathering area, a northern ecological conservation district, and a cultural leisure tourism district. Modern industrial industries mainly include: mechanical processing, modern logistics, e-commerce, food processing, and other industrial clusters, showing a strong tendency towards industrialization. Characteristic agricultural production mainly includes under-forest economy, the breeding industry, cash crops, etc.

(2) Interaction analysis between high-value functions

According to the calculation results for Spearman's correlation coefficient between regional functions, there is correlation between multiple pairs of regional functions. The minimum value of the correlation coefficient is 0.080 and the maximum value is 0.407 (Table 5).

There is a significant negative correlation between agricultural production and nonagricultural production functions, with a correlation coefficient of −0.407. Driven by urban–rural integration, nonagricultural production (heavy industry, light industry) has developed rapidly in rural areas, and nonagricultural construction land, production land, etc., have gradually occupied agricultural land. Farmers' lifestyle of living on agricultural production has gradually changed, and a large number of original agricultural populations have turned to nonagricultural production, which limits the structural stability of agricultural production personnel. At the same time, the red line of arable land and ecological protection requirements limit the expansion of nonagricultural production land, thereby restricting the development of nonagricultural production. Therefore, these reasons have created conflicting effects between agricultural production and nonagricultural production function.

Table 5. Spearman correlation coefficient between different functions in Jixi County. (* reprensts generally significant; ** reprensts extremely significant).

		Agricultural Production Function	Nonagricultural Production Function	Life and Leisure Function	Ecological Function
Agricultural production function	Correlation coefficient	1	−0.290 *	−0.080	0.299 *
	Significance (bilateral)	-	0.018	0.427	0.016
Nonagricultural production function	Correlation coefficient	−0.290 *	1	0.202	−0.407 **
	Significance (bilateral)	0.018	-	0.03	0.008
Life and leisure function	Correlation coefficient	−0.080	0.202	1	−0.094
	Significance (bilateral)	0.427	0.03	-	0.01
Ecological function	Correlation coefficient	0.299 *	−0.407 **	−0.094	1
	Significance (bilateral)	0.016	0.008	0.01	-

Agricultural production and leisure have a very small negative correlation, with a coefficient of −0.080. Leisure agriculture occupies a large proportion of the agricultural structure in Jixi. Leisure agriculture makes full use of the local cultural heritage and folk customs, and shows pleasant pastoral scenery and original ecological farming culture, forming rich tourism resources and producing tourism effects. Therefore, it forms the compatible effect of the agricultural production and leisure functions.

There is a general positive correlation between agricultural production and ecological function, with a correlation coefficient of 0.299. Jixi's landform has many hills and ravines, having less cultivated land but higher requirements for ecological protection. Therefore, agricultural production is mostly combined with ecological protection, and Jixi mainly develops under-forest economy. Generally speaking, the larger the biomass is, the stronger the ecological function is. As a result, it forms a collaborated effect between agriculture and ecology.

There is a general positive correlation between nonagricultural production and life and leisure, with a correlation coefficient of 0.202. This shows that nonagricultural production function has a positive synergy effect on life and leisure functions. This result is reflected in the intersection of the spatial pattern in Figures 7 and 8. Nonagricultural production is mostly in urban areas with dense populations, more residential land, and higher living functions. In addition, county towns have many cultural heritages and rich landscape resources; therefore, there is a collaborative effect between nonagricultural production and leisure functions.

There is a significant negative correlation between nonagricultural production and ecological function, with a correlation coefficient of −0.290. Areas with highest nonagricultural production function are Huayang Town and Linxi Town, where industrial distribution is dense, land development intensity is higher, human activities are stronger, and non-ecological uses of the land account for a large proportion of usage, so ecological functions and other functions are relatively weak. This creates conflicting effect between nonagricultural production and ecological functions.

There is a general negative correlation between leisure and ecological functions, with a coefficient of −0.094. Life and leisure require a large amount of construction land, which seriously threatens ecological security. In addition, Jixi has complex geology and a fragile ecology, so excessive life and leisure activities will cause pollution and damage to the ecological environment, resulting in ecological crisis. Therefore, there is conflict between leisure and ecological functions.

According to the interaction calculation result between the functions, the interaction type is obtained (Table 6).

Table 6. Interaction type between functions.

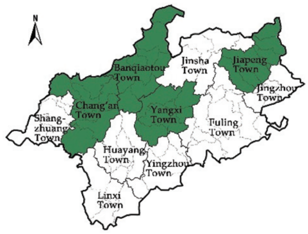
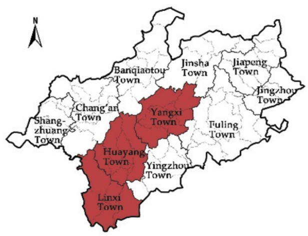
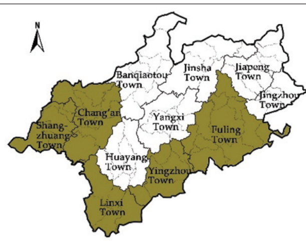
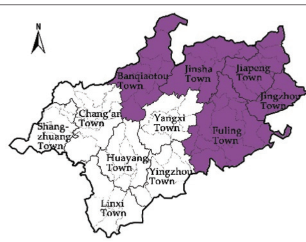
Functions	Interaction Type	Functions	Interaction Type
Agricultural production function—nonagricultural production function	Conflict	Agricultural production function—life and leisure function	Compatibility
Agricultural production function—ecological function	Collaboration	Nonagricultural production function—life and leisure function	Collaboration
Nonagricultural production function—ecological function	Conflict	Life and leisure function—ecological function	Conflict

(3) Criteria for Determining Dominant Functions

1. Function evaluation is the basis for determining the dominant function. For a town with only one function entering into "high-state strong potential area", its dominant function is determined according to the high-value function. For a town with more than two functions entering the "high-state strong potential area", its dominant function should be determined by integrating the needs of the town, the interactions between functions, and the comparative advantage of functions. For towns that do not have a function in the "high-state strong potential area", dominant functions are determined according to the resource conditions, development needs, direction of macro policies, and trend of social development [46].
2. Comparative advantage is an important support in the identification of dominant function. Only by relying on regional differences and comparative advantages can the dominant function form a unique competitive advantage and sustainable development momentum in the future development of towns [47]. There are three main criteria for the definition of comparative advantage: industrial development capacity, sustainable utilization of resources, and comprehensive quality of human settlements in towns. This means that the town can make full use of its characteristic resources for sustainable industrial development and effectively improve the comprehensive quality of human residential environment at the same time.
3. Upper-level planning determines the basic direction of the dominant function at the macro level. Therefore, the dominant function of a town should be in line with the county's overall planning, the main functional zoning of provinces and cities, and the overall planning among the provinces. Only from the perspective of the macro pattern—by considering the specific social, economic and cultural background of the town from the external system—can its dominant functions be accurately determined.

From the above calculation results, it can be seen that all the towns in Jixi have at least one function entering the "high-state strong potential area", so it is only necessary to comprehensively weigh the interaction between the different functions and the actual development environment in a town. The distribution rules and the influencing factors of "high-state strong potential area" are shown in Table 7, and they have a direct effect on determining the dominant function of a specific town.

Table 7. Visualization on the distribution of "high-state strong potential area" of town function.

Function Type	High-State Strong Potential Area	Influencing Factors of High Values	Type of Interaction with Other Functions
Agricultural production function		Terrain slope is small or moderate, suitable for planting, sufficient water source, good light, and less affected by urban development.	Significantly negatively correlated with nonagricultural production, showing a conflict effect. Taking into account the fact that Jixi's characteristic ecological agriculture is relatively developed, agricultural production is coordinated with life- leisure and ecosystem services
Nonagricultural production function		Location advantage, radiated by city expansion, transportation advantage, policy advantage, ecosystem stability.	Significantly negatively correlated with agricultural production and ecosystem services, showing conflict effects with it. Compatible with leisure.
Life and leisure function		Good industrial foundation, location advantage, profound cultural heritage, complete village layout and spatial structure.	Significantly negatively correlated with ecosystem services, showing conflicting effects with it. Synergy with agricultural production. Compatible with nonagricultural production.
Ecological function		High forest coverage, many natural scenic spots, obvious topographic features.	Significantly negatively correlated with nonagricultural production, compatible with characteristic agricultural production and characteristic natural scenery.

(4) Dominant Functions of Each Town

Integrating the distribution of "high-state strong potential area", the interactions between functions, upper-level planning, and the external environment, the dominant functions of each town are explained below (Figure 11).

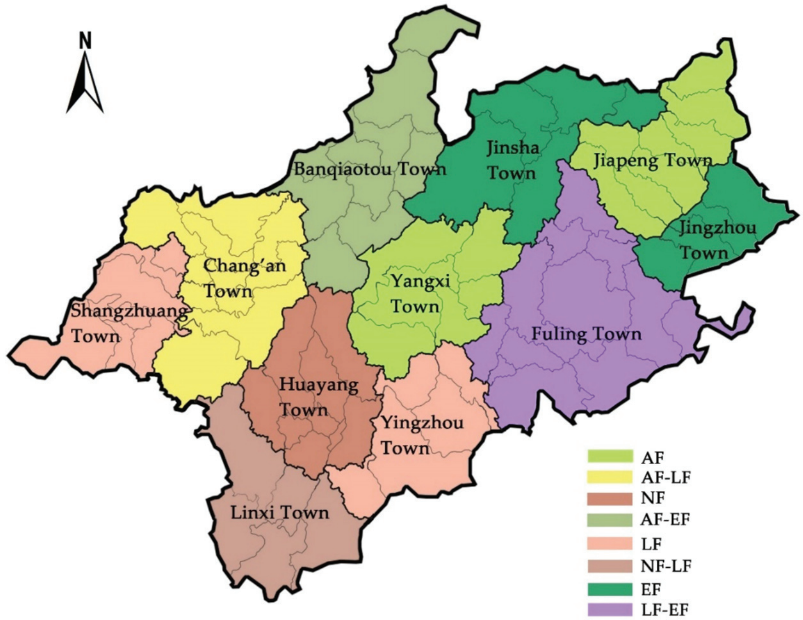


Figure 11. Dominant function of each town.

Huayang Town: nonagricultural production function. From Table 2, Figure 7, and Table 6, it can be seen that the nonagricultural production function value of Huayang Town is 0.6842, ranking first in the county. Among other functions, the leisure function stands out most. Huayang Town has the largest county high-speed railway station in China, which confers significant transportation advantages for the transportation of raw materials and products. Jixi is the main base for auto parts and mechanical processing in Xuancheng City. Huayang Town now has a high-end characteristic industrial cluster (base) of mechanical parts in Jixi County, Anhui Province. Huayang Town was named Taobao Town by the Ali Research Institute in 2019. The output value and scale of e-commerce have expanded year by year, which has established its dominant position in nonagricultural production. The old city of Huayang has a history stretching back more than 1400 years. In 2010, Huayang Town was included in China Huizhou Cultural and Ecological Protection Experimental Zone, which fully affirmed the cultural status and leisure functions of Huayang Town.

Chang'an Town: agricultural production–life and leisure function. From Table 2, Figure 6, Figure 8, and Table 6, it can be seen that the agricultural production function value of Chang'an Town is 0.5435, ranking fourth in the county. The basic farmland quantities in Chang'an Town accounts for 13.4% of the county, and Chang'an is an important camellia production base. Relying on the good natural landscape and pattern, a nicer agricultural landscape has been formed in some villages. At the same time, Chang'an Town is also the core of the Historical and Cultural Protection Area, with a complete traditional layout and structure in villages, so it has outstanding tourism services. The traffic condition in Chang'an Town is common, and the urbanization level is low, so it is less affected by industrial urbanization, which provides a natural barrier for the protection of traditional historical and cultural heritage. The simultaneous development of agricultural production and leisure in Chang'an Town shows the compatible effect of agricultural production and leisure functions.

Fuling Town: life and leisure–ecological function. Different from the general residential function that focuses on convenient living conditions, such as transportation advantage and economic development, this article focuses more on the leisure functions, such as cultural heritage, natural scenery, and cultural facilities. Fuling Town has many scenic spots, such as Huihang Ancient Road and Natural Scenery Exhibition Area, Qingliangfeng Nature Reserve, Dazhang Mountain Scenic Area, etc. It has comparative advantages in terms of natural leisure scenery that most towns do not have, so it mainly focuses on the leisure function.

Shangzhuang Town: leisure function. Shangzhuang Town is the core of the Lingbei Historical and Cultural Protection Area, and it is a key display area for the ancient villages of Lukun, Lingbei. It has a rich cultural heritage, complete traditional layout and structure of villages, and it can provide outstanding tourism services. Shangzhuang has a second-level tourist service center. Therefore, it mainly focuses on life and leisure functions.

Yangxi Town: agricultural production function. Surrounded by mountains and rivers, the soil is fertile, which is very suitable for agricultural production. Since the implementation of the "Forest Chief System", Jixi has taken advantage of its ecological advantages to develop a green economy with the improvement of forest ecological benefits. The under-forest economy is one of the important aspects in Yangxi. Yangxi Town is a production base of dual-use bamboo shoots in Jixi County, which forms the pillar industry of Yangxi Town and effectively helps villagers earn money. In 2018, the output value of bamboo shoots in Yangxi Town was as high as CNY 90 million, and the per capita income increased by more than CNY 1500. Therefore, Yangxi Town mainly focuses on the agricultural production function.

Linxi Town: nonagricultural production–life and leisure functions. Linxi Town is adjacent to Huayang Town. It enjoys the radiant function of the county, and has a higher traffic advantage and lower agricultural production and ecological functions. With its high level of urbanization, Linxi provides a good infrastructure and economy basis for life and leisure. The nonagricultural production of Linxi Town mainly comes from the tourism industry driven by cultural heritage. The nonagricultural industry creates a good economic foundation for life and leisure; the full use of life and leisure functions can also produce a certain spatial economic effect. All these factors reflect the synergistic effect of nonagricultural production and leisure.

Yingzhou Town: life and leisure function. It can be seen from Table 2, Figure 8 and Table 6 that the value of the life and leisure function of Yingzhou Town is 0.7885, ranking first in the county. Furthermore, Yingzhou Town has Longchuan National Scenic Spot.

Jinsha Town: ecological function. The vegetation types of forest ecosystem in Jinsha Town are bamboo forest, economic forest, and arbor forest.

Banqiaotou Town: agricultural production–ecological function. Banqiaotou Town is an important water–soil conservation ecological zone, and is also an ecological agricultural zone in the middle of Jixi. There is a green agricultural production base in Banqiaotou. The development of ecological agriculture will increase the effect of ecological function at the same time. The ecological function also protects the environmental atmosphere of the ecological agriculture and increases its value.

Jiapeng Town: ecological function. Jiapeng Town is an ecological conservation area in the north of Jixi. Together with Jinsha Town, it constitutes the Jiapeng–Jinsha water conservation and water–soil conservation ecological community. Its ecological function is outstanding.

Jingzhou Town: ecological function. Jingzhou Town is an ecological conservation area in the north of Jixi, which contains the Xianren Temple water conservation ecological district, and the Xiaojiuhua ecological tourism and water conservation ecological district. Its ecological function is outstanding.

4.3. Classification of Village Types

(1) Autocorrelation Analysis of Dominant Functions and Factors

1. Impact factors

The division of village types is related to dynamic factors, so the main factors that form the dominant function must be analyzed. Table 8 lists the influencing factors affecting function forming from a qualitative perspective, mainly focusing on resource allocation and environmental differences. This article adopts a quantitative method to analyze the intensity that the main influencing factors affecting on functions.

Table 8. Moran's I index between town function and various influencing factors.

Functional Categories	GDP	Traffic Superiority	Cultivated Land	Forest Coverage	Tourism Revenue	Farmer Income	Industrial Output	I-Level Eco-Scape
AF	−0.259	0.089	0.437	0.097	−0.183	−0.301	−0.261	0.156
NF	0.474	0.425	−0.216	−0.436	0.097	0.456	0.403	−0.287
LF	0.103	0.203	0.051	0.117	0.472	0.319	0.089	0.081
EF	−0.421	−0.402	0.098	0.154	−0.058	−0.342	−0.275	0.470
AF-LF	0.109	0.112	0.225	0.208	0.186	−0.095	0.105	0.128
NF-LF	0.307	0.193	−0.396	−0.267	0.201	0.246	0.093	0.091
AF-EF	−0.384	−0.277	0.267	0.191	−0.079	−0.137	−0.172	0.133
LF-EF	−0.285	0.137	0.104	0.097	0.361	0.166	−0.208	0.198

This study adopted the local correlation method in spatial autocorrelation. Based on the accuracy and difficulty of data acquisition, the influencing factors selected in this paper (Table 8) are the average GDP of a town in the most recent five years, traffic superiority, cultivated land, forest coverage, tourism revenue, net income per capita of farmers in the most recent five years, gross industrial output value, and I-level ecological function zone area.

The methods for calculating each influencing factor are as follows: (1) GDP reflects the economic development level of the unit. The data sources are the *2015–2019 Jixi County Statistical Yearbook* and the *2015–2019 Jixi County Town Government Work Report*. (2) Traffic superiority reflects traffic conditions and location levels. This paper has established a traffic superiority evaluation system for administrative villages that includes traffic network density, proximity to traffic facilities, and location dominance. The data come from the *2019 Jixi County Statistical Yearbook*. (3) The area of cultivated land reflects the level of agricultural production, and is calculated based on the 2019 Jixi Land Use Change Survey data. (4) Forest coverage reflects the level of ecological function and agricultural production, and is calculated by using the 2019 Jixi Land Use Change Survey data. (5) Tourism revenue reflects the development level of the leisure industry. The data come from the *2019 Jixi County Statistical Yearbook*. (6) Farmers' per capita net income in the past five years reflects the impact of different dominant functions on farmers' incomes. (7) The total industrial output value reflects the level of industrial development of a unit. (8) The area of the I-level ecological function zone reflects the ecological importance in the unit, and the data come from the *Jixi County Government Work Report (2015–2019)*.

2. Correlation analysis

In view of the low degree of government information at the early stage, and the poor availability of relevant statistical data, this study used data from 2015–2019 for analysis. The analysis results show that there is a more complicated relationship between the functional categories and their influencing factors, and the results are as follows (Table 8):

3. Local indicators of spatial association diagram

The multivariate LISA module of the Geoda095i software was used for statistical analysis and expressed in Moran's I index, forming a LISA cluster map (Figure A1) of the dominant functions and influencing factors.

(2) The Formation Mechanism of Different Dominant Functions

1. Formation mechanism of agricultural production function (AF)

The factor that has the strongest correlation with agricultural production function is the area of arable land, and its Moran's I index is 0.437, indicating that the amount of arable land has a direct role in promoting agricultural production. From 2006 to 2020, the area of arable land in Jixi decreased by 150.77 hectares, which indicates an ecological tendency in Jixi for agriculture. In addition, forest coverage, area of ecological function zones, and transportation advantage are also positively correlated with agricultural production. It can be seen from the LISA cluster map (Figure A1) that the agricultural production of Chang'an Town, which has a larger per capita area of arable land, has high–high clusters of agricultural production function. Banqiaotou Town, which has more forest and ecological function land, also has high–high clusters.

2. Formation mechanism of nonagricultural production function (NF)

The influencing factors of nonagricultural production functions and agricultural production functions present an opposite pattern. Nonagricultural production functions are positively correlated with GDP, transportation advantages, total tourism income, farmer per capita net income, and total industrial output. Among them, GDP and total industrial output have the highest correlation with NF. It can be seen from the LISA cluster map (Figure A1) that Huayang Town, which has convenient transportation, complete facilities, and industrial clusters, has high-high clusters of nonagricultural production.

3. Formation mechanism of life and leisure functions (LF)

Life and leisure functions are mainly affected by the total tourism income (Moran's I index is 0.472) and farmers' per capita net income. The correlation with other influencing factors is relatively low, indicating that the influencing factors of life and leisure functions are more complicated. It can be seen from the LISA cluster map (Figure A1) that there are fewer high–high clusters of life and leisure functions, but more low–low and low–high clusters. Among the positive correlation factors, the low–low clusters are mainly distributed in Banqiaotou Town, Jiapeng Town, and Jingzhou Town.

4. Formation mechanism of ecological functions (EF)

Ecological functions are sensitive functions and have relatively high correlations with most impact factors. They are negatively correlated with GDP, transportation advantages, farmers' per capita net income, and total industrial output. Industrial development and urbanization will occupy ecological and agricultural land, which results in a decline in the ecological functions of regional units. EF is positively correlated with the area of the I-level ecological function zone. It can be seen from the LISA cluster map (Figure A1) that the high–high clusters of ecological functions are in the northeast of the county, which is densely forested.

5. Formation mechanism of agriculture–leisure function (AF–LF)

The influencing factors of agriculture–leisure function are more complex and include almost all the elements, so the correlation with the influencing factors is not significant. The three factors with a higher correlation are cultivated land area, forest coverage area, and total tourism revenue. It can be seen from the LISA cluster map (Figure A1) that the high–high clusters of agriculture–leisure functions are in Chang'an Town, where tourism and agriculture are more developed.

6. Formation mechanism of nonagricultural–leisure function (NF–AF)

Nonagricultural–leisure functions mainly refer to the modern functions of rural areas, so, compared with the influencing factors of AF, NF–AF presents an opposite pattern. It can be seen from the LISA cluster map (Figure A1) that the high–high clusters of nonagricultural and leisure functions are in Linxi Town, where industry and cultural tourism are more developed.

7. Formation mechanism of agricultural–ecological functions (AF–EF)

Agricultural–ecological functions have a high correlation with GDP, transportation advantages, and cultivated land area, but a low correlation with other factors. It can be seen from the LISA cluster map (Figure A1) that the high–high clusters of agricultural-ecological functions are in Banqiaotou Town.

8. Formation mechanism of leisure and ecological function (LF–EF)

Ecological leisure requires the coexistence of a good infrastructure environment and ecological resources. It can be seen from the LISA cluster map (Figure A1) that the high-high clusters of life and leisure–ecological functions are in Fuling Town.

(3) Classification of characteristic villages

Among the measures proposed by the Chinese government to establish a "five-level three-category" Spatial Planning of National Land (Opinions of the CPC Central Committee and the State Council on establishing and supervising the implementation of the Spatial Planning of National Land. Available online: http://www.gov.cn/zhengce/2019-05/23/content_5394187.htm (accessed on 23 May 2019)), town planning belongs to the last level and focuses on implementation, while the village is non-planned and detailed. In the current large-scale rural revitalization and urban–rural integration development practice in China, village planning focuses more on regional adaptability and characteristics, so the village should be a practical carrier with sufficient operability. After determining the dominant function and the main influencing factors of towns, performing the characteristic classification of villages from a functional perspective is an important prerequisite for ensuring the implementation of the national *Main Functional Area Strategy*. The classification of villages can improve the competitiveness of villages effectively, and mobilize the enthusiasm of villagers to participate in rural construction.

Competitiveness stems from ontological elements, functional structure, and political environment [48]. In a town, spatial pattern determined by the dominant function—characteristic resources of the village are the main driving force for shaping the characteristic type and competitiveness [49]. The characteristic resources of the village help the rural regional system win higher scores in dominant functions. Characteristic resources mainly refer to natural ecological resources, agricultural production resources, tourism landscape resources, historical and cultural resources, and industrial production resources. The coupling result of characteristic resources with the main influencing factors of functions is the classification of characteristic villages.

In a village with a good human–land relationship operation environment, the essence of coupling is to dig deeper into the potential energy of characteristic resources, fully grasp the tolerance and stability threshold of characteristic resources, and, finally, to realize the optimal energy-efficient allocation of resources. The binding force in the coupling process mainly includes urban–rural relations, economic bases, and environmental policies (Figure 12). The spatial pattern of coupling is a characteristic mode of production, and it is also a resource expression of village spatial order. According to the characteristic resources of Jixi County and the coupling process, the types of characteristic village are classified as follows (Table 9).

The expression of the spatial pattern of nine characteristic villages in Jixi County is shown in Figure 13. According to the dominant function of the town, the division of the spatial pattern at the village level is helpful for a more precise and suitable assessment and classification of rural land. Villages are divided into types, and their development is divided into types. For example, the characteristic villages of industrial production should follow the concept of integration of primary, secondary, and tertiary industries, based on rural space, cultivating leading industries, strengthening the village economy, and building rural communities that are livable and professional. For large-scale villages with agricultural or ecological landscapes, it is necessary to improve infrastructure and public service facilities as the prerequisite, and focus on integrating land resources, developing characteristic industries, and improving living conditions to build central rural communities. Therefore, whether a village achieves differentiated development according to its foundation, ability, or level has become a landmark indicator to measure the effectiveness and quality of rural revitalization.

Table 9. Classification of characteristic villages.

Dominant Function of Town	Characteristic Resources Coupled	Types of Characteristic Villages
Agricultural production function	Agricultural production resources	Agricultural production characteristics
Nonagricultural production function	Industrial production resources	Industrial production characteristics
Life and leisure function	Historical and cultural resources	Settlement landscape characteristics
	Natural ecological resources	Natural landscape characteristics
Ecological—leisure function		
Ecological function	Natural ecological resources	Ecological characteristics
Ecological–agricultural production function	Ecological agricultural resources	Ecological agriculture characteristics
Agricultural production–leisure function	Agricultural landscape resources	Agricultural landscape characteristics
Nonagricultural production–leisure function	Local cultural resources	Local and folk custom characteristics
	Technology information resources	New industrial characteristics

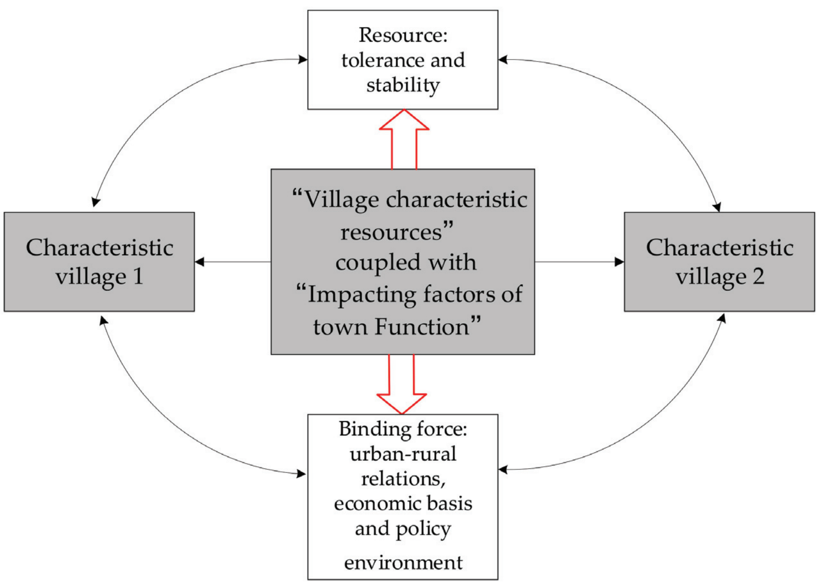


Figure 12. Coupling process of "village characteristic resources" with "impacting factors of town function".

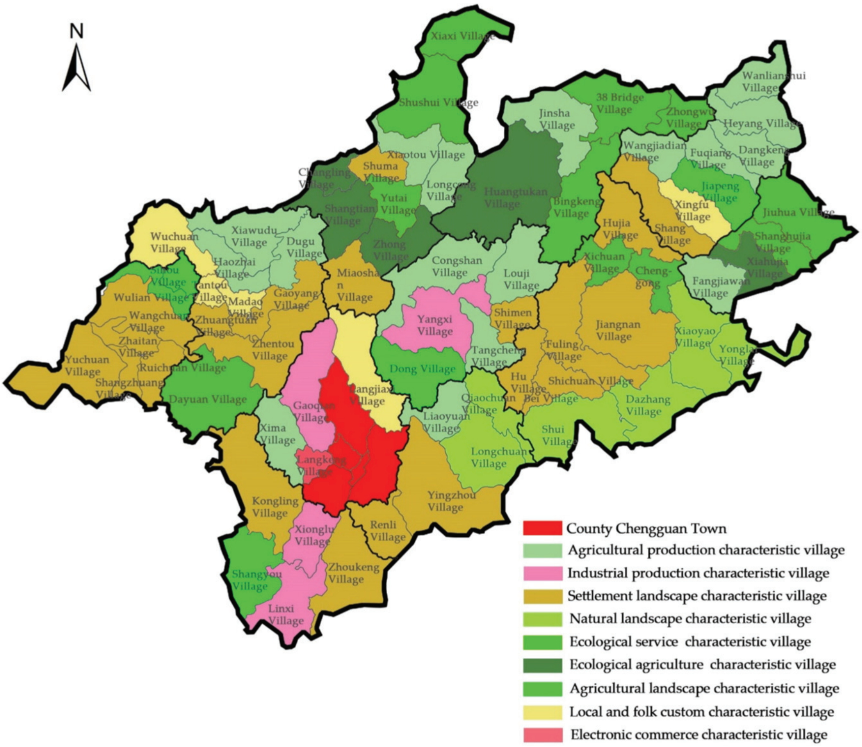


Figure 13. Spatial pattern map of characteristic village types.

5. Discussion

China's large-scale urbanization in the past 40 years has caused drastic turbulence and changes in the rural sociocultural structure and economic environment. Most villages are facing poverty and decline. In the process of economic globalization and rapid urbanization, the question of how to solve increasingly serious rural problems has become an important topic of global sustainable development. From the perspective of the diversification of rural regional functions, this paper provides guidance for the regulation of rural functions through the evaluation of rural functions and the study of regional differences. The result can promote rational division in the urban–rural integration system, and provide a scientific basis for the implementation of the Rural Revitalization Strategy and rural sustainable development.

At present, there are many studies on rural function, but the existing studies mainly focus on rural function classification and evaluation [20,50–53] and rarely introduce methods for measuring regional differences in rural function; as such, it is difficult to reveal the reasons behind rural regional differences. From the perspective of rural organism theory and regional difference measurement, this study extends the previous studies by using an evaluation model and GIS to measure and evaluate rural functions in south Anhui Province, China, and using Spearman's correlation coefficient and Moran's I index to analyze the interaction, spatial difference, and influencing factors between rural functions. Not only are the types of rural function divided, but the mechanisms leading to the difference are analyzed. After exploring the spatial differentiation law of regional functions, this paper provides a scientific basis for perfecting the spatial layout of rural functions, and improves the study logicality of rural function.

In addition, the research scale on rural function tends to be meso and macro (regional, provincial, municipal, etc.) [41,43,45], and less from the micro level (town, village). The lack of current micro-level studies has led to a gap in theories at the implementation level, such as the determination of village characteristics and development direction. On the meso–micro scale of town and village, this paper extends the previous studies by demonstrating division of the spatial pattern at the village level, which points out the most likely development paths of specific villages in the future. The micro level study has theoretical value for the refined understanding of versatility in rural area, and also has important practical significance for policy formulation and investment planning during the transition period.

6. Conclusions

(1) At the county level, the spatial differences and agglomeration characteristics of rural regional functions are significant in Jixi. The highest-value and higher-value areas of agricultural production are concentrated in the canyons between Dahui Mountain and Dazhang Mountain in the northeast of the county, which shows an obvious centralized distribution trend. The nonagricultural production function has an extremely high spatial accumulation, and there is a trend of decreasing outward from the county center to the surroundings. The highest-value and higher-value areas of life and leisure function are mainly concentrated in the southwest of the county, adjacent to the central area of the county. The highest-value and higher-value areas of ecological function are mainly concentrated in the north of Huiling Mountain and Dazhang Mountains.

(2) Combining the evaluation results of rural functions, the characteristics of functional differences, the interaction between functions, and the actual needs of town development, this paper divided the rural area in Jixi into eight functions: agricultural production function, agricultural production–life and leisure function, nonagricultural production function, agricultural production–ecological function, life and leisure function, nonagricultural production–life and leisure function, ecological function, and life and leisure–ecological function. According to the dominant functions of different towns, this paper puts forward some development suggestions for south Anhui Province, China, so as to promote rural transformation and urban–rural integration development.

(3) The difference of rural functions in the county is obvious. At the county level, considering the classification of characteristic villages, we can see that the differences within towns > between towns, which indicates that the overall differences in rural functions mainly come from differences within towns. From the contribution rate in function level, the contribution rate of difference in agricultural production function is east > west > middle, the contribution rate of difference in nonagricultural production function is west > east > middle, the contribution rate of difference in life and leisure function is east > west > middle, and the contribution rate of difference in ecological function is east > west > middle. This result indicates that the function difference in the west and east of the county has the greatest impact on regional differences, while the function difference in the middle has the least impact on regional differences.

(4) With the deepening implementation of urbanization and rural modernization in China, in addition to the four basic functions mentioned in this paper, there are still new functions emerging, and the indicator system needs to be improved further. Further research should also focus on how characteristic villages can enhance their competitiveness.

Funding: This research was funded by the China National Key R&D Plan 'Green Livable Technical Innovation for Villages and Towns' Special Project: "Research on the Protection and Renovation Planning Technology of Characteristic Villages and Towns" (2019YFD1100701) National Natural Science Foundation of China (51808106).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: We thank the People's Government of Jixi County, Anhui Province, China, for facilitating access to ArcGIS image analysis and other data of Jixi County (http://www.cnjx.gov.cn/ (accessed on 18 December 2020)), and for providing opportunities for government and social interviews. All figures and tables were drawn or made by the authors.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

LISA cluster map of regional functions and influencing factors in Jixi 11 towns (Section 4.3) is now supplied.

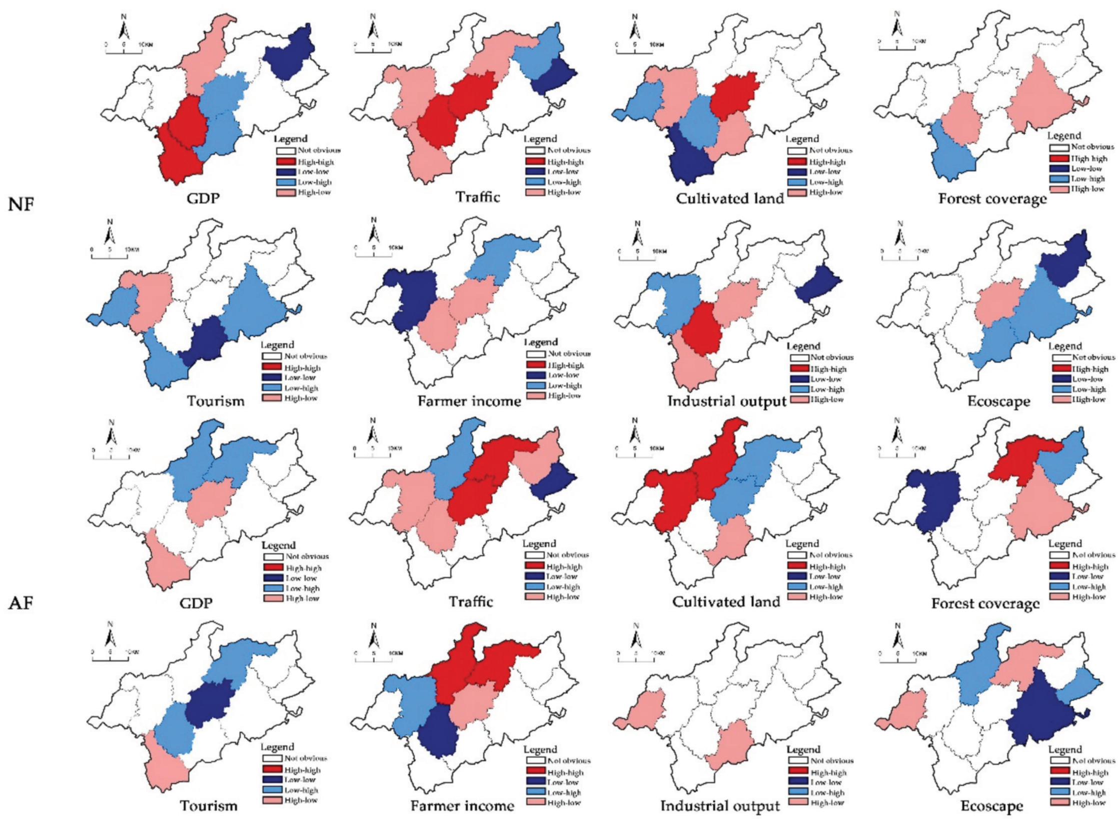


Figure A1. *Cont.*

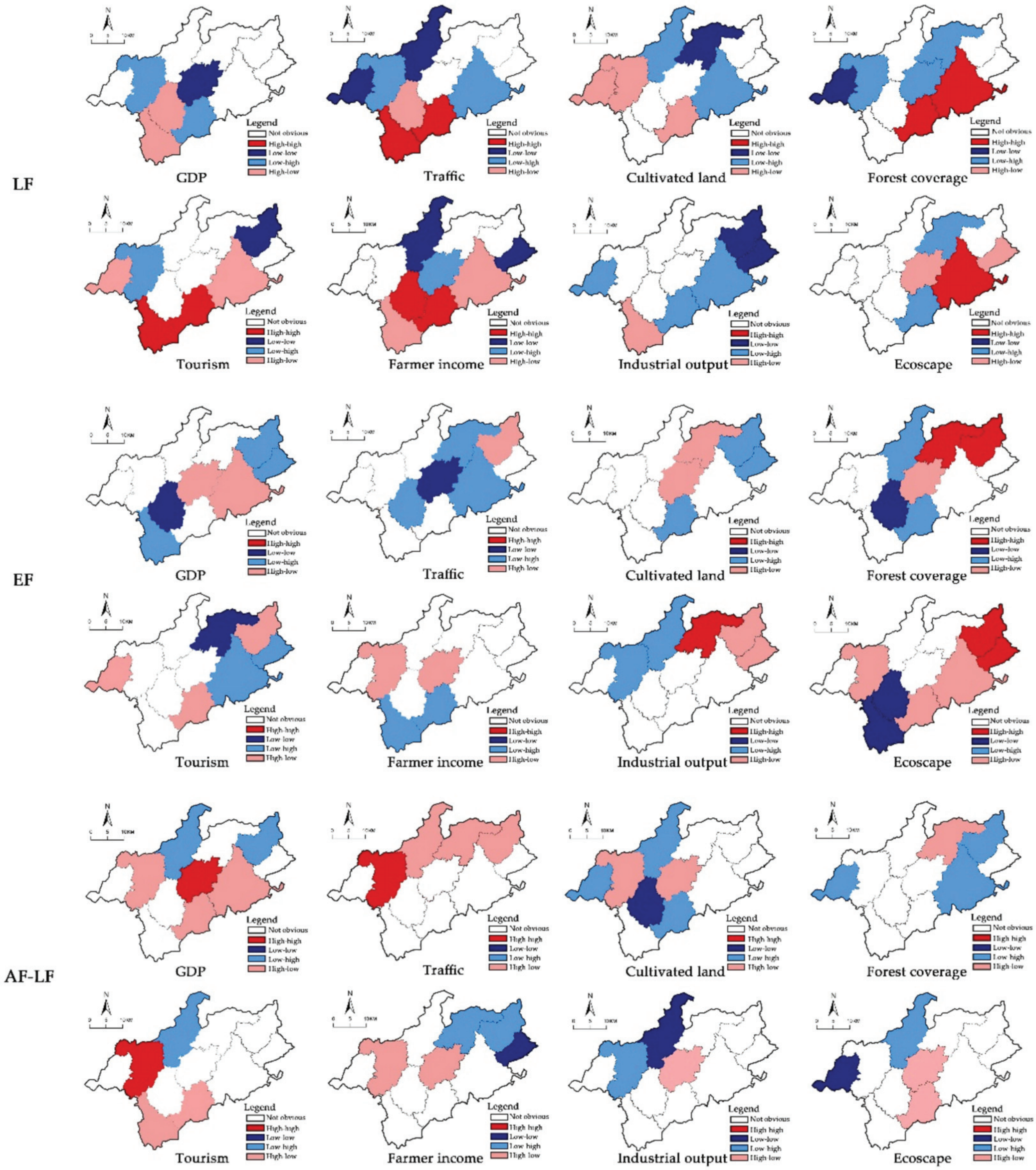


Figure A1. *Cont.*

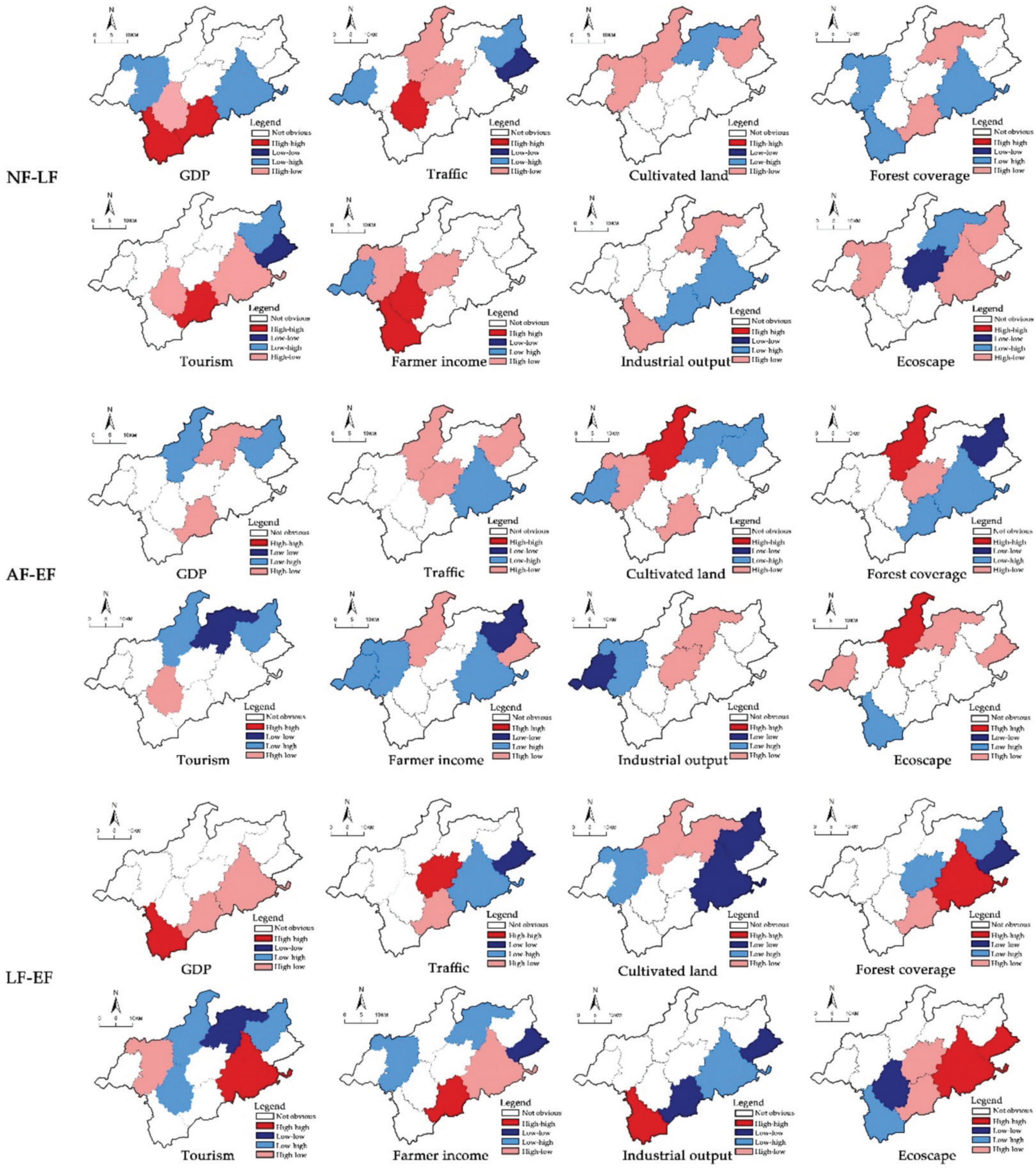


Figure A1. Cluster map of regional functions and influencing factors in 11 towns in Jixi County.

References

1. Long, H.; Li, Y.; Liu, Y.; Woods, M.; Zou, J. Accelerated restructuring in rural China fueled by 'increasing vs. decreasing balance' land-use policy for dealing with hollowed villages. *Land Use Policy* **2012**, *29*, 11–22. [CrossRef]
2. Yang, R.; Xu, Q.; Long, H. Spatial distribution characteristics and optimized reconstruction analysis of China's rural settlements during the process of rapid urbanization. *J. Rural. Stud.* **2016**, *47*, 413–424. [CrossRef]
3. Long, H.; Qu, Y.; Tu, S.; Zhang, Y.; Jiang, Y. Development of land use transitions research in China. *J. Geogr. Sci.* **2020**, *30*, 1195–1214. [CrossRef]
4. Liu, Y.; Zang, Y.; Yang, Y. China's rural revitalization and development: Theory, technology and management. *J. Geogr. Sci.* **2020**, *30*, 1923–1942. [CrossRef]

5. Clive, P. Agricultural policy discourses in the European post-Fordist transition: Neoliberalism, neomercantilism and multifunctionality. *Prog. Human Geogr.* **2005**, *29*, 581–600.
6. Beetstra, M.; Slagle, K.; Toman, E. Recognizing dynamic agricultural identities in changing rural landscapes and their impact on conservation practices. *Landsc. Urban Plan.* **2021**, *207*, 103999. [CrossRef]
7. Van Berkel, D.B.; Verburg, P.H. Spatial quantification and valuation of cultural ecosystem services in an agricultural landscape. *Ecol. Indic.* **2014**, *37*, 163–174. [CrossRef]
8. Mastrangelo, M.E.; Weyland, F.; Villarino, S.; Barral, M.; Nahuelhual, L.; Laterra, P. Concepts and methods for landscape multifunctionality and a unifying framework based on ecosystem services. *Landsc. Ecol.* **2014**, *29*, 345–358. [CrossRef]
9. Willemen, L.; Verburg, P.; Hein, L.; Mensvoort, M. Spatial characterization of landscape functions. *Landsc. Urban Plan.* **2008**, *88*. [CrossRef]
10. Ma, L.; Long, H.; Tu, S.; Zhang, Y.; Zheng, Y. Farmland transition in China and its policy implications. *Land Use Policy* **2020**, *92*, 104470. [CrossRef]
11. Tang, Y.; Mason, R.J.; Wang, Y. Governments' functions in the process of integrated consolidation and allocation of rural–urban construction land in China. *J. Rural. Stud.* **2015**, *42*, 43–51. [CrossRef]
12. Peng, J.; Chen, X.; Liu, Y.; Lü, H.; Hu, X. Spatial identification of multifunctional landscapes and associated influencing factors in the Beijing-Tianjin-Hebei region, China. *Appl. Geogr.* **2016**, *74*, 170–181. [CrossRef]
13. Sorensen, T. Regional development in an age of accelerating complexity and uncertainty: Towards survival strategies for a sparsely settled continent. *J. Local Econ. Policy Unit* **2014**, *30*, 41–52. [CrossRef]
14. Long, H.; Liu, Y. Rural restructuring in China. *J. Rural. Stud.* **2016**, *47*, 387–391. [CrossRef]
15. Renting, H.; Rossing, W.A.H.; Groot, J.C.J.; Van der Ploeg, J.D.; Laurent, C.; Perraud, D.; Stobbelaar, D.J.; Van Ittersum, M.K. Exploring multifunctional agriculture. A review of conceptual approaches and prospects for an integrative transitional framework. *J. Environ. Manag.* **2009**, *90* (Suppl. 2), 112–123. [CrossRef] [PubMed]
16. Li, Y.; Li, Y.; David, K.; Liu, Z.; Wang, Y.; Wang, J. Spatio-temporal pattern and driving forces of construction land change in a poverty-stricken county of China and implications for poverty-alleviation-oriented land use policies. *Land Use Policy* **2020**, *91*, 104267. [CrossRef]
17. Wang, Y.; Peng, P.; Li, Q.; Chen, Z.; Tang, W. Spatial Heterogeneity of Farmland Abandonment in the Sichuan Province, China. *Sustainability* **2020**, *12*, 3356. [CrossRef]
18. Ma, X.; Wang, J.; Zhao, L.; Han, J. The effects of social capital on farmers' wellbeing in China's undeveloped poverty-stricken areas. *China Agric. Econ. Rev.* **2019**, *12*, 108–121. [CrossRef]
19. Wang, Y.; Chen, Y.; Chi, Y.; Zhao, W.; Hu, Z.; Duan, F. Village-level multidimensional poverty measurement in China: Where and how. *J. Geogr. Sci.* **2018**, *28*, 1444–1466. [CrossRef]
20. Gu, X.; Xie, B.; Zhang, Z.; Guo, H. Rural multifunction in Shanghai suburbs: Evaluation and spatial characteristics based on villages. *Habitat Int.* **2019**, *92*, 102041. [CrossRef]
21. Borrelli, I.P. Territorial Sustainability and Multifunctional Agriculture: A Case Study. *Agric. Agric. Sci. Procedia* **2016**, *8*, 467–474. [CrossRef]
22. Lefebvre, H.; Nicholson-Smith, D. *The Production of Space*; Blackwell Publishing: Hoboken, NJ, USA, 1991.
23. Halfacree, K.H. Locality and social representation: Space, discourse and alternative definitions of the rural. *J. Rural. Stud.* **1993**, *9*, 23–37. [CrossRef]
24. Nelson, K.S.; Nguyen, T.; Brownstein, N.; Garcia, D.; Walker, H.; Watson, J.; Xin, A. Definitions, measures, and uses of rurality: A systematic review of the empirical and quantitative literature. *J. Rural. Stud.* **2021**, *82*, 351–365. [CrossRef]
25. Chen, X. The core of China's rural revitalization: Exerting the functions of rural area. *China Agric. Econ. Rev.* **2019**, *12*, 1–13. [CrossRef]
26. Bański, J.; Mazur, M. Classification of rural areas in Poland as an instrument of territorial policy. *Land Use Policy* **2016**, *54*, 17. [CrossRef]
27. Zhou, G.; He, Y.; Tang, C.; Yu, T.; Xiao, G.; Zhong, T. Dynamic mechanism and present situation of rural settlement evolution in China. *J. Geogr. Sci.* **2013**, *23*, 513–524. [CrossRef]
28. Tonts, M.; Plummer, P.; Argent, N. Path dependence, resilience and the evolution of new rural economies: Perspectives from rural Western Australia. *J. Rural. Stud.* **2014**, *36*, 362–375. [CrossRef]
29. Zhang, B.; Jiang, G.; Cai, W.; Sun, P.; Zhang, F. Productive functional evolution of rural settlements: Analysis of livelihood strategy and land use transition in eastern China. *J. Mt. Sci.* **2017**, *14*, 2540–2554. [CrossRef]
30. Leibold, M.A.; McPeek, M.A. Coexistence of the niche and neutral perspectives in community ecology. *Ecology* **2006**, *87*, 1399–1410. [CrossRef]
31. Song, B.; Robinson, G.; Bardsley, D. Measuring Multifunctional Agricultural Landscapes. *Land* **2020**, *9*, 260. [CrossRef]
32. Radford, K.G.; James, P. Changes in the value of ecosystem services along a rural–urban gradient: A case study of Greater Manchester, UK. *Landsc. Urban. Plan.* **2013**, *109*, 117–127. [CrossRef]
33. He, T.; Qiao, W.; Jia, K.; Chai, Y.; Hu, Y.; Sun, P.; Wang, Y.; Feng, T. Selecting Rural Development Paths Based on Village Multifunction: A Case of Jingjiang City, China. *Complexity* **2020**, *2020*, 1–15. [CrossRef]
34. Xue, Z.; Zhen, L. Impact of Rural Land Transfer on Land Use Functions in Western China's Guyuan Based on a Multi-Level Stakeholder Assessment Framework. *Sustainability* **2018**, *10*, 1376. [CrossRef]

35. García-Llorente, M.; Martín-López, B.; Iniesta-Arandia, I.; López-Santiago, C.; Aguilera, P.; Montes, C. The role of multi-functionality in social preferences toward semi-arid rural landscapes: An ecosystem service approach. *Environ. Sci. Policy* **2012**, *19–20*, 136–146. [CrossRef]
36. Yang, Y.; Bao, W.; Liu, Y. Coupling coordination analysis of rural production-living-ecological space in the Beijing-Tianjin-Hebei region. *Ecol. Indic.* **2020**, *117*, 106512. [CrossRef]
37. Hoefle, S.W. Multi-functionality, juxtaposition and conflict in the Central Amazon: Will tourism contribute to rural livelihoods and save the rainforest? *J. Rural. Stud.* **2016**, *44*, 24–36. [CrossRef]
38. Zhu, F.; Zhang, F.; Ke, X. Rural industrial restructuring in China's metropolitan suburbs: Evidence from the land use transition of rural enterprises in suburban Beijing. *Land Use Policy* **2018**, *74*, 121–129. [CrossRef]
39. Garbach, K.; Milder, J.; DeClerck, F.; Montenegro De, W.; Driscoll, L.; Gemmill-Herren, B. Examining multi-functionality for crop yield and ecosystem services in five systems of agroecological intensification. *Int. J. Agric. Sustain.* **2017**, *15*, 11–28. [CrossRef]
40. Mirshojaeian Hosseini, H.; Kaneko, S. Dynamic sustainability assessment of countries at the macro level: A principal component analysis. *Ecol. Indic.* **2011**, *11*, 811–823. [CrossRef]
41. Zou, L.; Liu, Y.; Yang, J.; Yang, S.; Wang, Y.; Zhi, C.; Hu, X. Quantitative identification and spatial analysis of land use ecological-production-living functions in rural areas on China's southeast coast. *Habitat Int.* **2020**, *100*, 102182.
42. Nowak, M.M.; Pędziwiatr, K. Modeling potential tree belt functions in rural landscapes using a new GIS tool. *J. Environ. Manag.* **2018**, *217*, 315–326. [CrossRef]
43. Tan, X.; Ouyang, Q.; An, Y.; Mi, S.; Jiang, L.; Zhou, G. Evolution and driving forces of rural functions in urban agglomeration: A case study of the Chang-Zhu-Tan region. *J. Geogr. Sci.* **2019**, *29*, 1381–1395. [CrossRef]
44. Tillé, Y.; Dickson, M.; Espa, G.; Giuliani, D. Measuring the spatial balance of a sample: A new measure based on Moran's I index. *Spat. Stat.* **2018**, *23*, 182–192. [CrossRef]
45. Liao, G.; He, P.; Gao, X.; Deng, L.; Zhang, H.; Feng, N.; Zhou, W.; Deng, O. The Production–Living–Ecological Land Classification System and Its Characteristics in the Hilly Area of Sichuan Province, Southwest China Based on Identification of the Main Functions. *Sustainability* **2019**, *11*, 1600. [CrossRef]
46. Etxano, I.; Barinaga-Rementeria, I.; Garcia, O. Conflicting Values in Rural Planning: A Multifunctionality Approach through Social Multi-Criteria Evaluation. *Sustainability* **2018**, *10*, 1431. [CrossRef]
47. Guštin, Š.; Potočnik Slavič, I. Conflicts as catalysts for change in rural areas. *J. Rural. Stud.* **2020**, *78*, 211–222. [CrossRef]
48. Crouch, G.I.; Ritchie, J.R.B. Tourism, Competitiveness, and Societal Prosperity. *J. Bus. Res.* **1999**, *44*, 137–152. [CrossRef]
49. Xie, Z.; Zhang, F.; Lun, F.; Gao, Y.; Ao, J.; Zhou, J. Research on a diagnostic system of rural vitalization based on development elements in China. *Land Use Policy* **2020**, *92*, 104421. [CrossRef]
50. Batman, Z.P.; Özer, P.; Ayaz, E. The evaluation of ecology-based tourism potential in coastal villages in accordance with landscape values and user demands: The Bursa-Mudanya-Kumyaka case. *Int. J. Sustain. Dev. World Ecol.* **2019**, *26*, 166–178. [CrossRef]
51. Willemen, L.; Hein, L.; Mensvoort, M.; Verburg, P. Space for people, plants, and livestock? Quantifying interactions among multiple landscape functions in a Dutch rural region. *Ecol. Indic.* **2010**, *10*, 62–73. [CrossRef]
52. Bennett, E.M.; Peterson, G.D.; Gordon, L.J. Understanding relationships among multiple ecosystem services. *Ecol. Lett.* **2009**, *12*, 1394–1404. [CrossRef] [PubMed]
53. Wang, Y.; Zhu, Y.; Yu, M. Evaluation and determinants of satisfaction with rural livability in China's less-developed eastern areas: A case study of Xianju County in Zhejiang Province. *Ecol. Indic.* **2019**, *104*, 711–722. [CrossRef]

land

Review

Dealing with Water Conflicts: A Comprehensive Review of MCDM Approaches to Manage Freshwater Ecosystem Services

Mónica de Castro-Pardo [1,*], Pascual Fernández Martínez [2], Amelia Pérez Zabaleta [3] and João C. Azevedo [4]

1 Department of Financial Economics and Actuarial and Statistics-Statistics and Operational Research, Campus of Somosaguas, Complutense University of Madrid, Pozuelo de Alarcón, 28223 Madrid, Spain
2 Department of Applied Economics I and History and Economic Institutions, UNESCO UNED-URJC Chair in Water and Peace, URJC, Faculty of Law and Social Sciences, Campus of Vicálvaro, Universidad Rey Juan Carlos, Tulipan, Móstoles, 28933 Madrid, Spain; pascual.fernandez@urjc.es
3 Department of Applied Economics, UNESCO UNED-URJC Chair in Water and Peace, UNED, Calle Bravo Murillo 38, 28015 Madrid, Spain; aperez@cee.uned.es
4 Centro de Investigação de Montanha, Campus de Santa Apolónia, Instituto Politécnico de Bragança, 5300-253 Bragança, Portugal; jazevedo@ipb.pt
* Correspondence: monica.decastro@ucm.es

Abstract: This paper presents a comprehensive review of the application of Multiple-Criteria Decision-Making (MCDM) approaches exclusively to water-related freshwater ecosystem services. MCDM analysis has been useful in solving conflicts and it works well in this framework, given the serious conflicts historically associated with water use and the protection of freshwater ecosystems around the world. In this study, we present a review of 150 papers that proposed the use of MCDM-based methods for the social, economic, or ecological planning and management of water ecosystem services over the period 2000–2020. The analysis accounts for six elements: ecosystem service type, method, participation, biogeographical realm, waterbody type, and problem to solve. A Chi-square test was used to identify dependence between these elements. Studies involving the participation of stakeholder groups adopted an integrated approach to analysing sustainable water management, considering provisioning, regulating, and cultural services. However, such studies have been in decline since 2015, in favour of non-participatory studies that were strictly focused on ecological and provisioning issues. Although this reflects greater concern for the health of freshwater ecosystems, it is a long way removed from the essence of ecosystem services, which entails an integrated approach to the interrelationships between hydrology, landscapes, ecology, and humans.

Keywords: Multiple-Criteria Decision-Making; water; ecosystem services; conflicts; freshwater ecosystems; stakeholders; protected areas

Citation: de Castro-Pardo, M.; Fernández Martínez, P.; Pérez Zabaleta, A.; Azevedo, J.C. Dealing with Water Conflicts: A Comprehensive Review of MCDM Approaches to Manage Freshwater Ecosystem Services. *Land* **2021**, *10*, 469. https://doi.org/10.3390/land10050469

Academic Editor: Eva Papastergiadou

Received: 25 March 2021
Accepted: 22 April 2021
Published: 30 April 2021

1. Introduction

Freshwater is vital for the functioning of all terrestrial ecosystems, for the flora and fauna that make up those ecosystems, and, of course, for humans. Humanity depends on water not only for drinking, but mostly for food production, industry, waste treatment, energy, and transport, to give just a few examples [1]. Hoekstra and Wiedmann [2] estimated that humans annually consume between 1000 and 1700 billion m^3 of the world's surface or groundwater resources per year; that is, through direct or indirect water use, between 22% and 150% of the annual global freshwater supply is consumed.

From an ecological perspective, water is an integral component of all ecosystems and their functioning and, thus, is key to ensuring ecosystem health and biodiversity. However, the sensitivity of freshwater ecosystems to a range of threat factors, including climate change, makes water ecosystem services especially vulnerable [3]. Freshwater ecosystems make a disproportionate contribution to global biological richness; however, freshwater species are among those at the greatest risk of extinction [4].

Water resources are an issue of major interest and concern for governments and international institutions. Faced with the prospect of billions of people experiencing serious water shortages and subsequent food shortages, there is a need for urgent strategic action on water resources management. Two billion people currently live in countries with high water stress, and it is estimated that, by 2030, as many as 700 million people could be displaced by intense water scarcity [5]. One of the most powerful international attempts to address this serious humanitarian problem is the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDG) [6]. Specifically, SDG-6 focus is to "Ensure availability and sustainable management of water and sanitation for all". This target broadly encompasses all aspects of both the water cycle and sanitation systems, and it is designed to be cross-cutting, such that it can contribute to the achievement of other SDGs, particularly in the areas of the environment, health, economy and education.

The current global freshwater crisis threatens the present and future supply of water as a resource for human beings. Although about 70% of the earth's surface is covered with water, only 2.5% of it is freshwater that is suitable for human consumption. Most of that freshwater is trapped in glaciers or icefields; as such, less than 1% of the world's water is freshwater accessible in liquid form. In turn, of this small percentage, most of the water is found flowing underground, in groundwater reserves, while easily-accessible surface water sources, such as rivers or lakes, account for only a fraction of it. This small proportion of freshwater is the driving force of human health, the global economy, and the wellbeing of societies in the broadest sense. Unfortunately, the world has not succeeded in ensuring the sustainable management of its water resources. Over the past century, freshwater came under increasing pressure as withdrawal rates increased almost sixfold. By 2014, the average global availability of renewable freshwater resources had dropped to less than 6000 m^3 per person per year, a sharp fall of about 40% since the 1970s. Moreover, freshwater resources are unevenly distributed throughout the world and they are affected by strong seasonality; as global demand for water continues to grow (by approximately 1% annually), available resources are further depleted [7]. This crisis has promoted the need for the development of a water-oriented circular economy and the optimization of water resources use [8,9] with the end goal of preservation of water resources.

The importance and vulnerability of freshwater has prompted growing concern and an interest in its analysis from the scientific community, as well as impelling international institutions to protect freshwater ecological systems. The Ramsar Convention, for example, is one of the most notable initiatives aimed at protecting wetlands. Adopted in 1971, it is the longest-standing treaty that seeks to preserve wetlands and aquatic bird species, and it has been responsible for the establishment of the world's largest network of protected areas [10]. The European Union Water Framework Directive (2000/60/EC; 22 December 2000, OJ L 327) provides a guide for the New European water policy. The novelty of the new framework is the integrated approach that it follows in opposition to fragmented water policy initiatives in the past, based on key aims, such as "expanding the scope of water protection to all waters, surface waters and groundwater", "achieving "good status" for all waters by a set deadline", "water management based on river basins", "combined approach" of emission limit values and quality standards", "getting the prices right", "getting the citizen involved more closely", and "streamlining legislation".

Large watercourses cover different territories, and they are often transboundary, involving different conservation and use objectives, different regulations, and different stakeholders with conflicting interests. As such, their integrated management is extremely complex. Many protected areas around the world (more than 100,000) include aquatic ecosystems, some of which are specifically protected as freshwater ecosystems, but they are often supplied by rivers outside the limits of the protected areas [11].

Planning for such areas is extremely difficult at the operational level, even within the same country. Implementing an environmental conservation programme for freshwater requires the cooperation of multiple stakeholder groups, which often span multiple ecosystems. The complexity increases substantially when the management involves multiple jurisdictions or countries. Although there is international regulation governing the protection and use of transboundary watercourses and international lakes (e.g, "The 1992 UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes and the EU Water Framework), as well as specific bilateral cooperation agreements, at the operational level, stakeholder groups must also decide on upkeep, enforcement, and assessment programmes [12], meaning that the decisions made are not isolated events but rather part of an ongoing decision-making process over time.

The scarcity of water resources, the protection of many aquatic ecosystems, and the complexity associated with the management of large watercourses have traditionally provoked fierce conflicts that are linked to their management. These disputes can block decision-making processes and even trigger armed clashes between countries [13]. That said, some studies have shown that actively involving stakeholders in decision-making processes can mitigate these problems and make it possible to work towards acceptable solutions [14]. Against this background, Multiple-Criteria Decision-Making (MCDM) methods have proven to be extremely useful for conflict management; in particular, they have been widely used for natural resource management [15]. Research on the development and use of MCDM methods to improve decision-making processes that are related to forestry has been very prolific. Kaya et al. [16], Diaz-Balteiro et al. [17], and Nordstrom et al. [18] are only some examples of this trend. Although these studies addressed the full range of ecosystem services provided, including freshwater ecosystem services, to date only a few reviews focused exclusively on the use of MCDM in water resources management have been conducted. Hajkowicz and Collins [19] reviewed 113 articles published between 1973 and 2005 and Herath [20] conducted a review of 89 articles relating to this topic published between 1975 and 2009.

In regard to water, MCDM approaches are used when the analysis incorporates multiple perspectives in order to reach a single decision relating to water management [21]. The capacity of MCDM analysis to assist in conflict resolution between stakeholder's groups is primarily due to its transparency. All parties must specifically express their preferences through a structured process, which makes it possible to identify areas of agreement and disagreement and ultimately manage conflicts [22]. This analysis of alternatives can be carried out by involving the different stakeholders, experts, or institutional/governmental agents (water negotiators), or by simulating different alternatives through stochastic processes. In any case, the opposition and interrelation of different criteria and alternatives give rise to a wide-ranging, complex workspace, where multiple conflicting positions are involved in a single decision-making process.

This framework is well suited to the planning and management of Freshwater Ecosystem Services (FES). Understanding FES requires an integrated view of the interrelationships between hydrology and ecology as well as the landscape. It also calls for a contextualization of how water influences human livelihoods and wellbeing, as well as how the ecosystems themselves are affected by human activities. In order to develop efficient, sustainable decision-making processes, a comprehension of these complex relationships is needed [1].

This article presents a review of 150 current articles covering the application of MCDM with three novel aspects: a focus on water as source of ecosystem services; a focus on natural freshwater ecosystems, the majority of them protected; and, an orientation of the discussion towards conflict resolution and stakeholder participation in decision-making processes. The objective of this review is to describe the use of MCDM techniques in FES planning and management, with a particular focus on conflict management. The aim of carrying out a systematic review is to collect all of the the empirical evidence that meets the pre-specified criteria above, in order to answer several research questions.

2. Methods

Bias is minimised by using explicit and systematic methods when reviewing articles [23]. The main advantage of systematic reviews is that they allow the researcher to determine whether an effect remains constant across various different studies, or to find out whether the type of study or sample level have an effect on the phenomenon under study [23].

The present review was conducted following the six steps proposed by Templier and Paré [24]: (i) formulating the research question and objective(s), (ii) searching the extant literature, screening for inclusion, assessing the quality of primary studies, (iii) extracting data, and (iv) analysing data.

2.1. Formulating the Research Questions and Objectives

The objective of this review is to characterise the use of MCDM techniques in FES planning and management, with a particular focus on conflict management. We addressed specifically the following research questions: (i) how have studies on MCDM applied to FES change over time?; (ii) how collaborative MCDM has been used to solve decisional problems?; (iii) how has stakeholders involvement in water decision-making processes changed over time?; (iv) what MCDM methods have been applied the most to deal with FES?; and, (v) how have these methods been used to solve different types of problems?

2.2. Searching the Extant Literature, Screening for Inclusion and Assessing the Quality of Primary Studies

The search of the literature was performed on the Web of Science (WoS) platform. As such, the only publications included in the search are those from journals indexed in the Journal Citation Report (JCR), thus ensuring the quality of the articles. Book chapters were not included in the queries. The articles were then screened to only select those in where water was analysed from an ecosystem perspective, discarding any articles oriented towards industrial uses of water or the improvement of artificial processes. The keywords used in the selections process included "water" and "ecosystem services" and "MCDM" or "multiple-criteria decision making" and "freshwater" or "water management" and "protected areas". Only articles that were published between 2000 and 2020 were selected. The analysis has been structured by grouping the publication years into four intervals: 2000–2004, 2005–2009, 2010–2014, and 2015–2020.

2.3. Extracting Data

Selected papers were classified according to the following categories in each of the six criteria (Ecosystem services, MCDM method, Participation, Biogeography, Waterbody type, and Problem):

- Ecosystem services class:

FES were categorised according to the Millennium Assessment (MA) [25] classification in provisioning, regulating, cultural, and supporting classes.

Provisioning (PROV): refers to water as a resource for human consumption;

Regulating (REG): refers to the ability of freshwater ecosystems to regulate nutrient cycles, atmospheric regulation and control of natural disasters, such as floods;

Cultural (CULT): refers to the recreational capacity of these ecosystems;

Supporting (SUPPORT): refers to the capacity of ecosystems to maintain their structure and functioning, including biodiversity.

- MCDM method:

Methods comprise eight classes:

Distances (DIS): distance-based methods, such as GP or TOPSIS methods, are based on the minimization of the distance between an alternative and one or several reference points that represent good preferential properties [17];

Fuzzy (FUZ): covers the articles that have used fuzzy sets, fuzzy functions, or fuzzy numbers rather than crisp numbers, approaches with a concrete mathematical structure dealing with the imprecision of the information [26];

Hierarchical (HIER): this group includes methods based on AHP or ANP, working with pairwise comparisons to quantify subjective information, such as preferences of decision-makers, and calculate relative importance (weights) of criteria and alternatives [27];

Mixed (MIX): hybrid models where no one type of method has particular prominence, but rather all are similarly important in the decision-making process. Ortiz-Urbina et al. [28] emphasised the proliferation of these methods in the last few decades;

Outranking (OUT): outranking methods such as the different versions of PROMETHEE or ELECTRE, based on the idea that alternative X outranks alternative Y if alternative X is at least as good as alternative Y, according to concordance and discordant concepts [29,30];

Soft (SOFT): non-structured MCDM methods, such as discussion groups, workshops, or various kinds of collaborative processes based on qualitative analyses [31];

Utility (UT): methods based on utility and value functions, assigning a cardinal value to each alternative considering simultaneously several criteria within a risk (utility) or no risk (value) context [32];

Other methods (Other): those not included in the previous groups.

- Participation:

The participatory approach employed has been assessed according to the extent to which all stakeholders are involved, only experts or institutional/governmental actors, or none of the above. Three groups have thus been identified: non-participatory (NO), experts (EXP), and stakeholders (YES).

- Biogeography:

This element has been analysed at the level of country and biogeographic realm, referring to the seven biogeographic divisions of the planet: Afrotropical (AFRO), Antarctic (AN), Australasia (AUS), Indomalaya (INDO), Nearctic (NEAR), Neotropical (NE), and Paleartic (PA) [33]. In cases the origin of the study was not indicated the publication was classified as Not identified (NI).

- Waterbody type:

The type of waterbody studied has been classified into five categories: estuary, groundwater, lake, river, and wetland. Although estuaries are not freshwater ecosystems, as their waters have some degree of salinity depending on the site, they are included in this study because they represent the transition between freshwater and marine ecosystems, and their management is still subject to conflict. Many studies do not analyse a single type of aquatic ecosystem, since it is very difficult to completely separate the interlacing subsystems that make up river networks. Rivers and lakes are often interconnected, and some studies have taken a comprehensive approach to analysing them. Similarly, in some river courses, it can be difficult to distinguish between estuaries and wetlands. For this reason, in the present review, the classification is based on the predominant type under analysis, unless it is specified that the analysis focuses on a river system.

- Problem:

The problem to be solved refers to the objective of the analysis conducted in the publications. Seven problem types have been identified:

Allocation (ALLOC): allocation and distribution of water as a resource; papers included in this group involve studies analysing best water sources and optimization of water resources distribution to population;

Conservation (CON): solutions to problems related to the conservation of sites and habitats and the survival of species. All of the studies are oriented to the improvement or maintenance of the actual condition of ecosystems;

Flood water analysis (FLOOD): analysis of water flows from river systems and freshwater ecosystems and the associated risks;

Impact/vulnerability assessment (IMPACT-VUL): the articles included in this group focus on measuring and evaluating the impact of human actions on the waterbody under study and assessing its vulnerability. Some also undertake an assessment of water quality;

Management (MAN): water resources planning and management from a broad perspective, excluding articles dealing specifically with the topics covered in the other classes;

Restoration (RESTOR): restoration of river systems and freshwater ecosystems;

Tourism (TOUR): issues related to tourism management in freshwater ecosystems and analysis of suitability of these sites for recreation.

2.4. Analysing and Synthesizing Data

The statistical dependence between the elements described in Section 2.3 was determined using the Pearson Chi-square test. The Chi-square statistic is a non-parametric tool designed to analyse group differences when the dependent variable is measured at a nominal level [34], i.e., this test allows for identifying the association between two categorical variables [35]. The analysis was undertaken using a pairwise comparison between the categories described in Section 2.3. In SPSS v15.0 (SPSS Inc., Chicago, IL, USA) software.

3. Results and Discussion

3.1. Overview

A total of 183 papers were initially found, of which 150 papers were finally selected and reviewed: 27 in the period 2000–2004, 30 in the period 2005–2009, 22 in the period 2010–2014, and 71 in the period 2015–2020. Thirty three papers were discarded because they did not address exclusively freshwater ecosystems. Figure 1 shows the percentage of papers reviewed by category (Section 2.3).

Globally, the studies that dealt with Regulating FES represented the highest frequency (40%) among selected publications, followed by the works that analysed FES in an integrated manner (27.3%). The most usual class of MCDM methods found was mixed (26.7%) and hierarchical (22.0%), and the majority of the studies did not involve the preferences of stakeholder groups, 57.8% did not involve any type of participation, and 28.27% only included expert preferences. Near sixty-one percent of the publications came from the Paleartic biogeographic realm, particularly Europe, the Middle East, and China. Rivers (46.7%) and wetlands (24.0%) were the most studied waterbody types and problems related with management (30.67%) and impact-vulnerability (26.67%) assessment were the most frequently analysed.

3.1.1. Ecosystem Services Class

The majority of publications in the 2000–2020 period were in the class of regulating ES (Figure 1). Since 2015, there has been a significant decline in studies jointly addressing all ecosystem service types, giving way to studies that analyse them separately, with a particularly notable focus on the regulating services: in the latest period, these studies accounted for 47.89% of all the articles reviewed (Figure 2). Articles dealing with supporting functions have shown a marked increase in the last period, as have articles analysing the recreational functions of ecosystem services, albeit to a lesser extent. Interest in provisioning functions declined from 2010 onwards, but has levelled off since coming second behind regulating ecosystem services in the last period, with 14.08% per cent of the articles reviewed in that period. These results reflect a growing concern regarding aquatic ecosystem health, probably prompted by the deterioration of aquatic ecosystems around the world, mainly wetlands.

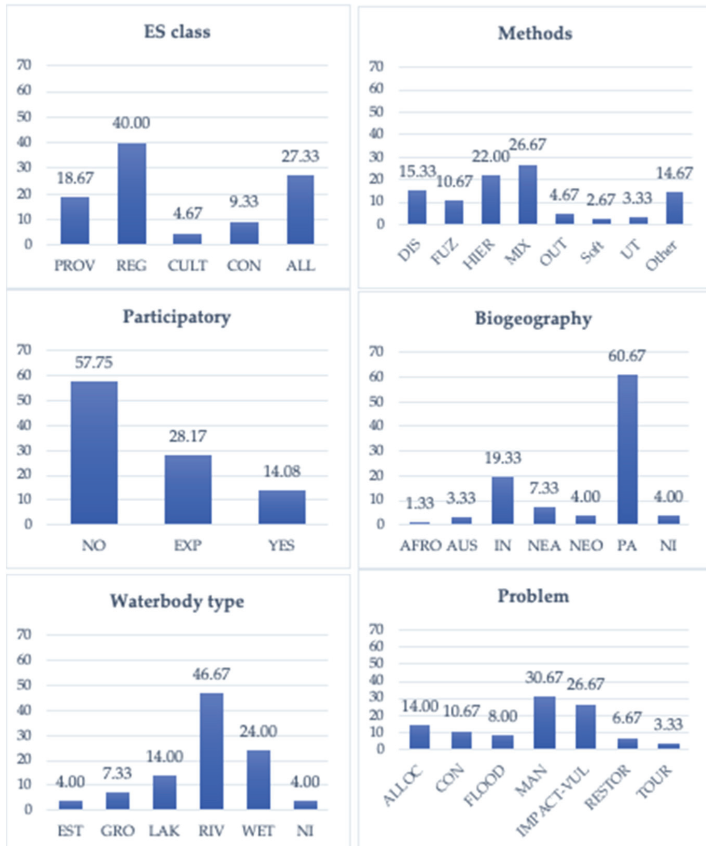


Figure 1. Percentage of papers by categories described in Section 2.3.

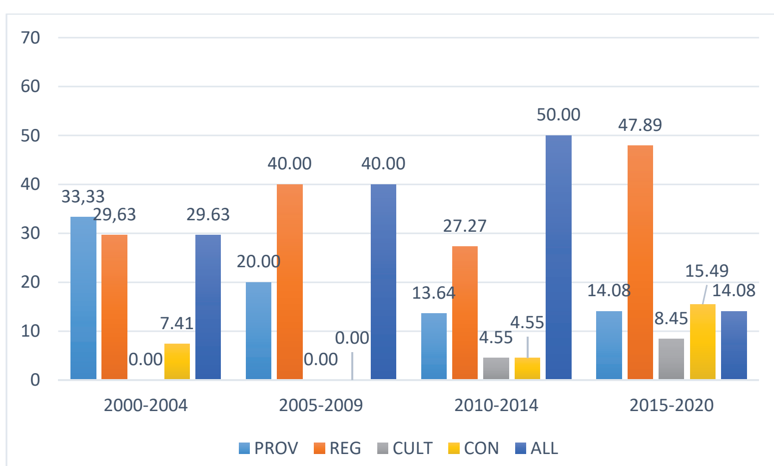


Figure 2. Percentage of papers by ecosystem service and period. For explanation of categories see Section 2.3.

3.1.2. MCDM Method

The most usual methods to the analysis of FES are mixed and hierarchical methods (Figure 1). Particularly interesting is the evolution of mixed methods, which have increased along the time, achieving 36.6% of the reviewed papers in the last (2015–2020) period (Figure 3). Hierarchical methods have been more or less stable, after they increased from 2005–2009 period (16.7%) to figures around 25–27%. Fuzzy, outranking, and utility methods have decreased over time. Utility methods, in fact, disappeared after 2010 (Figure 3). This could be because of the complexity of the collection of data to apply this type of methods, such as MAUT or MAVT. On the other hand, "Other methods" increased (Figure 3). This group includes new models and methods not included in the remaining classes. Particularly interesting are methods that are based on neural networks or random forest, which were applied in diverse manners to solve FES problems.

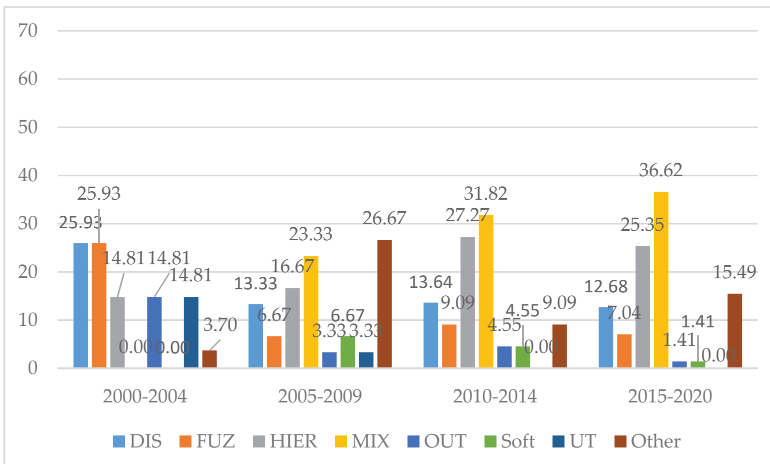


Figure 3. Percentage of papers by MCDM method and period. For explanation of categories see Section 2.3.

3.1.3. Participation

With regard to the evolution over time of participatory studies, the decrease in analyses involving stakeholder participation from the period 2005–2009 is particularly striking (Figure 4). It stands in contrast to the increase in studies that do not involve the participation of any type of stakeholder, or that relied on the participation of experts or water negotiators (Figure 4). This trend seems to be related to the decrease of studies that dealt with FES in an integrated manner since 2010. Taking into account that MCDM methods are particularly useful to the aggregation of different groups providing transparency and rigor to complex decision-making processes and the difficult to make strategic decisions by nations, regions, and local communities regarding water conflicts, this fact is unexpected. Section 3.2.5 discussed this more-in-depth.

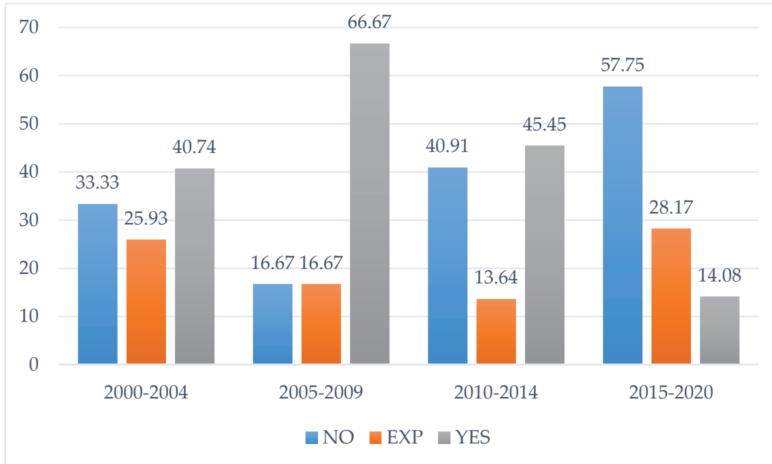


Figure 4. Percentage of papers by participatory approach and period. For explanation of categories see Section 2.3.

3.1.4. Biogeographic Realms

The Paleartic (PA) biogeographic realm was the one where the majority of FES studies were conducted, representing 53 to 64% of the reviewed papers (Figure 5). Indomalaya (INDO) was the second most important biogeographic realm, showing increasing importance over the period covered: 3.7% of the overall papers in 2000–2004 to near 27% in 2015–2020 (Figure 5). No papers were found for the Neartic biogeographic realm. As it would be expected, countries with more scarcity of water are the ones that are most concerned about studying FES, as is the case of Iran, Iraq, and Afghanistan in the Paleartic region or India in the Indomalaya region.

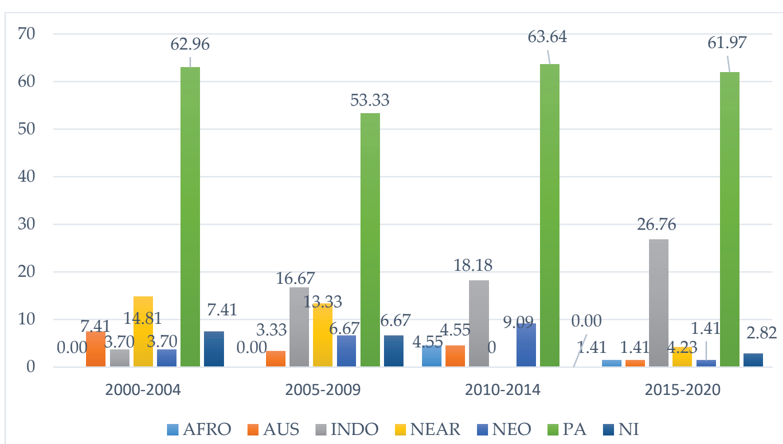


Figure 5. Percentage of papers by Biogeographic realm and period. For explanation of categories see Section 2.3.

Some works could not be included in a specific biogeographic realm because they were theoretical or modelling and simulation works, and were categorized as "Not identified" (NI).

3.1.5. Waterbody Type

Globally, rivers have been the most analysed freshwater ecosystem (46.7%) (Figure 1). However, since 2010, this waterbody type has decreased in frequency in favour of wetlands that have progressively increased ovel time representing 33.8% of the reviewed studies in 2015–2020 (Figure 6).

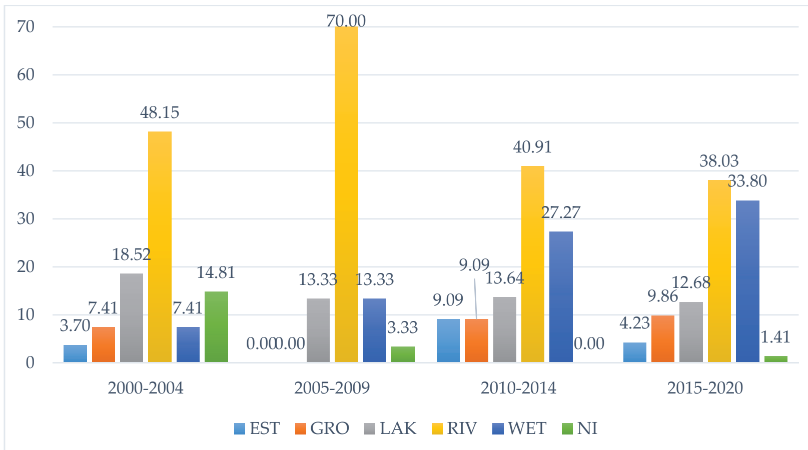


Figure 6. Percentage of papers by waterbody type and period. For explanation of categories see Section 2.3.

Groundwater studies increased in the last two periods, involving 9.9% of the papers that were reviewed between 2015 and 2020. Lakes have been slightly less studied, decreasing in frequency inform the first (18.5%) to the last period (12.7%). Estuaries have not followed a regular trend over the 20-year period considered (Figure 6).

Ninety-two percent of studies on wetlands sought to solve problems by analysing impact or vulnerability and conservation management and they were aimed at protecting the supporting and regulating FES.

According to the latest data, wetlands cover 12.1 million km2 globally. Between 1970 and 2015, 35% of natural wetlands were lost (three times the rate of forest loss), while 81% of inland wetland species populations and 36% of coastal species declined [36]. Increasing wetland pollution, invasive species, and rapid urban development currently present a grave threat to wetlands. These data certainly justify the studies aimed at preserving the ecological functions of wetlands.

3.1.6. Problems

Up to the period 2015–2020, the most commonly studied problem was water management (MAN), with 44.4 to 46.7% of the publications in each of the three initial periods, as shown in Figure 7. However, in the last period, the proportion of publications focused on water management dropped to 14.1%, accompanied by a growing interest in the assessment of the impact and vulnerability (IMPACT-VUL) of aquatic ecosystems (39.4%) and in conservation aspects (CON), 16.9% of the publications in this period.

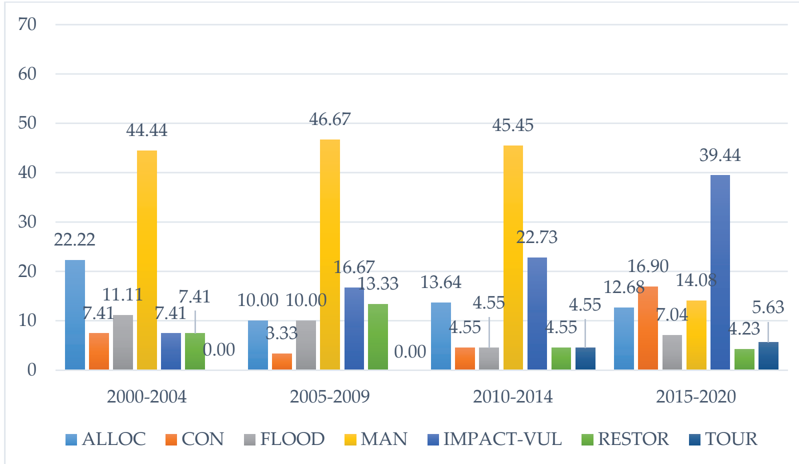


Figure 7. Percentage of papers by problem and period. For explanation of categories see Section 2.3.

Near 70% of all the participative studies dealt with management problems. This result could be expected since management problems are usually related with social an economic issues. Near 75% of the studies whose objective was related to conservation, 50% to restoration, and nearly 86% related to tourism, did not considered preferences of stakeholders. Although this could also be expected, this detachment of stakeholders in decision making is one of the most important problems in nature conservation, and it is a source of strong conflicts in rural areas, especially in protected areas. As an example, the restoration of a watershed involves many actions causing changes in the landscape and in different resources, often affecting a relevant number of stakeholders. Decisions regarding tourism planning also affect residents and other people with interests in specific sites. Failing to involve owners, managers, and residents in decision making in cases like these can create feelings of frustration within some stakeholders' groups, generating conflicts that sometimes result in environmental crimes, such as illegal fire-setting or wildlife poisoning [37].

3.2. Relationships among Attributes

The review identified a total of 28 (18. 7%) articles on provisioning, 60 (40.0%) on regulating, 7 (4.7%) on cultural, 14 (9.3%) on supporting, and 41 (27.33%) on simultaneously provisioning, regulating or cultural ecosystem services. Within each class of FES, we reviewed, in detail, the publications selected in this study adopting the classification described in Section 2.3. The Chi-square test indicated significant relationships between type of FES, biogeographic realm, method, problem, and participation ($p = 0.00$). These relationships are described and discussed in detail in Sections 3.2.1–3.2.5.

3.2.1. Provisioning FES

Although there has been a reduction in the number of articles analysing water as a provisioning ecosystem service since 2010, over the total period, 75% of the articles have, to a greater or lesser extent, analysed water from this perspective (Table 1). Most of these articles have focused on the Palearctic realm, especially arid and semi-arid regions, such as Iran, Afghanistan, or India, and they have addressed problems of resource allocation and the identification of potential sources of provisioning services. In this regard, a degree of dependence between countries and methods has been identified ($p = 0.051$), with the analysis showing a tendency to use hierarchical methods in India.

Water resources management has mainly been studied using mixed and hierarchical methods (46.43%) with the involvement of experts. AHP has been the most widely-used method to analyse water as a resource. To address related issues, Jaber and Mohsen [38], Chowdhuri et al. [39], Machiwal et al. [40], Machiwal et al. [41], Çelik [42], and Rana and Suruanarayana [43] used AHP; all but [38] combined it with GIS to do so. Swetha et al. [44] also used GIS with a hierarchical method, but in that case with ANP.

Two articles have been found that use outranking methods—Prato [45] and Hyde et al. [46]—and two others that have use utility functions—Arriaza et al. [47] and Lopez-Baldovi et al. [48], with the latter two both focusing on Spain.

The mixed methods that are applied in this type of analysis generally combine stochastic methods, such as Bayesian networks with utility functions, outranking, or fuzzy methods, usually with GIS.

Of the 28 articles that were reviewed in this group, only four have involved stakeholder participation in some way, while eight have involved expert participation, and 16 articles have proposed models that do not incorporate any type of participation. In the latter case, they have performed simulations or worked with analyses of non-participatory scenarios.

Arriaza et al. [47] are the only authors who adopted a semi-participatory approach to address the allocation of water resources, when considering the interests of the different groups of stakeholders. They proposed a model based on utility functions to improve efficiency in the allocation of water resources and examined a case study in the Guadalquivir River Basin (Spain) involving water allocation to three groups of farmers. Although the model did not incorporate the interaction of these groups, they were asked about their degree of agreement with the results.

Mysiak et al. [49] and Rouzbahani et al. [50] also involved stakeholders to resolve management problems. A tool was proposed by Mysiak et al. [49] for the integration of hydrological models in a decision support system for water management, while considering the preferences of different stakeholders and applying it in five European countries. Rouzbahani et al. [50] analysed a number of different scenarios for aquifer restoration in Iran, using Bayesian networks, TOPSIS, SAW, and PROMETHEE II methods, accounting for the socio-cultural acceptance of stakeholders. Although the focus was on the restoration of these aquifers, the purpose was to ensure water supply to the affected regions.

Zarghami [51] and Estalaki et al. [52] also considered stakeholders in their studies of the impact of different management policies. Different water management alternatives were analysed by Zarghami [51] by means of a stochastic approach, using fuzzy quantifiers to incorporate the assessment of various stakeholders. Fuzzy social choice was used by Estalaki et al. [52] to incorporate stakeholder participation in the assessment of the impact of management policies on water quality in Iran.

Finally, a relationship was found between problem and participation ($p = 0.015$); studies that solve problems aimed at addressing resource allocation issues are the least likely to consider stakeholder preferences, as opposed to impact/vulnerability studies.

Table 1. Reviewed papers that analyse water from a provisioning ecosystem service perspective classified by region, method, problem, participation, study area, and waterbody type.

Reference	Region	Method	Problem	Participation	Study area	Water Course Type
Jaber and Mohsen, 2001 [38]	Jordania	HIER	ALLOC	NO	Ceyhanand Seyhan River	River
Nayak and Panda, 2001 [53]	India	FUZ	ALLOC	EXP	Mahanadi Delta	River
Arriaza et al., 2002 [47]	Spain	UT	ALLOC	YES	Guadalquivir Valley	River
Mimi and Sawalhi, 2003 [22]	Jordania, Israel, Palestina	DIS	ALLOC	EXP	Jordan River	River
Prato, 2003 [45]	USA	OUT	MAN	NO	Missouri River	River
Hyde et al., 2004 [46]	Spain-Adelaide	OUT	ALLOC	EXP	Flumen Monegros-Northern Adelaide Plains	River
Karnib, 2004 [54]	Theoretical	FUZ	MAN	NO	-	-
McPhee and Yeh, 2004 [55]	USA	FUZ	MAN	NO	Upper San Pedro River Basin	River
Srdjevic et al., 2004 [56]	Brazil	DIS	ALLOC	NO	Paraguaçu River basin	River
Mysiak et al., 2005 [49]	Various	Other	MAN	YES	-	River
López-Baldoví et al., 2006 [48]	Spain	UT	ALLOC	NO	Guadalquivir Valley	River
Zarghaami, 2006 [57]	Irán	DIS	ALLOC	EXP	Polrud River basin	River
Raju and Vasan, 2007 [58]	India	MIX	ALLOC	NO	Various	River
Zarghami and Szidarovszky, 2009 [51]	Hungary	MIX	IMPACT-VUL	YES	Central Tisza River	River
Gómez-Limón and Riesgo, 2009 [59]	Spain	MIX	MAN	EXP	Duero basin	River

Table 1. *Cont.*

Reference	Region	Method	Problem	Participation	Study area	Water Course Type
Chowdhury et al., 2010 [39]	India	HIER	ALLOC	EXP	Subarnarekha and Kasai Rivers	Groundwater
Machiwal et al., 2011 [40]	Theoretical	HIER	ALLOC	NO	-	Lake
Opricovic, 2011 [60]	Serby	MIX	MAN	NO	Mlava River	River
Machiwal et al., 2015 [41]	India	HIER	ALLOC	NO	Ahar catchment	Groundwater
Estalaki et al., 2016 [52]	Iran	FUZ	IMPACT-VUL	YES	Chitgar Lake	Lake
Swetha et al., 2017 [44]	India	HIER	ALLOC	NO	Kuttiyadi River basin	Groundwater
Zeng et al., 2017 [61]	China	Other	ALLOC	NO	Guanting reservoir basin	River
Roozbahani et al., 2018 [50]	Iran	MIX	MAN	YES	Lake Urmia	Lake
Arabameri et al., 2019 [62]	Iran	DIS	ALLOC	NO	Shahroud plane	Groundwater
Bera and Bnik, 2019 [63]	India	Oher	ALLOC	NO	Kansachara watershed	River
Çelik, 2019 [42]	Turkey	HIER	ALLOC	EXP	Tigris River	Groundwater
Arabameri et al., 2020 [64]	Iran	MIX	ALLOC	NO	Bastam watershed	Groundwater
Rana and Suruanarayana, 2020 [43]	India	HIER	ALLOC	EXP	Vishwamitri watershed	River

3.2.2. Regulating FES

The 60 articles dealing with water from a regulating ecosystem service perspective (Table 2) have primarily studied problems relating to flood control and the vulnerability, impact and restoration of lakes and wetlands, and on the capacity of wetlands to regulate biological cycles.

The most commonly used methods in this group are hierarchical (28.3%) and mixed (25%), but the review yields a substantial number of studies using other methods (16.7%), distance-based methods (11.7%), and fuzzy sets (10%).

A total of 51.7% of the reviewed studies have addressed problems that are associated with impact or vulnerability, of which 41.9% involved expert participation and 54.8% did not include any type of participation. Only one article in this group took stakeholder preferences into account [65].

The only relationship of dependence found was between the problem to be solved and participation ($p = 0.019$). A mere 20% of the articles that were reviewed in this group incorporated stakeholder participation. For example, Janssen et al. [66] attempted to resolve management problems using the software package DEFINITE with GIS to assess wetland functions and the impact of three management alternatives: modern peat pasture, historical peat pasture, and dynamic mire.

Brouwer and Ek [67], Levy [68], Kenyon [69], Levy et al. [70], and Perrone et al. [71] focused on the study of flood control problems.

An integrated model of flood control policies was proposed by Ek [67] in the Netherlands, considering effects, such as land use change and floodplain restoration, using cost-benefit analysis and a multicriteria analysis in order to incorporate the participants' judgement in the model. Flood risk management was evaluated by Kenyon [69] in Scotland, using a participative approach. She used citizens' juries, deliberative monetary evaluation, and multi-criteria visual methods, considering criteria, such as looks, nature, cost, maintenance, safety, and flooding. Levy et al. [70] proposed a multi-criteria decision support tool to enhance communication among stakeholders and improve emergency management resource allocation in Tokai (Japan). A collaborative approach based on fuzzy methods was proposed by Perrone et al. [71] to manage flood risk in a river in Italy.

Rohde et al. [72], Randhir and Shriver [73], and Gross and Hagy [74] studied restoration issues. In an application to the Rhône-Thur river project, Rohde et al. [72] used GIS and MCDM for an integrated assessment of different river restoration strategies, jointly evaluating environmental criteria, such as natural flow and sufficient bed load material and socio-economic criteria associated with public attitude.

A deliberative attribute prioritization procedure using AHP was applied by Randhir and Shriver [73] to the case of subwatersheds for restoration in the Chicopee river in western Massachusetts, USA.

Restoration issues were also addressed by Gross and Hagy [74] using a participatory approach, in this case focusing on lakes and estuaries degraded by nutrient pollution. They analysed 16 case studies in different lakes and estuaries around the world to identify common attributes for nutrient management and variations thereof and explored the relationships between them using multicriteria analysis.

Daneshvar et al. [65] evaluated the impact of natural wetland implementation on total phosphorus reduction in the Saginaw River Watershed (Michigan) using the VIKOR method and SWAT model in order to provide a guide for policymakers.

Table 2. Reviewed papers that analyse water from a regulating ecosystem service perspective classified by region, method, problem, participation, study area, and waterbody type.

Reference	Region	Method	Problem	Participation	Study Area	Water Course Type
Arondel and Girardin, 2000 [75]	France	FUZ	IMPACT-VUL	EXP	Rhine Plain	Groundwater
Chuntian and Chau, 2002 [76]	China	FUZ	FLOOD	NO	Fengman Reservoir	River
Wang et al., 2003 [77]	China	HIER	IMPACT-VUL	NO	Jianghan Plain	Wetland
Bana e Costa et al., 2004 [78]	Portugal	UT	FLOOD	EXP	Livramento creek in the peninsula of Setúbal	River
Brouwer and Ek, 2004 [67]	Netherlands	Other	FLOOD	YES	River Rhine and Meuse Delta	River-Wetland
Herath, 2004 [79]	Victoria	HIER	MAN	YES	Wonga Wetlands	Wetland
Olenick et al., 2004 [80]	USA	DIS	MAN	NO	Edwards Aquifer and Twin Buttes watersheds	Other
Tzionas et al., 2004 [81]	Greece	FUZ	RESTOR	EXP	Lake Koronia	Lake
Almasri and Kaluarachchi, 2005 [82]	Whashington	NEU	IMPACT-VUL	NO	Sumas–Blaine aquifer	River
Janssen et al., 2005 [66]	Germany	Other	MAN	YES	Noord-Hollands Midden	Wetland
Lee and Chang, 2005 [83]	Taiwan	FUZ	IMPACT-VUL	NO	Tou-Chen River basin	River
Levy, 2005 [68]	China	HIER	FLOOD	YES	Tokai flood	River
Elshorbagy, 2006 [84]	Canadá	OUT	RESTOR	NO	Fort McMurray (reconstructed watershed)	River
Liu et al., 2006 [85]	New South Wales	DIS	RESTOR	EXP	Clarence River	Wetland
Rohde et al., 2006 [72]	Switzerland	Other	RESTOR	YES	Rhône-Thur Rivers	River
Kenyon, 2007 [69]	Scotland	SOFT	FLOOD	YES	Scotland (general)	River
Levy et al., 2007 [70]	Japan	HIER	FLOOD	YES	Shinkawa and the Shonai rivers (Tokai floods)	River

Table 2. *Cont.*

Reference	Region	Method	Problem	Participation	Study Area	Water Course Type
Li, 2007 [86]	China	HIER	CON	EXP	Chaohu Lake	Lake
Qin et al., 2008 [87]	Canadá	MIX	IMPACT-VUL	EXP	Georgia basin	River
Randhir and Shriver, 2009 [73]	USA	HIER	RESTOR	YES	Chicopee River	River
Olu-Owolabi et al., 2012 [88]	Nigeria	FUZ	IMPACT-VUL	NO	Ondo coast	Estuary
Sun et al., 2012 [89]	China	MIX	IMPACT-VUL	NO	Dayang Estuary	Wetland-Estuary
Wu et al., 2012 [90]	China	MIX	ALLOC	YES	Qixinghe	Wetland
Sener and Davraz, 2013 [91]	Turkey	HIER	IMPACT-VUL	NO	Egirdir Lake basin	Groundwater
Lee et al., 2014 [92]	Korea	MIX	FLOOD	NO	Han River	River
Malekmohammadi and Blouchi, 2014 [93]	Iran	HIER	IMPACT-VUL	EXP	Shadegan Wetland	Wetland
Chatterjee et al., 2015 [94]	India	MIX	IMPACT-VUL	NO	Keoladeo National Park	Wetland
McVittie et al., 2015 [95]	Theoretical	Other	IMPACT-VUL	NO	Theoretical	River
Meraj et al., 2015 [96]	India	Other	FLOOD	NO	Lidder and Rembiara watersheds of the Jhelum basin	River
Shafiee et al., 2015 [97]	Iran	MIX	IMPACT-VUL	NO	Heleh protected area	Wetland
Walker et al., 2015 [98]	Serbia	Other	IMPACT-VUL	NO	Danube River	River
Abd-El Monsef et al., 2017 [99]	Egypt	HIER	CON	NO	Sharm El-Bahari	Wetland
Daneshvar et al., 2017 [65]	USA	DIS	IMPACT-VUL	YES	Saginaw River watershed	Wetland
Duodu et al., 2017 [100]	Queensland	OUT	IMPACT-VUL	NO	Brisbane River	River
Gross and Hagy, 2017 [74]	Various	SOFT	RESTOR	YES	Various	Lake-Estuary
Man et al., 2017 [101]	China	HIER	CON	NO	Sanjiang plain	Wetland
Malekmohammadi and Jahanishakib, 2017 [102]	Iran	HIER	IMPACT-VUL	EXP	Choghakhor Wetland	Wetland
Rather et al., 2017 [103]	India	Other	IMPACT-VUL	NO	Jhelum Basin	River
Golbarg et al., 2018 [104]	Iran	HIER	IMPACT-VUL	EXP	Shadegan International Wetland	Wetland
Maleki et al., 2018 [105]	Afghanistan-Iran	HIER	RESTOR	NO	Hamun Wetlands	Wetland

Table 2. *Cont.*

Reference	Region	Method	Problem	Participation	Study Area	Water Course Type
Rahdari et al., 2018 [106]	Iran	MIX	CON	EXP	Gavkhooni Wetland-Plasjan sub-bsin	River-Wetland
Arabameri et al., 2019 [107]	Iran	DIS	IMPACT-VUL	EXP	Semnan watershed	River
Bid and Siddique, 2019 [108]	India	DIS	FLOOD	EXP	Damodar River-Panchet dam	River
de Souza et al., 2019 [109]	Brazil	MIX	IMPACT-VUL	EXP	Doce River basin	River
Ghosh and Das, 2019 [110]	India	MIX	IMPACT-VUL	NO	East Kolkata Wetland (Ramsar)	Wetland
Li et al., 2019 [111]	China	MIX	IMPACT-VUL	NO	Eastern Pearl River Delta	Estuary
Roy and Majumder, 2019 [112]	India	Other	IMPACT-VUL	NO	Loktak Lake	Lake
Xu et al., 2019 [113]	China	HIER	IMPACT-VUL	NO	Xiangjian River basin	River
Akay and Koçyigit, 2020 [114]	Turkey	MIX	FLOOD	NO	Akçay basin	River
Alamanos and Papaioannou, 2020 [115]	Canadá	HIER	IMPACT-VUL	EXP	Lake Erie watershed	Wetland
Arabameri et al., 2020 [116]	Iran	HIER	IMPACT-VUL	EXP	Kalvari basin	River
Bhattacharya et al., 2020 [117]	India	DIS	IMPACT-VUL	NO	Kangsabati basin	River
Ghaleno et al., 2020 [118]	Iran	MIX	IMPACT-VUL	EXP	Gorganrud basin	River
Ghosh and Das, 2020 [119]	India	NEU	IMPACT-VUL	EXP	East Kolkata Wetland (Ramsar)	Wetland
Perrone et al., 2020 [71]	Italy	FUZ	FLOOD	YES	Bradano River	River
Popovic et al., 2020 [120]	Serbia	MIX	RESTOR	NO	Lake Vrutci	Lake
Sarkar and Majumder, 2020 [121]	India	MIX	IMPACT-VUL	EXP	Tripura River	River
Souissi et al., 2020 [122]	Tunisia	HIER	FLOOD	EXP	Gabes region	River
Sun et al., 2020 [123]	China	MIX	FLOOD	NO	Yangtze River delta	River
Yang and Wang, 2020 [124]	China	DIS	IMPACT-VUL	EXP	Taihu basin	Lake-River

3.2.3. Cultural FES

A total of seven articles have been identified that deal with recreational services of freshwater ecosystems, six of them in the last period analysed (Table 3). Zhang et al. [125] used TOPSIS to evaluate competitive tourist destinations in the Yangtze River Delta (China) and Tang et al. [126] used fuzzy techniques to evaluate the coordinative green development of tourist experience and commercialization of tourism when considering the perspectives of tourists in the Ancient City of Pingyao and West Lake Cultural Landscape of Hangzhou (China). Aiping et al. [127] used AHP and GIS to identify and map ecotourism areas in one area of the Yellow River (China). Biglarfadafan et al. [128] and Tang et al. [126] both assessed impact/vulnerability, while the rest identified suitable places for tourism. The suitability of areas for birdwatching was identified by Biglarfadafan et al. [128] in wetlands, as well as the impact of ecotourism, and Tang et al. [126] studied the green development of tourism in a protected area. The studies were carried out in Iran and China, and none of them accounted for stakeholder preferences.

Table 3. Reviewed papers that analyse water as a cultural ecosystem service classified by region, method, problem, participation, study area, and waterbody type.

Reference	Region	Method	Problem	Participation	Study Area	Water Course Type
Zhang et al., 2011 [125]	China	DIS	TOUR	NO	Yangtze River Delta	River
Aiping et al., 2015 [127]	China	HIER	TOUR	NO	Yellow River	Wetland
Erfani et al., 2015 [129]	Iran	MIX	TOUR	NO	Hamoon Lake	Lake
Biglarfadafan et al., 2016 [128]	Irán	MIX	IMPACT-VUL	NO	Bazangan Lake	Wetland
Balist et al., 2019 [130]	Iran	MIX	TOUR	NO	Zarivar Lake	Lake
Maghsoudi et al., 2019 [131]	Iran	MIX	TOUR	NO	Shur River (Lut desert)	River
Tang et al., 2019 [126]	China	FUZ	IMPACT-VUL	NO	West Lake of Hangzhou	Wetland

3.2.4. Supporting FES

The 14 studies included in this group have a strict focus on site conservation, especially biodiversity conservation (Table 4). Only Qureshi and Harrison [132], Eliasson et al. [133], and Choulak et al. [134] incorporated stakeholder participation in resolving issues associated with supporting ES. The first of these studies evaluated different alternatives for riparian revegetation in a small sub-catchment in the Johnstone River catchment (North Queensland) while using hierarchical methods and a collaborative approach.

Eliasson et al. [133] evaluated the impact of the construction of a new road on an important glaciofluvial esker aquifer in Sweden. Scenario analysis and a multi-criteria decision model were used to examine the preferences of the main stakeholders in the affected municipalities, in order to assess four different alternatives accounting for conflicts with aquatic, agricultural, natural and cultural resources. A meta-decision analysis carried out by [134] in an application to wetland prioritization in the Bourgogne region (France), seeking to encourage and finance wetland conservation plans considering their contribution to biodiversity. Chen et al. [135] relied on expert participation in their study that aimed at improving wetland environmental protection plans, using DEMATEL and VIKOR techniques and a modified ANP. In this case, experts were consulted to identify four dimensions and 11 criteria to determine the best management alternative aimed at achieving the objective of wetland environmental protection.

Saha [136] and Talukdar et al. [137] focused on assessing the vulnerability of two Indian wetlands of the Atreyee River and Tangan River, respectively. The former used fuzzy logic, while the latter used random forest and neural networks to explore the habitat quality and Trophic State Index. Buruso [138] studied the suitability of Lake Tana as habitat for the African hippo, while Wu et al. [139] analysed the ecological value of 60 national parks (wetlands) in China. Jafari [140] also focused on analysing the ecological value of sites in Kavir National Park (Iran).

Table 4. Reviewed papers that analyse water from a supporting ecosystem service perspective classified by region, method, problem, participation, study area, and waterbody type.

Reference	Region	Method	Problem	Participation	Study Area	Water Course Type
Qureshi and Harrison, 2001 [132]	Queensland	HIER	CON	YES	Johnstone River catchment	River
Eliasson et al., 2003 [133]	Sweden	DIS	CON	YES	Aquifer Nybroåsen (Kalmar)	Groundwater
Dong et al., 2013 [141]	China	HIER	CON	NO	West Songnen Plain	Wetland
Kozlov et al., 2016 [142]	Rusia	Other	CON	NO	Volga-Akhtuba Wetlands	Wetland
Qiu et al., 2016 [143]	USA	MIX	CON	NO	Raritan River basin	River
Xue et al., 2016 [144]	China	FUZ	CON	NO	Yangtze River Estuary	Estuary
Buruso, 2018 [138]	Ethiopia	Other	CON	NO	Lake Tana Biosphere Reserve	Lake
Wu et al., 2017 [139]	China	HIER	CON	NO	60 National Wetlands Parks	Wetland
Qi et al., 2018 [145]	China	MIX	CON	NO	Lake Poyang	Lake
Chen et al., 2019 [135]	Taiwan	MIX	MAN	EXP	Guan-Du Wetland	Wetland
Choulak et al., 2019 [134]	France	MIX	CON	YES	Bourgogne comte	Wetland
Saha and Pal, 2019 [136]	India	FUZ	IMPACT-VUL	NO	Atreyee River	Wetland-River
Jafari et al., 2019 [140]	Iran	MIX	CON	NO	Kavir National Park	River
Talukdar et al., 2020 [137]	India	NEU	IMPACT-VUL	NO	Tangan River	Wetland-River

3.2.5. Integrated FES and Participation

The strong decrease in analyses involving stakeholder participation from the period 2005–2009, as shown in the results, can be primarily explained by the growing concern about conservation, in the strict sense, and provisioning issues, which have not traditionally incorporated stakeholder participation in decision-making processes. The review identified another group of studies that approach water as an integrative element, analysing problems that are associated with its provisioning, regulating, cultural, and sometimes supporting functions, and which consider the interests of different stakeholder groups. There was a very substantial increase in the publications of this type of study in the period 2000–2005 and, to a lesser extent, in the second period 2006–2010, before decreasing significantly from 2011 onwards and contributing to the gradual decline in participatory studies of FES from 2011 (Figure 4).

Thirty-one studies (75.6%) that take an integrated approach to analysing FES incorporated stakeholder participation. These studies were mainly conducted in European countries and address issues of sustainable management (Table 5). A high degree of dependence was identified between participation and the problem to be solved (p = 0.00): the articles dealing with solving management problems were the most participatory.

In this group, only two papers dealt with problems of impact/vulnerability and restoration: Gregory and Wellman [146] and Azarnivand et al. [147]. A participative tool was proposed by Gregory and Wellman [146] to restore the functioning of the Tillamook Bay estuary with the values assessed by community residents. Azarnivand et al. [147] evaluated different alternatives for the restoration of Lake Urmia in Iran. To that end, they used an extended fuzzy analytical hierarchy process and a SWOT-TOWS matrix, while considering the preferences of stakeholders, managers, and experts.

Among the studies that jointly examined provisioning and regulating services, those involving stakeholder participation were Derak et al. [148], Weng et al. [149], and Dowlatabadi et al. [150]. Land use alternatives were evaluated by Derak et al. [148] evaluated in Beni Boufrah Valley, a semi-arid area of Morocco, incorporating 67 stakeholders' preferences regarding water supply, soil fertility, protection against erosion, and food provision. To do so, they used an AHP model. Multi-objective programming was used by Weng et al. [149] and proposed a decision support system for water resources management and planning in the Haihe River Basin (China), in which stakeholders could include their preferences in the assessment of different management scenarios. This is the only study carried out in China that incorporates stakeholder preferences into the model. DEMATEL, AHP, and game theory were used by Dowlabati et al. [150] to resolve conflicts surrounding a transboundary wetland, Hawizeh Wetland/Hoor-Al-Azim, involving Iran, Iraq, Turkey, and Syria. By applying the model, the authors were able to identify three strong equilibrium points among 15 feasible alternatives: establishing a regional agreement among Iran, Iraq, and Turkey to reduce the effects of conflicts on the wetland; an Iran-Iraq coalition to motivate Turkey to reduce water withdrawal from the Tigris River; and, exchanging water release for the commodity market in Iran and Iraq for Turkey.

Finally, two papers were identified that jointly analysed regulating and cultural functions. Väntänen and Marttunen [151] proposed several ways to include stakeholder participation in order to assess the impact of different regulation strategies on recreational use and aquatic ecosystems in a Finnish lake. Wang et al. [152] addressed tourism development in a wetland in China, considering its effect on the biochemical conditions of the water. To do so, they used fuzzy neuronal networks, but did not rely on the participation of stakeholders or experts.

Environmental policies are implemented in complex socio-economic contexts, involving a large number of different stakeholder groups with diverse and often conflicting interests. Conflicts are exacerbated in a context of scarce resources, and often protected resources, as is the case with water. Nevertheless, although there are many links between water and conflicts, and many opposing interests have a bearing on its management, most disputes are resolved peacefully through negotiation processes; accordingly, since the early 2000s, different formulas for cooperation in water management have been promoted [153]. Generally speaking, economic cooperation between countries can be used as a negotiating tool for solving water problems [150].

Two key elements should be taken into account when it comes to managing water-related conflicts: the legislative framework and operational framework. Regarding the former, there is a need for a legal and regulatory framework to support the management of large watercourses. Indeed, in international river basins, water management institutions do not tend to manage conflicts if there is no treaty stating the rights and responsibilities of each nation, or any implicit agreement [153]. In terms of the operational framework, MCDM methods can be a very useful tool for identifying conflicts and efficiently managing them [154]. In addition to the scientific soundness of the models, participation plays a relevant role in a number of ways: on the one hand, expert recommendations are needed to improve their operability and support their legitimacy [134] and, on the other hand, incorporating participation in the early stages of the decision-making processes helps to minimise conflicts and facilitates their management in the development of public policies [155]. Alamanos et al. [156] provide an integrated decision support tool for evaluating water resource management strategies in a lake in Greece. They combined four MCDM techniques to assess seven alternative policies and involved experts and stakeholders to weight the analysed criteria and then compared the results. This illustrated the differences in the perception of the problems, and guided an integrated solution expressed by experts in the field of water management and by the responsible authorities. Moreover, this study compared several MCDM techniques, which is very useful for defining a complete framework of alternative possibilities when divergences between participants are strong. Papaioannou et al. Several multiple-criteria analysis methods were compared by [157] for potential flood prone areas mapping in the Xerias River watershed (Greece).

Although this is acknowledged by the scientific community and accepted by the general public, the present review has shown that, in recent years, there has been a trend towards the proliferation of non-participatory studies regarding MCDM methods aimed at solving problems of a strictly ecological nature without accounting for social preferences.

Table 5. Reviewed papers that analyse water as an integrated ecosystem service.

Reference	Region	Method	Problem	Ecosystem Service	Participation	Study Area	Water Course Type
De Marchi et al., 2000 [158]	Sicilia	FUZ	MAN	PROV-REG-CULT	YES	Dam and lake in Ancipa	Lake
Srinivasa et al., 2000 [159]	Spain	OUT	MAN	PROV-REG-CULT	NO	Flumen Monegros irrigation area (Hoya de Huesca and Monegros)	River
Gregory and Wellman, 2001 [146]	USA	UT	RESTOR	PROV-REG-CULT	YES	Tillamook Bay	Estuary
Hamalainen et al., 2001 [160]	Finland	DIS	MAN	PROV-REG-CULT	YES	Lake Päijänne-River Kymikoki	Lake
Pavlikakis and Tsihrintzis, 2003 [161]	Greece	DIS	MAN	PROV-REG-CULT	YES	National Park of river Nestos delta and Lakes Vistonida and Ismarida	Lake
Cai et al., 2004 [21]	China	DIS	MAN	PROV-REG-CULT	YES	Theoretical	NI
Mustajoki et al., 2004 [162]	Finland	UT	MAN	PROV-REG-CULT	YES	Lake Päijänne	Lake
Raju and Duckstein, 2004 [163]	Spain	OUT	MAN	PROV-REG-CULT	EXP	Flumen Monegros irrigation area	River
Vantanen and Marttunen, 2005 [151]	Finland	SOFT	IMPACT-VUL	REG-CULT	YES	Lake Kemijärvi	Lake
Wattage and Mardle, 2005 [164]	India	HIER	MAN	PROV-REG-CULT	YES	Muthurajawela Marsh and Negombo Lagoon	Wetland
Messner et al., 2006 [165]	Germany	Other	MAN	PROV-REG-CULT	YES	Spree river basin	River
Wang et al., 2006 [166]	China	FUZ	MAN	PROV-REG-CULT	YES	Lake Quionghai	Lake
Goosen et al., 2007 [167]	Holland	Other	MAN	PROV-REG-CULT	YES	Wormer and Jisperveld	Wetland
Marchamalo and Romero, 2007 [168]	Costa Rica	DIS	MAN	PROV-REG-CULT	YES	Birrís River	River
Srdjevic, 2007 [169]	Brazil	MIX	MAN	PROV-REG-CULT	YES	San Francisco river basin	River
Hajkowicz and Higgins, 2008 [170]	NI	Other	MAN	PROV-REG-CULT	YES	Various	NI
Marttunen and Hamalainen, 2008 [14]	Finland	Other	MAN	PROV-REG-CULT	YES	Lake Päijänne-RIV Kymikoki	Lake
Van Cauwenbergh et al., 2008 [171]	Spain	MIX	MAN	PROV-REG-CULT	YES	Andarax catchment	River
Chung and Lee, 2009 [172]	Korea	MIX	MAN	PROV-REG-CULT	YES	Anyangcheon watershed (Han river)	River
Ryu et al., 2009 [173]	Korea	DIS	MAN	PROV-REG-CULT	YES	Geum river basin	River
Calizaya et al., 2010 [174]	Bolivia	HIER	MAN	PROV-REG-CULT	YES	Lake Poopo Basin (Ramsar)	Lake

Table 5. *Cont.*

Reference	Region	Method	Problem	Ecosystem Service	Participation	Study Area	Water Course Type
Chen et al., 2010 [175]	Taiwan	MIX	MAN	PROV-REG-CULT	YES	Pei-Keng watershed	River
Silva et al., 2010 [176]	Brazil	OUT	MAN	PROV-REG-CULT	YES	Jabuatao River watershed	River
Yilmaz and Harmancioglu, 2010 [177]	Turkey	DIS	MAN	PROV-REG-CULT	YES	Gediz River basin	River
Weng et al., 2010 [149]	China	Other	MAN	PROV-REG	YES	Haihe river basin	River
Chen et al., 2011 [178]	China	FUZ	MAN	PROV-REG-CULT	EXP	Pei-Keng brook of catchments area	River
Lennox et al., 2011 [179]	New Zealand	SOFT	MAN	PROV-REG-CULT	YES	Canterbury region	River
Wang et al., 2012 [152]	China	NEU	IMPACT-VUL	REG-CULT	NO	Others-Theoretical	Wetland
Azarnivand et al., 2014 [147]	Iran	MIX	RESTOR	PROV-REG-CULT	YES	Lake Urmia	Lake
Aznar et al., 2014 [180]	Spain	MIX	MAN	PROV-REG-CULT	YES	Pego-Oliva Wetland	Wetland
Pinto et al., 2014 [181]	Portugal	DIS	MAN	PROV-REG-CULT	YES	Mondego Estuary	Estuary
Aher et al., 2017 [182]	India	HIER	ALLOC	PROV-REG	NO	Dhalai River	River
Derak et al., 2017 [148]	Morocco	HIER	MAN	PROV-REG	YES	Beni Boufrah Valley	River
Sheikhipour et al., 2018 [183]	Iran	MIX	MAN	PROV-REG-CULT	NO	Shahrekord aquifer	Groundwater
DasGupta et al., 2019 [184]	India	DIS	MAN	PROV-REG-CULT	YES	Indian Sundarban Delta	Estuary
Everard et al., 2019 [185]	India	other	MAN	PROV-REG-CULT	YES	SudhanyakhaliIsland-Gosaba Island-East Kolkata Wetland	Wetland
Hosseini et al., 2019 [186]	Iran	MIX	MAN	PROV-REG	EXP	Various	Groundwater
Kacem et al., 2019 [187]	Morocco	MIX	IMPACT-VUL	PROV-REG	EXP	Draden basin	River
Karabulut et al., 2019 [188]	Mediterranean region	DIS	MAN	PROV-REG	EXP	Theoretical-Mediterranean region	Theoretical
Yun et al., 2019 [189]	Korea	HIER	MAN	PROV-REG-CULT	EXP	Various	Wetland
Dowlatabadi et al., 2020 [150]	Iran-Irak-Turkey	MIX	CON	PROV-REG	YES	Tigris and Karkheh rivers and the Hawizeh/Hoor-Al-Azim wetland	Wetland

4. Conclusions

FES represent a source of conflict around the world, especially in countries where this resource is scarce. Moreover, their management becomes extremely complicated once waterbodies cross different regions and countries, involving different governments, cultures, and administrations—often already in conflict over other issues.

Multi-criteria models are very useful in helping to identify these conflicts and tackle them effectively. In addition, they provide a key tool for managing water-related decision-making processes by incorporating the preferences of different agents and dealing with conflicts from the outset.

Between 2000 and 2005, there was a marked increase in the number of studies addressing sustainable water management from an integrated perspective, jointly considering all of the ecosystem services and incorporating the preferences of all the relevant stakeholders. However, such articles are becoming less common, giving way to studies that separately explore strictly ecological functions of water and, to a lesser extent, provisioning services. This trend is reflected in the 78.88% reduction in studies involving participation since 2006.

In contrast, the substantial and serious loss of wetlands over the past decade has prompted an increase in studies focusing on these sites, which aimed at preserving their supporting and regulating functions. They are mainly concerned with solving problems of conservation management and analysing impact or vulnerability.

Articles dealing with provisioning, cultural, and supporting services individually do not involve stakeholder participation. Specifically, provisioning services are generally addressed by calling on the participation of experts or water negotiators. While analyses of the regulating ecosystem services of freshwater ecosystems have involved participation to a greater extent than other groups of studies, there is still a higher proportion of studies not involving stakeholders in decision-making processes.

International diplomacy should incorporate conflict management from the outset, while taking into account the interests of different stakeholder groups from the early stages of public policy planning, mainly in transboundary sites where conflicts are particularly challenging.

Studies on water management and conservation that reflect its essence from an ecosystem service point of view should be promoted; there is a need for studies that take an integrated approach to exploring the interrelationships between hydrology, landscapes, ecology, and humans. This scientific approach should be complemented with an integrated framework that is supported by legal and normative strategies of land and landscape management, to ensure the viability and sustainability of these initiatives.

Such an integrated approach should be broadly encouraged, seeking to involve all relevant stakeholders that are affected by national and international regulations and policies on water management. It is recommended that experts, governments, and water negotiators should continue to participate, but efforts should also be made to ensure that the preferences of the main stakeholder groups are represented in decision-making processes, in order to underscore their legitimacy. A particular emphasis should be placed on the concept of sustainability welfare, prudence, and justice. Given the expansive scope of this approach, it becomes possible to simultaneously achieve goals relating to the conservation of nature and peace, thereby helping to improve the wellbeing of humanity.

It is relevant to highlight that the decrease of participation found in this analysis is exclusively related to MCDM techniques. This does not correspond to efforts to apply participatory approaches in the implementation of water policy. In Europe, for example, the Water Framework Directive sets requirements to stakeholder participation in its implementation which has been followed by all Member States. In this sense, MCDM can contribute to the improvement of the implementation of European water policy. Moreover, it would be interesting to simultaneously combine experts and stakeholders in participatory initiatives, making these processes advance towards higher quality and integrated solutions.

From a methodological perspective, future research lines should be oriented to specific reviews separately analysing the function and usefulness of MCDM exclusively providing information and MCDM providing tools to the implementation of decision-making processes, as well as MCDM providing solutions to conflicts or guiding negotiation processes (decision support systems).

Author Contributions: Conceptualization, M.d.C.-P., P.F.M., A.P.Z. and J.C.A.; methodology, M.d.C.-P. and J.C.A.; writing—original draft preparation, M.d.C.-P.; writing—review and editing, J.C.A.; supervision, J.C.A.; project administration, P.F.M. and A.P.Z.; funding acquisition, A.P.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors thanks the UNESCO UNED-URJC Chair in Water and Peace institutional coverage to the development of this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Martin-Ortega, J.; Ferrier, R.C.; Gordon, I.J.; Khan, S. *Water Ecosystem Services: A Global Perspective*; UNESCO Publishing: Paris, France, 2015.
2. Hoekstra, A.Y.; Wiedmann, T.O. Humanity's unsustainable environmental footprint. *Science* **2014**, *344*, 1114–1117. [CrossRef] [PubMed]
3. Ormerod, S.J.; Dobson, M.; Hildrew, A.G.; Townsend, C. Multiple stressors in freshwater ecosystems. *Freshwater Biol.* **2010**, *55*, 1–4. [CrossRef]
4. Strayer, D.L.; Dudgeon, D. Freshwater biodiversity conservation: Recent progress and future challenges. *J. N. Am. Benthol. Soc.* **2010**, *29*, 344–358. [CrossRef]
5. United Nations. 2019. Available online: https://www.un.org/en/sections/issues-depth/water/ (accessed on 6 December 2020).
6. UN General Assembly. Transforming our World: The 2030 Agenda for Sustainable Development, 21 October 2015, A/RES/70/1. Available online: https://www.refworld.org/docid/57b6e3e44.html (accessed on 15 February 2021).
7. The Economist Intelligence Unit Limited. Blue Peace Index 2019. Available online: https://bluepeaceindex.eiu.com/#/ (accessed on 8 December 2020).
8. Pérez Zabaleta, A.; Gracia de Rentería, P.; Ballesteros, M.; Pérez Foguet, A.; Ezbakhe, F.; Guerra-Librero, A. *Analysis of Renewal Investment Needs of the Urban Water Cycle in Spain*; UNED: Madrid, Spain, 2020.
9. Pérez Zabaleta, A.; Gracia de Rentería, P.; Escalera-Izquierdo, G. Circular economy as a tool to mitigate the effects of climate change on water resources: The case of Spain. *DYNA* **2020**, *95*, 611–614.
10. Gaget, E.; Le Viol, I.; Pavón-Jordán, D.; Cazalis, V.; Kerbiriou, C.; Jiguet, F.; Abdou, W.A.I. Assessing the effectiveness of the Ramsar Convention in preserving wintering waterbirds in the Mediterranean. *Biol. Conserv.* **2020**, *243*, 108485. [CrossRef]
11. Kingsford, R.T.; Biggs, H.C.; Pollard, S.R. Strategic adaptive management in freshwater protected areas and their rivers. *Biol. Conserv.* **2011**, *144*, 1194–1203. [CrossRef]
12. Suski, C.D.; Cooke, S.J. Conservation of aquatic resources through the use of freshwater protected areas: Opportunities and challenges. *Biodivers. Conserv.* **2007**, *16*, 2015–2029. [CrossRef]
13. Chellaney, B. *Water, Peace, and War: Confronting the Global Water Crisis*; Rowman & Littlefield: Lanham, MD, USA, 2013.
14. Marttunen, M.; Hämäläinen, R.P. The decision analysis interview approach in the collaborative management of a large regulated water course. *Environ. Manag.* **2008**, *42*, 1026. [CrossRef]
15. De Castro-Pardo, M.; Urios, V. A critical review of multi-criteria decision making in protected areas. *Econ. Agrar. Recurs. Nat.-Agricult. Resour. Econ.* **2017**, *16*, 89–109. [CrossRef]
16. Kaya, A.; Bettinger, P.; Boston, K.; Akbulut, R.; Ucar, Z.; Siry, J.; Merry, K.; Cieszewski, C. Optimisation in forest Management. *Curr. For. Rep.* **2016**, *2*, 1–17. [CrossRef]
17. Diaz-Balteiro, L.; González-Pachón, J.; Romero, C. Measuring systems sustainability with multi-criteria methods: A critical review. *Eur. J. Operat. Res.* **2017**, *258*, 607–616. [CrossRef]
18. Nordström, E.M.; Nieuwenhuis, M.; Başkent, E.Z.; Biber, P.; Black, K.; Borges, J.G.; Zoccatelli, D. Forest decision support systems for the analysis of ecosystem services provisioning at the landscape scale under global climate and market change scenarios. *Eur. J. For. Res.* **2019**, *138*, 561–581. [CrossRef]
19. Hajkowicz, S.; Collins, K. A review of multiple criteria analysis for water resource planning and management. *Water Resour. Manag.* **2007**, *21*, 1553–1566. [CrossRef]
20. Herath, G. Multi-criteria decision making in water resources planning: What does the evidence show. *Rev. Manag. Innov. Creat.* **2010**, *3*, 38–55.

21. Cai, X.; Lasdon, L.; Michelsen, A.M. Group decision making in water resources planning using multiple objective analysis. *J. Water Resour. Plan. Manag.* **2004**, *130*, 4–14. [CrossRef]
22. Mimi, Z.A.; Sawalhi, B.I. A decision tool for allocating the waters of the Jordan River Basin between all riparian parties. *Water Resour. Manag.* **2003**, *17*, 447–461. [CrossRef]
23. Snyder, H. Literature review as a research methodology: An overview and guidelines. *J. Bus. Res.* **2019**, *104*, 333–339. [CrossRef]
24. Templier, M.; Paré, G. A framework for guiding and evaluating literature reviews. *Commun. Assoc. Inform. Syst.* **2015**, *37*, 112–137. [CrossRef]
25. Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being: Synthesis*; Island Press: Washington, DC, USA, 2005.
26. Zimmerman, H.J. Fuzzy programming and linear programming with several objective functions. *Fuzzy Sets Syst.* **1978**, *1*, 45–55. [CrossRef]
27. Saaty, T.L. Axiomatic foundation of the analytic hierarchy process. *Manag. Sci.* **1986**, *32*, 841–855. [CrossRef]
28. Ortiz-Urbina, E.; González-Pachón, J.; Diaz-Balteiro, L. Decision-making in forestry: A review of the hybridisation of multiple criteria and group decision-making methods. *Forests* **2019**, *10*, 375. [CrossRef]
29. Roy, B. Classement et choix en présence de points de vue multiples (La méthode de ELECTRE). *Rev. Franc. Inform. Rech. Opération.* **1968**, *6*, 57–75.
30. Brans, J.P.; Vincke, P.; Mareschal, B. Howtoselect andhow torank projects: The PROMETHEE methods. *Eur. J. Operat. Res.* **1986**, *24*, 228–238. [CrossRef]
31. Mendoza, G.A.; Martins, H. Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms. *For. Ecol. Manag.* **2006**, *230*, 1–22. [CrossRef]
32. Keeney, R.L.; Raiffa, H. *Decisions with Multiple Objectives: Preferences and Value Trade-Offs*; John Wiley and Sons: New York, NY, USA, 1976.
33. Levin, S.A. *Encyclopedia of Biodiversity*, 2nd ed.; Reference Work; Elsevier: Amsterdam, The Netherlands, 2013.
34. De la Fuente Fernández, S. *Aplicaciones de la Chi-Cuadrado: Tablas de Contingencia. Homogeneidad, Dependencia e Independencia*; UAM: Madrid, Spain, 2016.
35. Ugoni, A.; Walker, B.F. The Chi square test: An introduction. *COMSIG Rev.* **1995**, *4*, 61. [PubMed]
36. Ramsar Convention. *Global Wetland Outlook: State of the World's Wetlands and their Services to People*; Ramsar Convention: Ramsar, Iran; Gland, Switzerland, 2018.
37. De Castro-Pardo, M.; Azevedo, J.C. A Goal Programming Model to Guide Decision-Making Processes towards Conservation Consensuses. *Sustainability* **2021**, *13*, 1959. [CrossRef]
38. Jaber, J.O.; Mohsen, M.S. Evaluation of non-conventional water resources supply in Jordan. *Desalination* **2001**, *136*, 83–92. [CrossRef]
39. Chowdhury, A.; Jha, M.K.; Chowdary, V.M. Delineation of groundwater recharge zones and identification of artificial recharge sites in West Medinipur district, West Bengal, using RS, GIS and MCDM techniques. *Environ. Earth Sci.* **2010**, *59*, 1209. [CrossRef]
40. Machiwal, D.; Jha, M.K.; Mal, B.C. Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques. *Water Resour. Manag.* **2011**, *25*, 1359–1386. [CrossRef]
41. Machiwal, D.; Rangi, N.; Sharma, A. Integrated knowledge-and data-driven approaches for groundwater potential zoning using GIS and multi-criteria decision making techniques on hard-rock terrain of Ahar catchment, Rajasthan, India. *Environ. Earth Sci.* **2015**, *73*, 1871–1892. [CrossRef]
42. Çelik, R. Evaluation of groundwater Potential by GIS-Based Multicriteria Decision Making as a Spatial Prediction Tool: Case Study in the Tigris river Batman-Hasankeyf Sub-Basin, Turkey. *Water* **2019**, *11*, 2630. [CrossRef]
43. Rana, V.K.; Suryanarayana, T.M.V. GIS-based multi criteria decision making method to identify potential runoff storage zones within watershed. *Ann. GIS* **2020**, *26*, 149–168. [CrossRef]
44. Swetha, T.V.; Gopinath, G.; Thrivikramji, K.P.; Jesiya, N.P. Geospatial and MCDM tool mix for identification of potential groundwater prospects in a tropical river basin, Kerala. *Environ. Earth Sci.* **2017**, *76*, 428. [CrossRef]
45. Prato, T. Adaptive management of large rivers with special reference to the Missouri river. *J. Am. Water Resour. Assoc.* **2003**, *39*, 935–946. [CrossRef]
46. Hyde, K.M.; Maier, H.R.; Colby, C.B. Reliability-based approach to multicriteria decision analysis for water resources. *J. Water Resour. Plan. Manag.* **2004**, *130*, 429–438. [CrossRef]
47. Arriaza, M.; Gómez-Limón, J.A.; Upton, M. Local water markets for irrigation in southern Spain: A multicriteria approach. *Austr. J. Agricult. Resour. Econ.* **2002**, *46*, 21–43. [CrossRef]
48. López-Baldovin, M.J.; Gutiérrez-Martin, C.; Berbel, J. Multicriteria and multiperiod programming for scenario analysis in Guadalquivir river irrigated farming. *J. Operat. Res. Soc.* **2006**, *57*, 499–509. [CrossRef]
49. Mysiak, J.; Giupponi, C.; Rosato, P. Towards the development of a decision support system for water resource management. *Environ. Model. Softw.* **2005**, *20*, 203–214. [CrossRef]
50. Roozbahani, A.; Ebrahimi, E.; Banihabib, M.E. A framework for ground water management based on Bayesian network and MCDM techniques. *Water Resour. Manag.* **2018**, *32*, 4985–5005. [CrossRef]
51. Zarghami, M.; Szidarovszky, F. Stochastic-fuzzy multi criteria decision making for robust Water Resource Management. *Stochast. Environ. Res. Risk Assess.* **2009**, *23*, 329–339. [CrossRef]

52. Estalaki, S.M.; Kerachian, R.; Nikoo, M.R. Developing water quality management policies for the Chitgar urban Lake: Application of fuzzy social choice and evidential reasoning methods. *Environ. Earth Sci.* **2016**, *75*, 404. [CrossRef]
53. Nayak, R.C.; Panda, R.K. Integrated management of a canal command in a River Delta using multiobjective techniques. *Water Resour. Manag.* **2001**, *15*, 383–401. [CrossRef]
54. Karnib, A. An approach to elaborate priority preorders of water resources projects based on multi-criteria evaluation and fuzzy sets analysis. *Water Resour. Manag.* **2004**, *18*, 13–33. [CrossRef]
55. McPhee, J.; Yeh, W.W.G. Multi-objective optimisation for sustainable groundwater management in semi-arid regions. *J. Water Resour. Plan. Manag.* **2004**, *130*, 490–497. [CrossRef]
56. Srdjevic, B.; Medeiros, Y.D.P.; Faria, A.S. An objective multi-criteria evaluation of water management scenarios. *Water Resour. Manag.* **2004**, *18*, 35–54. [CrossRef]
57. Zarghaami, R. Integrated Water Resour. Manag. in Polrud Irrigation system. *Water Resour. Manag.* **2006**, *20*, 215–225. [CrossRef]
58. Raju, K.S.; Vasan, A. Multi attribute utility theory for irrigation. *Water Resour. Manag.* **2007**, *21*, 717–728. [CrossRef]
59. Gómez-Limón, J.A.; Riesgo, L. Alternative approaches to the construction of a composite indicator of agricultural sustainability: An application to irrigated agriculture in the Duero basin in Spain. *J. Environ. Manag.* **2009**, *90*, 3345–3362. [CrossRef]
60. Opricovic, S. Fuzzy VIKOR with an application to water resources planning. *Exp. Syst. Applicat.* **2011**, *38*, 12983–12990. [CrossRef]
61. Zeng, Y.; Li, J.; Cai, Y.; Tan, Q. Equitable and reasonable freshwater allocation based on a multi-criteria decision making approach with hydrologically constrained bankruptcy rules. *Ecol. Indicat.* **2017**, *73*, 203–213. [CrossRef]
62. Arabameri, A.; Rezaei, K.; Cerda, A.; Lombardo, L.; Rodrigo-Comino, J. GIS-based groundwater potential mapping in Shahroud plain, Iran. A comparison among statistical (bivariate and multivariate), data mining and MCDM approaches. *Sci. Total Environ.* **2019**, *658*, 160–177. [CrossRef]
63. Bera, K.; Banik, P. Multi-criteria decision analysis (MCDA) for surface water management plan, a case study of Kansachara sub-watershed, West Bengal, India. *Water Supply* **2019**, *19*, 2156–2162. [CrossRef]
64. Arabameri, A.; Lee, S.; Tiefenbacher, J.P.; Ngo, P.T.T. Novel Ensemble of MCDM-Artificial Intelligence Techniques for groundwater-Potential Mapping in Arid and Semi-Arid Regions (Iran). *Remote Sens.* **2020**, *12*, 490. [CrossRef]
65. Daneshvar, F.; Nejadhashemi, A.P.; Adhikari, U.; Elahi, B.; Abouali, M.; Herman, M.R.; Rohn, B.G. Evaluating the significance of wetland restoration scenarios on phosphorus removal. *J. Environ. Manag.* **2017**, *192*, 184–196. [CrossRef] [PubMed]
66. Janssen, R.; Goosen, H.; Verhoeven, M.L.; Verhoeven, J.T.; Omtzigt, A.Q.A.; Maltby, E. Decision support for integrated wetland management. *Environ. Model. Softw.* **2005**, *20*, 215–229. [CrossRef]
67. Brouwer, R.; Ek, R.V. Integrated ecological, economic and social impact assessment of alternative flood control policies in the Netherlands. *Ecol. Econ.* **2004**, *50*, 1–21. [CrossRef]
68. Levy, J.K. Multiple criteria decision making and decision support systems for flood risk management. *Stochast. Environ. Res. Risk Assess.* **2005**, *19*, 438–447. [CrossRef]
69. Kenyon, W. Evaluating flood risk management options in Scotland: A participant-led multi-criteria approach. *Ecol. Econ.* **2007**, *64*, 70–81. [CrossRef]
70. Levy, J.K.; Hartmann, J.; Li, K.W.; An, Y.; Asgary, A. Multi-criteria decision support systems for flood hazard mitigation and emergency response in urban watersheds 1. *J. Am. Water Resour. Assoc.* **2007**, *43*, 346–358. [CrossRef]
71. Perrone, A.; Inam, A.; Albano, R.; Adamowski, J.; Sole, A. A participatory system dynamics modeling approach to facilitate collaborative flood risk management: A case study in the Bradano river (Italy). *J. Hydrol.* **2020**, *580*, 124354. [CrossRef]
72. Rohde, S.; Hostmann, M.; Peter, A.; Ewald, K.C. Room for rivers: An integrative search strategy for floodplain restoration. *Landsc. Urban Plan.* **2006**, *78*, 50–70. [CrossRef]
73. Randhir, T.; Shriver, D.M. Deliberative valuation without prices: A multiattribute prioritization for watershed ecosystem management. *Ecol. Econ.* **2009**, *68*, 3042–3051. [CrossRef]
74. Gross, C.; Hagy, J.D., III. Attributes of successful actions to restore lakes and estuaries degraded by nutrient pollution. *J. Environ. Manag.* **2017**, *187*, 122–136. [CrossRef] [PubMed]
75. Arondel, C.; Girardin, P. Sorting cropping systems on the basis of their impact on groundwater quality. *Eur. J. Operat. Res.* **2000**, *127*, 467–482. [CrossRef]
76. Chuntian, C.; Chau, K.W. Three-person multi-objective conflict decision in reservoir flood control. *Eur. J. Operat. Res.* **2002**, *142*, 625–631. [CrossRef]
77. Wang, X.L.; Ning, L.M.; Hu, W.B. Application of analytic hierarchy process to assessing the ecological vulnerability of wetlands in the Jianghan Plain. *Chin. Geogr. Sci.* **2003**, *13*, 272–276. [CrossRef]
78. Bana e Costa, C.A.; Da Silva, P.A.; Correia, F.N. Multicriteria evaluation of flood control measures: The case of Ribeira do Livramento. *Water Resour. Manag.* **2004**, *18*, 263–283. [CrossRef]
79. Herath, G. Incorporating community objectives in improved wetland management: The use of the analytic hierarchy process. *J. Environ. Manag.* **2004**, *70*, 263–273. [CrossRef] [PubMed]
80. Olenick, K.L.; Wilkins, N.; Conner, J.R. Increasing off-site water yield and grassland bird habitat in Texas through brush treatment practices. *Ecol. Econ.* **2004**, *49*, 469–484. [CrossRef]
81. Tzionas, P.; Ioannidou, I.A.; Paraskevopoulos, S. A hierarchical fuzzy decision support system for the environmental rehabilitation of Lake Koronia, Greece. *Environ. Manag.* **2004**, *34*, 245–260. [CrossRef] [PubMed]

82. Almasri, M.N.; Kaluarachchi, J.J. Multi-criteria decision analysis for the optimal management of nitrate contamination of aquifers. *J. Environ. Manag.* **2005**, *74*, 365–381. [CrossRef] [PubMed]
83. Lee, C.S.; Chang, S.P. Interactive fuzzy optimization for an economic and environmental balance in a river system. *Water Res.* **2005**, *39*, 221–231. [CrossRef] [PubMed]
84. Elshorbagy, A. Multicriterion decision analysis approach to assess the utility of watershed modeling for management decisions. *Water Resour. Res.* **2006**, *42*. [CrossRef]
85. Liu, C.; Frazier, P.; Kumar, L.; Macgregor, C.; BLAK, N. Catchment-wide wetland assessment and prioritization using the multi-criteria decision-making method TOPSIS. *Environ. Manag.* **2006**, *38*, 316–326. [CrossRef] [PubMed]
86. Li, R. Dynamic assessment on regional eco-environmental quality using AHP-statistics model—A case study of Chaohu Lake Basin. *Chin. Geogr. Sci.* **2007**, *17*, 341–348. [CrossRef]
87. Qin, X.S.; Huang, G.H.; Chakma, A.; Nie, X.H. A MCDM-based expert system for climate-change impact assessment and adaptation planning. A case study for the Georgia Basin, Canada. *Exp. Syst. Applicat.* **2008**, *34*, 2164–2179. [CrossRef]
88. Olu-Owolabi, B.I.; Agunbiade, F.O.; Oseghe, E.O.; Adebowale, K.O. Fuzzy logic modeling of contamination degree of Ni and V metal species in sediments from the crude oil prospecting area of the Ondo coast, Nigeria. *Human Ecol. Risk Assess. Int. J.* **2012**, *18*, 902–918. [CrossRef]
89. Sun, Y.G.; Zhao, D.Z.; Zhang, F.S.; Wei, B.Q.; Chu, J.L.; Su, X. Spatiotemporal dynamic fuzzy evaluation of wetland environmental pollution risk in Dayang Estuary of Liaoning Province, Northeast China based on remote sensing. *Ying Yong Sheng Tai Xue Bao J. Appl. Ecol.* **2012**, *23*, 3180–3186.
90. Wu, J.; Wu, J.; Wang, X.; Zhong, M. Securing water for wetland conservation: A comparative analysis of policy options to protect a national reserve in China. *J. Environ. Manag.* **2012**, *94*, 102–111. [CrossRef]
91. Sener, E.; Davraz, A. Assessment of GRO vulnerability based on a modified DRASTIC model, GIS and an analytic hierarchy process (AHP) method: The case of Egirdir lake basin (Isparta, Turkey). *Hydrogeol. J.* **2013**, *21*, 701–714. [CrossRef]
92. Lee, G.; Jun, K.S.; Chung, E.S. Robust spatial flood vulnerability assessment for Han river using fuzzy TOPSIS with α-cut level set. *Exp. Syst. Applicat.* **2014**, *41*, 644–654. [CrossRef]
93. Malekmohammadi, B.; Blouchi, L.R. Ecological risk assessment of wetland ecosystems using multi criteria decision making and geographic information system. *Ecol. Indicat.* **2014**, *41*, 133–144. [CrossRef]
94. Chatterjee, K.; Bandyopadhyay, A.; Ghosh, A.; Kar, S. Assessment of environmental factors causing wetland degradation, using Fuzzy Analytic Network Process: A case study on Keoladeo National Park, India. *Ecol. Model.* **2015**, *316*, 1–13. [CrossRef]
95. McVittie, A.; Norton, L.; Martin-Ortega, J.; Siameti, I.; Glenk, K.; Aalders, I. Operationalizing an ecosystem services-based approach using Bayesian Belief Networks: An application to riparian buffer strips. *Ecol. Econ.* **2015**, *110*, 15–27. [CrossRef]
96. Meraj, G.; Romshoo, S.A.; Yousuf, A.R.; Altaf, S.; Altaf, F. Assessing the influence of watershed characteristics on the flood vulnerability of Jhelum basin in Kashmir Himalaya. *Nat. Hazards* **2015**, *77*, 153–175. [CrossRef]
97. Shafiee, M.; Saffarian, S.; Zaredar, N. Risk assessment of human activities on protected areas: A case study. *Human Ecol. Risk Assess. Int. J.* **2015**, *21*, 1462–1478. [CrossRef]
98. Walker, D.; Jakovljević, D.; Savić, D.; Radovanović, M. Multi-criterion water quality analysis of the Danube River in Serbia: A visualisation approach. *Water Res.* **2015**, *79*, 158–172. [CrossRef] [PubMed]
99. Abd-El Monsef, H.; Hassan, M.A.; Shata, S. Using spatial data analysis for delineating existing mangroves stands and siting suitable locations for mangroves plantation. *Comp. Electron. Agricult.* **2017**, *141*, 310–326. [CrossRef]
100. Duodu, G.O.; Ogogo, K.N.; Mummullage, S.; Harden, F.; Goonetilleke, A.; Ayoko, G.A. Source apportionment and risk assessment of PAHs in Brisbane RIV sediment, Australia. *Ecol. Indicat.* **2017**, *73*, 784–799. [CrossRef]
101. Man, W.D.; Liu, M.Y.; Wang, Z.M.; Mao, H.; Tian, Y.L.; Jia, M.M.; Ren, C.Y. Dynamics of habitat suitability for waterfowls from 1990 to 2015 in the ecological function zone of Sanjiang Plain, Northeast China. *Ying Yong Sheng Tai Xue Bao J. Appl. Ecol.* **2017**, *28*, 4083.
102. Malekmohammadi, B.; Jahanishakib, F. Vulnerability assessment of wetland landscape ecosystem services using driver-pressure-state-impact-response (DPSIR) model. *Ecol. Indicat.* **2017**, *82*, 293–303. [CrossRef]
103. Rather, M.A.; Kumar, J.S.; Farooq, M.; Rashid, H. Assessing the influence of watershed characteristics on soil erosion susceptibility of Jhelum basin in Kashmir Himalayas. *Arab. J. Geosci.* **2017**, *10*, 59. [CrossRef]
104. Golbarg, F.; Nabi Bidhendi, G.; Hoveidi, H. Environ. Manag. of oil pipelines risks in the wetland areas by Delphi and MCDM techniques: Case of Shadegan international wetland, Iran. *Pollution* **2018**, *4*, 195–210.
105. Maleki, S.; Soffianian, A.R.; Koupaei, S.S.; Pourmanafi, S.; Saatchi, S. Wetland restoration prioritizing, a tool to reduce negative effects of drought; An application of multicriteria-spatial decision support system (MC-SDSS). *Ecol. Eng.* **2018**, *112*, 132–139. [CrossRef]
106. Rahdari, V.; Soffianian, A.R.; Pourmanafi, S.; Ghaiumi, M.H.; Mosadeghi, R.; Amiri, F. A multi-objective approach for land conservation capability evaluation using multi-criterion evaluation models. *Appl. Ecol. Environ. Res.* **2018**, *16*, 1353–1367. [CrossRef]
107. Arabameri, A.; Cerda, A.; Rodrigo-Comino, J.; Pradhan, B.; Sohrabi, M.; Blaschke, T.; Tien Bui, D. Proposing a novel predictive technique for gully erosion susceptibility mapping in arid and semi-arid regions (Iran). *Remote Sens.* **2019**, *11*, 2577. [CrossRef]
108. Bid, S.; Siddique, G. Human risk assessment of Panchet dam in India using TOPSIS and WASPAS multi-criteria decision-making (MCDM) methods. *Heliyon* **2019**, *5*, e01956. [CrossRef] [PubMed]

109. De Souza Fraga, M.; da Silva, D.D.; Elesbon, A.A.A.; Guedes, H.A.S. Methodological proposal for the allocation of water quality monitoring stations using strategic decision analysis. *Environ. Monit. Assess.* **2019**, *191*, 776. [CrossRef] [PubMed]
110. Ghosh, S.; Das, A. Urban expansion induced vulnerability assessment of East Kolkata wetland using Fuzzy MCDM method. *Remote Sens. Applicat. Soc. Environ.* **2019**, *13*, 191–203. [CrossRef]
111. Li, S.; Chen, X.; Singh, V.P.; He, Y.; Bai, X. An improved index for water quality evaluation in an estuary region: A case study in the Eastern Pearl River Delta, China. *Water Policy* **2019**, *21*, 310–325. [CrossRef]
112. Roy, R.; Majumder, M. Assessment of water quality trends in Loktak Lake, Manipur, India. *Environ. Earth Sci.* **2019**, *78*, 383. [CrossRef]
113. Xu, X.; Sheng, D.; Li, G.; Chen, X.; Wang, X.; Xiao, C.; Hu, C. Comprehensive Assessment of the Water Ecological Security of the Xiangjiang River Basin Based on Physico-chemistry and Organisms Indices. *Appl. Ecol. Environ. Res* **2019**, *17*, 4547–4574. [CrossRef]
114. Akay, H.; Koçyiğit, M.B. Flash flood potential prioritization of sub-basins in an ungauged basin in Turkey using traditional multi-criteria decision-making methods. *Soft Comp.* **2020**, *24*, 14251–14263. [CrossRef]
115. Alamanos, A.; Papaioannou, G. A GIS Multi-Criteria Analysis Tool for a Low-Cost, Preliminary Evaluation of wetland Effectiveness for Nutrient Buffering at Watershed Scale: The Case Study of Grand River, Ontario, Canada. *Water* **2020**, *12*, 3134. [CrossRef]
116. Arabameri, A.; Tiefenbacher, J.P.; Blaschke, T.; Pradhan, B.; Tien Bui, D. Morphometric analysis for soil erosion susceptibility mapping using novel gis-based ensemble model. *Remote Sens.* **2020**, *12*, 874. [CrossRef]
117. Bhattacharya, R.K.; Chatterjee, N.D.; Das, K. Sub-basin prioritization for assessment of soil erosion susceptibility in Kangsabati, a plateau basin: A comparison between MCDM and SWAT models. *Sci. Total Environ.* **2020**, *734*, 139474. [CrossRef] [PubMed]
118. Ghaleno, M.R.D.; Meshram, S.G.; Alvandi, E. Pragmatic approach for prioritization of flood and sedimentation hazard potential of watersheds. *Soft Comput.* **2020**, *24*, 15701–15714. [CrossRef]
119. Ghosh, S.; Das, A. Wetland conversion risk assessment of East Kolkata Wetland: A Ramsar site using random forest and support vector machine model. *J. Clean. Prod.* **2020**, *275*, 123475. [CrossRef]
120. Popović, M.J.; Gušavac, B.Š.A.; Katić, A.S. Multiattribute Methods as a Means for Solving Ecological Problems in Water Resources—Lake Pollution. In *Advances in Operational Research in the Balkans*; Springer: Cham, Switzeland, 2020; pp. 77–94.
121. Sarkar, K.; Majumder, M. Application of AHP-based water quality index for quality monitoring of peri-urban watershed. *Environ. Dev. Sustain.* **2020**, *23*, 1780–1798. [CrossRef]
122. Souissi, D.; Zouhri, L.; Hammami, S.; Msaddek, M.H.; Zghibi, A.; Dlala, M. GIS-based MCDM–AHP modeling for flood susceptibility mapping of arid areas, southeastern Tunisia. *Geocarto Int.* **2020**, *35*, 991–1017. [CrossRef]
123. Sun, R.; Gong, Z.; Gao, G.; Shah, A.A. Comparative analysis of Multi-Criteria Decision-Making methods for flood disaster risk in the Yangtze River Delta. *Int. J. Dis. Risk Reduct.* **2020**, *51*, 101768. [CrossRef]
124. Yang, Z.; Wang, Y. The cloud model based stochastic multi-criteria decision making technology for river health assessment under multiple uncertainties. *J. Hydrol.* **2020**, *581*, 124437. [CrossRef]
125. Zhang, H.; Gu, C.L.; Gu, L.W.; Zhang, Y. The evaluation of tourism destination competitiveness by TOPSIS & information entropy–A case in the Yangtze river Delta of China. *Tour. Manag.* **2011**, *32*, 443–451.
126. Tang, C.; Zheng, Q.; Ng, P. A Study on the Coordinative Green Development of Tourist Experience and Commercialization of Tourism at Cultural Heritage Sites. *Sustainability* **2019**, *11*, 4732. [CrossRef]
127. Aiping, Z.; Linsheng, Z.; Yong, X.; Lijuan, D.; Bin, Z. Identifying and mapping wetland-based ecotourism areas in the First Meander of the Yellow River: Incorporating tourist preferences. *J. Resour. Ecol.* **2015**, *6*, 21–29. [CrossRef]
128. Biglarfadafan, M.; Danehkar, A.; Pourebrahim, S.; Shabani, A.A.; Moeinaddini, M. Application of strategic fuzzy assessment for environmental planning; case of bird watch zoning in wetlands. *Open J. Geol.* **2016**, *6*, 1380. [CrossRef]
129. Erfani, M.; Afrougheh, S.; Ardakani, T.; Sadeghi, A. Tourism positioning using decision support system (case study: Chahnime—Zabol, Iran). *Environ. Earth Sci.* **2015**, *74*, 3135–3144. [CrossRef]
130. Balist, J.; Heydarzadeh, H.; Salehi, E. Modeling, evaluation, and zoning of Marivan county ecotourism potential using fuzzy logic, FAHP, and TOPSIS. *Geogr. Pannon.* **2019**, *23*, 47–63. [CrossRef]
131. Maghsoudi, M.; Moradi, A.; Moradipour, F.; Nezammahalleh, M.A. Geotourism Development in World Heritage of the Lut Desert. *Geoheritage* **2019**, *11*, 501–516. [CrossRef]
132. Qureshi, M.E.; Harrison, S.R. A decision support process to compare Riparian revegetation options in Scheu Creek catchment in North Queensland. *J. Environ. Manag.* **2001**, *62*, 101–112. [CrossRef]
133. Eliasson, Å.; Rinaldi, F.M.; Linde, N. Multicriteria decision aid in supporting decisions related to groundwater protection. *Environ. Manag.* **2003**, *32*, 589–601. [CrossRef]
134. Choulak, M.; Marage, D.; Gisbert, M.; Paris, M.; Meinard, Y. A meta-decision-analysis approach to structure operational and legitimate environmental policies–With an application to wetland prioritization. *Sci. Total Environ.* **2019**, *655*, 384–394. [CrossRef] [PubMed]
135. Chen, V.Y.C.; Lin, J.C.L.; Tzeng, G.H. Assessment and improvement of wetlands environmental protection plans for achieving sustainable development. *Environ. Res.* **2019**, *169*, 280–296. [CrossRef] [PubMed]
136. Saha, T.K.; Pal, S. Exploring physical wetland vulnerability of Atreyee river basin in India and Bangladesh using logistic regression and fuzzy logic approaches. *Ecol. Indicat.* **2019**, *98*, 251–265. [CrossRef]

137. Talukdar, S.; Pal, S.; Chakraborty, A.; Mahato, S. Damming effects on trophic and habitat state of riparian wetlands and their spatial relationship. *Ecol. Indicat.* **2020**, *118*, 106757. [CrossRef]
138. Buruso, F.H. Habitat suitability analysis for hippopotamus (*H. amphibious*) using GIS and remote sensing in Lake Tana and its environs, Ethiopia. *Environ. Syst. Res.* **2018**, *6*, 6. [CrossRef]
139. Wu, H.J.; Dan, X.Q.; Liu, S.H.; Huang, Y.; Shu, Y.; Cao, H.; Wu, Z.B. Protection value evaluation of national wetlands parks in Hunan province, China. *J. Appl. Ecol.* **2017**, *28*, 239–249.
140. Jafari Shalamzari, M.; Zhang, W.; Gholami, A.; Zhang, Z. Runoff Harvesting Site Suitability Analysis for Wildlife in Sub-Desert Regions. *Water* **2019**, *11*, 1944. [CrossRef]
141. Dong, Z.; Wang, Z.; Liu, D.; Li, L.; Ren, C.; Tang, X.; Liu, C. Assessment of habitat suitability for waterbirds in the West Songnen Plain, China, using remote sensing and GIS. *Ecol. Eng.* **2012**, *55*, 94–100. [CrossRef]
142. Kozlov, A.; Kozlova, M.; Skorik, N. A simple harmonic model for FAPAR temporal dynamics in the wetlands of the Volga-Akhtuba floodplain. *Remote Sens.* **2016**, *8*, 762. [CrossRef]
143. Qiu, Z.; Dosskey, M.G.; Kang, Y. Choosing between alternative placement strategies for conservation buffers using Borda count. *Landsc. Urban Plan.* **2016**, *153*, 66–73. [CrossRef]
144. Xue, S.; Sun, T.; Zhang, H.; Shao, D. Suitable habitat mapping in the Yangtze River Estuary influenced by land reclamations. *Ecol. Eng.* **2016**, *97*, 64–73. [CrossRef]
145. Qi, L.; Huang, J.; Huang, Q.; Gao, J.; Wang, S.; Guo, Y. Assessing Aquatic Ecological Health for Lake Poyang, China: Part I Index Development. *Water* **2018**, *10*, 943. [CrossRef]
146. Gregory, R.; Wellman, K. Bringing stakeholder values into environmental policy choices: A community-based estuary case study. *Ecol. Econ.* **2001**, *39*, 37–52. [CrossRef]
147. Azarnivand, A.; Hashemi-Madani, F.S.; Banihabib, M.E. Extended fuzzy analytic hierarchy process approach in water and Environ. Manag. (case study: Lake Urmia Basin, Iran). *Environ. Earth Sci.* **2015**, *73*, 13–26. [CrossRef]
148. Derak, M.; Cortina, J.; Taiqui, L. Integration of stakeholder choices and multi-criteria analysis to support land use planning in semiarid areas. *Land Use Policy* **2017**, *64*, 414–428. [CrossRef]
149. Weng, S.Q.; Huang, G.H.; Li, Y.P. An integrated scenario-based multi-criteria decision support system for Water Resource Management and planning–A case study in the Haihe River Basin. *Exp. Syst. Applicat.* **2010**, *37*, 8242–8254. [CrossRef]
150. Dowlatabadi, N.; Banihabib, M.E.; Roozbahani, A.; Randhir, T.O. Enhanced GMCR model for resolving conflicts in a transboundary wetland. *Sci. Total Environ.* **2020**, *744*, 140816. [CrossRef] [PubMed]
151. Väntänen, A.; Marttunen, M. Public involvement in multi-objective water level regulation development projects—evaluating the applicability of public involvement methods. *Environ. Impact Assess. Rev.* **2005**, *25*, 281–304. [CrossRef]
152. Wang, L.; Li, X.; Cui, W. Fuzzy neural networks enhanced evaluation of wetland surface water quality. *Int. J. Comp. Applicat. Technol.* **2012**, *44*, 235–240. [CrossRef]
153. Wolf, A.T.; Kramer, A.; Carius, A.; Dabelko, G.D. *Managing Water Conflict and Cooperation, State of the World 2005: Redefining Global Security*; The Worldwatch Institute: Washington, DC, USA, 2005; pp. 80–95.
154. de Castro-Pardo, M.; Pérez-Rodríguez, F.; Martín-Martín, J.M.; Azevedo, J.C. Planning for Democracy in Protected Rural Areas: Application of a Voting Method in a Spanish-Portuguese Reserve. *Land* **2019**, *8*, 145. [CrossRef]
155. Nordström, E.M.; Eriksson, L.O.; Öhman, K. Integrating multiple criteria decision analysis in participatory forest planning: Experience from a case study in northern Sweden. *For. Policy Econ.* **2010**, *12*, 562–574. [CrossRef]
156. Alamanos, A.; Mylopoulos, N.; Loukas, A.; Gaitanaros, D. An integrated multicriteria analysis tool for evaluating water resource management strategies. *Water* **2018**, *10*, 1795. [CrossRef]
157. Papaioannou, G.; Vasiliades, L.; Loukas, A. Multi-criteria analysis framework for potential flood prone areas mapping. *Water Resour. Manag.* **2015**, *29*, 399–418. [CrossRef]
158. De Marchi, B.; Funtowicz, S.O.; Lo Cascio, S.; Munda, G. Combining participative and institutional approaches with multicriteria evaluation. An empirical study for water issues in Troina, Sicily. *Ecol. Econ.* **2000**, *34*, 267–282. [CrossRef]
159. Srinivasa Raju, K.; Duckstein, L.; Arondel, C. Multi-criteria analyses for sustainable water resources planning: A case study of Spain. *Water Resour. Manag.* **2000**, *14*, 435–456. [CrossRef]
160. Hämäläinen, R.; Kettunen, E.; Marttunen, M.; Ehtamo, H. Evaluating a framework for multi-stakeholder decision support in water resource management. *Group Decis. Negot.* **2001**, *10*, 331–353. [CrossRef]
161. Pavlikakis, G.E.; Tsihrintzis, V.A. Integrating humans in ecosystem management using multi-criteria decision making. *J. Am. Water Resour. Assoc.* **2003**, *39*, 277–288. [CrossRef]
162. Mustajoki, J.; Hämäläinen, R.P.; Marttunen, M. Participatory multicriteria decision analysis with Web-HIPRE: A case of lake regulation policy. *Environ. Model. Softw.* **2004**, *19*, 537–547. [CrossRef]
163. Raju, K.S.; Duckstein, L. Integrated application of cluster and multicriterion analysis for ranking water resources planning strategies: A case study in Spain. *J. Hydroinform.* **2004**, *6*, 295–307. [CrossRef]
164. Wattage, P.; Mardle, S. Stakeholder preferences towards conservation versus development for a wetland in Sri Lanka. *J. Environ. Manag.* **2005**, *77*, 122–132. [CrossRef]
165. Messner, F.; Zwiner, O.; Karkuschke, M. Participation in multi-criteria decision support for the resolution of a water allocation problem in the Spree River Basin. *Land Use Policy* **2006**, *23*, 63–75. [CrossRef]

166. Wang, L.; Meng, W.; Guo, H.; Zhang, Z.; Liu, Y.; Fan, Y. An interval fuzzy multiobjective watershed management model for the Lake Qionghai Watershed, China. *Water Resour. Manag.* **2006**, *20*, 701–721. [CrossRef]
167. Goosen, H.; Janssen, R.; Vermaat, J.E. Decision support for participatory wetland decision-making. *Ecol. Eng.* **2007**, *30*, 187–199. [CrossRef]
168. Marchamalo, M.; Romero, C. Participatory decision-making in land use planning: An application in Costa Rica. *Ecol. Econ.* **2007**, *63*, 740–748. [CrossRef]
169. Srdjevic, B. Linking analytic hierarchy process and social choice methods to support group decision making in water management. *Decis. Supp. Syst.* **2007**, *42*, 2261–2273. [CrossRef]
170. Hajkowicz, S.; Higgins, A. A comparison of multiple criteria analysis techniques for water resource management. *Eur. J. Operat. Res.* **2008**, *184*, 255–265. [CrossRef]
171. Van Cauwenbergh, N.; Pinte, D.; Tilmant, A.; Frances, I.; Pulido-Bosch, A.; Vanclooster, M. Multi-objective, multiple participant decision support for water management in the Andarax catchment, Almeria. *Environ. Geol.* **2008**, *54*, 479–489. [CrossRef]
172. Chung, E.S.; Lee, K.S. Prioritization of water management for sustainability using hydrologic simulation model and multicriteria decision making techniques. *J. Environ. Manag.* **2009**, *90*, 1502–1511. [CrossRef]
173. Ryu, J.H.; Palmer, R.N.; Jeong, S.; Lee, J.H.; Kim, Y.O. Sustainable Water Resour. Manag. in a Conflict Resolution Framework 1. *J. Am. Water Resour. Assoc.* **2009**, *45*, 485–499. [CrossRef]
174. Calizaya, A.; Meixner, O.; Bengtsson, L.; Berndtsson, R. Multi-criteria decision analysis (MCDA) for integrated Water Resour. Manag. (IWRM) in the Lake Poopo Basin, Bolivia. *Water Resour. Manag.* **2010**, *24*, 2267–2289. [CrossRef]
175. Chen, Y.C.; Lien, H.P.; Tzeng, G.H. Measures and evaluation for environment watershed plans using a novel hybrid MCDM model. *Exp. Syst. Applicat.* **2010**, *37*, 926–938. [CrossRef]
176. Silva, V.B.; Morais, D.C.; Almeida, A.T. A multicriteria group decision model to support watershed committees in Brazil. *Water Resour. Manag.* **2010**, *24*, 4075–4091. [CrossRef]
177. Yilmaz, B.; Harmancioglu, N. Multi-criteria decision making for water resource management: A case study of the Gediz River Basin, Turkey. *Water SA* **2010**, *36*. [CrossRef]
178. Chen, V.Y.; Lien, H.P.; Liu, C.H.; Liou, J.J.; Tzeng, G.H.; Yang, L.S. Fuzzy MCDM approach for selecting the best environment-watershed plan. *Appl. Soft Comput.* **2011**, *11*, 265–275. [CrossRef]
179. Lennox, J.; Proctor, W.; Russell, S. Structuring stakeholder participation in New Zealand's water resource governance. *Ecol. Econ.* **2011**, *70*, 1381–1394. [CrossRef]
180. Aznar, J.; Estruch-Guitart, V.; Vallés-Planells, M. Valuation of environmental assets by the multicriteria AMUVAM method and its application to the Pego-Oliva wetland. *Environ. Eng. Manag. J.* **2014**, *13*, 597–610.
181. Pinto, R.; da Conceição Cunha, M.; Roseta-Palma, C.; Marques, J.C. Mainstreaming sustainable decision-making for ecosystems: Integrating ecological and socio-economic targets within a decision support system. *Environ. Process.* **2014**, *1*, 7–19. [CrossRef]
182. Aher, S.; Shinde, S.; Guha, S.; Majumder, M. Identification of drought in Dhalai River watershed using MCDM and ANN models. *J. Earth Syst. Sci.* **2017**, *126*, 21. [CrossRef]
183. Sheikhipour, B.; Javadi, S.; Banihabib, M.E. A hybrid multiple criteria decision-making model for the sustainable management of aquifers. *Environ. Earth Sci.* **2018**, *77*, 712. [CrossRef]
184. DasGupta, R.; Hashimoto, S.; Okuro, T.; Basu, M. Scenario-based land change modelling in the Indian Sundarban delta: An exploratory analysis of plausible alternative regional futures. *Sustain. Sci.* **2019**, *14*, 221–240. [CrossRef]
185. Everard, M.; Kangabam, R.; Tiwari, M.K.; McInnes, R.; Kumar, R.; Talukdar, G.H.; Das, L. Ecosystem service assessment of selected WETs of Kolkata and the Indian Gangetic Delta: Multi-beneficial systems under differentiated management stress. *Wetlands Ecol. Manag.* **2019**, *27*, 405–426. [CrossRef]
186. Hosseini, S.M.; Parizi, E.; Ataie-Ashtiani, B.; Simmons, C.T. Assessment of sustainable groundwater Resour. Manag. using integrated environmental index: Case studies across Iran. *Sci. Total Environ.* **2019**, *676*, 792–810. [CrossRef] [PubMed]
187. Kacem, H.A.; Fal, S.; Karim, M.; Alaoui, H.M.; Rhinane, H.; Maanan, M. Application of fuzzy analytical hierarchy process for assessment of desertification sensitive areas in North West of Morocco. *Geocarto Int.* **2019**, *7*, 1–18. [CrossRef]
188. Karabulut, A.A.; Udias, A.; Vigiak, O. Assessing the policy scenarios for the Ecosystem Water Food Energy (EWFE) nexus in the Mediterranean region. *Ecosyst. Serv.* **2019**, *35*, 231–240. [CrossRef]
189. Yun, H.J.; Kang, D.J.; Kim, D.K.; Kang, Y. A GIS-Assisted Assessment and Attribute-Based Clustering of Forest Wetland Utility in South Korea. *Sustainability* **2019**, *11*, 4632. [CrossRef]

land

MDPI

Article

Impact of Sustainable Cultural Contact, Natural Atmospherics, and Risk Perception on Rural Destination Involvement and Traveler Behavior in Inner Mongolia

Heesup Han [1], Che Chen [1] Antonio Ariza-Montes [2], Felipe Hernández-Perlines [3], Luis Araya-Castillo [4] and Jongsik Yu [5,*]

[1] College of Hospitality and Tourism Management, Sejong University, 98 Gunja-Dong, Gwanjin-Gu, Seoul 143-747, Korea; heesup@sejong.ac.kr (H.H.); g2015sfj001@sju.ac.kr (C.C.)
[2] Social Matters Research Group, Universidad Loyola Andalucía, 14004 Córdoba, Spain; ariza@uloyola.es
[3] Department of Business Administration, University of Castilla-La Mancha, 45071 Toledo, Spain; felipe.HPerlines@uclm.es
[4] Facultad de Economía y Negocios, Universidad Andrés Bello, Santiago de Chile 7591538, Chile; luis.araya@unab.cl
[5] College of Business Division of Tourism and Hotel Management, Cheongju University, 298 Daesung-ro, Cheongwon-gu, Cheongju-si 28503, Korea
* Correspondence: jsyu@cju.ac.kr

Citation: Han, H.; Chen, C.; Ariza-Montes, A.; Hernández-Perlines, F.; Araya-Castillo, L.; Yu, J. Impact of Sustainable Cultural Contact, Natural Atmospherics, and Risk Perception on Rural Destination Involvement and Traveler Behavior in Inner Mongolia. *Land* **2021**, *10*, 568. https://doi.org/10.3390/land10060568

Academic Editors: Mónica de Castro-Pardo, Joao C. Azevedo and Pascual Fernández

Received: 27 April 2021
Accepted: 24 May 2021
Published: 28 May 2021

Abstract: Rural tourism is emerging in the tourism industry; however, little is known about traveler behaviors at rural destinations. This study explored the role of cultural contact, natural atmospherics, and risk perception in generating destination involvement and approach behaviors for rural tourism in Inner Mongolia. A quantitative data analysis was used to obtain the research objective. Our findings showed that cultural contact and natural atmospherics significantly increased traveler destination involvement and their approach behaviors. Cultural contact included a stronger impact on destination involvement than natural atmospherics. In contrast, natural atmospherics contained a stronger influence on approach behaviors than cultural contact. In addition, rural traveler risk perception moderated the magnitude of the effect of cultural contact on approach behaviors. Overall, the proposed theoretical framework encompassed a sufficient level of anticipation power for involvement and approach behaviors. Our findings can be helpful for inventing rural tourism development strategies in Inner Mongolia.

Keywords: cultural contact; natural atmospherics; risk perception; destination involvement; approach behaviors; Inner Mongolia

1. Introduction

For the past few decades, rural areas worldwide have undergone challenges associated with economic decline [1]. In many rural destinations, the problems associated with an ageing population, out-migration, and traditional employment loss have geared up the economic decline [2]. Given this situation, it is often believed that tourism is an effective way of increasing economic activities in such areas [2]. Indeed, many rural destinations around the world are active in developing tourism for attaining economic recovery and social revitalization [1]. More specifically, the quality of life of rural residents is improving through rural tourism, which stimulates rapid economic growth and creates more jobs [3]. Furthermore, rural tourism contributes to the local economy and social dynamic by offering various income-generating opportunities to residents [4]. Recently, rural tourism is an emerging phenomenon in the global tourism sector [5]. The local government, tourism officials, and tourism practitioners in Inner Mongolia are also eager to grow the rural tourism industry as a means of economic development and residents' life quality enhancement. Thus, rural tourism in Inner Mongolia is currently moving forward to the growth stage from the introductory stage of its life cycle.

Despite this growth, the competition in the rural tourism market across the world, particularly in China, is however getting fierce [5]. To improve the destination competitiveness, it is essential to increase tourism destination involvement and elicit traveler approach behaviors for rural tourism in Inner Mongolia. Many studies in diverse hospitality and tourism contexts have endeavored to uncover what factors drive traveler involvement and positive post-purchase intentions/behaviors for a place/company/brand [6,7]. In particular, there exists some evidence that cultural contact is considered a crucial construct in generating traveler place involvement and approach behaviors for a local destination [8,9]. In addition, researchers agree that natural atmospherics or green physical environment are critical in increasing place/product involvement and traveler retention [10–13]. However, despite the importance of cultural contact and natural atmospherics in traveler behavior, little research has assessed the combined influence of these two concepts in visitor response and behaviors. In addition, scant research has been conducted to unearth the formation of rural tourism destination involvement and approach behaviors in Inner Mongolia.

Moreover, some studies showed that the associations between involvement and approach behaviors and their antecedents are not as simple as they may seem, especially in the tourism sector [14]. These researchers indicated that the relationships could be under the impact of individuals' perceived level of risk related to traveling [14]. Indeed, considering the influence of risk perception suggests having a clear understanding of traveler responses, decision-making process, and post-purchase behaviors [14]. However, despite the importance of risk perception in destination studies, little is known about how risk perception moderates cultural contact and natural atmospherics on traveler behaviors in the rural tourism context. For filling these voids, this study was designed to assess the possible effect of cultural contact and natural atmospherics on traveler involvement and approach behaviors for rural tourism in Inner Mongolia. In addition, we attempted to explore the moderating role of rural traveler risk perception and examine the comparative importance of cultural contact and natural atmospherics in determining involvement and approach behaviors, respectively. The conceptualization of study variables and existing literature review are presented in the next section. Subsequently, research methodology and data analysis results are provided. Lastly, the discussions for researchers and practitioners are presented.

2. Literature Review

2.1. Rural Tourism Destination Involvement

The concept of involvement indicates a deep level of interest of patrons in a product/service [7]. Similarly, a high level of involvement indicates high absorption, strong belonging, and high attachment [7]. Much of the current literature on involvement pay particular attention to destination image and tourist behavior [15,16]. Therefore, the term, involvement, is interchangeably utilized with such terms as engagement, attachment, and absorption. Involvement in the present research refers to travelers' feeling of attachment and sense of belonging to rural tourism destinations in Inner Mongolia. Strong traveler involvement in a destination often maximizes their tourism experiences at the place [7]. In addition, when customers feel involved, they like the place/product/brand and often engage in purchase behaviors that are favorable for the place/product/brand [17].

2.2. Approach Behavior for Rural Tourism in Inner Mongolia

Boosting customer approach behaviors is essential for a destination/company/brand [6,18–20]. Repeat visitation/purchase, word-of-mouth, and recommendation are essential facets of customer approach responses/behaviors [20–22]. The term, approach responses/behaviors, is alternatively used with loyalty responses/behaviors since customer loyalty comprises repurchase and recommendation intentions/activities as its key constituents [21,23]. From a company's perspective, eliciting approach responses results in customer retention and recommendation behaviors favorable for the firm and its survival in the competitive marketplace [21,22]. Given this, approach behaviors in this study indicate travelers' behaviors (e.g., revisit and recommendation) that ultimately bring benefits to rural tourism destinations in Inner Mongolia.

2.3. Cultural Contact

Many travelers often make cultural contact and experience cultural activities during their visit to a local destination [24]. The concept of cultural contact indicates that visitors contact a different culture of a specific place [9]. Consistently, cultural contact in the present research refers to travelers' contact with a minority and ethnic culture of rural tourism destinations in Inner Mongolia. Unlike the archaeology literature that focuses mainly on the relation between natives and colonists when describing cultural contact [25], the tourism sector deals with the intensity of traveler cultural experiences at a local destination when conceptualizing cultural contact [9,26]. Irrefutably, an increasing number of individuals want to know a specific destination more and understand its local/ethnic culture in the contemporary tourism marketplace [24]. Therefore, cultural contact is becoming more and more crucial in the recent tourism industry [9], especially in the rural tourism sector, where cultural experience is the major aspect of its tourism product [24].

Some studies in the existing hospitality and tourism literature showed the essential role of cultural contact in explicating traveler behaviors [8,9]. For instance, in the cultural tourism context, Chen and Rahman [9] found that cultural contact is a critical driver of destination loyalty. Their research also demonstrated that cultural contact boosts visitors' memorable tourism experiences and increases intentions to revisit and recommend the place. This finding was consistent with Chandralal and Valenzuela's [8] assertion that cultural contact through experiencing diverse forms of local culture (e.g., authentic/ethnic local festivals, rituals, events, and programs) generates traveler positive response/behavior for a place and induces a memorable tourism experience. In addition, in the island destination tourism sector, Moon and Han [27], in their recent study, uncovered that cultural contact as a form of tourists' destination experiences results in enhanced destination involvement and increased loyalty. While travelling, the depth of cultural experience can differentiate the particular local destination from its rival places in the tourism marketplace [24,27]. Based on these studies, the significant relationships between cultural contact and destination involvement and between cultural contact and approach behaviors can be posited as follows:

Hypothesis 1 (H1). *Cultural contact positively influences rural tourism destination involvement.*

Hypothesis 2 (H2). *Cultural contact positively influences approach behaviors for rural tourism in Inner Mongolia.*

2.4. Natural Atmospherics

Nature is an effective means of providing solutions to various societal and ecological challenges [28]. In addition, individuals' psychological stress, emotional well-being, and life satisfaction are often under the influence of natural environments near their residential area and workplace [11,29]. Natural atmospherics are also considered influential to consumption behaviors and destination image [30–32]. Loureiro, Stylos, and Bellou [30] argued that the multiple factors (landscape, historical site, hotels, and infrastructure) make up the overarching sense in which tourists make decisions in a destination's atmospheric cues. Especially in the tourism sector, recent studies repeatedly indicated that the natural atmospherics induces travelers' attachment to the place and increases revisit intention [33]. Therefore, natural environments can be a crucial motivating factor for purchasing a tourism product and being absorbed into the product [10].

Natural scenery (e.g., mountains, rivers, lakes, parks, oceans), green surfaces, plants/flowers/trees are essential constituents of natural atmospherics [29]. According to Han et al. [33], green outdoor atmospherics of a hotel building and its attributes are the critical facets of hotel product performance estimation. Similarly, Jiang et al. [10] asserted the criticality of green attributes and atmospherics in generating traveler positive responses and behaviors for a product/place. Based on this evidence, the significant associations between atmospherics and rural tourism destination involvement and between natural atmospherics and approach behaviors are hypothesized as follows:

Hypothesis 3 (H3). *Natural atmospherics positively influence rural tourism destination involvement.*

Hypothesis 4 (H4). *Natural atmospherics positively influence approach behaviors for rural tourism in Inner Mongolia.*

2.5. Rural Traveler Risk Perception

Risk perception is frequently considered a core factor affecting traveler purchase decision-making processes/behaviors [34,35]. The scope of this concept includes potential/possible loss in diverse types, possible uncertainty regarding product/service performance, and potential safety/health risk [35,36]. Coherently, in this research, risk perception indicates that travelers' diverse types of possible uncertainty are associated with rural destination choice and tourism in Inner Mongolia. Furthermore, in customer behavior, it is indisputable that individuals perceive a certain degree of risk as vital as it influences their intention formation and future consumption behaviors [14,35,36].

Researchers in the extant tourism studies have made empirical endeavors to unearth the function of risk perception in generating customer approach decisions/behaviors [14,35]. Quintal et al. [35] examined the role of risk perception in the tourism sector. Their research result showed that traveler risk perception has a considerable influence on his/her attitude and approach decision formation. In their research in the airline sector, Han et al. [37] explored the role of perceived risk. Their empirical findings revealed that the relations among air traveler attitude toward an airline product, confidence in the product, and approach intentions for the product are under the influence of perceived risk. Finally, in the international tourism context, Chua et al. [38] investigated the role of risk perception in generating traveler short-term and long-term approach behaviors. They uncovered that the degree of the relationship power between approach behaviors and their antecedents are significantly affected by traveler risk perception. Based on these studies that emphasize the importance of risk perception in traveler behavior, the following hypotheses were developed:

Hypothesis 5a (H5a). *Rural traveler risk perception has a significant influence on the relation between cultural contact and rural tourism destination involvement.*

Hypothesis 5b (H5b). *Rural traveler risk perception has a significant influence on the relation between cultural contact and approach behaviors for rural tourism in Inner Mongolia.*

2.6. Proposed Research Model

A research model of this study, which was developed based on the above-mentioned theoretical background, is exhibited in Figure 1. The theoretical framework depicts the hypothesized associations among cultural contact, natural atmospherics, rural tourism destination involvement, and approach behaviors for rural tourism in Inner Mongolia. In addition, rural traveler risk perception was incorporated into the framework as a moderator. Finally, the model had five research hypotheses.

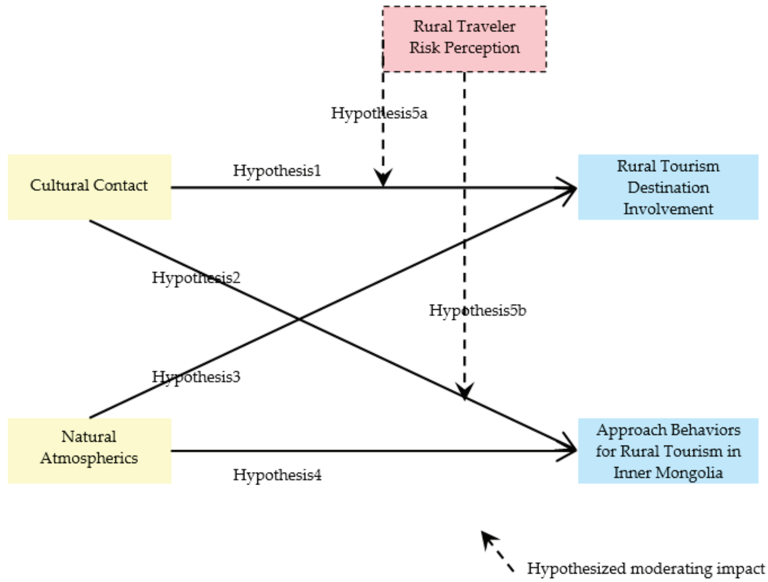


Figure 1. Proposed research mode.

3. Research Method

3.1. Measurement Tools

The measurement instruments were borrowed from existing studies [9,21,22,30,37–39]. Multi-items and a 7-point scale, which ranged from "strongly disagree" (1) to "strongly agree" (7), were used. Specifically, to measure cultural contact, a total of 5 items were used. For the assessment of natural atmospherics, we utilized 3 items. To evaluate rural traveler risk perception, 3 items were used. In addition, we utilized 3 items to measure rural tourism destination involvement. Lastly, to evaluate approach behaviors for rural tourism in Inner Mongolia, a total of 4 items were used. The items' internal consistency reliability was confirmed by Cronbach's α and composite reliability (CR). All of the values had excellent reliability, exceeding the suggested cut off level of 0.60 [40]. The average variance extract (AVE) values constant was higher than the minimum recommended cut off level of 0.50 [41]. Above all, the measurement model results meant the data adapted the proposed theoretical model and tested the structural model (Table 1).

Table 1. Measurement model assessment.

Measurement	Average	S.D.
Cultural contact (CR = 0.902, AVE = 0.649, α = 0.900)		
The minority culture that I experienced is authentic.	5.600	1.208
The ethnic culture of Inner Mongolia left a great impression on me.	5.663	1.123
The place where I stayed has programs to learn about local history.	5.723	1.366
I'm interested in Mongolian culture.	5.773	1.249
Folk villages represent the life and culture of minority people authentically.	5.490	1.289
Natural atmospherics (CR = 0.884, AVE = 0.719, α = 0.882)		
The natural scenery of Inner Mongolia is appealing to me.	5.893	1.197
The natural scenery of Inner Mongolia is very attractive to me.	5.737	1.194
The natural scenery is the reason that I visited Inner Mongolia.	5.897	1.218

Table 1. *Cont.*

Measurement	Average	S.D.
Rural traveler risk perception (CR = 0.856, AVE = 0.665, α = 0.855)		
I can't find others to go with me to Inner Mongolia.	3.933	1.703
I don't really feel it's safe to visit Inner Mongolia.	3.907	1.872
I have a lack of understanding of Inner Mongolia.	4.167	1.823
Rural tourism destination involvement (CR = 0.919, AVE = 0.790, α = 0.907)		
Inner Mongolia means a lot to me.	5.660	1.413
I am very attached to the place where I stayed.	5.517	1.348
I feel a strong sense of belonging to the place where I stayed.	5.510	1.542
Approach behaviors for rural tourism in Inner Mongolia (CR = 0.903, AVE = 0.700, α = 0.911)		
I will revisit Inner Mongolia in the future.	5.610	1.105
I will expend effort on revisiting Inner Mongolia in the future.	5.873	1.144
I will recommend others to visit Inner Mongolia for traveling.	5.693	1.139
I will encourage others to visit Inner Mongolia for traveling.	5.850	1.160

3.2. Survey Questionnaire Development and Data Collection

The draft survey questionnaire version included these measures for research constructs, research explanation, and inquiries for demographic information. This initial questionnaire version was pre-tested with tourism researchers. Based on this pre-test result, a slight modification and improvement on the questionnaire were made. The final version of the questionnaire was made through academic experts' reviews and improvement. A field survey was conducted in tourist sites (The Mausoleum of Genghis Khan) in Inner Mongolia. We contacted the Mausoleum of Genghis Khan tourist guide to collect data. The survey was conducted from 6 July 2020, to 26 July 2020, when we went to collect data during "Tsagaansurek" (the Genghis Khan shrine for spring ritual in Mongolia). Unfortunately, due to COVID-19, "Tsagaansurek" was canceled in 2020. With fewer tourists than last year, we took about 3 weeks to collect the data. The questionnaires were distributed to domestic tourists who visited Inner Mongolia. In addition, the surveyors distributed the questionnaire to individuals who were traveling to Inner Mongolia. In particular, the surveyors approached visitors of Inner Mongolia and asked their willingness for survey participation. Upon the agreement of their participation, the surveyors thoroughly explained the research and its purposes. In addition, the respondents were requested to read every question and fill the questionnaire thoroughly. Finally, the completed questionnaire was returned onsite. Through this procedure, a total of 378 respondents were collected. After eliminating incomplete responses (e.g., only answer a portion of questions) and straight-line responses (e.g., selecting "Agree" for all questions), 300 usable responses were obtained. These responses were utilized for analysis for the achievement of our research objectives. According to the rate of sample size (n) to the number of model parameters (q), the sample size proved to be sufficient because it exceeded the recommended sample size of 90 (18 parameters $\times$ 5 observations for each parameter) [42,43].

3.3. Demographic Information of Samples

In Table 2, 184 participants were female travelers whereas 116 participants were male travelers. About 54.7% of the respondents reported that their age is less than 30 years old, followed by between 31 years old and 60 years old (45.0%), and more than 60 years old (0.3%). In terms of education level, most participants reported that they held a college degree (56.0%), followed by graduate degree holders (21.3%), high-school diploma holders or less (17.7%), and other professional degree holders (5.0%). Regarding the visit frequency to Inner Mongolia, about 40.7% indicated that it was their first time to travel to Inner Mongolia, followed by 2–3 times (26.0%), over 6 times (24.3%), and 4–5 times (9.0%). Of the participants, about 50.7% reported that they were traveling with a tour group, followed by traveling with family/relatives (38.0%), traveling alone (6.3%), traveling with others (5.0%). When the travel purpose was asked, most respondents indicated for pleasure (69.7%).

Table 2. Demographic information of samples (n = 300).

Categorize	Variable	Frequency	Percent
Gender	Male	184	61.3
	Female	116	38.7
Age	Less than 30 years old	164	54.7
	Between 31 and 60 years old	135	45.0
	More than 60 years old	1	0.3
Education level	High-school diploma	53	17.7
	Collage degree	168	56
	Graduate-degree	64	21.3
	Other professional degree	15	5.0
Visit frequency	First time	122	40.7
	2–3 times	78	26.0
	4–5 times	27	9.0
	Over 6 times	73	24.3
Travel type	Tour group	152	50.7
	Family/relatives	114	38.0
	Alone	19	6.3
	Others	15	5.0
Purpose	Pleasure	209	69.7
	Business and professional	20	6.0
	Visit local friends/relatives Conventions	57	17.2
	Not specified	46	13.8

4. Data Analysis and Results

4.1. Measurement Model Evaluation

The measurement model was created by using the confirmatory factor analysis. The generated model had the acceptable level of goodness-of-fit statistics (χ^2 = 230.330, df = 124, p < 0.001, χ^2/df = 1.857, RMSEA = 0.054, CFI = 0.974, IFI = 0.975, TLI = 0.968). All values of composite reliability were above Hair et al. [41] suggested cutoff of 0.70 (cultural contact = 0.902, natural atmospherics = 0.884, rural traveler risk perception = 0.856, rural tourism destination involvement = 0.919, approach behaviors = 0.903). This demonstrated the internal consistency of the construct measures. AVE values were generated. The generated values all exceeded the Hair et al. [41] minimum threshold of 0.50 (cultural contact = 0.649, natural atmospherics = 0.719, rural traveler risk perception = 0.665, rural tourism destination involvement = 0.790, approach behaviors = 0.700). In addition, the values surpassed the correlation (squared) between variables. This result demonstrated the convergent and discriminant validity of the measures. Table 3 showed the details about the measurement quality testing.

Table 3. Result of the data quality testing (n = 300).

Research Constructs	1	2	3	4	5	Mean (SD)	CR (AVE)
1. Cultural Contact	1.000					5.650 (1.056)	0.902 (0.649)
2. Natural Atmospherics	0.790 [a] (0.624) [b]	1.000				5.842 (1.082)	0.884 (0.719)
3. Rural Traveler Risk Perception	−0.023 (0.001)	−0.059 (0.003)	1.000			4.002 (1.585)	0.856 (0.665)
4. Rural Tourism Destination Involvement	0.706 (0.498)	0.605 (0.366)	−0.079 (0.006)	1.000		5.562 (1.319)	0.919 (0.790)
5. Approach Behaviors for Rural Tourism	0.814 (0.662)	0.836 (0.704)	−0.050 (0.003)	0.656 (0.430)	1.000	5.853 (1.072)	0.903 (0.700)

Note. Goodness-of-fit statistics for the measurement model: χ^2 = 230.330, df = 124, p < 0.001, χ^2/df = 1.857, RMSEA = 0.054, CFI = 0.974, IFI = 0.975, TLI = 0.968. [a] Correlations between constructs. [b] Squared correlations.

4.2. Structural Model Evaluation

The structural model was created. The structural model included a proper level of goodness-of-fit statistics (χ^2 = 175.618, *df* = 84, $p < 0.001$, χ^2/df = 2.091, RMSEA = 0.060, CFI = 0.975, IFI = 0.976, TLI = 0.969). The structural analysis results are reported in Table 4 and Figure 2. The hypothesized model in general sufficiently explained the variance in destination involvement and approach behaviors. In particular, approximately 58.6% of the total variance in rural tourism destination involvement was accounted for by its determinants. In addition, about 89.7% of the variance in approach behaviors for rural tourism was accounted for by its predictors within the proposed theoretical framework.

Table 4. Result of the structural analysis (n = 300).

Hypotheses	Paths	Coefficients	T-Values
H1	Cultural contact → Rural tourism destination involvement	0.773	5.379 **
H2	Cultural contact → Approach behaviors for rural tourism in Inner Mongolia	0.405	4.081 **
H3	Natural atmospherics → Rural tourism destination involvement	−0.008	−0.061
H4	Natural atmospherics → Approach behaviors for rural tourism in Inner Mongolia	0.568	5.696 **

Variance explained: R^2 (rural tourism destination involvement) = 0.586. R^2 (approach behaviors for rural tourism in Inner Mongolia) = 0.897. ** $p < 0.01$. Goodness-of-fit statistics for the structural model: χ^2 = 175.618, *df* = 84, $p < 0.001$, χ^2/df = 2.091, RMSEA = 0.060, CFI = 0.975, IFI = 0.976, TLI = 0.969.

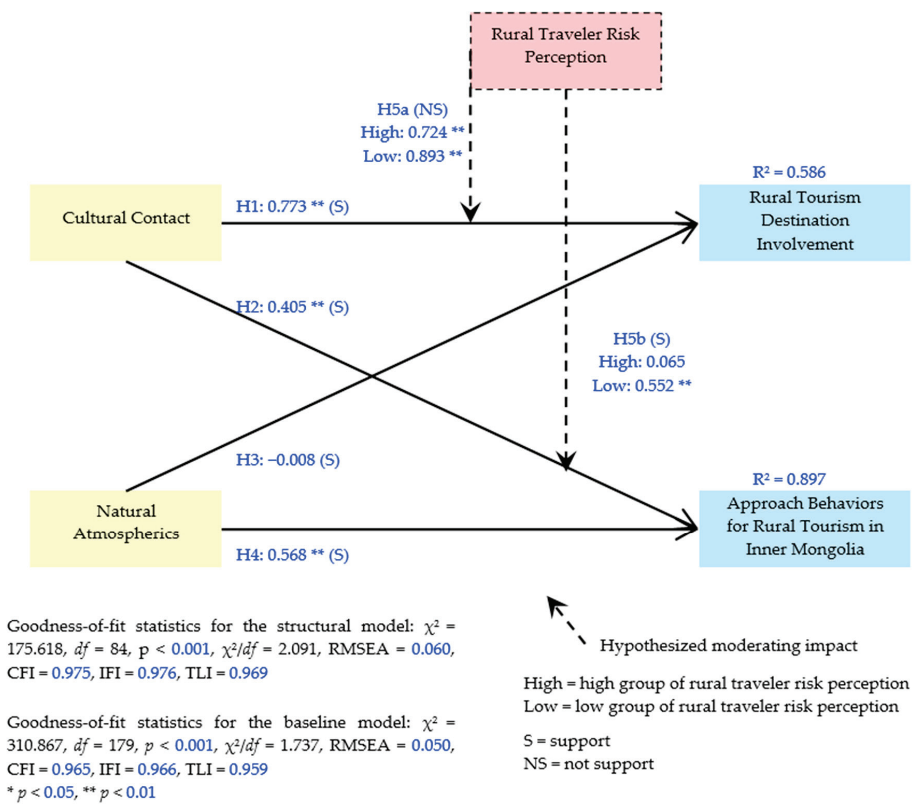


Figure 2. Structural analysis and invariance assessment results.

The hypothesized effect of cultural contact on destination involvement was tested. As anticipated, the impact of cultural contact on destination involvement was significant ($\beta = 0.773$, $p < 0.01$). This finding supported our hypothesis. The proposed relation between cultural contact and approach behaviors was evaluated. Our results showed the significant linkage from cultural contact to approach behaviors ($\beta = 0.405$, $p < 0.01$). The finding supported Hypothesis 2. Next, the hypothesized effect of natural atmospherics was examined. Results showed that the relationship between natural atmospherics and destination involvement was not significant ($\beta = -0.008$, $p > 0.05$). Therefore, Hypothesis 3 was not supported. The effect of natural atmospherics on approach behaviors was assessed. Our finding revealed that the association between natural atmospherics and approach behaviors was significant ($\beta = 0.568$, $p < 0.01$). This finding supported Hypothesis 4.

4.3. Metric Invariance Assessment

An empirical test for metric invariance was conducted in order to examine the moderating role of rural tourism risk perception. The responses were divided into high and low risk perception groups on the basis of a K-means cluster analysis result. The high-risk perception group had 137 responses whereas the low-risk perception group had 163 responses. Afterward, we generated a baseline model containing both risk perception groups. Within this baseline model, all loadings were equally restricted. Our finding showed that the baseline model had an adequate fit to the data ($\chi^2 = 310.867$, $df = 179$, $p < 0.001$, $\chi^2/df = 1.737$, RMSEA = 0.050, CFI = 0.965, IFI = 0.966, TLI = 0.959). Figure 2 and Table 5 included the detailed outcomes of the invariance test.

Table 5. Result of the invariance model assessment.

Linkages	High Group of Rural Tourism Risk Perception (N = 137)		Low Group of Rural Tourism Risk Perception (N = 163)		Baseline Model (Freely Estimated)	Nested Model (Constrained to Be Equal)
	β	T-Values	β	T-Values		
Cultural contact → Rural tourism destination involvement	0.724	2.663 **	0.893	5.735 **	χ^2 (179) = 310.867	χ^2 (180) = 312.273 [a]
Cultural contact →Approach behaviors for rural tourism	0.065	0.340	0.552	4.468 **	χ^2 (179) = 310.867	χ^2 (180) = 318.460 [b]
Chi-square difference test: ** $p < 0.01$	[a] $\Delta\chi^2$ (1) = 1.406, $p > 0.05$ H5a: Not supported [b] $\Delta\chi^2$ (1) = 7.593, $p < 0.01$ H5b: Supported					

The generated model was then compared to a nested model where a specific path linking two variables is equally constrained across the groups. The result showed that the linkage from cultural contact to rural tourism destination involvement did not statistically differ between two groups ($\Delta\chi^2$ (1) = 1.406, $p > 0.05$). Hence, the proposed influence of risk perception on the linkage from cultural contact to rural tourism destination involvement (Hypothesis 5a) was not supported. Yet, the link from cultural contact to approach behaviors for rural tourism in Inner Mongolia was significantly different between high and low risk perception groups ($\Delta\chi^2$ (1) = 7.593, $p < 0.01$). This result supported the proposed moderating influence of rural traveler risk perception on the relation between cultural contact and approach behaviors (Hypothesis 5b).

5. Discussion and Implication

With a lack of understanding of rural tourism in Inner Mongolia, this research attempted to comprehend visitors' involvement and post-purchase behaviors. A survey method and a quantitative approach were used. A confirmatory factor analysis, structural analysis, and metric invariance assessment were employed as key data analysis techniques. The present study uncovered the alleged role of cultural contact and natural atmospherics in generating destination involvement and approach behaviors for a rural tourism destination in Inner Mongolia. The hypothesized conceptual framework encompassing the strong associations among research constructs sufficiently accounted for the variance in involvement and approach behaviors. In addition, the integration of rural traveler risk perception and its influence on our study model was discovered to be critical for better understanding of such post-purchase behaviors that are positive for the destinations. Our empirical findings are helpful when destination marketers and tourism officials invent valuable tactics for traveler retention and attraction. Moreover, the present study made an enormous contribution to enriching the extant literature about rural traveler behaviors in Inner Mongolia.

When travelers make cultural contact through experiencing cultural activities at a certain destination, their attitude and behaviors toward the destination often become positive [9,44]. Our findings showed that cultural contact among rural travelers increases their destination involvement and approach behaviors in line with this indication. Especially, travelers' cultural contact has a more significant influence on destination involvement than natural atmospherics. Indeed, Fisher's Z-test demonstrated the comparative importance of cultural contact on involvement ($p < 0.01$). Given this, to boost rural tourism destination involvement, it is unavoidable to deal with cultural contact. The existing studies showed that cultural contact plays a vital role in tourist behaviors [8,9,24]. Agritourism as a part of rural tourism can improve local, sustainable tourism. Significantly, the destination's unique identity and culture can highlight its authenticity and become more attractive [45,46]. Ger (aka "Yurts"), as traditional accommodation spaces for Mongolian people, was also one of the most distinctive features of Mongolian nomadic life. A previous study points out that cultural contact can improve tourist destination involvement and loyalty [25,26,47]. According to current research results, the destination hotel industry combines traditional Mongolian accommodation to make unique hotels. Destination practitioners, therefore, should make a diverse investment in developing various cultural contact programs. Offering the visitors an opportunity to contact the destination's traditional/authentic culture (e.g., Ordos wedding ceremony, traditional Mongolian events, Mausoleum of Genghis Khan) would eventually result in visitors' sense of belonging to rural tourism destinations in Inner Mongolia.

Natural atmospherics was uncovered as a prominent variable in influencing rural traveler behaviors. Coherent with extant studies [30–33], our finding stressed the importance of these natural surroundings as a key driver of approach behaviors for rural tourism. However, this study's relationship between natural atmospherics and destination involvement does not support the previous research [10,47]. Previous studies have shown that natural atmospherics and green buildings make a person's emotional well-being, such as heathlands and natural vegetation [11,29]. This study produced results that corroborate the findings of the previous research. Based on this evidence, destination practitioners should make maximum use of rural destinations' natural atmospherics in inducing visitor positive responses and behaviors. For instance, enhancing the visibility of natural outdoor surroundings in diverse tourist places (e.g., hotel guestrooms, hotel lobby area, cafés, restaurants, museums) by increasing glass windows and glass walls can be efficient. In addition, practitioners should invest diverse resources in greening the grey surfaces of the buildings. The previous studies have demonstrated the association between natural atmospherics and destination tourism competitiveness [48]. Hence, increasing green surfaces (green walls, vertical garden, green rooftop) can help create visitors' perception/belief that they are in the middle of nature, which eventually helps them feel mental well-being and have a stronger approach decision.

The present study revealed that the association between cultural contact and approach behaviors was under the significant impact of rural traveler risk perception. The cultural contact and approach behavior relation was stronger in the low-risk perception group ($\beta = 0.552$, $p < 0.01$) than in the high group ($\beta = 0.065$, $p > 0.05$). This finding indicated the significant moderating role of rural traveler perception, implying that tourists who have low-risk perception at a similar level of cultural contact, actively engage in approach behaviors for destinations in Inner Mongolia than those who perceive high tourism risk. The findings agree with prior studies, which showed risk perception is a key factor influencing the tourist approach behaviors and purchase intention [14,35–37]. From the theoretical point of view, the present study deepened the conceptual framework explaining the formation of traveler approach behaviors for rural tourism destinations by satisfactorily taking risk perception and its effect into account. Our result also broadened the extant knowledge regarding the moderating role of risk perception to the rural tourism sector. Practically, for the efficient increase of traveler approach responses, destination marketers must minimize any possible factor that induces risk perception among visitors when traveling to rural destinations at Inner Mongolia.

The present study has several limitations. First, the major aspect of the present study centered on the cognitive process. Nevertheless, some recent studies asserted the emerging role of affect/emotion variables in tourists' post-purchase decision-making process and behaviors [49,50]. Therefore, it is also recommended for future research to consider the impact of affective/emotional process and cognitive factors for better explication of rural tourists' behaviors in Inner Mongolia. Second, this research utilized a field survey methodology. To reach a broader range of samples, employing an online survey method is recommended for future studies.

6. Conclusions

Rural tourism has quickly evolved into an important strategy in China [1,3]. Inner Mongolia was the first region in China to achieve the status of an autonomous ethnic region and the third largest province in China. The city is rich in tourism resources because of its unique natural atmospherics (e.g., grasslands, deserts, forests) and ethnic cultural contact (e.g., nomadic lifestyle, Naadam festival, the Genghis Khan Mausoleum).

This research entailed a survey questionnaire of 300 tourists who visited Inner Mongolia. Due to the lack of the previous study of rural tourism in Inner Mongolia, the present study has argued that cultural contact, natural atmospherics, destination involvement, and approach behavior for rural tourism in Inner Mongolia. Cultural contact can enhance cross-cultural interactions in a culturally distinct environment [24]. The previous study shows that Western tourists prefer to experience local life, which elicits higher satisfaction [24]. Inner Mongolia as a minority area, it is necessary to examine marketing strategies aimed at international tourists. This research has also shown that natural atmospherics has significantly affected approach behavior for rural tourism in Inner Mongolia. Natural landscape destinations play an important role in attracting tourists [30,31]. Inner Mongolia is fascinating for its unique natural landscapes. Especially, grasslands are the pillar of its tourism resources (e.g., Hulunbuir grassland, Xilamuren grassland, Xilingol grassland, et al.). Hence, local governments need to promote sustainable economic growth while preserving the area's pristine environment.

The risk perception has been designed as a moderate value method to evaluate cultural contact, tourism destination involvement, and approach behaviors for rural tourism in Inner Mongolia. The current study findings demonstrated the moderating role of risk perception in cultural contact, destination involvement, and approach behaviors for rural tourism in Inner Mongolia, thus having a critical practical and theoretical meaning. Risk perception influences tourist attitudes to visit the destination [35]—for example, global pandemics such as COVID-19, safety issues, climate and natural disaster risk. To reduce and minimize the risk, the tourism organization needs to provide various information on the destination. Overall, this research can be helpful for tourism enterprises and local governments developing tourism strategies and promote Inner Mongolia tourism.

Author Contributions: Conceptualization, H.H. and J.Y.; methodology, H.H.; software, A.A.-M.; validation, F.H.-P.; formal analysis, C.C. and J.Y.; investigation, C.C.; resources, A.A.-M. and L.A.-C.; data curation, C.C.; writing—original draft preparation, H.H.; writing—review and editing, C.C.; visualization, C.C. and L.A.-C.; supervision, F.H.-P. and J.Y.; project administration, H.H. and J.Y.; funding acquisition, A.A.-M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Because of the observational nature of the study, and in the absence of any involvement of therapeutic medication, no formal approval of the Institutional Review Board of the local Ethics Committee was required. Nonetheless, all subjects were informed about the study and participation was fully on a voluntary basis. The study was conducted in accordance with the Helsinki Declaration.

Informed Consent Statement: Not applicable.

Data Availability Statement: The dataset used in this research is available upon request from the corresponding author. The data are not publicly available due to restrictions i.e., privacy or ethical.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Liu, C.; Dou, X.; Li, J.; Cai, L.A. Analyzing government role in rural tourism development: An empirical investigation from China. *J. Rural. Stud.* **2020**, *79*, 177–188. [CrossRef]
2. Carson, D.A.; Carson, D.B. International lifestyle immigrants and their contributions to rural tourism innovation: Experiences from Sweden's far north. *J. Rural. Stud.* **2018**, *64*, 230–240. [CrossRef]
3. Yang, J.; Yang, R.; Chen, M.H.; Su, C.H.; Zhi, Y.; Xi, J. Effects of rural revitalization on rural tourism. *J. Hosp. Tour. Manag.* **2021**, *47*, 35–45. [CrossRef]
4. Cunha, C.; Kastenholz, E.; Carneiro, M.J. Entrepreneurs in rural tourism: Do lifestyle motivations contribute to management practices that enhance sustainable entrepreneurial ecosystems? *J. Hosp. Tour. Manag.* **2020**, *44*, 215–226. [CrossRef]
5. Zhang, H.; Fang, J.; Yang, L. The current situation and trend of leisure agriculture and rural tourism in China. Chin. *J. Agric. Res. Reg. Plan.* **2017**, *38*, 205–208.
6. Byun, J.; Jang, S. Can signaling impact customer satisfaction and behavioral intentions in times of service failure?: Evidence from open versus closed kitchen restaurants. *J. Hosp. Mark. Manag.* **2019**, *28*, 785–806. [CrossRef]
7. Kuhzady, S.; Cadici, C.; Olya, H.G.T.; Mohajer, B.; Han, H. Couchsurfing involvement in non-profit peer-to-peer accommodations and its impact on destination image, familiarity, and intentions. *J. Hosp. Tour. Manag.* **2020**, *44*, 131–142. [CrossRef]
8. Chandralal, L.; Valenzuela, F.-R. Exploring memorable tourism experiences: Antecedents and behavioural outcomes. *J. Econ. Bus. Manag.* **2013**, *1*, 177–181. [CrossRef]
9. Chen, H.; Rahman, I. Cultural tourism: An analysis of engagement, cultural contact, memorable tourism experience and destination loyalty. *Tour. Manag. Perspect.* **2018**, *26*, 153–163. [CrossRef]
10. Jiang, J.; Zhang, J.; Zhang, H.; Yan, B. Natural soundscape and tourist loyalty to nature-based tourism destinations: The mediating effect of tourist satisfaction. *J. Travel Tour. Mark.* **2018**, *35*, 218–230. [CrossRef]
11. Liang, H.H.; Chen, C.P.; Hwang, R.L.; Shih, W.M.; Lo, S.C.; Liao, H.Y. Satisfaction of occupants toward indoor environment quality of certified green office buildings in Taiwan. *Build Environ.* **2014**, *72*, 232–242. [CrossRef]
12. Nimri, R.; Patiar, A.; Jin, X. The determinants of consumers' intention of purchasing green hotel accommodation: Extending the theory of planned behavior? *J. Hosp. Tour. Manag.* **2020**, *45*, 535–543. [CrossRef]
13. Pietilä, M.; Neuvonen, M.; Borodulin, K.; Korpela, K.; Sievänen, T.; Tyrväinen, L. Relationships between exposure to urban green spaces, physical activity and self-rated health. *J. Outdoor Recreat. Tour.* **2015**, *10*, 44–54. [CrossRef]
14. Tseng, S.-Y.; Wang, C.-N. Perceived risk influence on dual-route information adoption processes on travel websites. *J. Bus. Res.* **2016**, *69*, 2289–2296. [CrossRef]
15. Han, H.; Al-Ansi, A.; Olya, H.G.; Kim, W. Exploring halal-friendly destination attributes in South Korea: Perceptions and behaviors of Muslim travelers toward a non-Muslim destination. *Tour. Manag.* **2019**, *71*, 151–164.
16. Kiatkawsin, K.; Han, H. An alternative interpretation of attitude and extension of the value–attitude–behavior hierarchy: The destination attributes of Chiang Mai, Thailand. *Asia Pac. J. Tour. Res.* **2017**, *22*, 481–500. [CrossRef]
17. Taheri, B.; Jafari, A.; O'Gorman, K. Keeping your audience: Presenting a visitor engagement scale. *Tour. Manag.* **2014**, *42*, 321–329. [CrossRef]
18. Bitner, M.J. Servicescapes: The impact of physical surroundings on customers and employees. *J. Mark.* **1992**, *56*, 57–71. [CrossRef]
19. Yeh, T.-M.; Chen, S.-H.; Chen, T.-F. The relationships among experiential marketing, service innovation, and customer satisfaction—A case study of tourism factories in Taiwan. *Sustainability* **2019**, *11*, 1–12.
20. Zeithaml, V.A.; Berry, L.L.; Parasuraman, A. The behavioral consequences of service quality. *J. Mark.* **1996**, *60*, 31–46. [CrossRef]
21. Oliver, R.L. *Satisfaction: A Behavioral Perspective on the Consumer*, 2nd ed.; Taylor & Francis: New York, NY, USA, 2010.
22. Taylor, S.A.; Baker, T.L. An assessment of the relationship between service quality and customer satisfaction in the formation of consumer's purchase intention. *J. Retail.* **1994**, *70*, 163–178. [CrossRef]
23. Han, H.; Hyun, S. Role of motivations for luxury cruise traveling, satisfaction, and involvement in building traveler loyalty. *Int. J. Hosp. Manag.* **2018**, *70*, 75–84. [CrossRef]
24. Kang, S.; Lee, C.; Lee, D. Examining cultural worldview and experience by international touirists: A case of traditional house stay. Asia Pac. *J. Tour. Res.* **2016**, *21*, 477–499.

25. Lightfoot, K.G. Culture contact studies: Redefining the relationship between prehistoric and historical archaeology. *Am. Antiq.* **1995**, *60*, 199–217. [CrossRef]
26. Gnoth, J.; Zins, A.H. Developing a tourism cultural contact scale. *J. Bus. Res.* **2013**, *66*, 738–744. [CrossRef]
27. Moon, H.; Han, H. Tourist experience quality and loyalty to an island destination: The moderating impact of destination image. *J. Travel Tour. Mark.* **2019**, *36*, 43–59. [CrossRef]
28. Nesshöver, C.; Assmuth, T.; Irvine, K.N.; Rusch, G.M.; Waylen, K.A.; Delbaere, B.; Wittmer, H. The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Sci. Total Environ.* **2017**, *579*, 1215–1227. [CrossRef] [PubMed]
29. De Vries, S.; Nieuwenhuizen, W.; Farjon, H.; van Hinsberg, A.; Dirkx, J. In which natural environments are people happiest? Large-scale experience sampling in the Netherlands. *Landsc. Urban Plan.* **2021**, *205*, 103972. [CrossRef]
30. Loureiro, S.M.C.; Stylos, N.; Bellou, V. Destination atmospheric cues as key influencers of tourists' word-of-mouth communication: Tourist visitation at two Mediterranean capital cities. *Tour. Recreat. Res.* **2021**, *46*, 85–108. [CrossRef]
31. Sirgy, M.J.; Su, C. Destination image, self-congruity, and travel behavior: Toward an integrative model. *J. Travel Res.* **2000**, *38*, 340–352. [CrossRef]
32. Chung, K.H.; Shin, J.I. The relationship between destination cues of Asian countries and Korean tourist images. *Asia Pac. J. Mark. Logist.* **2004**, *16*, 82–100. [CrossRef]
33. Han, H.; Yu, J.; Hyun, S. Effects of nature-based solutions (NBS) on eco-friendly hotel guests' mental health perceptions, satisfaction, switching barriers, and revisit intentions. *J. Hosp. Mark. Manag.* **2020**, *29*, 592–611. [CrossRef]
34. Kurtz, D.L.; Clow, K.E. *Services Marketing*; John Wiley & Sons: New York, NY, USA, 1997.
35. Quintal, V.A.; Lee, J.A.; Soutar, G.N. Risk, uncertainty and the theory of planned behavior: A tourism example. *Tour. Manag.* **2010**, *31*, 797–805. [CrossRef]
36. Hong, I.B. Understanding the consumer's online merchant selection process: The roles of product involvement, perceived risk, and trust expectation. *Int. J. Inf. Manag.* **2015**, *35*, 322–336. [CrossRef]
37. Han, H.; Yu, J.; Kim, W. An electric airplane: Assessing the effect of travelers' perceived risk, attitude, and new product knowledge. *J. Air Transp. Manag.* **2019**, *78*, 33–42. [CrossRef]
38. Chua, B.; Al-Ansi, A.; Lee, M.J.; Han, H. Impact of health risk perception on avoidance of international travel in the wake of a pandemic. *Curr. Issues Tour.* **2020**, *24*, 985–1002. [CrossRef]
39. Ajzen, I. The theory of planned behavior. *Organ. Behav. Hum. Decis. Process.* **1991**, *50*, 179–211. [CrossRef]
40. Bagozzi, R.P.; Yi, Y.; Nassen, K.D. Representation of measurement error in marketing variables: Review of approaches and extension to three-facet designs. *J. Econ.* **1998**, *89*, 393–421. [CrossRef]
41. Hair, J.F.; Black, W.C.; Babin, B.J.; Anderson, R.E. *Multivariate Data Analysis*, 7th ed.; Prentice-Hall: Upper Saddle River, NJ, USA, 2010; pp. 600–638.
42. Comrey, A.L.; Lee, H.B. Interpretation and application of factor analytic results. In *A first Course in Factor Analysis*, 2nd ed.; Taylor & Francis Group: Abingdon, UK, 1992.
43. Myers, N.D.; Ahn, S.; Jin, Y. Sample size and power estimates for a confirmatory factor analytic model in exercise and sport: A Monte Carlo approach. *Res. Q. Exerc Sport* **2011**, *82*, 412–423. [CrossRef]
44. Eusebio, C.; Carneiro, M.J.; Kastenholz, E.; Figueiredo, E.; Soares da Silva, D. Who is consuming the countryside? An activity-based segmentation analysis of the domestic rural tourism market in Portugal. *J. Hosp. Tour. Manag.* **2017**, *31*, 197–210. [CrossRef]
45. Palmi, P.; Lezzi, G.E. How Authenticity and Tradition Shift into Sustainability and Innovation: Evidence from Italian Agritourism. *Int. J. Environ. Res. Public Health* **2020**, *17*, 5389. [CrossRef] [PubMed]
46. Bhatta, K.; Ohe, Y. A Review of Quantitative Studies in Agritourism: The Implications for Developing Countries. *Tour. Hosp.* **2020**, *1*, 23–40. [CrossRef]
47. Lee, T.H.; Shen, Y.L. The influence of leisure involvement and place attachment on destination loyalty: Evidence from recreationists walking their dogs in urban parks. *J. Environ. Psychol.* **2013**, *33*, 76–85. [CrossRef]
48. Roman, M.; Roman, M.; Prus, P.; Szczepanek, M. Tourism Competitiveness of Rural Areas: Evidence from a Region in Poland. *Agriculture* **2020**, *10*, 569. [CrossRef]
49. Sul, H.; Chi, X.; Han, H. Measurement development for tourism destination business environment and competitive advantages. *Sustainability* **2020**, *12*, 8587. [CrossRef]
50. Yu, J.; Ariza-Montes, A.; Giorgi, G.; Lee, A.; Han, H. Sustainable relationship development between hotel company and its employees: Linking job embeddedness, job satisfaction, self-efficacy, job performance, work engagement, and turnover. *Sustainability* **2020**, *12*, 7168. [CrossRef]

land

Article

Comprehensive Evaluation and Quantitative Research on the Living Protection of Traditional Villages from the Perspective of "Production–Living–Ecology"

Lingyu Kong, Xiaodong Xu *, Wei Wang, Jinxiu Wu and Meiying Zhang

School of Architecture, Southeast University, Nanjing 210096, China; 230208006@seu.edu.cn (L.K.); weiwang@seu.edu.cn (W.W.); wu_jinxiu@seu.edu.cn (J.W.); meiyingzh@seu.edu.cn (M.Z.)
* Correspondence: xuxiaodong@seu.edu.cn

Abstract: Aiming at the current isolated, static protection method of traditional villages, a comprehensive evaluation system for the living protection of traditional villages has been constructed based on the land use function integration concept in "Production–Living–Ecology" (PLE). By combining the "horizontal" PLE coupling coordination analysis with the "vertical" correlation analysis of the elements at each layer, the comprehensive evaluation and quantitative analysis of six traditional villages of different types and grades in the Taihu Lake area are carried out to quantitatively reflect the interactive relationship and integration mechanism of PLE in traditional villages. The results show that: (1) The PLE development of traditional villages is a dynamic process. Even if the villages are close in the PLE score, they may be in different stages of PLE development and coupling coordination type. (2) The "living" function has the highest correlation with the coupling coordination degree of PLE, and it acts as the engine and bridge of benign interaction between the PLE. (3) Even if the national traditional villages have a favorable ecology background, they may not get high scores, or even fail in the PLE score. (4) Among the sub-indicators, the natural environmental characteristics, the ecological vitality of political organizations, and the level of human settlement facilities show a significant linear correlation with the PLE score. Additionally, the ecological vitality of political organizations is the strongest. It can be therefore concluded that a positive policy organization is an important guarantee for realizing the PLE integration of traditional villages.

Keywords: production–living–ecology integration; traditional villages; living protection; coupling coordination degree; Taihu Lake area

check for updates

Citation: Kong, L.; Xu, X.; Wang, W.; Wu, J.; Zhang, M. Comprehensive Evaluation and Quantitative Research on the Living Protection of Traditional Villages from the Perspective of "Production–Living–Ecology". *Land* **2021**, *10*, 570. https://doi.org/10.3390/land10060570

Academic Editors: Mónica de Castro-Pardo, Joao C. Azevedo and Pascual Fernández

Received: 27 April 2021
Accepted: 21 May 2021
Published: 28 May 2021

1. Introduction

Both the countryside and the city are the formal manifestations of human activities of production, living, and ecology, and the two have an isomorphic relationship; traditional Chinese cities dominate rural areas politically, but rely on them economically for survival [1,2]. Villages vastly outnumber cities. Countless villages are scattered on the vast land of China, where hundreds of millions of people live, giving birth to a world-famous agricultural civilization [3]. Traditional villages are one type of village. In the past, it used to be called "ancient village", which means that the village formed earlier. It has rich cultural and natural resources, and has certain historical, cultural, scientific, artistic, economic, and social values. Compared with general villages, they reflect the wisdom of the overall spatial pattern and engineering construction, and the harmonious state of integration and symbiosis between humankind and the original ecological environment during the farming period. They are of high artistic and scientific value, and are the living fossils of China's thousand-year agricultural civilization. With rapid urbanization, a large amount of intangible rural cultural heritage has failed to be handed down from past generations, so the intangible culture in traditional villages is endangered and lacks vitality [4]. Doubts and reflections have been aroused on the conventional way of preserving traditional villages by making them into "museums", which is only a preservation of the lifeless remains. At present, the previous research on the protection and utilization of traditional villages is mostly based on a one-sided, static protection, which has encountered many difficulties and resistance in practice, and the effect is not ideal [5,6]. It is therefore urgent to carry out research on the living protection of traditional villages.

The concept of Production–Living–Ecology (PLE) was first put forward in "Our Common Future" by the World Commission on environment and development in 1987. Under the promotion of the report, countries (regions) worldwide have reached a consensus on "sustainable development". After that, the "Rio Declaration on environment and development" and "Convention on biological diversity" signed in the 1990s and "transforming our world: the 2030 agenda for sustainable development" was signed in the 21st century, and they all expressed their continuous concern for sustainable development. As rural agricultural production is a part of rural life and ecological environment, and the food, energy, and resources of rural life come from agricultural production and ecological environment, respectively, the sustainable development of rural areas is considered as the integrated development of PLE [7]. It is an inexorable trend to integrate the development concept of PLE into the living protection of traditional villages.

Rural policies in Europe all show concern for PLE, with the introduction of the Agenda 2000 reforms, rural development was established in the European Union as the so-called second pillar of the Common Agricultural Policy (CAP), aiming at sustainably developing the rural area as a whole [8]. Based on Council Regulations 1257/1999 and 1698/2005, rural development plans (RDP) require Member States to pay more attention to maintaining the diversity of the ecosystem and ensuring the vitality of the village and the quality of the village's living environment in addition to strengthening the development of rural economy. In terms of funding, more funds are invested in sustainable ecological economic development, improvement of rural living quality, characteristic economy, and rural tourism [9]. In addition, many countries have their own unique plans, such as Poland's "Rural Renewal Programs" in the Warmia and Mazury Region, promoting the quality of production, living and ecology of the village systematically through "small grants", which then stimulate the comprehensive vitality of the village [10]. As for Germany, according to the German Territorial Order Act, the primary principle of territorial planning includes the construction of high-quality and healthy living and working environments throughout the country. Starting from the important significance of agriculture to production, living, and ecology, the principle of saving cultivated land resources and making better use of cultivated land resources is emphasized [11]. In addition, in the Weyarn Municipality, a rural area of upper Bavaria in southern Germany, village renewal under the framework of the Federal Land Consolidation Act provided a broad range of instruments: the local government makes full use of the land resources, actively develops the village economy, and, at the same time, takes into account the sustainable ecological development and the improvement of people's living quality, so that the village can be revitalized [12]. In China, 2017, the rural revitalization strategy emphasized the new requirements of thriving industries, a pleasant living environment, and a prosperous life in its overall development route, pushing the development concept of PLE to a new height. The living protection of traditional villages characterized by the development concept of PLE integration is a new practice. The basic connotation of PLE integration covers the material and spiritual achievements from the harmonious coexistence of humankind and nature, and from the construction of better human settlements. For traditional villages, ecological space is their natural foundation, while living space and production space are products derived from the environment where human beings live. In the long-term process of human activities, they react on the ecological space, thus forming a relatively stable overall pattern.

Domestic and foreign research on evaluation methods of traditional villages in related fields has yielded certain results, and the quantitative methods are increasingly concerned. For example, Yang et al. constructed an evaluation system and comprehensive evaluation function of cultural inheritance from the aspects of preservation and acceptance, and put forward corresponding protection strategies and suggestions [13]. Zou et al. constructed an index system for evaluating the vitality level of traditional villages from the three aspects of material heritage, intangible heritage, and village residents. They obtained data through field surveys, literature review, questionnaires, and other methods, and then quantitatively evaluated the vitality level of three types of traditional villages in West Hunan, China [14]. Ipekoglu proposed a grading system-based approach to evaluate the external and internal characteristics of traditional buildings in Odunpazari, Turkey, by their architectural, historical, environmental, visual, and aesthetic features, and divided these buildings into four groups of different values, A, B, C, and D, which would help make better decisions on cultural heritage [15]. Hu et al. constructed a multi-dimensional framework to understand the spatial reconstruction of traditional villages from the three levels of material space, social space, and cultural space. They preliminarily analyzed the spatial reconstruction mechanism of traditional villages under the interaction of social, political, and capital forces [16]. Guo et al. analyzed the Dang Village, a traditional village in Shaanxi Province, by combining qualitative and quantitative methods from social, economic, and environmental perspectives [17].

The current research results have the following shortcomings: First, the evaluation framework is relatively one-sided. Due to different research perspectives and evaluation objectives, the organic integrity of the village and the complexity of its internal system are ignored. To explore the influence mechanism of internal factors, a more comprehensive evaluation system is needed. Second, the quantitative evaluation research is relatively weak, and the reliability judgment of parameter compound operation lacks a systematic approach and accuracy of data processing. Third, the biggest feature of traditional villages is that the boundaries of PLE spaces are indistinct, and the degree of coupling coordination is high. During the integrative development of PLE in traditional villages, their interaction and integration mechanism is still vague [18].

In view of this, this paper attempts to construct a PLE comprehensive evaluation system of traditional villages. Taking the traditional villages around Taihu Lake as the research object, this paper quantitatively evaluates the PLE development levels of various traditional villages. By combining the horizontal PLE coupling coordination analysis with the vertical correlation analysis of indicators at different layers, the internal mechanism between PLE during the living protection of traditional villages is thoroughly analyzed, and appropriate multiple paths and strategies are proposed.

2. Materials and Methods

2.1. Study Area

The research team selected six traditional villages with typical characteristics in the Taihu Lake area for case study, covering different grades (national grade and provincial grade) and different types (mountainous, urban-suburbs, and water-network intensive). The basic information of these villages is shown in Figure 1 and Table 1.

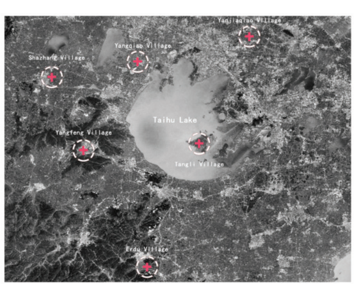


Figure 1. Distribution of typical traditional villages around Taihu Lake.

Table 1. Basic information of villages.

Village Name	Geographical Position	Type	Grade	Basic Information and Characteristics
Yangfeng	Huaikan Township, Changxing County	mountainous type	national grade	A population of 1453 (2019); the main industries are forestry, mining resources development, and tourism; a forest coverage rate of more than 80%. Yangfeng village has a large number of historical sites of the Communist Party, known as "little Yanan in the south of the Yangtze River".
Erdu	Xiazhuhu street, Deqing County	water-network intensive type	provincial grade	A population of 1775 (2019), the main industries are ecological agriculture, aquaculture, and tourism services. It is known as the most beautiful wetland in China and an important part of Xiazhu Lake National Wetland Park.
Shazhang	Kunlun Street, Liyang City	urban-suburbs type	national grade	A population of 1014 (most of which have moved to the New Village), the main industry is concentrated aquaculture. Shazhang Village Lane presents a structure of two horizontal and six vertical, which is famous for its features of "ancient village, ancient water, ancient tomb and ancient trees".
Yanjiaqiao	Yangjian Town, Xishan District	urban-suburbs type	national grade	A population of 5770 (2019), the main industries are ecological agriculture, processing and manufacturing, and eco-tourism. In the 1920s and 1930s, the village was a famous trading dock for rice, books, cloth, and medicine in Wuxi, and also a famous birthplace of Xi opera.
Yangqiao	Qianhuang Town, Wujin District	water-network intensive type	national grade	A population of 5211 (2019), the main industries are traditional cultivation, aquaculture, and tourism services. There are about 13,000 square meters of ancient buildings from the Ming and Qing Dynasties and the Republic of China. About 1000 square meters of stone revetments have been well preserved.
Tangli	Jinting Town, Wuzhong District	mountainous type	national grade	A population of 2991 (2019); the main industries are traditional planting and tourism. There are more than 30 single buildings and cultural relics, among which Diaohua hall, Rongde hall, and Qinyuan hall are typical.

The research data was obtained mainly through field surveys, on-site surveys, questionnaires, and a literature review. In August 2020, the research team conducted field surveys, on-site interviews, and questionnaire surveys for more than 20 days. Indicators D8–18 were from field surveys; D22, D30, and D38 from questionnaire surveys; and D1–2, D5–7, D19–20, and D23–25 from the literature review. Some indicators came from multiple sources. For example, D3–4, D26–30, and D36–37 were obtained through on-site interviews supplemented by literature review, whereas D21 and D32–35 were obtained through a questionnaire survey and field survey.

2.2. Methods

A comprehensive evaluation system was constructed based on the PLE integration with the principles of high feasibility and strong operability. The major steps were as follows: preliminary screening of indicators, expert consultation, determination of weights, determination of scoring standards, distribution of survey questionnaires, fuzzy comprehensive evaluation, correlation analysis of internal factors, etc. In terms of quantitative methods, the statistical method of "reliability analysis and Z-score unified standardization" was adopted to ensure the objectivity of scale analysis. By combining the horizontal PLE coupling coordination analysis with the vertical correlation analysis of the indicators at different layers, the interaction and integration of PLE of traditional villages are quantitatively reflected.

2.2.1. Construction of the Proposed Comprehensive Evaluation System

The specific evaluation process is shown in Figure 2 below.

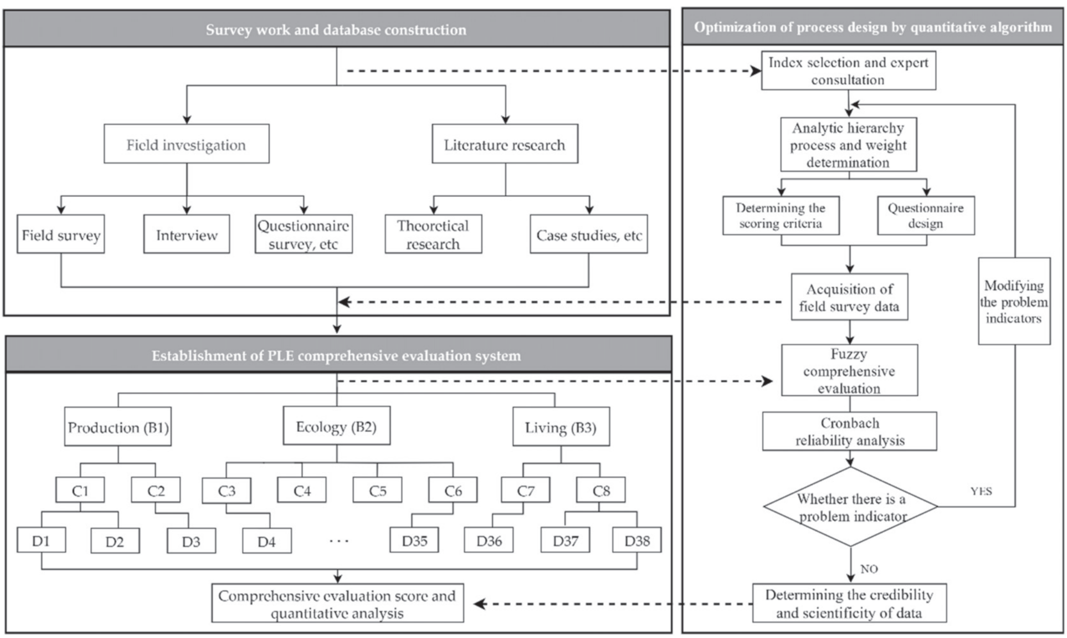


Figure 2. Flowchart for the comprehensive evaluation system.

2.2.2. Index Screening and Expert Consultation

Preliminary screening of indicators: Analyze and sort out relevant evaluation indicators for village economic production [19–23], human settlement environment [15,24–27], village ecological and cultural value [28–30], diversity of traditional village [31–34], policy efficiency index [35,36], and adaptability of rural tourism [17,32,37–39] from available literature. Finally, a total of 52 evaluation indicators were selected according to the objectives and principles mentioned above.

Expert consultation: The consulting experts were composed of four parts: experts in the field of traditional village protection, representatives of villagers, managers of village-related administrative organizations, and tourists, at a proportion of 4:3:2:1. By distributing the index consultation forms after the preliminary screening and analyzing the collected consultation forms and questionnaires [40], 38 key indicators were singled out (see Table A1 in Appendix A). These indicators were from 3 major categories (layer B), 8 medium categories (layer C), and 38 small categories (layer D).

1. Production B1

Comprehensive economic vitality C1 can roughly reflect the overall economic development level of the village [41]. A higher villagers' annual income per capital D1 and village collective annual average income D2 means better economic development. A strong industry means an economy of scale but not necessarily with distinctive features. As a result, the landscape and cultural characteristics of the village have not been fully explored. Therefore, the indexes D3 and D4 in the characteristic industry vitality C2 need to be treated differently. The deeper the future industrial development of the village integrates with the local characteristics [42], the higher the vitality level of its production field. Generally, the number of tourists reflects the real vitality of the tourism industry in the village. D6 and D7 reflect the talent leadership in the field of village production; the larger the number of leaders and the higher their income, the better the economic production vitality of the village [43].

2. Ecology B2

The products of the interaction between human beings and the environment include material ecology as well as spiritual ecology, such as society and humanities. Ecological civilization is the sum of material and spiritual results produced in the process of long-term coexistence and mutual influence between humans and the environment [44]. Academics have put forward the "pan-ecology" viewpoint which refers to the generalization of ecology in a broader sense. It is the sum of the material and spiritual achievements made by human beings in the interaction with the original ecological environment. Thus, the ecology B2 includes two major parts: material ecology and spiritual ecology [45].

Specifically, material ecology herein consists of the characteristics of natural environment C3 and the spatial characteristics of the village C4; the higher the scores of D8, D9, and D10, the better the natural environment of the village [46]. The material heritage features can be divided into three layers: overall layout, public space, and single building. The indexes in each layer are evaluated according to their quantity and quality. The larger the quantity of material heritages and the more distinctive and the more diversified the village, the higher the score for the ecology of the village [47].

The spiritual ecology is composed of political organization ecology C5 and cultural ecology C6 [48]. In addition to the evaluation of system management, the former index also includes the government's execution power and villagers' participation in protection work, thus forming a systematic evaluation system from top-level management to personnel implementation to villagers' cooperation and participation. The more complete the system, the higher the degree of implementation and the better the villagers' awareness and participation, the more effective the political organization ecology of the village. The latter is selected according to principle of "quantity + quality". The score of cultural ecology C6 is higher if the sub-indexes—history (D23–24), influence of historic figures and events (D25), cultural features (D26), villagers' participation in cultural activities (D27), and cultural inheritance—have higher scores.

3. Living B3

As for the layer of human settlement facilities (C7) [31], the higher the scores of such sub-indexes such as traffic (D32), living facilities (D33), and service facilities (D34), the better the living environment of the village, the stronger its attraction, and the more conducive it is to the living protection of the village. Meanwhile, it is necessary to pay more attention to the actual returned population and talent attraction of the village [49], especially the returned young population (D36), the attractiveness to foreign entrepreneurs (D37), and social inclusiveness (D38).

2.2.3. Analytic Hierarchy Process and Weight Determination

The weights are determined by the classical Analytic Hierarchy Process (AHP) [50]. That is, a tree hierarchical structure is constructed according to the comprehensive evaluation framework of PLE integration, and then Yaahp program distributes the score questionnaire to experts and scholars in the field. After experts determine the weight scores, the software will generate a judgment matrix to obtain the weight of each index in the comprehensive evaluation index system (see Table A1 in Appendix A).

2.2.4. Determination of Scoring Standards and Survey Questionnaire Design

Comprehensive evaluation includes qualitative and quantitative indicators. The graded scoring method for qualitative indicators [51]. There are five grades of evaluation scores (I, II, III, IV, and V), and each grade is assigned 20 points, that is, the scores of the grades are in the interval of 0–20, 21–40, 41–60, 61–80, and 81–100, respectively [52]. For quantitative indicators, a five-grade centesimal system similar to the above method is developed in combination with relevant standards for scoring. For the types of questionnaire and interview indicators, the majority opinion results of questionnaire interview are the final evaluation results. Copies of the survey questionnaire formulated by experts were distributed to local villagers. The collected valid questionnaires for each village were ensured to be more than 50.

2.2.5. Fuzzy Comprehensive Evaluation

Experts in the field were invited to score according to the above criteria. In the evaluation layer domain U, in order to obtain the index membership degree, it was necessary to uniformly sort and analyze the indexes of each layer to form a fuzzy evaluation matrix R.

Then, compound operation was carried out for the fuzzy matrix. According to the weight of each index w = (w_1, w_2, ..., w_n) [53] and fuzzy evaluation matrix R obtained in the above steps by AHP [54], the following operations are started:

$$B = W \cdot R = [\mathrm{w}_1, \mathrm{w}_2, \cdots, \mathrm{w}_\mathrm{n}] \cdot \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} = (B_1, B_2, \cdots, B_n) \quad (1)$$

Similarly, a complete resulting score scale for groups A, B, C, and D of the comprehensive evaluation index system for traditional village living protection can be obtained.

2.2.6. Reliability Analysis

The reliability analysis—Cronbach reliability analysis—was performed on the PLE comprehensive score scale to estimate the internal consistency of the test.

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum S_i^2}{S_x^2}\right) \quad (2)$$

α is the reliability coefficient, K is the number of test items, S_i^2 is the score variation of all subjects on the i-th question, and S_x^2 is the variance of the total scores obtained by all subjects.

In the above analysis, if the reliability coefficient is less than 0.35, it is considered to be low reliability, indicating the unreliability of the scale data. A reliability coefficient larger than 0.8 is acceptable. If the value is above 0.9, the scale is of high reliability. If the comprehensive evaluation scale fails to have high reliability, adjustments should be made on the related indexes according to the modification suggestions of experts.

2.2.7. Weight Calculation Based on Entropy Weighting Method and PLE Coupling Coordination Model

The process of the horizontal PLE coupling coordination model is shown in Figure 3.

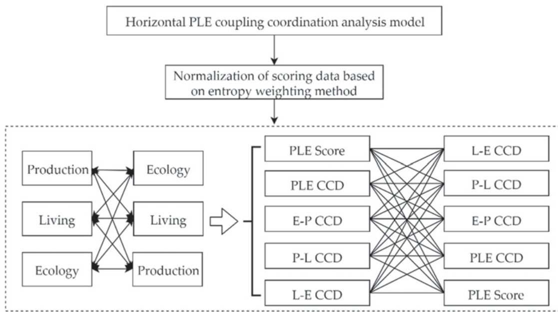


Figure 3. Process of the horizontal PLE coupling coordination model.

The range method is adopted in this paper normalize the dimensionless data:

$$x = \frac{x - x_{\min}}{x_{\max} - x_i} \tag{3}$$

where x_i=x_1,x_2, ... ,x_n; $x_{\max}$ and $x_{\min}$ respectively are the maximum and minimum of the index i.

The index weight is determined by calculating information entropy and information entropy redundancy. After the weights are determined, the comprehensive scores of PLE system can be calculated [55].

$$\mathrm{f}(x) = \sum_{i=1}^{m} a_i x_i \tag{4}$$

$$g(y) = \sum_{i=1}^{n} b_i y_i \tag{5}$$

$$h(z) = \sum_{i=1}^{k} c_i z_i \tag{6}$$

Here, $\mathrm{f}(x)$, $g(y)$, and $h(z)$ are the comprehensive scores of production, living, and ecology, respectively. a_i, b_i, and c_i are the weights of the production, living, and ecology system, respectively, and they are dimensionless values.

$$C = \left\{ \frac{\mathrm{f(x)} \times \mathrm{g(y)} \times \mathrm{h(z)}}{\left[\frac{\mathrm{f(x)+g(y)+h(z)}}{3}\right]^3} \right\}^{\frac{1}{3}} \tag{7}$$

The value of the coupling degree C ranges within (0, 1). The closer C is to 1, the greater the coupling degree between the systems; the closer C is to 0, the smaller the coupling degree between systems, and the order parameters are in a state of independent and disorderly development.

$$D = \sqrt{C \times T} \tag{8}$$

$$T = \partial f(x) + \beta g(y) + \delta h(z) \tag{9}$$

D is the coordination degree of the interaction coupling between the PLE functions, C is the coupling degree, and T is the comprehensive evaluation index of the coupling coordination degree. ∂, β, and δ are the weights of the PLE systems, which are assigned to 1/3, 1/3, and 1/3, respectively. Similarly, the pairwise mutual influence between production, living, and ecology can be calculated, respectively, such as ecology–production (E–P), living–ecology (L–E) and production–living (P–L) [56–59].

The lower the coordination (D value), the weaker the interaction among the three functions, and the greater the conflict among them. With reference to relevant research results and the actual development stage of the village, the results are divided into 4 categories and 10 subcategories [56] (see Table 2).

Table 2. Classification of PLE coupling coordination degree.

PLE Development Stage	Coupling Coordination Type	Coupling Coordination Degree
Coordination and integration period	Type I integration Type II integration Type IIIintegration	0.9~1.0 0.8~0.9 0.7~0.8
Running-in and adjustment period	Type I adjustment Type II adjustment	0.6~0.7 0.5~0.6
Antagonistic and contradictory period	Type I contradiction Type II contradiction	0.4~0.5 0.3~0.4
Declining and maladjusted period	Type I maladjustment Type II maladjustment Type IIImaladjustment	0.2~0.3 0.1~0.2 0~0.1

2.2.8. Z-Score Normalization and the Vertical Correlation Analysis Model

The process of the vertical correlation analysis model is shown in Figure 4.

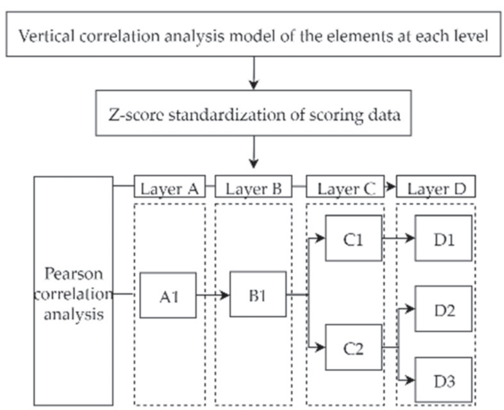


Figure 4. Process of the vertical correlation analysis model.

To ensure the results of different dimensions or layers of the fuzzy comprehensive evaluation [60] are comparable, it is necessary to normalize the evaluation vector results in the SPSS software. Z-score processing method is used to convert the data so that they have a mean value of 0 and a standard deviation of 1. The conversion formula is:

$$x^* = \frac{x - \overline{x}}{\sigma} \quad (10)$$

where x^* is the Z-score, x is the score of the indicator, $\overline{x}$ is the mean of the original data, and σ is the standard deviation of the original data.

Finally, the Pearson correlation analysis is adopted to measure the closeness of two or more variables in the PLE systems, so as to explore the mutual influence mechanism of the internal factors [61].

The Pearson's correlation coefficient is defined as:

$$r = \frac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)\left(Y_i - \overline{Y}\right)}{\sqrt{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}\sqrt{\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2}} \quad (11)$$

Obviously, $-1 \leq r \leq 1$. When $r < 0$, the two variables are negatively correlated; when $r \geq 0.8$, the two variables are highly correlated; when $0.8 > r \geq 0.5$, they are moderately correlated; when $0.5 > r \geq 0.3$, they are slightly correlated; and when $r < 0.3$, they are roughly independent. The significance test results show that when the significance is less than 0.05, the samples have a relatively significant linear correlation; when the significance is below 0.01, the samples have an extreme significant linear correlation [62].

3. Results

3.1. Evaluation Results

According to the operation process of the comprehensive evaluation index system constructed above, the fuzzy evaluation is carried out, and the scores are shown in Table 3. In this table, village names are abbreviated, such as Yangfeng (YF), Erdu (ED), Shazhang (SZ), Yanjiaqiao (YJQ), Yangqiao (YQ), Tangli (TL).

Table 3. Comprehensive evaluation index result.

Layer C	Score						Average Score	Layer D	Score						Average Score
	YF	ED	SZ	YJQ	YQ	TL			YF	ED	SZ	YJQ	YQ	TL	
C1	3.75	4.66	0.66	4.35	4.63	4.71	3.78	D1	1.53	1.55	0.22	1.11	1.52	1.59	1.24
								D2	2.22	3.10	0.44	3.24	3.11	3.12	2.53
C2	9.31	11.73	2.77	10.39	8.01	10.11	8.72	D3	1.93	2.48	0.82	2.48	1.38	1.94	1.84
								D4	3.15	4.02	1.35	4.05	3.15	4.05	3.29
								D5	1.29	1.66	0.18	0.92	0.55	1.29	0.98
								D6	0.96	0.96	0.13	0.96	0.96	0.96	0.82
								D7	1.99	2.56	0.28	1.99	1.99	1.99	1.81
C3	3.89	4.27	1.89	3.51	3.62	4.51	3.62	D8	0.53	0.29	0.29	0.41	0.53	0.53	0.43
								D9	1.21	1.20	0.67	0.93	0.93	1.22	1.02
								D10	2.14	2.76	0.92	2.14	2.12	2.76	2.14
C4	9.72	5.46	9.03	10.86	10.44	11.76	9.55	D11	1.11	0.61	1.11	0.86	0.86	0.86	0.90
								D12	1.28	1.00	1.13	1.28	1.00	1.56	1.09
								D13	1.48	1.06	1.47	1.48	1.90	1.92	1.55
								D14	0.72	0.52	0.72	0.75	0.72	0.52	0.66
								D15	0.66	0.37	0.07	0.37	0.66	0.51	0.44
								D16	0.61	0.61	1.44	1.03	1.44	1.85	1.16
								D17	0.95	0.95	2.21	2.27	2.23	2.23	1.80
								D18	2.86	0.31	0.95	2.86	1.59	2.86	1.90
C5	4.12	4.51	1.47	4.12	3.73	4.51	3.74	D19	0.60	0.61	0.21	0.61	0.63	0.66	0.53
								D20	0.79	0.79	0.61	0.79	0.79	0.79	0.76
								D21	1.39	1.34	0.45	1.33	1.31	1.37	1.21
								D22	1.34	1.72	0.19	1.34	0.96	1.72	1.21
C6	9.86	9.32	4.87	10.34	7.44	9.89	8.62	D23	0.83	0.83	0.59	0.83	0.59	0.59	0.71
								D24	0.62	0.37	0.86	0.62	0.62	0.62	0.62
								D25	1.27	0.91	0.91	1.27	0.54	0.91	0.97
								D26	0.22	0.38	0.38	0.22	0.38	0.53	0.35
								D27	1.14	1.14	0.49	1.47	0.49	1.14	0.98
								D28	0.24	0.14	0.04	0.24	0.24	0.24	0.19
								D29	0.39	0.39	0.07	0.07	0.23	0.71	0.31
								D30	3.56	3.51	1.18	2.77	2.77	3.56	2.89
								D31	1.56	1.56	0.31	2.81	1.56	1.55	1.55
C7	12.11	11.65	1.31	11.71	8.23	11.73	9.46	D32	2.01	2.01	0.22	2.01	2.01	2.01	1.71
								D33	3.94	3.94	0.43	3.94	3.06	3.94	3.21
								D34	4.59	4.59	0.51	4.59	2.55	4.59	3.57
								D35	1.44	1.12	0.16	1.44	0.82	1.46	1.07
C8	9.12	10.75	7.37	7.42	7.98	15.99	9.77	D36	1.31	1.31	3.94	1.31	1.31	6.58	2.63
								D37	4.14	5.80	0.82	2.48	2.48	5.82	3.59
								D38	3.21	3.65	2.61	3.85	3.67	3.59	3.43
Amount	61.88	62.35	29.37	62.71	54.08	73.21	57.26		61.88	62.35	29.37	62.71	54.08	73.21	57.26

3.2. Reliability Analysis

The Cronbach reliability analysis results show that the average value of the Alpha index of the evaluation scale for the above-mentioned villages reach 0.952, and the Alpha index of each indicator is above 0.94, indicating that the scale has high consistency and strong reliability (Table 4).

Table 4. Comprehensive evaluation index result.

Layer D	Cronbach's Alpha	Layer D	Cronbach's Alpha
D1	0.949	D20	0.951
D2	0.949	D21	0.954
D3	0.950	D22	0.953
D4	0.948	D23	0.952
D5	0.950	D24	0.952
D6	0.949	D25	0.949
D7	0.949	D26	0.951
D8	0.953	D27	0.949
D9	0.953	D28	0.949
D10	0.950	D29	0.952
D11	0.950	D30	0.955
D12	0.949	D31	0.953
D13	0.955	D32	0.953
D14	0.952	D33	0.951
D15	0.952	D34	0.949
D16	0.954	D35	0.951
D17	0.949	D36	0.949
D18	0.955	D37	0.949
D19	0.955	D38	0.950

3.3. Horizontal Analysis: PLE Score and Coupling Coordination Analysis Results

Through the comparison of the PLE score and coupling coordination degree (CCD) scores, the CCD contain PLE CCD and pairwise mutual CCDs of production, living and ecology, respectively, Pearson correlation analysis method is adopted to explore the evaluation content such as the integration and correlation of PLE, so as to quantitatively express the interaction and integration mechanism of PLE of traditional villages.

As shown in Table 5 and Figure 5, the PLE score and the PLE CCD are not strongly correlated. Yangfeng Village (61.88), Erdu Village (62.35) and Yanjiaqiao Village (62.71) have similar PLE scores. Among them, Yangfeng Village is the lowest, but it has reached coordination and integration period in PLE development stage (0.76), higher than the other two villages' 0.63 and 0.68 (Running-in and adjustment period).

Table 5. The score of PLE, coupling coordination degree scores and Z-score processing results.

Village Name	PLE Score	PLE CCD	L–E CCD	P–L CCD	E–P CCD	Z-Score PLE Score	Z-Score PLE CCD	Z-Score L–E CCD	Z-Score P–L CCD	Z-Score E–P CCD
Yangfeng	61.88	0.76	0.74	0.71	0.77	0.30833	0.65011	0.37047	0.69616	0.32223
Erdu	62.35	0.63	0.82	0.84	0.56	0.33975	0.07989	0.28871	−0.40151	0.91481
Shazhang	29.37	0.28	0.31	0.29	0.19	−1.86449	−1.52665	−1.38747	−1.45669	−1.61181
Yanjiaqiao	62.71	0.68	0.82	0.51	0.76	0.36381	0.29119	0.68375	0.65367	−0.56392
Yangqiao	54.08	0.45	0.39	0.61	0.42	−0.21298	−0.75418	−1.06993	−0.66116	0.12344
Tangli	73.21	0.89	0.92	0.87	0.89	1.06558	1.25965	1.11448	1.16953	1.06212

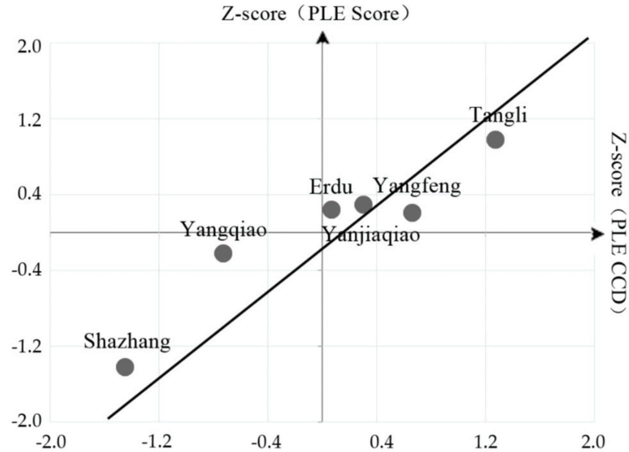


Figure 5. The relationship between PLE score with PLE CCD.

The internal mechanism reason for that scoring performance can be found from the pairwise mutual CCDs, as shown in Figure 6. Erdu village and Yanjiaqiao village show Type II adjustment performance, respectively in the pairwise mutual CCDs on L–E (0.56) and P–L (0.51). Even though they show a relatively high score on other CCDs, their scores of PLE coordination will be affected by the buckets effect. It thus can be concluded that the PLE development of village is a dynamic process, the coordination among PLE functions constrain and contribute each other. In Yangfeng Village, the three functions of space begin to balance and cooperate with each other, which shows the characteristics of benign coupling coordination. Different from Yangfeng Village, Erdu village and Yanjiaqiao village face the problem of antagonism at CCD in L–E and P–L. Their dominant function become stronger and occupy the space for the development of disadvantaged functions. Consequently, these disadvantaged functions would become weaker and weaker.

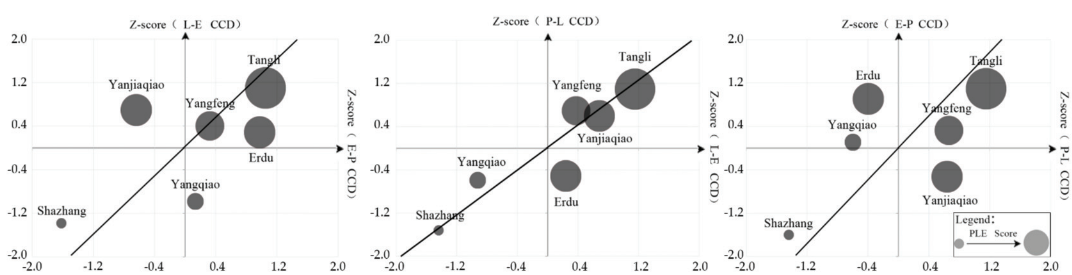


Figure 6. The relationship among pairwise mutual CCDs.

After Z-score processing, the relationships among the CCDs of PLE, L–E, P–L, and E–P can be seen more intuitively (Figure 7). Figure 8 shows the significance of Pearson results between the PLE score, PLE CCD, and pairwise mutual CCDs. When the significance is less than 0.05, the samples have a relatively significant linear correlation (light red); when the significance is below 0.01, the samples have an extreme significant linear correlation (bright red). Specifically, the PLE CCD shows a strong linear relationship with P–L (0.002) and L–E (0.003), respectively, as shown in Table A2 of Appendix A. Moreover, P–L shows a strong correlation of 0.005 with L–E. It can be seen that the living function acts as a bridge for the interaction between the production and ecology functions. It has demonstrated that the living protection for traditional villages is a key link to realize the coordinated development of PLE, which is inconsistent with the general belief that the better the production or ecology, the better the PLE development of village. In addition, PLE CCD shows a strong correlation of 0.006 with PLE score, demonstrating that the comprehensive development of three aspects is an effective way to realize the living development trend of "seeing people, things, and living" in traditional villages.

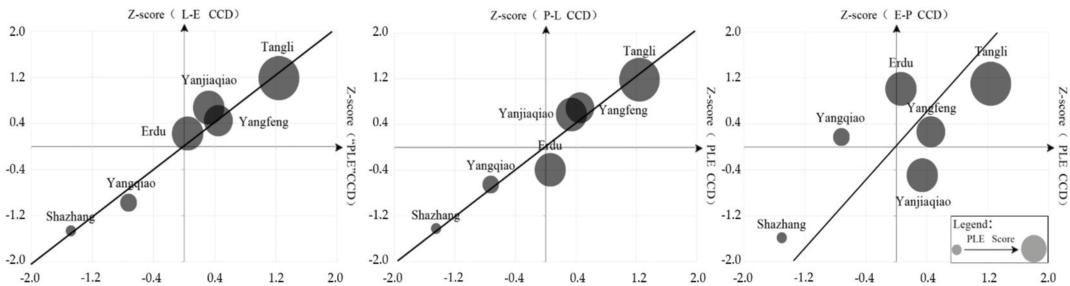


Figure 7. The relationship of PLE CCD with pairwise mutual CCDs.

	PLE Score	PLE CCD	E–P CCD	P–L CCD	L–E CCD
PLE Score		0.006	0.026	0.019	0.017
PLE CCD	0.006		0.076	0.002	0.003
E–P CCD	0.026	0.076		0.208	0.156
P–L CCD	0.019	0.002	0.208		0.005
L–E CCD	0.017	0.003	0.156	0.005	

Legend: 0.300, 0.100, 0.050, 0.020, 0.010, 0.005, 0.000

Figure 8. The significance of Pearson results between the PLE score, PLE CCD, and pairwise mutual CCDs.

3.4. Vertical Analysis: PLE Score (Layer A) and Analysis Results of PLE Dimensions (Layer B)

Overall, the average score of the six studied villages only reached 57.26. This indicates that although they are located around the Taihu Lake, a developed region covering Zhejiang and Jiangsu provinces, their PLE development is not ideal. Among them, only Tangli Village scores over 70, and three villages (Yangfeng, Erdu, and Yanjiaqiao) score a little over 60. Furthermore, among the villages with scores below 60 points, Yangqiao only achieves 54.08, while Shazhang shows the lowest score of 29.37. In addition to Erdu, which is a provincial grade traditional village, the others are all at the national grade. This shows that the villages may score low even if they have a fine ecology, and that their development strategy should be adapted to the concept of PLE integration.

The difference among the studied villages in terms of production, living, and ecology can be directly seen after Z-score normalization (Table 6). To better show the difference, the villages' Z-scores of production, living, and ecology at layer B can be transformed and put into a coordinate system (Figure 9). The larger the circular area in the figure, the higher the village's Z-score in the production.

Table 6. Z-score normalization results of production, living, and ecology.

Village Name	Production	Living	Ecology	Z-Score (Production)	Z-Score (Living)	Z-Score (Ecology)
Yangfeng	13.1	27.6	21.1	0.12263	0.44273	0.28009
Erdu	16.4	23.5	22.4	0.83674	−0.41484	0.47871
Shazhang	3.5	17.2	8.7	−1.95480	−1.73256	−1.61436
Yanjiaqiao	14.6	28.8	18.4	0.44722	0.69372	0.02037
Yangqiao	12.7	25.2	15.9	0.03607	−0.05926	−0.51435
Tangli	14.9	30.6	28.1	0.51214	1.07022	1.34954

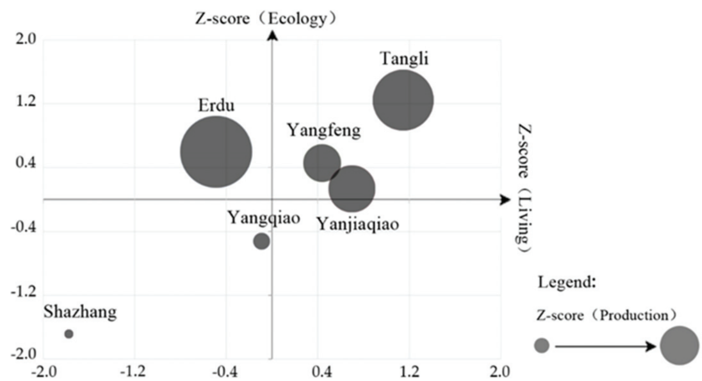


Figure 9. Z-scores of production, living, and ecology after normalization.

1. Production dimension

In terms of production, provincial grade traditional village Erdu has the highest score (16.4 points), followed by the national grade traditional villages, Yanjiaqiao, Tangli and Yangfeng, ranking 2nd, 3rd, and 4th, respectively. There are not many historical sites and features in Erdu Village, and its score for spatial and environmental characteristics (C4) are not high. However, Erdu has benefited greatly from large projects and events nearby, such as the Xiazhu Lake Wetland Park completed in 2013 and the pastoral expo held in 2019. Yanjiaqiao is a traditional suburban village, 4 km away from Yangjian Industrial Park in Wuxi City, 12 km from East Railway Station, and 20 km from the downtown. In recent years, it has developed an economy through suburban tourism and urban industry, so the villagers' income and the collective income of the village are both high. In addition, Tangli Village is located in the Xishan Island Scenic Spot, with high artificial and natural ecological values. The development of tourism helps the village score relatively high in the production dimension. Moreover, Yangfeng is a mountainous type of village with a forest coverage rate of more than 80%. This village develops forestry and mining industries based on its own superior natural conditions and sees a sound economic boost. It shows that the rational use of their own and surrounding environmental resources is the key to maintaining the economic vitality of traditional villages.

The villages with lower scores are Yangqiao and Shazhang. Yangqiao Village has a favorable material ecology (C3 and C4), yet the lack of large-scale development projects in its surrounding area and the poor planning and management of the political organization ecology (C5) have resulted in a low production score. In contrast, the economy of Shazhang is more sluggish, and the low score of political organization is one of the main reasons for the decline in its production. According to the on-site interview, the local government organized the aborigines to move out for the protection of historic sites. There were more than 200 households, more than 180 of which have moved out. Those still live there are mostly the elderly. Shazhang village is almost an empty village where only some lonely elderly villagers visit each other during the day. As most of the residents have moved out, many century-old houses in the village are worn down by the years without repair, and even collapsed, showing a dilapidated scene.

2. Living dimension

As can be seen in Figure 9, Shazhang, Yangqiao, and Erdu have relatively low scores for the living dimension. Although Erdu sees an outstanding economic increase, as well as a trend of labor returning (a subindicator at layer D), its social amenities are insufficient. As a result, the livability is poor, which partly affects the progress in its living protection. For Shazhang and Yangqiao, as mentioned above, in addition to regional differences, the quality of policy organization plays a crucial role in their development. Despite a large number of material ecological remains and various historical sites, Yangqiao is poor in livability and living protection owing to the lagged policy and organization.

The villages with relatively high scores in the living dimension, such as Yangfeng, Yanjiaqiao, and Tangli, also face the same issues. The living facilities are relatively complete, and a certain number of migrants come to the village to start businesses, such as opening homestays, restaurants, and studios. However, the indicator D36 shows that only a small proportion of young people in Tangli have returned to the village. Additionally, this figure for the other two villages is almost zero.

3. Ecology dimension

In this dimension, except for the relatively weak Shazhang and Yangqiao, the remaining four villages all show high scores. Comparison between Yangqiao and Yanjiaqiao shows that, under the same material ecology (natural environment and material heritage), the villages with better spiritual ecology (political organization ecology and cultural ecology) have a higher level in production and living dimensions.

It can also be found that the material ecology and cultural ecology of Erdu (a provincial grade traditional village) are significantly inferior to Yangqiao (a national grade traditional village), whereas Erdu's scores for the production dimension are significantly higher. This further confirms the importance of organizational ecology mentioned above in Pearson correlation analysis. Thus, the local government should appropriately develop and utilize the resources of the village and those nearby, which is a necessary guarantee for the village to achieve a sustainable development of PLE integration. The production, living and ecology are closely related and complement each other, the absence of any of which will impact the sound, sustainable development of the whole system.

3.5. Vertical Analysis: Analysis Results of Sub-Indicators (Layer C and Layer D)

The indicators of layer C are standardized by Z-score processing mentioned above, and the results are shown in Table 7. The data are visualized to analyze the differences between specific indicators, as shown in Figure 10.

Table 7. Normalized results of Z-scores for sub-indicators at layer C.

Layer C	Z-Score (Yangfeng)	Z-Score (Erdu)	Z-Score (Shazhang)	Z-Score (Yanjiaqiao)	Z-Score (Yangqiao)	Z-Score (Tangli)
C1	−0.02749	0.54987	−1.98799	0.35319	0.53084	0.58159
C2	0.18651	0.95150	−1.88088	0.52791	−0.22444	0.43940
C3	0.29680	0.70693	−1.86177	−0.11333	0.00540	0.96596
C4	0.07919	−1.84845	−0.23304	0.59503	0.40499	1.00228
C5	0.32716	0.66591	−1.97457	0.32716	−0.01158	0.66591
C6	0.59043	0.33330	−1.78556	0.81898	−0.56186	0.60471
C7	0.62550	0.51706	−1.92051	0.53121	−0.28918	0.53592
C8	−0.19728	0.29617	−0.72706	−0.71192	−0.54239	1.88248

Figure 10. The Z-score of each index in C layer.

From the score of indicator C1 (overall economic vitality), it can be observed that all the other villages are at or above the mean, except for Shazhang. This shows that the traditional villages in the affluent area around Taihu Lake in Jiangsu and Zhejiang provinces have excellent economic performance.

The indicators C2 (characteristic industrial vitality), C5 (ecological vitality of political organizations), C6 (cultural ecological vitality), and C7 (the level of human settlement facilities) exhibit consistent characteristics in their standardized images That is, except Yangqiao and Shazhang, the scores of other villages are close to each other. These indicators are closely related to the administration level of government.

Shazhang Village has been unmanaged in recent years, so the surrounding environment is overgrown with weeds, and its natural features have been seriously damaged. Consequently, this village scores low at the natural environment features C3 and spatial environment features C4. Erdu Village, a provincial grade traditional village, is not comparable to the other five national grade traditional villages in terms of material heritage characteristics due to fewer historical sites and cultural relics. Nevertheless, the outstanding characteristic industries, political organizations, and the human settlement environment have contributed to Erdu's PLE score above the average level.

Through the standardization of Z-score and Pearson analysis, the correlation results between the PLE scores and the C-layer indicators are obtained (Table A3 in Appendix A). In order to make the data more intuitive, the significance of correlation results between the PLE scores and the C-layer indicators table is drawn (Figure 11). When the significance is less than 0.05, the samples have a relatively significant linear correlation (light red); when the significance is below 0.01, the samples have an extreme significant linear correlation (bright red).

	PLE Score	C1	C2	C3	C4	C5	C6	C7	C8
PLE Score		0.013	0.010	0.003	0.696	0.002	0.006	0.003	0.161
C1	0.013		0.010	0.009	0.865	0.003	0.050	0.019	0.390
C2	0.010	0.010		0.010	0.808	0.001	0.009	0.002	0.386
C3	0.003	0.009	0.010		0.984	0.001	0.034	0.010	0.137
C4	0.696	0.865	0.808	0.984		0.966	0.788	0.917	0.747
C5	0.002	0.003	0.001	0.001	0.966		0.009	0.001	0.291
C6	0.006	0.050	0.009	0.034	0.788	0.009		0.001	0.397
C7	0.003	0.019	0.002	0.010	0.917	0.001	0.001		0.379
C8	0.161	0.390	0.386	0.137	0.747	0.291	0.397	0.379	

Legend: 1.000, 0.800, 0.500, 0.100, 0.010, 0.005, 0.000

Figure 11. The significance of Pearson results between the PLE scores and the C-layer indicators.

Natural environment features, ecological vitality of political organizations, and the level of human settlement facilities show a linear correlation with the PLE score. Among them, the significance between the ecological vitality of political organizations and the score is 0.002, indicating the strongest correlation. This indicates that positive policy organization is the key factor a key factor in realizing the PLE integration of villages. In addition, in C5 column, the number of bright red color blocks is the most, indicating that the index has the strongest correlation with other elements.

In addition, the correlation value of the PLE score with spatial environmental features and population vitality of the village is 0.696 and 0.161, respectively, showing a weak linear correlation. It is thus can be concluded that the village can still find a suitable path for PLE integration based on its own strengths even if its spatial environment is not excellent. Moreover, there is a certain correlation between spatial environment and population vitality (0.137). This indicates that a favorable natural environment is the foundation of the village's development and population increase.

4. Discussions

Figure 12 shows the visualization results of the indicators at layer C. Then, each quadrant in the z-score coordinate system (Figure 9) of each village is classified and summarized, and the influence mechanism and related issues of the village are explored from the perspective of PLE, so that the suitable strategy can be proposed.

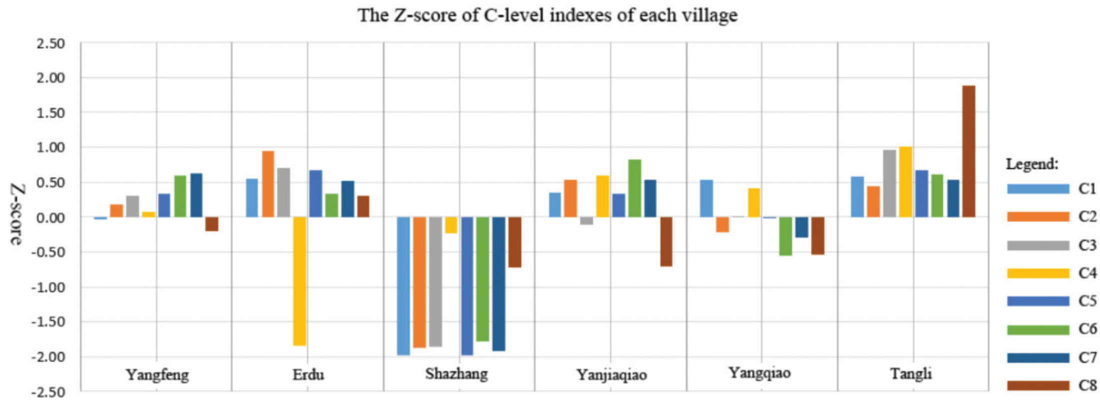


Figure 12. Normalized Z-scores of villages' indicators at layer C.

(1) The villages in the first quadrant are Yangfeng, Yanjiaqiao, and Tangli, all national grade villages. They score above the average in the PLE dimensions and have achieved all-around progress in PLE integration. These villages all make full use of natural and cultural resources, forming unique village characteristics, and providing a high-class ecological and cultural foundation for further living protection (Figure 9).

For such traditional villages, we should adhere to the strategy of "inheritance first". Moreover, they should actively promote local culture and characteristic industries, and develop tourism, which can in turn contribute to heritage preservation. Furthermore, it is necessary to guide villagers to participate in the village protection, ensure they are the masters of the village, and expand the cultural heritage team to achieve internal improvement. It is suggested to attract young people to return and inject vitality into the sustainable development of the village by creating more employment opportunities. In addition, it is also suggested to adhere to continuous protection plan of villages and unify the historic style of traditional villages from the overall spatial environment, individual buildings, and interior space. At the same time, multiple functional spaces for photography, painting, and cultural experience can be constructed.

(2) The villages in the second (fourth) quadrant are those with above-average scores in one of the ecology and living functions and below-average scores in the other. These villages have a single characteristic. Only Erdu is in this quadrant, and it is a provincial grade traditional village. Thanks to the major projects nearby, this village boosts its economy by developing corresponding service industry. However, Erdu is weak in preservation of historical characteristics. Many of the traditional features are not well conserved, and there are few traditional buildings left (Figure 9).

Such traditional villages should adopt the strategy of "development first". They should promote the construction of "one village and one featured product", explore the diversified value of traditional villages according to local conditions, clarify the major characteristics, establish their own brands, and actively develop tourism and its surrounding industries. They need to improve infrastructure and enhance the overall livability and tourism service quality in the village, so as to attract talents to return. Furthermore, they also need to restore the traditional buildings and unify the traditional style. To ensure the living protection of traditional villages does not deviate from the masses, the government should play a leading role in establishing a long-term preservation mechanism. Meanwhile, the government should provide more opportunities for villagers to fully express their opinions so that they can better participate in the development of villages.

(3) In the third quadrant, there are Shazhang and Yangqiao. Their scores of ecology and living dimensions are lower than the average, so they belong to the villages with lagged PLE development. The common problems these villages face are as follows: First, the

village characteristics are not distinct, the exploration of connotative values is limited, and the economy is sluggish. Second, a large number of villagers go out to work, which makes it more difficult to protect and inherit the culture and building technology of traditional villages. Additionally, the architectural heritage with cultural and historical value have not received enough attention (Figure 9).

Therefore, such traditional villages should adhere to the strategy of "protection first". With low productivity and serious population loss, these villages should not take tourism as their leading industry. Instead, they should preserve the main historical remains of traditional villages and meanwhile develop agriculture as a basic industry while protecting the heritage. In addition, they should actively expand their diversified and compound functions, and integrate them with industries such as culture, tourism, and education. Furthermore, they are suggested to extend the industrial chain and develop related service industries based on the natural and cultural resources and historic remains of traditional villages. In general, the key to a virtuous revival of traditional villages lies in enhancing infrastructure construction and retaining villagers. In terms of material ecology, the priority should be given to its protection, and the heritages at different spatial levels should be properly preserved. As for political ecology, the social capital should play a leading role in the development of rural tourism based on government guidance and public participation.

5. Conclusions

Based on the development concept of PL integration, this paper conducts a comprehensive evaluation and quantitative study of the living protection of traditional villages. The case study is based on a number of traditional villages of different grades and types in the Taihu Lake area. The evaluation research in this paper is based on quantitative evaluation and supplemented by qualitative evaluation. In data processing, the reliability analysis is combined with Z-score normalization to ensure that the evaluation indicators are comparable. Through the horizontal PLE coupling coordination analysis with the vertical correlation analysis of the elements at each layer, the relationship between the internal factors of the living protection of traditional villages and the mutual influence mechanism are thoroughly analyzed. The major preliminary conclusions can be drawn as follows:

(1) The PLE development of traditional villages is a dynamic process. Even if the villages are close in the PLE score, they may be in different stages of PLE development and coupling coordination type. For example, in the coupling coordination stage, the villages' production, living, and ecology functions restrict and contribute to each other, showing a benign coupling. However, the villages in the adjustment stage would have confrontation between different dimensions. The stronger the predominant function of traditional villages, the less space for the development of other functions. As a result, these disadvantaged functions would be weakened.

(2) The living function serves as a bridge between production and ecology functions. This is inconsistent with the general belief that the better the production or ecology, the better the PLE development of villages. It has also demonstrated that the living protection of traditional villages is a key link to realizing the coordinated development of PLE. The PLE integration development is an effective way to practice the living protection of traditional villages.

(3) Villages may score low even if they are national grade traditional villages with a high-quality ecological environment. Thus, their development strategy should be adapted to the concept of PLE integration. By contrast, even if the spatial and environmental characteristics of the villages are not distinct, they can still pursue suitable PLE integration according to the local conditions.

(4) There is a significant linear correlation between the ecological vitality of political organizations and PLE score. This shows that a positive policy organization is the fundamental guarantee for the PLE integration of traditional villages.

The evaluation results can clarify the interaction mechanism of the internal factors of the village, pinpoint problems, and provide a research reference for formulating targeted optimization measures. The comprehensive evaluation system established based on the PLE perspectives breaks through the traditional isolated, static protection method. For China and other countries and regions, it is of positive significance to discuss the quantitative evaluation of traditional villages' living protection in terms of methods. In theory, it can broaden the ideas of traditional villages' activation and protection, and in practice, it can provide basis and reference for the activation of traditional villages.

As it is still exploratory research, the interaction mechanism between the internal elements of traditional villages may be more complex network structure or composite structure, and even need more than two multi factor correlation comparative study. Follow up studies need to continue to optimize the traditional mechanism analysis methods. For example, the way of AHP, Pearson correlation analysis of paired comparison, the construction of evaluation index system and the selection of case villages need to be further improved.

Author Contributions: Conceptualization, L.K. and X.X.; Data curation, W.W.; Formal analysis, L.K.; Funding acquisition, X.X.; Methodology, L.K. and W.W.; Project administration, M.Z.; Visualization, J.W.; Writing–original draft, L.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by National Key R&D Program of China, grant number: 2019YFD1100904, Demonstration of Integration of Key Techniques for the Living Protection and Utilization of Traditional Villages.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing not applicable.

Acknowledgments: We sincerely thank Haining Wang from the school of architecture, Southeast University, for his efforts in the research process and the students' participation in the investigation and survey.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The comprehensive evaluation system for the living protection of traditional villages.

Layer A	Layer B	Weight	Order	Layer C	Weight	Order	Layer C	Weight	Order
The comprehensive evaluation system for the living protection of traditional villages	Production B1	0.2000	2	Comprehensive economic vitality C1	0.0667	2	Villagers' annual income per capital D1	0.0222	2
							Village collective annual average income D2	0.0444	1
				Characteristic industry vitality C2	0.1333	1	Development of strong industries D3	0.0276	3
							Development of characteristic industries D4	0.0450	1
							Daily average number of tourists in Tourism D5	0.0185	4
							Number of rich leaders D6	0.0138	5
							Annual output value of rich leaders D7	0.0285	2

Table A1. *Cont.*

Layer A	Layer B	Weight	Order		Layer C	Weight	Order	Layer C	Weight	Order
	Ecology B2	0.4000	1	Material ecology	Characteristics of landscape and natural environment C3	0.0500	1	Water green area coverage D8	0.0059	3
								Landscape environmental quality and overall continuity D9	0.0134	2
								Uniqueness of ecological environment D10	0.0307	1
					Characteristics of village space environment C4	0.1500	2	characteristics of traditional village pattern D11	0.0123	6
								Landform adaptability D12	0.0143	5
								Overall features of the village D13	0.0212	3
								Public space and the number of important nodes D14	0.0104	7
								Public space and quality of important nodes D15	0.0074	8
								Types of ancient buildings and cultural relics D16	0.0206	4
								Number of ancient buildings and cultural relics D17	0.0319	1
								Characteristics of ancient buildings and cultural relics D18	0.0318	2
				Spiritual ecology	Ecological vitality of political organizations C5	0.0500	1	Integrity of village management system D19	0.0067	4
								Integrity of traditional village protection system D20	0.0088	3
								Implementation of traditional village protection measures D21	0.0153	2
								Villagers' participation in protection work D22	0.0192	1
					Cultural ecological vitality C6	0.1500	2	Historical value and importance of villages D23	0.0119	6
								Number of important historical events and figures D24	0.0124	5
								Important historical events and influence of figures D25	0.0182	3
								Quantity of traditional intangible culture D26	0.0076	7
								Characteristics of traditional intangible culture D27	0.0164	4
								Quantity of traditional products D28	0.0048	9
								Characteristics of traditional products D29	0.0079	8
								Participation in Villagers' cultural life D30	0.0396	1
								Number of cultural inheritors D31	0.0312	2

Table A1. *Cont.*

Layer A	Layer B	Weight	Order	Layer C	Weight	Order	Layer C	Weight	Order
	Living B3	0.4000	1	The level of human settlement facilities C7	0.1333	2	Traffic convenience in the village D32	0.0224	3
							Living infrastructure D33	0.0438	2
							Integrated service facilities D34	0.0511	1
							Recreational facilities D35	0.0160	4
				Village popularity and vitality C8	0.2667	1	The number of young people returning to villages D36	0.1316	1
							Number of foreign talents D37	0.0829	2
							Social Inclusiveness D38	0.0522	3

Table A2. Pearson correlation analysis Z-score results between PLE score, PLE CCD and pairwise mutual CCDs.

		Z-Score (PLE Score)	Z-Score (PLE CCD)	Z-Score (E–P CCD)	Z-Score (P–L CCD)	Z-Score (L–E CCD)
Z-score (PLE Score)	Pearson correlation	1	0.937 **	0.864 *	0.884 *	0.893 *
	Significance (2- tailed)		0.006	0.026	0.019	0.017
	Number of cases	6	6	6	6	6
Z-score (PLE CCD)	Pearson correlation	0.937 **	1	0.766	0.961 **	0.958 **
	Significance (2- tailed)	0.006		0.076	0.002	0.003
	Number of cases	6	6	6	6	6
Z-score (E–P CCD)	Pearson correlation	0.864 *	0.776	1	0.600	0.658
	Significance (2- tailed)	0.026	0.076		0.208	0.156
	Number of cases	6	6	6	6	6
Z-score (P–L CCD)	Pearson correlation	0.884 *	0.961 **	0.600	1	0.924 **
	Significance (2- tailed)	0.019	0.002	0.208		0.005
	Number of cases	6	6	6	6	6
Z-score (L–E CCD)	Pearson correlation	0.893 *	0.958 *	0.658	0.924 **	1
	Significance (2- tailed)	0.017	0.003	0.156	0.005	
	Number of cases	6	6	6	6	6

Note: **, at 0.01 level (2-tailed), the correlation is strong significant; *, at 0.05 level (2-tailed), the correlation is significant.

Table A3. Pearson correlation analysis Z-score results between PLE scores and the C-layer indicators.

		Z-Score (PLE Score)	Z-Score (C1)	Z-Score (C2)	Z-Score (C3)	Z-Score (C4)	Z-Score (C5)	Z-Score (C6)	Z-Score (C7)	Z-Score (C8)
Z-score (“PLE” Score)	Pearson correlation	1	0.904 *	0.919 *	0.958 **	0.206	0.968 **	0.937 **	0.955 **	0.652
	Significance (2- tailed)		0.013	0.010	0.003	0.696	0.002	0.006	0.003	0.161
	Number of cases	6	6	6	6	6	6	6	6	6
Z-score (C1)	Pearson correlation	0.904 *	1	0.916 *	0.921 **	0.091	0.956 **	0.812 *	0.886 *	0.434
	Significance(2- tailed)	0.013		0.010	0.009	0.865	0.003	0.050	0.019	0.390
	Number of cases	6	6	6	6	6	6	6	6	6
Z-score (C2)	Pearson correlation	0.919 **	0.916 *	1	0.919 **	−0.128	0.975 **	0.922 **	0.960 **	0.437
	Significance(2- tailed)	0.010	0.010		0.010	0.808	0.001	0.009	0.002	0.386
	Number of cases	6	6	6	6	6	6	6	6	6
Z-score (C3)	Pearson correlation	0.958 **	0.921 **	0.919 **	1	0.011	0.970 **	0.845 *	0.917 *	0.680
	Significance(2- tailed)	0.003	0.009	0.010		0.984	0.001	0.034	0.010	0.137
	Number of cases	6	6	6	6	6	6	6	6	6
Z-score (C4)	Pearson correlation	0.206	0.091	−0.128	0.011	1	0.023	0.143	0.055	0.170
	Significance(2- tailed)	0.696	0.865	0.808	0.984		0.966	0.788	0.917	0.747
	Number of cases	6	6	6	6	6	6	6	6	6
Z-score (C5)	Pearson correlation	0.968 **	0.956 **	0.975 **	0.970 **	0.023	1	0.924 **	0.975 **	0.519
	Significance(2- tailed)	0.002	0.003	0.001	0.001	0.966		0.009	0.001	0.291
	Number of cases	6	6	6	6	6	6	6	6	6
Z-score (C6)	Pearson correlation	0.937 **	0.812 *	0.922 **	0.845 *	0.143	0.924 **	1	0.978 **	0.428
	Significance(2- tailed)	0.006	0.050	0.009	0.034	0.788	0.009		0.001	0.397
	Number of cases	6	6	6	6	6	6	6	6	6
Z-score (C7)	Pearson correlation	0.955 **	0.886 *	0.960 **	0.917 *	0.055	0.975 **	0.978 **	1	0.443
	Significance(2- tailed)	0.003	0.019	0.002	0.010	0.917	0.001	0.001		0.379
	Number of cases	6	6	6	6	6	6	6	6	6
Z-score (C8)	Pearson correlation	0.652	0.434	0.437	0.680	0.170	0.519	0.428	0.443	1
	Significance(2- tailed)	0.161	0.390	0.386	0.137	0.747	0.291	0.397	0.379	
	Number of cases	6	6	6	6	6	6	6	6	6

Note: **, at 0.01 level (2-tailed), the correlation is strong significant; *, at 0.05 level (2-tailed), the correlation is significant.

References

1. Ye, C.; Ma, X.; Gao, Y.; Johnson, L. The lost countryside: Spatial production of rural culture in Tangwan village in Shanghai. *Habitat Int.* **2020**, *98*, 102137. [CrossRef]
2. Ye, C.; Liu, Z. Rural-urban co-governance: Multi-scale practice. *Sci. Bull.* **2020**, *65*, 778–780. [CrossRef]
3. Chen, M.; Zhou, Y.; Huang, X.; Ye, C. The Integration of New-Type Urbanization and Rural Revitalization Strategies in China: Origin, Reality and Future Trends. *Land* **2021**, *10*, 207. [CrossRef]
4. Yu, B.; Lu, Y.; Zeng, J.; Zhu, Y. Progress and Prospect on Rural Living Space. *Scientia Geographica Sinica* **2017**, *37*, 375–385.
5. Long, H.; Zou, J.; Pykett, J.; Li, Y. Analysis of rural transformation development in China since the turn of the new millennium. *Appl. Geogr.* **2011**, *31*, 1094–1105. [CrossRef]
6. Xu, J.; Lu, Z.; Huo, X. The evolution and adaptive development of traditional dwelling in Southern Shaanxi, China. *Environ. Sci. Pollut. Res.* **2019**, *26*, 13914–13930. [CrossRef]
7. Lennon, B. What next for sustainable development? Our Common Future at Thirty. *Eurasian Geogr. Econ.* **2019**, *61*, 338–340. [CrossRef]
8. Zasada, I.; Piorr, A. The role of local framework conditions for the adoption of rural development policy: An example of diversification, tourism development and village renewal in Brandenburg, Germany. *Ecol. Indic.* **2015**, *59*, 82–93. [CrossRef]
9. Ilbery, B. Book Review: Geographies of agriculture: Globalisation, restructuring and sustainability. *Prog. Hum. Geogr.* **2005**, *29*, 803–805. [CrossRef]
10. Jaszczak, A.; Žukovskis, J.; Antolak, M. The role of rural renewal program in planning of the village public spaces: Systematic approach. *Manag. Theory Stud. Rural. Bus. Infrastruct. Dev.* **2017**, *39*, 432–441. [CrossRef]
11. Liu, C.-Z. The Village Renewal in Germany and Its Implications for Taiwan. *J. Agric. Econ.* **2001**, *69*, 129–165. [CrossRef]
12. Chigbu, U. Village renewal as an instrument of rural development: Evidence from Weyarn, Germany. *Community Dev.* **2012**, *43*, 209–224. [CrossRef]
13. Yang, L.; Liu, P. The Inheritance and Its Evaluation System of Traditional Village Culture: A Case Study of Traditional Village in Hunan Province. *Econ. Geogr.* **2017**, *37*, 203–210.
14. Zou, J.; Liu, Y.; Tan, F.; Liu, P. Landscape Vulnerability and Quantitative Evaluation of Traditional Villages: A Case Study of Xintian County, Hunan Province. *Sci. Geogr. Sin.* **2018**, *38*, 1292–1300.
15. Ipekoğlu, B. An architectural evaluation method for conservation of traditional dwellings. *Build. Environ.* **2006**, *41*, 386–394. [CrossRef]
16. Hu, X.; Li, H.; Zhang, X.; Chen, X.; Yuan, Y. Multi-dimensionality and the totality of rural spatial restructuring from the perspective of the rural space system: A case study of traditional villages in the ancient Huizhou region, China. *Habitat Int.* **2019**, *94*, 102062. [CrossRef]
17. Guo, Z.; Sun, L. The planning, development and management of tourism: The case of Dangjia, an ancient village in China. *Tour. Manag.* **2016**, *56*, 52–62. [CrossRef]
18. Sun, C.; Zhang, S.; Song, C.; Xu, J.; Fan, F. Investigation of Dynamic Coupling Coordination between Urbanization and the Eco-Environment—A Case Study in the Pearl River Delta Area. *Land* **2021**, *10*, 190. [CrossRef]
19. Rosner, A.; Wesołowska, M. Deagrarianisation of the Economic Structure and the Evolution of Rural Settlement Patterns in Poland. *Land* **2020**, *9*, 523. [CrossRef]
20. Martínez, P.F.; De Castro-Pardo, M.; Barroso, V.M.; Azevedo, J.C. Assessing Sustainable Rural Development Based on Ecosystem Services Vulnerability. *Land* **2020**, *9*, 222. [CrossRef]
21. Chen, Q.; Xie, H. Temporal-Spatial Differentiation and Optimization Analysis of Cultivated Land Green Utilization Efficiency in China. *Land* **2019**, *8*, 158. [CrossRef]
22. Perchinunno, P.; Rotondo, F.; Torre, C.M. The Evidence of Links between Landscape and Economy in a Rural Park. *Int. J. Agric. Environ. Inf. Syst.* **2012**, *3*, 72–85. [CrossRef]
23. Cerreta, M.; Poli, G. A Complex Values Map of Marginal Urban Landscapes. *Int. J. Agric. Environ. Inf. Syst.* **2013**, *4*, 41–62. [CrossRef]
24. Renes, H.; Centeri, C.; Kruse, A.; Kučera, Z. The Future of Traditional Landscapes: Discussions and Visions. *Land* **2019**, *8*, 98. [CrossRef]
25. Guo, R.; Bai, Y. Simulation of an Urban-Rural Spatial Structure on the Basis of Green Infrastructure Assessment: The Case of Harbin, China. *Land* **2019**, *8*, 196. [CrossRef]
26. Duan, Z.; Lyu, H.; Yang, X.; Yang, Y. Green Improvement Technology of Wind Environment of Traditional Courtyard House A Case Study of Fang Zhaotu House in Fangding Village, Zhengzhou. *Build. Sci.* **2019**, *35*, 25–31.
27. Shao, T.; Zheng, W.; Jin, H. Analysis of the Indoor Thermal Environment and Passive Energy-Saving Optimization Design of Rural Dwellings in Zhalantun, Inner Mongolia, China. *Sustainability* **2020**, *12*, 1103. [CrossRef]
28. Xu, M.; Hu, W.-Q. A research on coordination between economy, society and environment in China: A case study of Jiangsu. *J. Clean. Prod.* **2020**, *258*, 120641. [CrossRef]
29. Mitchell, C.J.A.; VanderWerf, J. Creative Destruction and Trial by Space in a Historic Canadian Village. *Geogr. Rev.* **2010**, *100*, 356–374. [CrossRef]
30. Martellozzo, F. Forecasting High Correlation Transition of Agricultural Landscapes into Urban Areas. *Int. J. Agric. Environ. Inf. Syst.* **2012**, *3*, 22–34. [CrossRef]

31. Tong, W.; Lo, K.; Zhang, P. Land Consolidation in Rural China: Life Satisfaction among Resettlers and Its Determinants. *Land* **2020**, *9*, 118. [CrossRef]
32. Makhzoumi, J.M. Unfolding Landscape in a Lebanese Village: Rural Heritage in a Globalising World. *Int. J. Herit. Stud.* **2009**, *15*, 317–337. [CrossRef]
33. Yu, H.; Luo, Y.; Li, P.; Dong, W.; Yu, S.; Gao, X. Water-Facing Distribution and Suitability Space for Rural Mountain Settlements Based on Fractal Theory, South-Western China. *Land* **2021**, *10*, 96. [CrossRef]
34. Long, H.; Tu, S.; Ge, D.; Li, T.; Liu, Y. The allocation and management of critical resources in rural China under restructuring: Problems and prospects. *J. Rural. Stud.* **2016**, *47*, 392–412. [CrossRef]
35. Attardi, R.; Cerreta, M.; Sannicandro, V.; Torre, C.M. Non-compensatory composite indicators for the evaluation of urban planning policy: The Land-Use Policy Efficiency Index (LUPEI). *Eur. J. Oper. Res.* **2018**, *264*, 491–507. [CrossRef]
36. Torre, C.M.; Morano, P.; Tajani, F. Saving Soil for Sustainable Land Use. *Sustainability* **2017**, *9*, 350. [CrossRef]
37. Li, W.; Zhou, Y.; Zhang, Z. Strategies of Landscape Planning in Peri-Urban Rural Tourism: A Comparison between Two Villages in China. *Land* **2021**, *10*, 277. [CrossRef]
38. Tang, C.; Zheng, Q.; Wang, X.; Zou, Z. Discussion on the model of green development of tourism in traditional village. *J. Arid Land Resour. Environ.* **2019**, *33*, 203–208.
39. Liu, T.; Liu, P.; Wang, L. The protection and tourism development path of ancient villages and old towns under the background of new-type urbanization:A case study of old town of Xuanzhou in Hunan province. *Geogr. Res.* **2019**, *38*, 133–145.
40. Yu, S.-H.; Deng, W.; Xu, Y.-X.; Zhang, X.; Xiang, H.-L. Evaluation of the production-living-ecology space function suitability of Pingshan County in the Taihang mountainous area, China. *J. Mt. Sci.* **2020**, *17*, 2562–2576. [CrossRef]
41. Yang, F.; Chi, G.; Wang, G.; Tang, S.; Li, Y.; Ju, C. Untangle the Complex Stakeholder Relationships in Rural Settlement Consolidation in China: A Social Network Approach. *Land* **2020**, *9*, 210. [CrossRef]
42. Dharmawan, A.H.; Mardiyaningsih, D.I.; Komarudin, H.; Ghazoul, J.; Pacheco, P.; Rahmadian, F. Dynamics of Rural Economy: A Socio-Economic Understanding of Oil Palm Expansion and Landscape Changes in East Kalimantan, Indonesia. *Land* **2020**, *9*, 213. [CrossRef]
43. Tu, S.; Long, H.; Zhang, Y.; Ge, D.; Qu, Y. Rural restructuring at village level under rapid urbanization in metropolitan suburbs of China and its implications for innovations in land use policy. *Habitat Int.* **2018**, *77*, 143–152. [CrossRef]
44. Yu, Z.; Xu, E.; Zhang, H.; Shang, E. Spatio-Temporal Coordination and Conflict of Production-Living-Ecology Land Functions in the Beijing-Tianjin-Hebei Region, China. *Land* **2020**, *9*, 170. [CrossRef]
45. Meng, F.; Guo, J.; Guo, Z.; Lee, J.C.; Liu, G.; Wang, N. Urban ecological transition: The practice of ecological civilization construction in China. *Sci. Total. Environ.* **2021**, *755*, 142633. [CrossRef]
46. Salvia, R.; Egidi, G.; Vinci, S.; Salvati, L. Desertification Risk and Rural Development in Southern Europe: Permanent Assessment and Implications for Sustainable Land Management and Mitigation Policies. *Land* **2019**, *8*, 191. [CrossRef]
47. Li, Y.; Fan, P.; Liu, Y. What makes better village development in traditional agricultural areas of China? Evidence from long-term observation of typical villages. *Habitat Int.* **2019**, *83*, 111–124. [CrossRef]
48. Head, L. Cultural ecology: Adaptation-retrofitting a concept? *Prog. Hum. Geogr.* **2010**, *34*, 234–242. [CrossRef]
49. Qiu, L.; Zeng, W.; Kant, S.; Wang, S. The Role of Social Capital in Rural Households' Perceptions toward the Benefits of Forest Carbon Sequestration Projects: Evidence from a Rural Household Survey in Sichuan and Yunnan Provinces, China. *Land* **2021**, *10*, 91. [CrossRef]
50. Long, Y.; Xu, G.; Ma, C.; Chen, L. Emergency control system based on the analytical hierarchy process and coordinated development degree model for sudden water pollution accidents in the Middle Route of the South-to-North Water Transfer Project in China. *Environ. Sci. Pollut. Res.* **2016**, *23*, 12332–12342. [CrossRef]
51. Chand, B.; Kaushik, H.B.; Das, S. Lateral Load Behavior of Traditional Assam-Type Wooden House. *J. Struct. Eng.* **2019**, *145*, 04019072. [CrossRef]
52. Bu, X.; Pu, L.; Shen, C.; Xie, X.; Xu, C. Study on the Spatial Restructuring of the Village System at the County Level Oriented toward the Rural Revitalization Strategy: A Case of Jintan District, Jiangsu Province. *Land* **2020**, *9*, 478. [CrossRef]
53. Long, Y.; Yang, Y.; Lei, X.; Tian, Y.; Li, Y. Integrated Assessment Method of Emergency Plan for Sudden Water Pollution Accidents Based on Improved TOPSIS, Shannon Entropy and a Coordinated Development Degree Model. *Sustainability* **2019**, *11*, 510. [CrossRef]
54. Fu, J.; Zhou, J.; Deng, Y. Heritage values of ancient vernacular residences in traditional villages in Western Hunan, China: Spatial patterns and influencing factors. *Build. Environ.* **2021**, *188*, 107473. [CrossRef]
55. Gong, W.; Wang, N.; Zhang, N.; Han, W.; Qiao, H. Water resistance and a comprehensive evaluation model of magnesium oxychloride cement concrete based on Taguchi and entropy weight method. *Constr. Build. Mater.* **2020**, *260*, 119817. [CrossRef]
56. Wang, D.; Jiang, D.; Fu, J.; Lin, G.; Zhang, J. Comprehensive Assessment of Production–Living–Ecological Space Based on the Coupling Coordination Degree Model. *Sustainability* **2020**, *12*, 2009. [CrossRef]
57. Wang, H. Regional Ecological Risk Assessment with Respect to Human Disturbance in the Poyang Lake Region (PYLR) Using Production–Living–Ecology Analysis. *J. Indian Soc. Remote. Sens.* **2021**, *49*, 449–460. [CrossRef]
58. Wei, C.; Lin, Q.; Yu, L.; Zhang, H.; Ye, S.; Zhang, D. Research on Sustainable Land Use Based on Production-Living-Ecological Function: A Case Study of Hubei Province, China. *Sustainability* **2021**, *13*, 996. [CrossRef]

59. Lin, J.; Song, G.; Zhang, Y. Synergistic Evolution Mechanism of Production-Living-Ecology Functions in Spatial Planning System: A Case Study of Fuxin City. *China Land Sci.* **2019**, *33*, 9–17.
60. Geng, Y.; Zhang, H. Coordination assessment of environment and urbanization: Hunan case. *Environ. Monit. Assess.* **2020**, *192*, 637. [CrossRef]
61. Qiao, W.; Hu, Y.; Jia, K.; He, T.; Wang, Y. Dynamic modes and ecological effects of salt field utilization in the Weifang coastal area, China: Implications for territorial spatial planning. *Land Use Policy* **2020**, *99*, 104952. [CrossRef]
62. Zhai, R.; Liu, Y. Dynamic evolvement of agricultural system and typical patterns of modern agriculture in coastal China: A case of Suzhou. *Chin. Geogr. Sci.* **2009**, *19*, 249–257. [CrossRef]

land

MDPI

Article

Analysis of Replicability of Conservation Actions across Mediterranean Europe

Daniel Ibarra-Marinas, Francisco Belmonte-Serrato, Ramón García-Marín and Gustavo Ballesteros-Pelegrín *

Department of Geography, Campus La Merced, University of Murcia, 30001 Murcia, Spain; adaniel.ibarra@um.es (D.I.-M.); franbel@um.es (F.B.-S.); ramongm@um.es (R.G.-M.)
* Correspondence: gabp1@um.es

Abstract: In the Regional Park of Las Salinas and Arenales of San Pedro del Pinatar, in southeastern Spain, an environmental restoration and conservation project is being developed whose principle actions include adaptation of hillocks with a saline substrate to improve the reproduction habitat of aquatic birds and increasing the production of salt, dune restoration and conservation, protection of the first dune ridge through the collection of seagrass tops, and designing and implementation of a salt quality seal, which may be useful for reproduction in other sites in the Natura 2000 network, especially in the European Mediterranean area and in the Black Sea environment. The objective of this research study was to analyse and locate the sites that could possibly replicate the actions of the project. In order to do this, spatial databases were used from the Natura 2000 network, salt flats, and marshes as well as Ramsar sites and SPAMI sites, and from them a shape file of points was created in the places with the presence of maritime dunes associated with marsh systems/salt flats. One hundred thirty-one sites in the Natura 2000 network were located, of which in 105 cases, one or more of the four actions considered in this research study can be replicated. Of these, 24 cases have active or recently abandoned salt flats in which the two main actions of the project can be replicated, and 11 of these sites meet characteristics for the replicability of the four actions, of which three have not been implemented by the LIFE projects developed on those sites.

Keywords: environmental restoration; conservation; replicability; Natura 2000 network; coastal salt flats; wetlands; dune systems, natural parks

Citation: Ibarra-Marinas, D.; Belmonte-Serrato, F.; García-Marín, R.; Ballesteros-Pelegrín, G. Analysis of Replicability of Conservation Actions across Mediterranean Europe. *Land* **2021**, *10*, 598. https://doi.org/10.3390/land10060598

Academic Editors: Mónica de Castro-Pardo, Joao C. Azevedo and Pascual Fernández

Received: 9 April 2021
Accepted: 2 June 2021
Published: 4 June 2021

1. Introduction

Wetlands are some of the most productive and ecologically valuable ecosystems [1]. According to Barbier et al. [2], wetlands perform critical ecosystem functions and services as stopovers for migratory birds, critical nursing grounds, production of raw materials and food, maintenance of coastal fisheries, coastal protection, erosion control, and carbon sequestration. Despite their importance and increased efforts to preserve them, wetlands are still being transformed for urban development and other activities like aquaculture at a rapid pace [3]. Some authors indicate the existence of a greater awareness of the importance of wetland ecosystem functions as well as growing concerns among environmentalists [4], and this growing restlessness has resulted in a range of conservation and management approaches [5–8]. These approaches include policy instruments at different administrative levels [4] such as implementing various wetland restoration programs [9] in order to mitigate the negative impacts of socioeconomic development on these unique ecosystems [10,11] and provide resources and monetary incentives for their conservation [12,13].

There are numerous highly productive wetlands with varied ecosystem services [14] affected by anthropogenic stress due to the large coastal population [15,16]. One of the main problems encountered affects the reduction and disappearance of biological diversity, a consequence of habitat modification, usually due to conversion and degradation of wetlands [17]. The objectives in these cases are to promote the reduction of ecosystem stress through the identification of environmental problems in a diagnostic analysis, then establishing strategic action programs [18]. Normally, among the programmed strategies, public awareness campaigns are carried out to increase environmental awareness directed at different levels of society [19–21], including parliamentary workshops for politicians, training events for local government officials, scientific conferences, and the participation of scientists in research and reporting to university and high school students, sometimes conducting environmental camps [22].

Networks are also usually created and associations that collaborate and work with environmental organizations and NGOs [23,24] carry out biodiversity assessments that have contributed to scientific development toward the improvement of densities, distributions, and genetic diversity of populations of endangered and endemic species as well as favourable actions for the maintenance of habitats according to norms and regulations and a reduction of the risk of introduced species. The final goal of these programsis to ensure that biodiversity remains present to benefit future generations.

There seems to be, therefore, an urgent need to develop and improve ecological restoration methods to rehabilitate or restore degraded coastal wetlands. And in this context, the LIFE Project [25] that we describe below is framed.

Scholars, practitioners, and environmentalists are increasingly supportive of collaborative, ecosystem-based approaches to coastal resource management [26]. However, few researchers have focused their attention on trying to promote satisfactory improvement actions in wetlands and salt ponds that can be used in other places with similar environmental characteristics.

In this sense, the objective of this research study was to analyse and locate the sites that could possibly replicate the actions of the project, that is, those places with similar characteristics to the study area (European Mediterranean coastal environments) and with a greater possibility of being able to successfully transfer the management and tasks or studies developed in the Regional Park of Las Salinas and Arenales of San Pedro del Pinatar.

2. The Project and Study Area

2.1. The Project

A project is being developed in the Regional Park of Arenales and Salinas of San Pedro del Pinatar (southeastern of Spain) (LIFE-Salinas) in which the field of nature conservation, restoration, and improvement in the production of salt and its interrelation with the tourism industry is being studied.

The main objective is the conservation of the Audouin's gull (*Larus audouinii*) and the following priority habitats: 1510 *, Mediterranean saline steppes (*Limonietalia*); and 2250 *, littoral dunes with *Juniperus* spp. in the Site of Community Importance (SCI) and Special Protection Areas for Birds (SPAs) ES0000175 "Salinas y Arenales de San Pedro del Pinatar". On the other hand, as an added value, the project will allow favouring habitats to be included in the Habitat Directive and increase the integration and ecosystem cohesion of the SCI and SPAs. Likewise, as an added objective, the project aims to facilitate the transfer and replicability of some of its main actions outside its territorial scope (other regions or countries).

This project is expected to increase habitats of special interest after the construction of 1800 m of new salt mines and the repair of other mines, covering them with a substrate of lagoons that heat the ground and prevent the development of vegetation. The recovery of the water circuit of the Coterillo lagoon (saline wetland) will allow for the recovery of endangered species, such as the Spanish tooth carp (*Aphanius iberus*), and will expand the feeding area of the Audouin gull. It is also expected to halt erosion in the adjacent La Llana beach and recover and protect the ridge of dunes in its first 500 m south of the port of San Pedro del Pinatar, an important areaof habitat for 1510 Mediterranean saline steppes. Stopping the erosion of the dune system of Playa de la Llana will improve the conservation of priority habitat 1510 * and benefit 10 other habitats in Annex I of the Habitat Directive. In addition, the actions related to the improvement of the dune–beach system will make it possible to face the challenges of climate change (the rise in sea level and increase in the frequency of storms) and prevent Mediterranean waters from invading the salt lagoons adjacent to the colony of Audouin's gulls and other species.

The most transferable action of the project is the design and implementation of a quality and environmental protection certificate for the salt produced in the Mediterranean salt flats that are included in the Natura 2000 network.In the following link all the information on this project can be found: https://lifesalinas.es/en/home/ (accessed on 31 May 2021).

2.2. Study Area

The project intervention area is limited to the Regional Park of the Salinas and Arenales de San Pedro del Pinatar (Figure 1) in the extreme north of the coast of the Region of Murcia (southeastern Spain) within the municipality of San Pedro del Pinatar, its northern limit coinciding with the provincial limit between the provinces of Murcia and Alicante and in its southern limit borders the area called Las Encañizadas, an area of natural communication between the Mediterranean and the Mar Menor, with very shallow depths (50–100 cm) where a traditional method of fishing called Encañizada is still actively used. This space is about 65 km long and 1.4 km at its widest part, and geomorphologically constitutes the northern closure of the La Manga del Mar Menor spit, a 22 km long strip that separates the Mediterranean from the coastal lagoon called the Mar Menor (the largest salt lake in Europe). This lagoon is the remnant of an old bay, wider than the current lagoon, filled over the last 10 million years [27]. The closure of the spit has been occurring since the beginning of the Quaternary period via sediments from the mouth of the Segura River, transported south by the littoral current that is cut off in Cabo de Palos. The sediments were deposited around some islands of volcanic origin, more or less aligned in a north–south direction (Calnegre and Monte Blanco), and on the Tertiary sandstone reefs of Pedrucho, Estacio and Punta de Algas [28]. The almost definitive closure already occurred about 2000 years ago, but communication with the Mediterranean is maintained through artificial channels or natural gullies [29].

It is aprotected natural area made up of a complex set of wetlands, occupied mainly by extensive areas destined for salt exploitation and adjacent ecological systems of great interest. There is an important biota adapted to the presence of water [30,31], and if we look at the definition of wetlands established at the Ramsar Convention, which states that "For the purposes of this Convention, wetlands are extensions of areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water the depth of which at low tide does not exceed six meters", this natural space can be considered to be a unique wetland.

It was declared a Nature Park, or Protected Nature Reserve, in 1985, with a total area of 856 hectares, and in 1992 it acquired the status of Regional Park. Since 1994 it has been included in the List of Wetlands of International Importance (according to the Ramsar Convention). The importance of this wetland as a nesting, wintering, and migration site for a large number of migratory birds, such as flamingos, avocets, stilts, etc., led to it being declared a Special Protection Area for Birds (SPAB) in 1998 (Resolution of 13 October 1998; BORM nº 246 of 24 October 1998), with an area of 841.75 ha, thus becoming part of the Natura 2000 network of the European Union.

As an integral part of the Mar Menor, it is also a Specially Protected Area of Mediterranean Importance (SPAMI). In addition, due to its fauna values (reptiles such as the red-tailed lizard, the *Pimelia* sp. beetle, endangered fish such as the Spanish tooth carp, small crustaceans such as *Artemia* sp., and various species of bats, in addition to the aforementioned birds) and flora (tamarisks, salicornias, marjoram trees and rushes in the salt marshes, and Aleppo pine, mastic, black hawthorn, birds-foot-trefoil, lily, thistle or sea caterpillar, on the dune ridge), and practically coinciding with the SPAB space, it was also declared a Place of Community Importance.

Figure 1. Area of study. Source: own elaboration from a PNOA image.

The majority of the park, about 500 hectares of the 856 total, is occupied by the premises of the salt mine, consisting of three types of salt ponds and the processing facilities of the Spanish company Salinera Española, owner of the salt works prior to the delimitation of the Maritime Public Domain and current operating owner. In front of the Mediterranean-facing side of the park, between 0.50 m and 30 m deep, there are extensive meadows of *Posidonia oceanica*, a seagrass exclusive to the Mediterranean. Posidonia, an important primary producer, provides a high amount of oxygen and regulates CO_2. Furthermore, due to its positioning parallel to the coast, it forms an effective barrier that considerably reduces and dissipates wave energy [32]. Likewise, it traps the sand moved by the waves, preventing its transport beyond the closing depth of the submerged beach. On the other hand, the dead parts of the plant are transported by the waves to the beach, where they end up forming important accumulations of banquettes that serve as a refuge and nesting place for some birds, such as the black-footed plover (*Charadrius alexandrinus*), in addition to being food for many species of crustaceans and molluscs, which, in turn, feed the many seabirds in the area. Likewise, after being removed from the beach during the tourist season, it has been used to protect the dune ridge from the onslaught of waves in storms with winds coming from the east, with the dead parts of the plant accumulating on the dune front.

3. Materials and Methods

The study of the replicability and transferability of the project actions required the analysis and extrapolation of the environmental characteristics of the study area. Although most of the actions can be carried out in places with characteristics that are very different from the target area of the project. An attempt was made to exclusively identify areas that may have similar attributes from a conservation point of view, for which the analysis of spatial data has been necessary in order to optimize the choice of potential areas of replicability and transferability of some of the improvement and conservation actions contemplated in the project. In particular, the specific actions subject to transferability would be the following:

(a) The adaptation of hillocks with saline substrate: These actions are aimed at improving the reproduction habitat of aquatic birds and increasing the production of salt. This action has a twofold objective: (i) on the one hand, the adaptation of hillocks with saline substrate aims to increase the production of salt by 3%, since it is intended to repair the deteriorated hillocks and build new ones to expand the circulation circuit of the water, which will accelerate heating; (ii) on the other, it represents an improvement in the nesting conditions of Larus audouinii, since it aims to increase the nesting habitat of this and other species in Annex I of the Birds Directive by 17% (*Recurvirostra avosetta*, *Charadrius alexandrinus*, *Gelochelidon nilotica*, *Sterna hirundo*, *Sternula albifrons*, and *Sterna sandvicensis*). At the end of the 1990s, only two colonies of Larus audouinii made up 85% of its world population. The most important was located in the Ebro Delta, with 60% of the world population [33], and the second largest colony was in the Chafarinas Islands, which had 25% of the total population. In recent decades, and despite the increase in breeding pairs, the wintering population of Larus audouinii has been reduced and dispersed [34]. The survival of the chicks depends on several factors such as the quality of the parents, the availability of food, the hatching order, the rates of predation, diseases, and climatic and habitat conditions [35–39]. Despite the variety of spaces used for breeding, both in the Ebro Delta and in the Salinas and Arenales Regional Park of San Pedro del Pinatar, the species Larus audouinii selects the hillocks of the salt ponds as habitats. A very favourable habitat is sandy saline patches and sandy areas without vegetation or with a moderate vegetation cover. The high salt content of the salt substrate used in this action favours this type of condition, and the correct circulation of the water in the saltworks will allow for the expected increase in production. For the selection of spaces, three minimum criteria have been considered: that the area is Mediterranean, that it is included in the Natura 2000 network, and that it has an area of artificial salt marshes/salt marshes.

(b) Dune restoration and conservation: The objective of this action is to stabilize the dunes located in the first 500 m at sea level of the Port of San Pedro del Pinatar (Figure 1) through the installation of sand collectors. This action will allow the reduction of wind speed, reducing the load of sand transported outside the dune–beach system, increasing the volume of deposits [40]. In addition, the action includes the elimination of the paths formed by the trampling of pedestrians along the dune system, for which perimeter fencing around those first 500 m of dune ridge from the north access will be made, which are the most deteriorated by the continuous passing of bathers during the summer months. The action will also include the recovery of the accumulated sand in one of the salt ponds and its transfer to the eroded area of the dune to restore its original state. The criteria for the selection of replicable spaces are the presence of dune–beach systems with the possibility of installing sand collectors, and the possibility of eliminating exotic species and introducing or revegetating with species included in Habitats of Community Interest (Annex I, Directive Habitats).

(c) Protection of the first dune ridge (the only ridge in some cases) through the collection on the dune front of seagrass tops (*Posidonia oceanica*, *Zostera marina*, *Cymodocea nodosa*, etc.) that accumulate on the beaches during coastal storms.

(d) Designing and implementation of a salt quality seal: To design and apply the methods, procedures, and criteria for obtaining a salt quality certificate for salt flats in the Natura 2000 network, compatible with the conservation of the territory and biodiversity.

3.1. Data Sources

Once the criteria for the actions with the possibility of replication were established, several spatial databases were used that contain the areas of the European Union with characteristics similar to those of the Salinas and Arenales Regional Park in San Pedro del Pinatar. The spatial data sources that were used are the following:

(a) Natura 2000 network: Provided by the European Environmental Agency, it contains, in shapefile format, the points and polygons of the spaces included in the Natura 2000 instrument, an ecological network of protected areas created to guarantee the survival of the most valuable species and habitats in Europe. Natura 2000 is based on the 1979 Birds Directive and the 1992 Habitats Directive. This version covers reporting since 2017. The database includes 27,738 sites within the scope of the European Union, with codes, types of places, and release dates.

(b) Salt flats and marshlands: This dataset shows the distribution of marshlands and salt flats (currently active or active until recently that still conserve salt structures) worldwide in polygon and point shapefile format. The database has been created and provided by the World Conservation Monitoring Center (UNEP-WCMC). All the sources used for its elaboration are included in the metadata [41] and include articles, reports, and documents reviewed by peers as well as databases created by non-governmental and governmental organizations, universities, institutes of independent research, and researchers worldwide. In total, it outlines 26,398 places around the world, with relevant data such as altitude, area, type, name, and international codes.

(c) Ramsar sites: Provided by the Ramsar Sites Information Service, contained in CSV format, this dataset contains information on the criteria, name, region of location, ecosystems, main threats, and coordinates of the 2342 Ramsar sites around the world.

(d) SPAMIs: For the treatment of spatial data related to the SPAMI areas, two KML (Keyhole Markup Language) files were used, one of points and the other of polygons. The data were obtained through the Mediterranean Centre for Marine and Environmental Research (CMIMA).

(e) Dune–beach system zones: From the previous data sources, a shapefile of points was generated for the places with the presence of maritime dunes associated with the marshland/salt marsh systems. This database was created from a photointerpretation of the Mediterranean Coast.

The treatment of spatial data was carried out with the free software QGIS, an open-sourcegeographic information system (GIS), licensed under the General Public License (GNU) that constitutes a project of the Open-Source Geospatial Foundation (OSGeo). QGIS enables the processing of spatial data in raster and vector file formats. The version used in the present study was 2.18.

3.2. Procedure

From the coordinates of the Ramsar sites database, the CSV file was transformed into a shapefile. Once the databases shared the same format, the data was cross referenced in order to obtain the places that meet the requirements of the Salinas and Arenales of San Pedro del Pinatar Regional Park, located in the Mediterranean, which belong to the Ramsar Convention, and will be represented in the UNEP-WCMC database of salt flats and marshes and included in the Natura 2000 network of the European Union. The crossing of the three databases was carried out from the vector data management tools of the QGIS software. The expected results when carrying out this methodology were the location of spaces similar to the target area of the LIFE-Salinas Project.

Using aerial photographs, the elements of each location were located and information, such as the presence of dunes and activity or abandonment of the saltworks, wascollected through photointerpretation (Figure 2).

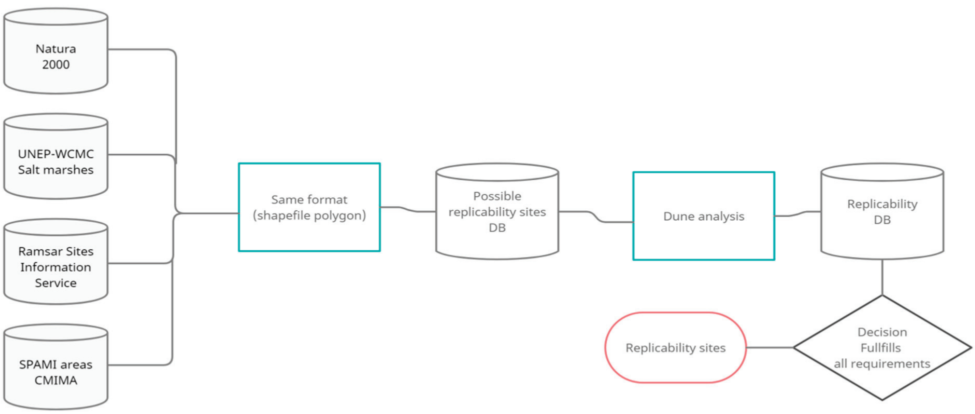


Figure 2. Conceptual scheme of the methodology followed. Source: ewn elaboration.

4. Results and Discussion

4.1. The Natura 2000 Network in the Area of the European Mediterranean and the Black Sea

In the Natura 2000 network database, 131 sites located on the European Mediterranean coast, the Black Sea, and Portugal were identified that meet all or some of the conditions and attributes of the Regional Park of the Salinas and Arenales of San Pedro del Pinatar, always from the point of view of conservation. That is, coastal lagoons/marshes, wetlands and/or salt structures currently active or inactive but easily recoverable, and coastal beaches and dunes with or without the presence of seagrass meadows on the nearby and underlying marine platform.

After analysing the conditions for the replicability of some of the four actions contemplated in this research study, 26 sites were eliminated that, although being marshes or other types of coastal wetland, do not have salt structuresor dune ridges, and, consequently, do not meet the conditions for the replicability of any of the four actions that are proposed as replicable. It should be noted that Malta also has some active salt flats [42], such as the Bugibba salt flats, but this site was dismissed because it is in an excessively urban environment in which there is no beachor, of course, a dune ridge; and also the historic Qbajjar salt flats, which are more than 2000 years old and dug directly into the sandstone of a fossil beach, which today is about 3 m above sea level.

Thus, after this initial screening, 105 sites were selected in which one or more of the four actions considered can be replicated (Appendix A and Figure 3). Of these, 26 do not have any other protection figure apart from belonging to the Natura 2000 network.

Forty-five are, in addition to the Natura 2000 network, Ramsar sites, 62 are ZEPIM sites, and in 28 cases both figures overlap.

By country, Italy (IT) is by far the country with the most sites in the Natura 2000 network in which one or more project actions can be carried out (43 sites). Spain (ES) has 19 sites, in France (FR) 14 sites were located, Greece (GR) has 11 sites, in Portugal (PT) there are 6 sites, Croatia (HR) has 5 sites, and in Bulgaria (BG) 4 sites were located. Finally, in Estonia (SI), Romania (RO), and Cyprus (CY), one site was located in each of them (Appendix A).

Figure 3. Sites of the Natura 2000 network and location of the 11 sites where the hillocks repair actions with a saline substrate, quality sealing and dune restoration, and conservation can be replicated. The boxed codes correspond to the 11 most favourable replicability sites. Source: own elaboration.

4.2. Replicability

Although there are numerous scientific articles that offer methodologies and proposals for actions to be carried out in places with similar environmental characteristics, there are not so many that describe actions developed in LIFE projects and specifically address their replicability and transferability to other projects that contain related environmental improvement objectives [43,44]. In this sense, it is necessary to search for projects with similar objectives in order to establish replicable actions and obtain a certain guarantee of the expected results. On the other hand, when its intention is to find out the scope of the transferability of a project, geography as a discipline and its currently most common work tools, such as geographic information systems (GIS), facilitate the search for locations with similar environmental patterns [45].

The analysis of the possibilities of replication of the actions of the aforementioned project showed that the dune restoration and conservation actions (sand collectors, control of exotic species, and revegetation) could be replicated in 103 of the 105 selected sites (Appendix A). Only two sites lack a dune ridge: Saline di Priolo, a small salty lagoon in southwestern Sicily in which at some point in the past there was a small saline installation, and Paludi presso il Golfo di Manfredonia, some salt pans located in a small inland lake separated from the Adriatic Sea by just over 2 km, which is completely urbanized today. According to Irene Prisco et al. [46], various regulatory and management tools are commonly used to prevent the negative effects of human trampling on sand dune habitats, but few studies have attempted to assess the effects of walks on the vegetation of the dunes. Several studies have highlighted the value of the ecosystem and the diversity of these habitats, threats, vulnerability, and the need for urgent conservation actions. Among other authors, Bonari et al. [47] provided examples of restoration and effective management. In addition, Bezzi et al. [48] developed a coastal dune management geodatabase, while Pinna et al. [49] applied sand trap systems to replant key dune species with the help of fences and boardwalks to reduce human trampling.

Of these 103 sites with the possibility of dune restoration and conservation, in 62 this action could be supported with the collection of banquettes of seagrasses for their protection against maritime storms [50–52], since in front of the coast of these sites there are oceanic Posidonia meadows or other phanerogams capable of generating banquettes that can be used for the protection of the dune front.

On the other hand, the actions of the repair of hillocks with a saline substrate and implementation of a quality seal in the production of salt could only be replicated in 24 sites where saltwork structures with current activity (industrial or artisanal) were located, or even sites with recently inactive saltworks, meaning that the salt structures are still in good condition and could eventually be used again for the production of salt. In this sense, the sites with salt flats located in this study differ from those mentioned in the "guidelines for the environmental management of salt flats in the Mediterranean and the Black Sea" [19], which include a list of the most recently located salt flats in the Mediterranean and the Black Sea, in which there are 80 salt flats, not including those in Portugal, a country in which we located two salt flats. Of the 80 salt flats, the document considers 37 (13 more than those mentioned in this study, or 15 if we subtract the two in Portugal) to be active. But it was found that, for example, some of the salt flats that were counted in Spain are salt flats that had been abandoned for a long time [53,54], and, in some cases, as occurs in the site of Lo Poyo in the Mar Menor, it is a saline wetland where salt activity was never exerted; so given the discrepancies with the list of salt flats presented in the aforementioned document, and as long as an in-depth review of the salt sites is not carried out, updating and preparing a new list of industrial and artisanal salt flats, active and not active in the Mediterranean and the Black Sea, we could consider the sites located in this study as valid.

Regarding the 24 salt flat sites located in our research study, in 11 of them the replication of the repair actions of hillocks with a saline substrate and a quality seal can be accompanied by those of the restoration and conservation of dunes and protection of dunes through the collection of gorse of phanerogams. That is, there are 11 sites where the four proposed actions can be replicated, the location of which is shown in the following cartography (Figure 3).

To determine if conservation actions were carried out in the selected sites, equal to or similar to those contemplated in this project, and, therefore, if replicability would be repetitive, a search was carried out of the LIFE projects and their general objectives developed at different sites (Table 1).

It was verified that conservation projects linked to the LIFE program were carried out in 18 sites with proposals for actions that are in some way related to the proposals in this study. In two of those sites there were 2 and 3 linked projects. In another 7 sites it is possible that projects were developed, perhaps not linked to the LIFE program, or perhaps, for which information was not found (sometimes the projects that were found developed actions that are very different from those contemplated and listed here). Therefore, in principle, these are very suitable sites for the replicability of the actions of this project. In some cases, all the actions could be replicated, as in the Stagno di Santa Caterina site on the island of Sardinia, one of the most favourable places due to its similarity with the surroundings of the Regional Park of Salinas and Arenales of San Pedro del Pinatar, since it has active salt flats, dune ridges in the process of erosion, and oceanic Posidonia meadows that generate a large number of banquettes. In fact, among the activities of the LIFE-Salinas Project, a visit to the Stagno di Santa Caterina site is planned to explore the possibility of collaboration with its managers and to transfer and replicate the actions set out in this paper. In addition, the sites located in Portugal, Ria Formosa and Sapais de Castro Marim, which despite being close to the Atlantic meet Mediterranean environmental and climatic conditions, are conducive to replicating the repair of hillocks with a saline substrate, implementation of a quality seal, and dune restoration and conservation; but it would be little or not at all viable for the protection of the dune ridge with tufts of seagrasses.

Sousa et al. [55], when studying long-term land use change in Ria Formosa, argued that in areas of high conservation value, new policies that stimulate the development of an ecosystem approach to economic activities should be considered. According to these authors, aquaculture simultaneously improves regional environmental status and sustainable socioeconomic development.

In other cases, actions would only be feasible in the salt flats, such as at the Salinas di Trapani site, which is without an appreciable dune ridge, and at the Marais et zones humides liÚs Ó l'Útang de Berre site in France. Likewise, at the Embouchure du Stabiaccu, Domaine Public Maritime et îlot Ziglione site on the island of Corsica (with inactive but recoverable salt pans), actions on dunes could be replicated.

Of the sites where projects had been developed, 7 (4 in Italy, 2 in France, and 1 in Bulgaria) were co-participants in the same project, the LIFE MC SALT, whose main objective was "conservation, management, and rehabilitation of active salt flats, dunes, and coastal wetlands", and in which actions similar to those proposed in this paper had been developed. However, it was not possible to verify that the hillock repair had been carried out with a saline substrateor that a quality seal had been implemented or that the dune ridge had been protected with seagrass tops. In this sense, they are also sites where at least these three actions could be replicated.

In Limnothalassa Angelochoriou (Greece), the LIFE 09/NAT/E/000343 project (2010–2015) also developed actions, in some cases, similar to those proposed in this paper, but it did not it develop actions to restore hillocks with a salt substrateor implement a quality seal for the salt produced or protect the dune ridge with banquettes. The situation is similar in Seoveljske soline" (Slovenia), where the LIFE 09/NAT/SI/000376-MANSALT project (2010–2019) had as objectives (i) to establish control over the water regime of the salt flat and restore degraded areas, (ii) raise awareness about the importance of traditional salt production, which preserves nature and allows sustainable development of the local community, and (iii) present a model of good practice on the use of traditional methods in the reconstruction of the salt mine, that are closely related to many of the objectives of our LIFE-Salinas project but none of the four actions proposed in this research study are exactly considered as replicable and would greatly improve the rest of the actions of restoration and environmental conservation.

In Spain, the LIFE09 NAT/ES/000520 (LIFE-Delta Lagoon) project, developed between 2010 and 2014, carried out actions quite similar to those proposedin this paper (Table 1), but as in the rest of the projects found, it did not contemplate the recovery of hillocks with a salt substrate or the implementation of a quality seal for the salt produced, since its objective in the old San Antonio salt flats was only to recover the connectivity of the salt ponds. There were also no actions on the dunes, so the replicability of the actions of this project is also feasible. In the other 8 remaining sites, the objectives and actions of the developed projects are further from the replicable actions proposed, so they are sites with many possibilities of replication of the actions proposed here.

Among the projects prior to LIFE-Salinas that had generated replicability through their actions, we can mention some whose methodologies inspired actions carried out in our LIFE-Salinas project. Thus, for example, in a Mediterranean environmental context, we can cite the project "MC-SALT—Environmental Management and Restoration of Mediterranean Salt Works and Coastal Lagoons", with actions in Italy, France, and Bulgaria over the period (2013–2016), and with the objective of preserving native species and dunes. This project had a precedent in the LIFE Valli di Comacchio [56], focused on the ecological restoration and conservation of habitats in the salt flats and SCI of the same name, but in the case of the LIFE MC-SALT, for the first time the optimization of the water flow in the salt flats was contemplated to improve their performance.

Outside the Mediterranean area, the ARCOS LIFE 2014–2018 project focused on actions aimed at improving the state of conservation of the dune ecosystems of the Cantabrian coast (northern Spain), starting from a fragile situation due to both natural and anthropic threats [57]. Its actions included the elimination of non-native tree cover, the elimination of exotic species, the planting of dune species, and the installation of sand traps for the development of the dunes. These last two actions are key to proper management of Mediterranean dunes [58] and are usually carried out in any project that includes dune restoration.

Table 1. Sites of the Natura 2000 network with industrial or artisanal salt flats and projects developed in them related to one or more of the actions proposed in this study.

Site Code	Sites	Condition *	Related Life Projects	
			Project	Main Objective
BG0000270	**Atanasovsko ezero**	A	LIFE17 NAT/BG/000277 (2010–2014)	Improving the management of the coastal wetland complex
			LIFE17 NAT/BG/000362 (2012–2018)	Establishing a functional and efficient structure for the management of the water of the coastal area
			LIFE17 NAT/BG/000558 (2018–2024)	Improving the state of coastal lagoons and their long-term conservation
ES0000140	Bay of Cádiz	R	LIFE Litoral Cádiz. LIFE03 NAT/E/000054 (2003–2006)	Restoration, conservation, and management actions in coastal ecosystems (wetlands, dunes)
FR9310019	Camargue	A	LIFE MC SALT LIFE 10/NAT/IT/000256 (2011–2015)	Conservation, management, and rehabilitation of active salt flats, dunes, and coastal wetlands
			LIFE + ENVOLL LIFE 12 NAT/FR/000538 (2013–2018)	Protection of seabirds in saline environments
GR2310001	**Delta Acheloou, Limnothalassa Mesolongiou—Aitolikou, Ekvoles Evinou, Nisoi Echinades, Nisos Petalas**	A	LIFE95 NAT/GR/001111 (1995–1999)	Contribute to the conservation of the slender curlew (Numenius temuirostris)
ES0000020	**Delta de l'Ebre**	A/R	LIFE09 NAT/ES/000520 LIFE-Delta Lagoon (2010–2014)	Improving the ecological status and hydrological connectivity of the Alfacada lagoon. Mitigating the effects of the coastal regression. Improving the status of priority habitats and species. Improving the ecological status and hydrological connectivity of the old San Antonio salt flats (La Tancada lagoon area) Developing monitoring and dissemination measures of the ecological values of the restored areas.

Table 1. *Cont.*

Site Code	Sites	Condition *	Related Life Projects	
			Project	Main Objective
FR9400586	Embouchure du Stabiaccu, Domaine Public Maritime et îlot Ziglione	R	-	-
FR9112006	Etang de Lapalme	R	LIFE + ENVOLL LIFE 12 NAT/FR/000538 (2013–2018)	Preparatory actions in the Sigean salt flats and conservation of the old marshes
FR9112007	Étangs du Narbonnais	A/R	LIFE + ENVOLL LIFE 12 NAT/FR/000538 (2013–2018)	Preparatory actions in the Sigean salt flats and conservation of the old marshes
ES0000485	**Mata and Torrevieja Lagoons**	A	LIFE Salinas Torre Vieja LIFE 08/NAT/E/000077 (2010–2011)	Creation of a decantation and ecological recovery circuit for the La Mata and Torrevieja lagoons
GR1220005	**Limnothalassa Angelochoriou**	A	LIFE 09/NAT/E/000343 (2010–2015)	Improving the conservation status of coastal lagoons, salty steppes, and beds of posidonia (Posidonia oceanica), as well as priority seabird species such as the curl (Numenius tenuirostris) and the pygmy cormorant (Microcarbo pygmeus)
FR9301597	Marais et zones humides liÚs Ó l'Útang de Berre		-	-
IT9110038	Paludi presso il Golfo di Manfredonia	A	LIFE 09/NAT/E/000150 (2010–2019)	Improving the conservation status of priority wetlands, lagoons, coastal dunes, and saline steppes
FR9101406	Petite Camargue	A	LIFE MC SALT LIFE 10/NAT/FR/000256 (2011–2016)	Conservation, management and rehabilitation of active salt flats, dunes, and coastal wetlands
BG0000152	**Pomoriysko ezero**	A	LIFE MC SALT LIFE 10/NAT/BG/000256 (2011–2016)	Conservation, management and rehabilitation of active salt flats, dunes, and coastal wetlands
PTZPE0017	Ria Formosa	A	?	-
IT4070007	Salina di Cervia	A	LIFE MC SALT LIFE 10/NAT/IT/000256 (2011–2016)	Conservation, management, and rehabilitation of active salt flats, dunes, and coastal wetlands
ITA090013	Saline di Priolo	R	LIFE MC SALT LIFE 10/NAT/IT/000256 (2011–2016)	Conservation, management, and rehabilitation of active salt flats, dunes, and coastal wetlands
ITA010007	**Saline di Trapani**	A	-	-
FR9312008	Salins d'Hybres et des Pesquiers	R	LIFE MC SALT LIFE 10/NAT/FR/000256 (2011–2016)	Conservation, management, and rehabilitation of active salt flats, dunes, and coastal wetlands
PTZPE0018	Sapais de Castro Marim	A	-	-
SI5000018	**Seoveljske soline**	A	LIFE 09/NAT/SI/000376-MANSALT (2010–2019)	Establish control over the water regime of the saline and restore degraded areas. Raise awareness about the importance of traditional salt production, which preserves nature and allows sustainable development of the local community. Present a model of good practices on the use of traditional methods in the reconstruction of the saline.

Table 1. *Cont.*

Site Code	Sites	Condition *	Related Life Projects	
			Project	Main Objective
ES0000084	**Ses Salines d'Eivissa i Formentera**	A	-	-
ITB044003	**Stagno di Cagliari**	A	GILIA LIFE96 NAT/IT/003106 (1997–2002)	Restore the environmental quality of the Stagno di Cagliari. Elimination of landfills. Cessation of the entry of wastewater.
ITB040022	**Stagno di Molentargius e territori limitrofi**	A	LIFE MC SALT LIFE 10/NAT/IT/000256 (2011–2016)	Conservation, management, and rehabilitation of active salt flats, dunes, and coastal wetlands
ITB042223	**Stagno di Santa Caterina**	A	-	-

* **Note:** Salinas: A = active; R = recoverable. **In Bold:** sites where the four proposed actions can be replicated. Source: own elaboration.

According to Sun et al. [59], coordination between different scales and administrative levels, as well as international cooperation, should be fundamental strategies for improving the management and conservation of wetlands.Likewise, according to Gumiero et al. [60], the successful management of natural resources is much more than developing good science, it requires working together with the many agents and/or actors involved, and above all sharing knowledge through diverse case studies.

5. Conclusions

LIFE projects require the dissemination of actions and their replication at the European level. In this context, the LIFE-Salinas Project has always sought to implement a large part of its actions. The methodology used in its nature conservation actions is transferable and replicable in a large part of the Mediterranean area, and transferability is optimal in coastal places with dune systems and with saline exploitations, especially if they are located within the Natura 2000 network. Beyond the economic and social importance of Mediterranean salt pans, this research study highlights the importance of maintaining their activity, since it is key in the conservation of coastal wetlands.

The creation and use of spatial databases constitute a key tool when analysing the replicability of actions of environmental improvement projects such as the one at hand. In addition to providing information, they allow working with different variables in a unified way.

In short, the actions of the project contemplated in this paper can be replicated for a large number of sites in the Natura 2000 network in the Mediterranean area. Among these actions, it is worth highlighting, as a novel contribution, the repair of hillocks with a salt substrate, which improves the production of salt and the habitat of seabirds, and the implementation of a quality seal for the production of salt.

Author Contributions: Conceptualization, D.I.-M., F.B.-S., G.B.-P. and R.G.-M.; methodology, D.I.-M. and F.B.-S.; formal analysis, D.I.-M., G.B.-P. and R.G.-M.; investigation, D.I.-M., F.B.-S., G.B.-P. and R.G.-M.; data curation, D.I.-M. and R.G.-M.; writing—original draft preparation, F.B.-S., D.I.-M., G.B.-P. and R.G.-M.; writing—review and editing, D.I.-M., F.B.-S., G.B.-P. and R.G.-M.; supervision, R.G.-M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Environment and Climate Action Program (LIFE), managed by the European Commission, grant number LIFE17 NAT/ES/000184, and the APC was funded by the same project. The LIFE-SALINAS Project, Conservation of habitats and aquatic birds in the LIC (Community Interest Area) and ZEPA (Special Areas for the Protection for Birds) ES0000175 "Salinas y Arenales de San Pedro del Pinatar" (southeastern Spain), is based on sustainable development, since it improves the conservation of priority fauna species and habitats in the European Union, in addition to enhancing the ecosystem services by increasing production and improving the quality of salt. More information about the project can be found at: https://lifesalinas.es/ (accessed on 31 May 2021).

Data Availability Statement: Not applicable.

Acknowledgments: This article was written thanks to the co-financing of LIFE funds from the European Union, through the LIFE17/ES/000184 Project, Conservation of habitats and aquatic birds in the LIC, and SPA ES0000175 "Salinas and Arenales of San Pedro del Pinatar"(LIFE-SALINAS). The authors want to thank anonymous reviewers for their suggestions, which have helped to significantly improve the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Sites of the Natura 2000 network. Characteristics and replicability.

Sites	Code	Ha	Ramsar	SPAMI	Replicability		
					1	2	3
Aiguamolls de l'Alt Empordà	ES0000019	10,850.6				X	
Alimini	IT9150011	3719.6		X		X	X
Alykes Larnakas	CY6000002	1568.6	X	X		X	X
Amvrakikos Kolpos, Limnothalassa Katafourko Kai Korakonisia	GR2110004	23,227.2		X		X	X
Atanasovsko ezero	BG0000270	7218.2	X	X	X	X	X
Bahía de Cádiz	ES0000140	10,550.7	X		X	X	
Basse plaine de l'Aude	FR9110108	4839.2				X	
Bosco Pantano di Policoro e Costa Ionica Foce Sinni	IT9220055	1798.7		X		X	X
Camargue	FR9310019	220,509	X		X	X	
Capo di Pula	ITB042216	1582.1				X	
Complexe lagunaire de Salses-Leucate	FR9112005	7668.1				X	
Comporta	PTCON0034	32,149.2	X			X	
D'Addaia a s'Albufera	ES0000233	2817.1		X		X	X
Delta Acheloou, Limnothalassa Mesolongiou—Aitolikou, Ekvoles Evinou, Nisoi Echinades, Nisos Petalas	GR2310001	35,730.0		X	X	X	X
Delta Axiou—Loudia—Aliakmona—Alyki Kitrous	GR1220010	28,926.6	X	X		X	X
Delta de l'Ebre	ES0000020	48,627.5	X	X	X	X	X
Delta del Po	IT3270023	24,988.8		X		X	X
Delta Dunrii i Complexul Razim—Sinoie	ROSPA0031	507,816	X	X		X	X
Delta Evrou	GR1110006	12,397.7	X	X		X	X
Delta Neretve	HR5000031	23,836.8		X		X	X
Duna del Lago di Burano	IT51A0032	98.2				X	
Duna e Lago di Lesina—Foce del Fortore	IT9110015	9845.0		X		X	X
Ekvoles Kalama	GR2120001	8637.7		X		X	X
Embouchure de l'Argens	FR9301627	1379.5	X			X	
Embouchure du Stabiaccu, Domaine Public Maritime et îlot Ziglione	FR9400586	195.8			X	X	
Est et sud de BÚziers	FR9112022	6085.8				X	
Estuario do Tejo	PTCON0009	44,132.7				X	
Etang de Lapalme	FR9112006	3911.9			X	X	
Étang de Mauguio	FR9112017	7020.0				X	
Étang de Thau et lido de SÞte Ó Agde	FR9112018	7750.7				X	

Table A1. *Cont.*

Sites	Code	Ha	Ramsar	SPAMI	Replicability		
					1	2	3
Étangs du Narbonnais	FR9112007	12,257.2	X		X	X	
Étangs palavasiens	FR9101410	6599.5	X	X		X	X
FernÒo Ferro/Lagoa de Albufeira	PTCON0054	4330.5	X			X	
Foce dell'Isonzo—Isola della Cona	IT3330005	2668.5		X		X	X
Lago di Burano (b)	IT51A0033	490.0				X	
Laguna di Caorle—Foce del Tagliamento	IT3250033	4377.6		X		X	X
Laguna di Marano e Grado	IT3320037	16,363.4	X	X		X	X
Laguna di Orbetello	IT51A0026	3698.4				X	
Laguna di Venezia	IT3250046	55,148.0	X			X	
Lagunas de la Mata y Torrevieja	ES0000485	3742.9	X	X	X	X	X
l'Albufera	ES0000471	29,338.5	X			X	
L'Albufereta	ES0000226	444.2	X	X		X	X
Le Cesine	IT9150014	648.0		X		X	X
Limnes Vistonis, Ismaris—Limnothalasses Porto Lagos, Alyki Ptelea, Xirolimni, Karatza	GR1130010	17,740.8	X	X		X	X
Limnothalassa Angelochoriou	GR1220005	373.6		X	X	X	X
Limnothalassa Kotychi—Alyki Lechainon	GR2330009	2350.6		X		X	X
Litorale di Gallipoli e Isola S. Andrea	IT9150015	7016.4		X		X	X
Litorale di Ugento	IT9150009	7255.1				X	
Mandra—Poda	BG0000271	6146.6	X	X		X	X
Marais et zones humides liÚs Ó l'Útang de Berre	FR9301597	1559.6			X	X	
Marismas de Isla Cristina	ES6150005	2499.9				X	
Marismas del Odiel	ES0000025	6626.9	X			X	
Marismas del río Piedras y Flecha del Rompido	ES6150006	2411.6				X	
Marjal de la Safor	ES5233030	1247.6		X		X	X
Marjal dels Moros	ES0000470	627.9		X		X	X
Ortazzo, Ortazzino, Foce del Torrente Bevano	IT4070009	1254.7	X	X		X	X
Padule della Trappola, Bocca d'Ombrone	IT51A0013	490.0				X	
Padule di Diaccia Botrona	IT51A0011	1349.2				X	
Paludi di Capo Feto e Margi Span	ITA010006	351.0		X		X	X
Paludi presso il Golfo di Manfredonia	IT9110038	14,470.3	X	X	X		X
Pantani della Sicilia sud-orientale, Morghella, di Marzamemi, di Punta Pilieri e Vendicari	ITA090029	3575.5		X		X	X
Parco Nazionale del Circeo	IT6040015	22,205.0	X			X	
Petite Camargue	FR9101406	34,410.6	X		X	X	
Pialassa dei Piomboni, Pineta di Punta Marina	IT4070006	463.9		X		X	X
Pineta di Cervia	IT4070008	194.2	X	X		X	X
Pomoriysko ezero	BG0000152	922.1	X	X	X	X	X
Prat de Cabanes i Torreblanca	ES0000467	1945.5				X	
Privlaka—Ninski zaljev—Ljubaki zaljev	HR4000005	2001.0		X		X	X
Promontorio, dune e zona umida di Porto Pino	ITB040025	2707.0				X	
Punta Entinas-Sabinar	ES0000048	1980.9	X	X		X	X
Ria de Alvor	PTCON0058	1459.4	X			X	

Table A1. *Cont.*

Sites	Code	Ha	Ramsar	SPAMI	Replicability		
					1	2	3
Ria Formosa	PTZPE0017	23,362.6	X		X	X	
Sacca di Goro, Po di Goro, Valle Dindona, Foce del Po di Volano	IT4060005	4867.7	X	X		X	X
S'Albufera de Mallorca	ES0000038	2207.0	X	X		X	X
S'Albufera des Grau	ES0000234	2544.9		X		X	X
Salina di Cervia	IT4070007	1095.2	X	X	X		X
Salinas de Santa Pola	ES0000120	2511.4	X	X		X	X
Saline di Augusta	ITA090014	63.6		X		X	X
Saline di Trapani	ITA010007	1010.1		X	X	X	X
Salins d'HyÞres et des Pesquiers	FR9312008	961.1	X		X	X	
Sapais de Castro Marim	PTZPE0018	2154.0			X	X	
Seoveljske soline	SI5000018	968.8	X	X	X	X	X
Ses Salines d'Eivissa i Formentera	ES0000084	16,488.1	X	X	X	X	X
Shablenski ezeren kompleks	BG0000156	3177.0	X	X		X	X
Son Bou i barranc de sa Vall	ES0000238	1177.7		X		X	X
Stagni di Colostrai e delle Saline	ITB040019	1154.8				X	
Stagni e Saline di Punta della Contessa	IT9140003	2861.7		X		X	X
Stagno di Cabras	ITB030036	4810.0	X			X	
Stagno di Cagliari	ITB044003	3769.5	X	X	X	X	X
Stagno di Corru S'Ittiri	ITB030032	5730.0	X			X	
Stagno di Mistras di Oristano	ITB030034	1626.5	X			X	
Stagno di Molentargius e territori limitrofi	ITB040022	1279.7	X	X	X	X	X
Stagno di Putzu Idu (Salina Manna e Pauli Marigosa)	ITB030038	599.4				X	
Stagno di Santa Caterina	ITB042223	627.5			X	X	
Torre Colimena	IT9130001	2682.6		X		X	X
Torre Guaceto	IT9140008	548.8		X		X	X
Torre Manfria, Biviere e Piana di Gela	ITA050012	25,166.5		X		X	X
Torre Veneri	IT9150025	1743.2				X	
UÜe Mirne	HR3000433	125.5		X		X	X
Valle Bertuzzi, Valle Porticino—CanneviÞ	IT4060004	2689.0	X	X		X	X
Velo i Malo Blato	HR4000004	661.2		X		X	X
Vene di Bellocchio, Sacca di Bellocchio, Foce del Fiume Reno, Pineta di Bellocchio	IT4060003	2242.4	X	X		X	X
Ygrotopoi Neas Fokaias	GR1270013	422.4		X		X	X
Ygrotopos Ekvolon Kalama Kai Nisos Prasoudi	GR2120005	8649.1		X		X	X
Ygrotopos Schinia	GR3000016	2102.3		X		X	X

Note: In this table, the sites that have conditions for the replicability of one or more actions of the project have been marked. Replicable actions: 1 = saline substrate in hillocks and a quality seal (meaning that there are active saline structures at present or those that were active until recently on which this action can be implemented; 2 = sand collectors, removal of exotic species, and revegetation (meaning that it has dune/beach systems); 3 = protection of the dune ridge by means of seagrass tops (meaning that there are seagrass meadows that can provide seagrass tops).Source: own elaboration.

References

1. Millennium Ecosystem Assessment (MEA). *Ecosystems and Human Well-Being*; Island Press: Washington, DC, USA, 2005.
2. Barbier, E.B.; Hacker, S.D.; Kennedy, C.; Koch, E.W.; Stier, A.C.; Silliman, B.R. The value of estuarine and coastal ecosystem services. *Ecol. Monogr.* **2011**, *81*, 169–193. [CrossRef]

3. Zedler, J.B.; Kercher, S. WETLAND RESOURCES: Status, Trends, Ecosystem Services, and Restorability. *Annu. Rev. Environ. Resour.* **2005**, *30*, 39–74. [CrossRef]
4. Kim, S.G. The evolution of coastal wetland policy in developed countries and Korea. *Ocean Coast. Manag.* **2010**, *53*, 562–569. [CrossRef]
5. Cools, J.; Johnston, R.; Hattermann, F.; Douven, W.; Zsuffa, I. Tools for wetland management: Lessons learnt from a comparative assessment. *Environ. Sci. Policy* **2013**, *34*, 138–145. [CrossRef]
6. Morzaria-Luna, H.N.; Castillo-López, A.; Danemann, G.D.; Turk-Boyer, P. Conservation strategies for coastal wetlands in the Gulf of California, Mexico. *Wetl. Ecol. Manag.* **2013**, *22*, 267–288. [CrossRef]
7. Zhao, Q.; Bai, J.; Huang, L.; Gu, B.; Lu, Q.; Gao, Z. A review of methodologies and success indicators for coastal wetland restoration. *Ecol. Indic.* **2016**, *60*, 442–452. [CrossRef]
8. Qu, Y.; Luo, C.; Zhang, H.; Ni, H.; Xu, N. Modeling the wetland restorability based on natural and anthropogenic impacts in Sanjiang Plain, China. *Ecol. Indic.* **2018**, *91*, 429–438. [CrossRef]
9. Verhoeven, J.T. Wetlands in Europe: Perspectives for restoration of a lost paradise. *Ecol. Eng.* **2013**, *66*, 6–9. [CrossRef]
10. Rubec, C.D.A.; Hanson, A.R. Wetland mitigation and compensation: Canadian experience. *Wetl. Ecol. Manag.* **2009**, *17*, 3–14. [CrossRef]
11. Burgin, S. 'Mitigation banks' for wetland conservation: A major success or an unmitigated disaster? *Wetl. Ecol. Manag.* **2009**, *18*, 49–55. [CrossRef]
12. Brinson, M.M.; Eckles, S.D. U.S. Department of Agriculture conservation program and practice effects on wetland ecosystem services: A synthesis. *Ecol. Appl.* **2011**, *21*, S116–S127. [CrossRef]
13. Neuman, A.D.; Belcher, K.W. The contribution of carbonbased payments to wetland conservation compensation on agricultural landscapes. *Agric. Syst.* **2011**, *104*, 75–81. [CrossRef]
14. Blackwell, M.; Pilgrim, E.S. Ecosystem services delivered by small-scale wetlands. *Hydrol. Sci. J.* **2011**, *56*, 1467–1484. [CrossRef]
15. Bassi, N.; Kumar, M.D.; Sharma, A.; Pardha-Saradhi, P. Status of wetlands in India: A review of extent, ecosystem benefits, threats and management strategies. *J. Hydrol. Reg. Stud.* **2014**, *2*, 1–19. [CrossRef]
16. Sun, G.; Hallema, D.; Asbjornsen, H. Ecohydrological processes and ecosystem services in the Anthropocene: A review. *Ecol. Process.* **2017**, *6*, 1–9. [CrossRef]
17. Gallego-Fernandez, J.B.; García-Mora, M.R.; García-Novo, F. Small wetlands lost: A biological conservation hazard in Mediterranean landscapes. *Environ. Conserv.* **1999**, *26*, 190–199. [CrossRef]
18. Calhoun, A.J.; Mushet, D.M.; Bell, K.P.; Boix, D.; Fitzsimons, J.A.; Isselin-Nondedeu, F. Temporary wetlands: Challenges and solutions to conserving a 'disappearing'ecosystem. *Biol. Conserv.* **2017**, *211*, 3–11. [CrossRef]
19. Angeler, D.G. Management and conservation of temporary ponds: Opportunities and challenges in the new millennium. In *International Conference on Temporary Ponds*; Proceedings & Abstracts; Consell Insular de Menorca, Recerca Maó: Menorca, Spain, 2009; Volume 14, pp. 299–306.
20. Moss, B.; Hering, D.; Green, A.J.; Aidoud, A.; Becares, E.; Beklioglu, M.; Bennion, H.; Boix, D.; Brucet, S.; Carvalho, L.; et al. Climate Change and the Future of Freshwater Biodiversity in Europe: A Primer for Policy-Makers. *Freshw. Rev.* **2009**, *2*, 103–130. [CrossRef]
21. McGreavy, B.; Calhoun, A.; Jansujwicz, J.; Levesque, V. Citizen science and natural resource governance: Program design for vernal pool policy innovation. *Ecol. Soc.* **2016**, *21*. [CrossRef]
22. Walton, M. Biodiversity conservation and the Yellow Sea Large Marine Ecosystem project. *J. Korean Soc. Mar. Environ. Energy* **2010**, *13*, 335–340.
23. Hahn, T.; Olsson, P.; Folke, C.; Johansson, K. Trust-building, knowledge generation and organizational innova-tions: The role of a bridging organization for adaptive comanagement of a wetland landscape around Kristianstad, Sweden. *Hum. Ecol.* **2006**, *34*, 573–592. [CrossRef]
24. Ibrahim, I.; Aziz, N.A. The Roles of International NGOs in the Conservation of Bio-Diversity of Wetlands. *Procedia Soc. Behav. Sci.* **2012**, *42*, 242–247. [CrossRef]
25. Trokanova, L. CANCELLED: EU LIFE PROGRAMME Contributing for Nature Conservation in Practice. In Proceedings of the 5th European Congress of Conservation Biology, Jyväskylä, Finland, 12–15 June 2018.
26. Imperial, M.T. Analyzing Institutional Arrangements for Ecosystem-Based Management: Lessons from the Rhode Island Salt Ponds SAM Plan. *Coast. Manag.* **1999**, *27*, 31–56. [CrossRef]
27. Rodríguez Estrella, T. Geología de la Región de Murcia. In *El medio Físico de la Región de Murcia*; García, C.C., Ed.; Universidad de Murcia: Murcia, Spain, 2006; pp. 11–46.
28. Romero Díaz, A.; Belmonte Serrato, F. Los paisajes Geomorfológicos de la Región de Murcia como recurso turístico. *Cuad. Tur.* **2002**, 103–122. Available online: https://revistas.um.es/turismo/article/view/21931 (accessed on 5 February 2021).
29. Lillo Carpio, M. Geomorfología litoral del Mar Menor. In *Papeles de Geografía*; Universidad de Murcia: Murcia, Spain, 1978; pp. 9–53.
30. Ballesteros Pelegrín, G.A. El Parque Regional de las Salinas y Arenales de San Pedro del Pinatar. In *Actividades Humanas y Conservación*; Universidad de Murcia: Murcia, Spain, 2014; p. 367.
31. Mitsch, W.J.; Gosselink, J.G. *Wetlands*, 4th ed.; John Wiley & Sons: Hoboken, NJ, USA, 2007; p. 582.

32. Munar, R.I.; Xavier, F.; Prieto, J.A.M. Efectos de la retirada de bermas vegetales de Posidonia oceanica sobre playas de las islas Baleares: Consecuencias de la presión turística. *Investig. Geogr.* **2005**, *57*, 40–52. [CrossRef]
33. Oro, D.; Ruxton, G.D. The formation and growth of seabird colonies: Audouin's gull as a case study. *J. Anim. Ecol.* **2002**, *70*, 527–535. [CrossRef]
34. Bertolero, A.; Genovart, M.; Martínez-Abraín, A.; Molina, B.; Mouriño, J.; Oro, D.; Tavecchia, G. *Gaviotas Cabecinegra, Picofina, de Audouin y Tridáctila, y Gavión Atlántico en España. Población en 2007 y Método de Censo*; SEO/BirdLIFE: Madrid, Spain, 2008.
35. Hébert, P.N. Effect of Fog on Herring Gull (Larus argentatus) Chick Survivorship and Parental Foraging Patterns. *Colon. Waterbirds* **1987**, *10*, 103. [CrossRef]
36. Bolton, M. Determinants of Chick Survival in the Lesser Black-Backed Gull: Relative Contributions of Egg Size and Parental Quality. *J. Anim. Ecol.* **1991**, *60*, 949. [CrossRef]
37. Kilpi, M.; Hillström, L.; Lindström, K. Egg-size variation and reproductive success in the Herring Gull Lams argentatus: Adaptive or constrained size of the last egg? *IBIS* **1996**, *138*, 212–217. [CrossRef]
38. Monaghan, P.; Nager, R.G.; Houston, D.C. The price of eggs: Increased investment in egg production reduces the offspring rearing capacity of parents. *Proc. Biol. Sci.* **1998**, *265*, 1731–1735. [CrossRef]
39. Prieto, J.; Jover, L.; Ruiz, X. Efectos del aporte de refugios sobre la supervivencia de pollos de Gaviota de Audouin. *Sci. Mar.* **2003**, *67*, 103–108. [CrossRef]
40. Cornelis, W.M.; Gabriels, D. A simple low-cost sand catcher for wind-tunnel simulations. *Earth Surf. Process. Landf.* **2003**, *28*, 1033–1041. [CrossRef]
41. McOwen, C.J.; Weatherdon, L.V.; Van Bochove, J.-W.; Van, B.J.-W.; Blyth, S.; Zockler, C.; Stanwell-Smith, D.; Kingston, N.; Martin, C.S.; Spalding, M.; et al. A global map of saltmarshes. *Biodivers. Data J.* **2017**, *5*, e11764. [CrossRef]
42. Schembri, J.A. Coastal Land Use in the Maltese Islands: A Descriptionand Appraisal. Ph.D. Thesis, Durham University, Durham, UK, August 2003. Available online: http://etheses.dur.ac.uk/4417/ (accessed on 20 March 2021).
43. Liberti, F.; Pistolesi, V.; Massoli, S.; Bartocci, P.; Bidini, G.; Fantozzi, F. i-REXFO LIFE: An innovative business model to reduce food waste. *Energy Procedia* **2018**, *148*, 439–446. [CrossRef]
44. Vagnoni, E.; Atzori, A.S.; Molle, G. Sheeptoship Life: Integration of Environmental Strategies with Rural Development Policies. In *Planning, Nature and Ecosystems Services*; Gargiulo, C., Zoppi, C., Eds.; Federico II Open Access University Press: Naples, Italy, 2019; pp. 366–374. [CrossRef]
45. Goodchild, M.F. Geographic information systems and science: Today and tomorrow. *Ann. GIS* **2009**, *15*, 3–9. [CrossRef]
46. Prisco, I.; Acosta, A.T.R.; Stanisci, A. A bridge between tourism and nature conservation: Boardwalks effects on coastal dune vegetation. *J. Coast. Conserv.* **2021**, *25*, 1–12. [CrossRef]
47. Bonari, G.; Těšitel, J.; Migliorini, M.; Angiolini, C.; Protano, G.; Nannoni, F.; Schlaghamerský, J.; Chytrý, M. Conservation of the Mediterranean coastal pine woodlands: How can management support biodiversity? *For. Ecol. Manag.* **2019**, *443*, 28–35. [CrossRef]
48. Bezzi, A.; Pillon, S.; Martinucci, D.; Fontolan, G. Inventory and conservation assessment for the management of coastal dunes, Veneto coasts, Italy. *J. Coast. Conserv.* **2018**, *22*, 503–518. [CrossRef]
49. Pinna, M.S.; Bacchetta, G.; Orrù, H.; Cogoni, D.; Sanna, A.; Fenu, G. Results of the Providune project: Restoration of the "Coastal dunes with Juniperus spp." priority habitat in Sardinia. *Plant. Sociol.* **2017**, 73–84. [CrossRef]
50. Gacia, E.; Granata, T.; Duarte, C.M. An approach to measurement of particle flux and sediment retention within seagrass (Posidonia oceanica) meadows. *Aquat. Bot.* **1999**, *65*, 255–268. [CrossRef]
51. Spalding, M.D.; Ruffo, S.; Lacambra, C.; Meliane, I.; Hale, L.Z.; Shepard, C.C.; Beck, M.W. The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. *Ocean Coast. Manag.* **2014**, *90*, 50–57. [CrossRef]
52. Vuik, V.; Jonkman, S.; Borsje, B.W.; Suzuki, T. Nature-based flood protection: The efficiency of vegetated foreshores for reducing wave loads on coastal dikes. *Coast. Eng.* **2016**, *116*, 42–56. [CrossRef]
53. Dias, M.P. Use of Salt Ponds by Wintering Shorebirds throughout the Tidal Cycle. *Waterbirds* **2009**, *32*, 531–537. [CrossRef]
54. Dias, M.P.; Lecoq, M.; Moniz, F.; Rabaça, J.E. Can Human-made Saltpans Represent an Alternative Habitat for Shorebirds? Implications for a Predictable Loss of Estuarine Sediment Flats. *Environ. Manag.* **2014**, *53*, 163–171. [CrossRef]
55. Sousa, C.A.; Cunha, M.E.; Ribeiro, L. Tracking 130 years of coastal wetland reclamation in Ria Formosa, Portugal: Opportunities for conservation and aquaculture. *Land Use Policy* **2020**, *94*, 104544. [CrossRef]
56. Pellizzari, M.; Barbieri, C.; Caramori, G.; Pagnoni, G.; Piccoli, F. La vegetazione della Salina di Comacchio (Ferrara, Parco del Delta del Po): Ripristino ecologico e conservazione degli hábitat. *Fitosociologia* **2007**, *44*, 77–82.
57. Fernández Iglesias, E.; Ramos-Guajardo, A.B.; González-Rodríguez, G.; Marquínez, J. Role of littoral processes on the sand movement in the Northern Spanish coast by fitting regression models. In Proceedings of the 3rd International Conference in Econometrics and Statistics (EcoStats 2019), Taichung, Taiwan, 25–27 June 2019.
58. Van Der Meulen, F.; Salman, A.H.P.M. Management of Mediterranean coastal dunes. *Ocean Coast. Manag.* **1996**, *30*, 177–195. [CrossRef]
59. Sun, Z.; Sun, W.; Tong, C.; Zeng, C.; Yu, X.; Mou, X. China's coastal wetlands: Conservation history, implementation efforts, existing issues and strategies for future improvement. *Environ. Int.* **2015**, *79*, 25–41. [CrossRef]
60. Gumiero, B.; Mant, J.; Hein, T.; Elso, J.; Boz, B. Linking the restoration of rivers and riparian zones/wetlands in Europe: Sharing knowledge through case studies. *Ecol. Eng.* **2013**, *56*, 36–50. [CrossRef]

land

Article

An Easy Mixed-Method Analysis Tool to Support Rural Development Strategy Decision-Making for Beekeeping

Silvia Novelli *,†, Monica Vercelli † and Chiara Ferracini

Department of Agricultural, Forest and Food Sciences (DISAFA), University of Torino, 10095 Grugliasco, Italy; monica.vercelli@unito.it (M.V.); chiara.ferracini@unito.it (C.F.)
* Correspondence: silvia.novelli@unito.it; Tel.: +39-0116708723
† First and second authors have contributed equally.

Abstract: The EU has long-recognised the functions and contributions of beekeeping in sustainable rural area development. In 2018, the EU adopted the Pollinator Initiative to strengthen its pollinator conservation policies. To support the design of effective rural development actions, this work describes and tests an easy-to-apply, mixed-method tool for use with SWOT analysis. A two-step methodology was trialled with beekeepers in Piedmont Region (NW Italy). In step one, two independent groups of beekeepers operating in separate protected and intensive agricultural areas completed a SWOT matrix. In step two, three expert panels (beekeeper association leaders, honey market organisation leaders, and entomologists) prioritised the effects of the SWOT items with a quantitative weighting and rating process. Results suggest that the sector needs better-targeted incentives and that 'soft' policies on extension, advisory, and institutional measures could play a relevant role. The method was also confirmed as suitable for use with non-expert evaluators, such as policy officers and practitioners.

Keywords: rural development policies; SWOT analysis; mixed methods; beekeeping; honey bee; ecosystem services; climate change

Citation: Novelli, S.; Vercelli, M.; Ferracini, C. An Easy Mixed-Method Analysis Tool to Support Rural Development Strategy Decision-Making for Beekeeping. *Land* **2021**, *10*, 675. https://doi.org/10.3390/land10070675

Academic Editors: Mónica de Castro-Pardo, Joao C. Azevedo and Pascual Fernández

Received: 3 June 2021
Accepted: 23 June 2021
Published: 26 June 2021

1. Introduction

Beekeeping is an important agricultural activity globally that contributes to sustainable rural area development in two ways—economic (income) support and ecological support from honey bees [1–5].

From an income perspective, beekeeping as either a main or secondary income source is especially an opportunity for marginal rural areas [6]. In such places, beehive products, livestock, and pollination services have the potential to generate and diversify income quickly on farms with little land and/or limited capital [7,8]. The beehive product market is sizeable. In 2019, there were 18.2 million hives in the European Union (EU) and 1.6 million hives in Italy, managed by about 612,000 (EU) and 56,000 (Italy) beekeepers [9]. Although approximately 95% of European beekeepers are non-professionals (only 3% own more than 150 beehives), Europe produced the second largest amount of honey in the world after China in 2018 (283,000 tons). Italy produced about 23,000 tons of different honey types [10–12]. The sector generates not only an annual value of EUR 1 billion in Europe, but pollinators also contribute at least EUR 22 billion to European agriculture by ensuring crop yields [13].

Beekeeping activities also contribute to rural-area environmental and social goals by providing multiple ecosystem services [5,6]. Pollinators provide provisioning, regulating, and cultural ecosystem services [14,15]. The best-known service is pollination, which ensures crop yields and conserves wild plant biodiversity [16–22]. Honey bees, as the most significant pollinators, suppliers of food, and providers of a wide range of benefits to society, also bear cultural and social values [5,14,15,23]. Moreover, they are used in research studies on environmental issues, including those on heavy metal and chemical environmental contamination [24,25].

The flow of market and public goods and services provided by honey bees and beekeeping activity is threatened by several anthropic and biotic stresses, such as diseases, pesticides, land-use changes, and agricultural intensity [14,15,26–30]. Recent studies have highlighted significant losses to honey bee colonies due to the direct and indirect effects of climate change [31–33], as well as the consequent alteration of the plant-insect interactions on pollination synchrony and mutualism [34,35].

In 2018, the European Commission adopted a Communication on the first-ever EU initiative on pollinators [36]. The EU Pollinators Initiative set strategic objectives and actions to be taken at different levels in Europe to address pollinator decline while promoting their conservation. The initiative called for EU policy strategies to increase pollinator conservation in the coming years through an integrated approach using effective existing tools and policies.

For market products, climate change effects in recent years have led to unpredictable fluctuations in honey yields and alarming decreases in honey production, particularly recorded in the principal-producing countries of Southern and Eastern Europe. Negative effects have concerned high-value honey varieties, such as acacia honey [37,38]. Similarly, climate change stresses in Italy, such as drought, late frosts, and high temperatures, have recently caused considerable damage to the beekeeping sector. In various areas, a real zeroing of the honey production occurred, such as the case of acacia honey. It has been estimated that the loss of revenues for this honey variety amounted in 2019 to more than € 55 million in Italy with a massive impact on beekeeping profitability [37].

Few studies exist on the impact of beekeeper perceptions of direct and indirect climate change on beekeeping activities [39,40]. In light of this, local beekeepers in the Piedmont Region (NW Italy) completed a qualitative survey under the auspices of the Interreg V-A Alcotra project between Italy and France "CClimaTT—Climate Changes within Cross-Border Territories" (2017–2020). The general aim of this work was to analyse the perceptions of climate change effects held by local beekeepers and the adaptation strategies they adopted to handle those changes [40]. Part of the analysis identified the main favourable and unfavourable factors affecting beekeeping to perform a SWOT (Strengths, Weaknesses, Opportunities, Threats) matrix based on current challenges to the sector. The research was intended to provide a tool for identifying strategies aimed at maintaining or strengthening beekeeping farm viability and sector capacity to tackle its main threats, and climate change, in particular.

SWOT analysis is the standard approach to considering problems and issues, but is limited by its subjective and qualitative nature [41]. By producing a list of equally important and unrelated items, the method fails to prioritise among items, to explain the extent to which a favourable factor can reduce the effect of an unfavourable one (and vice versa), or to evaluate the overall effect of the SWOT items [42]. To supplement the qualitative result of SWOT analysis, a quantitative technique was integrated into the analysis to prioritise items in the matrix and to generate strategies based on the relationships among items.

Many studies have indicated that SWOT analysis could be enhanced with a determination of the relative importance of items and ranking relevant strategies. Typically, these studies develop hybrid approaches that combine classic SWOT analysis with quantitative models [43]. Some authors have utilised the so-called A'WOT technique, which integrates SWOT analysis with an analytic hierarchy process (AHP) [44–48]. As a means by which to consider the mutual effects of SWOT factors and their potential relationships and dependencies, other authors have introduced the analytic network process (ANP) to quantify SWOT analyses (e.g., [49–52]). Several mixed methods have also been created that integrate SWOT and many other Multi Criteria Decision Making methods (MCDM), including those introducing fuzzy set theory to deal with the uncertainty caused by unquantifiable, incomplete, or unobtainable information (see [43,53]).

To date, these methods have contributed greatly to the scientific literature across many fields [48], including apiculture [54,55]. Operationally, they require advanced methodological and statistical skills and/or specific software. This paper offers an easy-to-apply mixed method that requires a relatively low cognitive effort to weight and rank SWOT items. Furthermore, simple calculations can be completed by non-expert evaluators to obtain quick preliminary prioritisations.

In the following sections, the methodology is presented and applied as a tool to formulate rural development strategies for beekeeping. Preceding the discussion is an excursus on current sector policies within the framework of the EU Common Agricultural Policy (CAP).

2. Beekeeping in the Common Agricultural Policy

EU policymakers recognise the multi-functional role of beekeeping, by appreciating that the sector contributes to the development of rural areas, whilst honey bee colonies are indispensable for agriculture and the environment, ensuring pollination services and conserving biodiversity [9]. Thus, measures aimed at supporting beekeeping fall under both pillars of the CAP. The first pillar concerns market measures and direct payments (i.e., annual payments to farmers to stabilise revenues) and the second pillar pertains to rural development policies aimed at balancing territorial development, environmentally-sustainable farming, competition, and innovation.

The post-2013 Common organization of the markets (CMO) in agricultural products was regulated by Regulation (EU) No. 1308/2013. For beekeeping, regulation preliminary considerations have focused on the rise of hive invasions (varroosis, in particular) and their effects on honey production. Specifically, the regulation requires Member States to draw up three-year national apiculture programmes in collaboration with sector organisations to enhance the production and marketing of apiculture products. Moreover, the regulatory framework permits grants to beekeepers and/or their associations for many measures: technical assistance, varroa mite control, transhumance rationalisation (i.e., hive re-siting to better nutritive sources and climatic conditions), apiculture product laboratory analysis, hive restocking support, applied apiculture research programme access, market monitoring, and product quality enhancement. As for programme funding, the EU and the Member State each bear half.

In Italy, the three-year national programmes are defined by the Ministry of Agricultural, Food and Forestry Policies (MiPAAF) under national legislation Ministerial Decree No. 2173/2016. This decree allows regional administrations to develop their own regional apiculture programmes that arise from the specificity of their territories and/or local beekeeping sector. The over-arching goal of the EU-based regulation is to help beekeepers at all levels to exploit the market potential of their products. Market measures aimed at this goal also contribute to rural area beekeeping economic sustainability by reducing production costs and improving sector competitiveness. Additionally, they support the entire system of economic activities related to beekeeping [9].

Beekeeping support can also be included in the Rural Development Programs (RDPs) financed across the Member States and the regions of the Union within the first pillar of the CAP. These strategies are implemented through a set of measures defined for the 2014–2020 programming period by Regulation (EU) No. 1305/2013 on rural development support. These policies reinforce CAP market measures and income supports with actions designed to strengthen EU agri-food and forestry sectors, environmental sustainability, and rural area well-being generally [56]. A range of rural development measures can benefit beekeepers: knowledge and information transfer actions, advisory services, farm management and relief services (in particular, those targeting farm economic resilience), agricultural product schemes, and/or physical asset investments (honey extraction laboratory, equipment for bee product packaging, processing, and marketing). To ensure the effective and efficient use of the EU funds for apiculture, the Commission established rules to avoid double funding between Member States' and RDPs.

In 2018, the EU used the Omnibus Regulation (Regulation (EU) No. 2017/2393) to modernise and simplify the CAP regulations on direct payments, rural development, common market organisations, and horizontal regulation. The Omnibus Regulation, implemented by the Commission, amended EU budget-related financial rules and strengthened existing EU rules on a wide range of agricultural issues [57,58]. The Omnibus regulation indirectly affects the apiculture sector since it introduces improved environmental measures, and in particular, those related to ecological focus areas (EFAs). EFAs are farm areas of ecological interest that receive direct payments to safeguard and improve farm biodiversity, as established under "greening of the CAP" (Regulation (EU) No. 1307/2013). The Omnibus regulation recognised land lying fallow for melliferous plants (i.e., pollen and nectar rich species) as a distinct ecological focus area type, since this vegetation coverage may positively affect biodiversity. In addition to pollination services and biodiversity, conserving pollinator habitat can enhance the provision of other ecosystem services: soil protection and water quality through runoff and soil erosion mitigation, rural aesthetics, and pest control [20].

The EU has confirmed its support of apiculture for the 2021–2027 programming period, although the approach for the delivery of the new policies will be different. The main novelty is that Member States shall submit only one strategic plan, covering income support, sectorial strategies, and rural development. The Commission will provide a toolbox of broad policy measures for EU countries to shape around their own needs and capabilities to ease execution and reduce administration [59].

While waiting for the new policy tools, Member States have already submitted their national apicultural programmes to the EU for 2020–2022. With the Commission Implementing Decision (EU) No. 2019/974, the European Commission approved and devoted EUR 120 million Union contribution for the national plans. Therefore, total spending, including the Member State contributions, to implement the programmes in the current three-year period is EUR 240 million, an 11% increase over 2017–2019 funding [9].

3. Materials and Methods

An easy-to-apply mixed method to integrate results from a SWOT analysis on the state of the beekeeping sector with the relative ranking of its items was created and trialled in the Piedmont Region located in northwestern Italy. The analysis was conducted in two steps as shown in Figure 1.

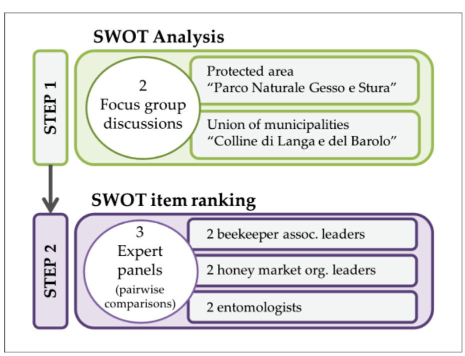


Figure 1. Diagram of methodological approach.

In step one, beekeepers completed a SWOT matrix designed to elicit their perceptions of the favourable and unfavourable factors affecting the sector, able to enhance or diminish bee farm resilience to many threats, and in particular, climate change. The source of this information came from that collected in focus group discussions (FGDs) organised within the CClimaTT Project [42]. The FGDs were conducted in November 2018 in two areas in Cuneo province (Piedmont Region, Italy). The areas are characterised by different governance, land uses, and economic opportunities.

One group of beekeepers operated in “Parco Naturale Gesso e Stura”, a protected river park balancing conservation of a river ecosystem and the human activities practiced there for centuries. The part-flat and part-hilly area is a mosaic of river environments, agricultural lands, and forests, where several professional beekeepers own large farms, manage permanent apiaries, and practice transhumance. The second group of participants was located in the administrative union of municipalities “Colline di Langa e del Barolo”. The mostly hilly area is an intensive wine-growing area, with a prevalence of vineyards inter-mixed with hazelnut orchards and wooded patches. The beekeeping is mainly conducted in permanent apiaries as a secondary activity by part-time beekeepers on small to medium-sized farms.

The literature suggests six to eight participants for focus groups and no more than 12 [60–62]. On the other hand, some authors endorse groups of just three to four when the group shares specialised knowledge or experience [62–64]. Based on the prevalence of beekeeping in the two areas, 11 River Park beekeepers and five intensive wine-growing area beekeepers were recruited from a network of local beekeepers previously involved in CClimaTT project activities. Each group included small and large farms (15 to 1200 managed beehives) and varying levels of beekeeping expertise (5 to 50 years of activity).

FDGs were used to explore perceptions held by beekeepers about the effects of climate change on honey bees and beekeeping. The first portion of the meetings discussed climate change effects noted by the beekeepers during the last 10 years and the management and practice adaptations made in response [40]. A second set of discussions were undertaken for the present paper. The focus of these conversations was to elicit the positive aspects and principal difficulties of beekeeping given the challenges to the sector. The major topics and issues were identified from a transcription of the discussion using a scissor-and-sort technique [65,66]. The topics were divided into internal factors (strengths and weaknesses) that sector operators have some control over and can try to change or manage and external factors (opportunities and threats) derived from the environment, market, or regulations outside beekeeper control [67].

To exceed a simple qualitative examination of the internal and external items, the SWOT analysis was integrated with an easy-to-apply quantitative technique during step two. Specifically, the SWOT matrix was combined with a simple pairwise comparison of items using basic computations in an Excel® spreadsheet [68,69] using three panels of evaluators, each comprised of two beekeeping experts. The experts were asked to perform a pairwise comparison of the SWOT items and to weight and rate their mutual effects to identify relationships among strengths, weaknesses, opportunities, and threats.

All of the SWOT items were displayed on both the column and row headers in a double-entry table (Figure 2).

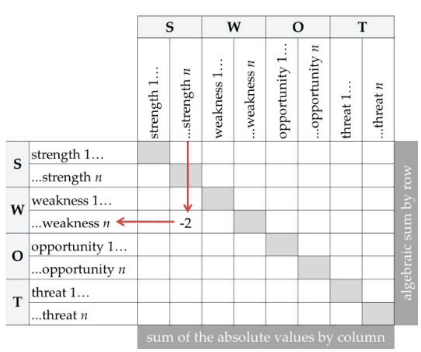


Figure 2. The spreadsheet used for the pairwise comparison of the items.

Panel participants were asked to compare each item in the column headers with all the other items in the row headers, irrespective of type (i.e., strength, weakness, opportunity, or threat), and to assign a score of between −2 and +2 to each couple. A positive value indicates that the effect of the item in the row is increased by the effect of the column item, while a negative value implies that the column item impedes or decreases the effect of the item in the row. Scoring criteria were as follows:

- −2 = the effects of the row item are strongly hampered by the column item,
- −1 = the effects of the row item are hampered by the column item,
- 0 = the two items are independent,
- +1 = the effects of the row item are increased by the column item,
- +2 = the effects of the row item are strongly increased by the column item.

Figure 2 presents an example in which the *n*-th strength strongly reduced the effect of the *n*-th weakness.

Rating the impact that each item of the SWOT matrix has on any other item, and then summing the scores along the rows and columns allowed identification of items that are more influenced by the overall effect of other items and which items more effectively influence others. In brief, the algebraic sum along the rows indicates the net capacity of the row items to exert their effects as a result of the influence of all the other items. This is true because some of them reinforce the effect of the row item and others weaken it, making the SWOT items in the rows dependent variables. Summing the absolute values of the scores in the columns weights the strength with which the column items are able to influence the other elements, strengthening or weakening them. In this case, the column items are analysed as independent (or explanatory) variables.

With this approach, two rankings are compiled with the SWOT elements. When ranking was based on row sums, beekeeping farm resilience depended on the positioning at the top of the rank of favourable conditions (strengths/opportunities) or unfavourable conditions (weaknesses/threats). On the other hand, ranking based on column sums highlighted elements that could be leveraged to boost strengths/opportunities and limit weaknesses/threats.

To complete the exercise, two representatives from each of three groups were invited to participate in the process: two from beekeeper associations (one operating in northern Italy and one in central Italy), two honey market experts (one from a producers' cooperative and one from the Italian National Honey Observatory), and two entomologists. Association, cooperative, and observatory representatives were board leaders in their respective organisations. The expected result was to collect different views on the state of the beekeeping sector, based on the different backgrounds, experiences, and perspectives of the participants. To facilitate the weighting process and to clarify the reasoning behind the evaluations, each panel of experts was asked to discuss the scores assigned to each couple of items and to come to a consensus on the relevant rating.

4. Results

In the following sections, after proposing a synthesis of the results of the first part of the FGDs (see details in [40]), the SWOT matrix discussed by the beekeepers and the SWOT item ranking were displayed.

4.1. Beekeeper Perceptions of Climate Change and Adaptation Strategies Adopted

In order to introduce the general context of the analysis, it seems worthy to recap the main results from the beekeeper FDGs on the perceived effects of climate change and the management adaptations adopted [40].

Groups operating in both areas claimed that climate change has reduced the availability of the nectar, pollen, and honeydew essential for honey bees, and indicated that the weakened or reduced colonies produced less or no honey. They ascribed the increase in varroa mite infestations and the spreading of new diseases to mild winters. The main strategies adopted by each group to ensure the colony survival and to cope with higher temperatures, drought, and spring frosts were also similar. Beekeepers have begun to practice intense transhumance and increased the provision of season-specific supplemental feeding (sugar syrup or candy), even during nectar flow. These strategies all add farm labour and management cost. Moreover, beekeepers have increased varroa mite control treatments, practiced winter season biotechniques, and undertaken professional practices that add expense and decrease revenues (e.g., honey production falls as actions are taken to ensure colony survival).

4.2. SWOT Analysis

During the FGD section to analyse the favourable and unfavourable factors affecting beekeeping, beekeepers discussed actions that strengthened/weakened sector resilience to a variety of threats and climate change, in particular. The transcribed discussion was analysed for presence and frequency of topic/issue, topic order (i.e., top of mind topics are generally expressed early), and elapsed time on a given topic [66]. This approach allowed the beekeepers to select issues in accordance with their perceived relevance and to set the discussion order for Step 2 of the method.

Table 1 shows the final SWOT matrix based on the selected criteria. The matrix also reports which group emphasised each specific item (1 = protected area; 2 = intensive vine-growing area).

Table 1. SWOT matrix of the beekeeping sector in the surveyed areas.

Strengths	Weaknesses
– Strong motivation of beekeepers **(1 + 2)** – Collaboration among beekeepers (between generation as well) **(1)**	– Lack of time and labour for facing the adoption of new time consuming and labour-intensive practices **(1)** – Lack of financial resources for bearing higher management costs **(1 + 2)**
Opportunities	**Threats**
– Recent increase of retail prices of bee products (FGDs were set up in 2018) **(1)** – Public interest in honey bees as environmental bioindicators (‘environmental sentinels’) and in typical honey productions **(1 + 2)**	– Reduced strength of the honey bee colonies due to climatic, anthropic (pesticides) and biotic (diseases) stresses **(1 + 2)** – Insufficient and mistargeted public financial support to the beekeeping sector **(1 + 2)** – Lower prices of low-quality honey supplied by foreign competitors on the market **(1 + 2)**

(1) Protected area “Parco Naturale Gesso e Stura”; **(2)** Intensive vine-growing area “Colline di Langa e del Barolo”.

For both groups, unfavourable factors related mostly to different types of external stresses (climatic, anthropic, and biotic) and institutional or market issues (lack of adequate institutional and financial support, competition with cheap, poor quality products). Beekeepers also emphasised long-standing organisational and structural internal issues, such as the lack of (family or skilled) labour and financial resources. Furthermore, they complained that the effects of these weaknesses are worsening due to new challenges related to climate change. For instance, new practices to control the varroa mite are labour intensive, especially in the protected area. Other farm practices, such as supplemental feeding and intensive transhumance, entail higher variable operating costs.

Based on the FGDs, the strength to cope with these weaknesses and threats rests with the beekeepers themselves. They stated that they are motivated to address these challenges based on their commitment to beekeeping. Along with their passion and satisfaction for the work, beekeepers operating in the protected area also recognised the fundamental collaborative spirit between and within generations of beekeepers. Both groups shared the opinion that these internal factors are boosted by the growing public interest in honey bees as environmental sentinels and by the growing consumer demand for typical honey productions (e.g., mountain blossom honey). Honey product price increases experienced during the 2018 that resulted from a lower supply due to colony declines was welcomed by beekeepers. At the same time, the opportunity was understood to relate to price volatility in the global market.

4.3. Ranking of the SWOT Items

As described, three panels of experts discussed the items highlighted by the beekeepers. The experts then completed the matrices reported in Appendix A through pairwise comparison of the column and rows items using the prescribed scoring criteria.

The sign and value of the score assigned to each item couple arises from the differing perceptions and opinions of the panels. For example, honey market organisation leaders assigned a −2 to the couple "strong motivation of beekeepers (S) + lack of financial resources to bear higher management costs (W)" (Table A2) to indicate their belief that the motivation of beekeepers strongly reduces the negative effect from the high cost of rescue operations. That is, honey market experts believe the determination of beekeepers incentivises them to find effective strategies for adapting to the challenge with a cost-efficient practice. On the contrary, association leaders believe that beekeeper motivation strongly increases (+2), or in the case of entomologists somewhat increases (+1) management costs (Tables A1 and A3). They observed that sometimes beekeepers, driven by their enthusiasm, do everything possible to save their colonies before considering more efficient strategies.

The algebraic sums of the scores along the rows quantify the net effect of SWOT items as if they were dependent variables with their outcomes able to be increased or decreased as a consequence column item influence. For instance, the honey market experts and the entomologists rate the threat of insufficient and mis-targeted public support as mitigated by the overall effect of the other items (Tables A2 and A3), while beekeeper association leaders hold the opposite as true (Table A1). The sum of the absolute values in each column indicates the capacity of the items to exert their effect on the other items, considering them as independent variables. From this quantification, the panels identified different items as most influential: association leaders identified higher management costs, honey market experts found strong motivation of beekeepers, and entomologists named recently increased retail prices of bee products (Tables A1–A3).

To reduce the value variability and facilitate comparison of the rankings, the sums of the scores by row and by column were normalised to a common scale (0–1) using a simple min-max normalisation technique [70][1]. Table 2 shows the ranking of the mutual effects of the SWOT items based on the normalised values of the algebraic sums per row, according to each expert panel. The coloured cells indicate the highest values (those ranked between 0.666 and 1.000) and highlight favourable items in green and unfavourable items in red. An indicator of farm resilience to handle particular challenges is based on the top position rank of favourable (strengths/opportunities) or unfavourable conditions (weaknesses/threats). From this perspective, producer representatives were most pessimistic about the state of the sector. In their opinion, many issues may jeopardize beekeeping success; in particular, they identified expensive and time-consuming rescue operations, reduced strength of the colonies, and honey price competition from foreign competitors. To both entomologists and market organisation leaders, the state of beekeeping seems less precarious, with the entomologists having ranked an even number of favourable and unfavourable items as top (important) factors. Honey market organisation leaders were also positive, and more so than the entomologists. Despite these differences, all panels placed the collaboration among beekeepers among the top factors affecting beekeeping farm resilience, namely their networking capacity to share their know-how and assets.

[1] The normalised value of the ith value of the sums per row (or per column) S_i is calculated as $(S_i - S_{min})$ / $(S_{max} - S_{min})$. Where S_{min} is the minimum value of the sums per row (or per column) and S_{max} is the maximum value of the sums per row (or per column).

Table 2. Ranking of the mutual effects—algebraic sums of the scores per row (normalised values).

Item Type	SWOT Item	Beekeeper Assoc. Leaders	Honey Market Org. Leaders	Entomologists
S	Strong motivation of beekeepers	0.143	0.429	1.000
S	Collaboration among beekeepers	0.929	1.000	0.714
W	Lack of time and labour	0.714	0	0.286
W	Higher management costs	1.000	0.571	1.000
O	Recently increased retail prices of bee products	0	0.286	0.143
O	Public and consumer interest	0.643	0.857	0.714
T	Reduced strength of honey bee colonies	0.857	0.571	0.714
T	Insufficient and mis-targeted public support	0.571	0	0
T	Lower honey prices from foreign competitors	0.786	0.857	0.714

Colours highlight the highest values (0.666–1.000). Green: favourable items; Red: unfavourable items.

Table 3 shows the ranking of the mutual effects of items based on the normalised values of the sums per column. Again, the highest values are highlighted in green and red for favourable and unfavourable, respectively. The ranking weights the strength with which the SWOT items are able to influence the other elements, strengthening or weakening them. The resulting general framework shows that the most influential aspects are mostly negative. In particular, those that scored higher in more than one panel were high costs for rescue operations and the reduced strength of the colonies. Again, the evaluation given by the representatives of producers was more pessimistic, since they placed all unfavourable items as top factors able to affect other items adversely. Alternatively, entomologists ranked 'recently increased retail prices' and market experts ranked 'strong motivation of beekeepers', both favourable items, at the top of their rankings.

Table 3. Ranking of the mutual effects—sums of the absolute values of the scores per column (normalised values).

Item Type	SWOT Item	Beekeeper Assoc. Leaders	Honey Market Org. Leaders	Entomologists
S	Strong motivation of beekeepers	0	1.000	0
S	Collaboration among beekeepers	0	0.333	0.200
W	Lack of time and labour	0.625	0	0.200
W	Higher management costs	1.000	0.667	0.600
O	Recently increased retail prices of bee products	0.375	0.500	1.000
O	Public and consumer interest	0.250	0.157	0
T	Reduced strength of honey bee colonies	0.875	0.500	0.800
T	Insufficient and mis-targeted public support	0.625	0.667	0.200
T	Lower honey prices from foreign competitors	0.875	0	0

Colours highlight the highest values (0.666–1.000). Green: favourable items; Red: unfavourable items.

5. Discussion

SWOT analysis is instrumental for development strategy formulation [41]. Although originally used as a private sector organisational method, the EU now mandates that it be employed to draft or evaluate regional and national strategic plans [69,71]. SWOT analysis in rural development programming has been summarised by Knierim and Nowicki [72], who highlighted its potential use in participatory decision-making.

Apiculture programmes as well have turned to *ex ante* evaluation of SWOT analysis to determine sector strategic approaches [73]. In Italy the apiculture programmes were developed by MiPAAF and regional administrations in cooperation with representative organisations of the beekeeping sector. Conversely, in our study, a bottom-up approach was used to directly involve local beekeepers in SWOT matrix definition. Then, the analysis was complemented with an expert-based approach aimed at ranking the SWOT item effects.

The FGDs revealed two important facts that honey bees and the beekeeping sector are facing from now-evident climate change effects. One is that the effects have placed additional constraints on the capacity of the honey bees and beekeeping to cope with new and traditional stresses, such as agricultural intensity, pesticides, and diseases. Second is that any adaptations to these stresses require additional labour and/or variable operating cost outlays. Nevertheless, both the intensity of the impacts and the resilience of the sector depend on the local environmental and institutional conditions. Beekeepers operating in the two areas showed different capacities to face these adversities. Despite the institutional and economic constraints (e.g., extensive and less profitable farming), those operating in the protected area benefit from the favourable ecological and environmental conditions of the park. Close mountain proximity reduces transhumance costs and allows typical and higher-priced honey types to be produced. Moreover, landscape heterogeneity and a consequent richer and longer blossom period, improve colony strength and reduce supplemental feeding costs. Different economic and environmental conditions also influence the type of farming adopted by beekeepers. In the protected area, beekeeping is practiced mostly by medium and large specialised beekeeping farms, as opposed to the beekeeping practised as complementary to other farming (specialist vineyards or mixed vineyard and hazelnut farms types) in the intensive wine-growing area.

All expert panels ranked reduced strength of the honey bee colonies and higher management costs as the most important issues to tackle. They were ranked among the top items, both for their capacity to influence other items and for the strength of their negative effects as a result of other items. Nonetheless, the three expert groups held different views on the state of the sector. Specifically, the item prioritisation projected by the beekeeper association leaders was far more dismal than that resulting from prioritisation by the honey market organisation leaders and entomologists. One explanation for this result may rest with the fact that beekeeper association representatives work closely with producers, which may make them more aware of the day-to-day difficulties and sector challenges. In this way, the involvement of different expert types and the interplay of top-down and bottom-up strategies have the potential to enrich the analysis [74], and minimise the criticism that SWOT is a top-down approach that separates 'those who think' and 'those who do' [75].

In the face of higher variable operating costs, beekeepers have complained of insufficient and mis-targeted public support. Moreover, the experts also scored higher costs and inefficient support as items that compounded the adverse effects of one another. Beekeepers stressed that EU grants for the sector mainly support capital investment activities (e.g., machine and equipment purchase). Instead, they believe that additional operating cost support would be more appropriate to meet the out-of-pocket running costs of climate change-related adaptations, such as supplemental feeding and hive transhumance.

These results show that if the needs of rural communities are not correctly addressed, then the intended policy effects may not be fully achieved. In light of this, the post-2020 CAP approach guarantees EU countries more flexibility to align their needs and fund allocation design within EU standards and rules. While not yet defined, compensation tools already provided to farmers through the second pillar of CAP will be part of the strategic national plans post-2020 that will integrate income support, CMOs, and rural development. One anticipated legal challenge to these changes is operating cost reimbursement inclusion, as it may be considered to distort production and trade and lead to unfair competition. This is why, as of today, examples of such an approach in Italy are few and usually implemented as exceptional and temporary measures. In 2019, the Friuli Venezia Giulia Region (NE Italy) provided grants to professional beekeepers in the form of reimbursement for supplemental feeding product expenditures through Regional Law No. 6/2010. In Piedmont Region, similar measures were adopted in 2020 and introduced into the 2014–2020 RDP to support farmers particularly affected by the COVID-19 crisis. Commercial bee farms managing more than 52 beehives were included in this exceptional support scheme. During an extended period of limited movement of seasonal labour, transhumance, pollination services, direct selling, and so on, beekeepers suffered considerable colony losses as they struggled to maintain and feed their bees. The support consisted of a one-time payment to cover ordinary bee farm operating costs [73].

Although EU competition rules may be a constraint, beekeepers believe that the costs associated with adaptation strategies should be steadily subsidised both in farms where beekeeping is the main income source (specialised farms) and in areas where maintenance of biodiversity and conservation of wild flora and fauna is a valued service to the ecosystem.

Focus group participants identified the extraordinary value of strong beekeeper motivation and their willingness to collaborate (resource sharing, input purchasing, and technical information exchanging). A collaborative spirit was unanimously recognised by all expert panels as the item most enhanced by the effects of other items, followed by public and consumer interest in honey bee health and hive products. In the case of beekeeper association leaders, personal motivation was indicated as the main item to leverage with targeted policies.

To optimise these unique qualities while avoiding hasty and inefficient management choices, advisory and institutional measures (technical assistance and extension) are considered the best tools to inform beekeepers of cost-efficient practices to cope with climate change. Extension services are also great guarantors of the labour, organisational, and marketing skills necessary to block farm management mistakes and sector threats. Advisory measures could also be used to address consumer education issues. For example, a campaign, built on the interest and demand of consumers for typical honey productions might reduce the strong net negative capacity effect identified by all three expert panels as attributable to the market influx of low-priced, low-quality honey supplied by foreign competitors. Improved labelling to identify local and high-quality products would serve both consumers and the sector well [76,77].

Several comments are worth noting on use of the method to weight and rank SWOT item effects. While easy to implement, the method also allows the mutual dependencies of the items to be analysed, making it possible for any outcomes from an item to be considered both as causes and effects of other items. This technique has already been applied in Italy in the field of policy programming and evaluation, e.g., for context analysis in the *ex ante* evaluation of the Friuli Venezia Giulia and Sardinia Region RDPs 2014–2020, involving a partnership of institutional, economic, social and environmental representatives both for the definition of the SWOT matrix and the prioritisation task [78,79].

In the analysis in this application, the experts of each panel discussed and agreed on the scores to be assigned to the pairwise comparisons. Matrices were completed in about two hours. Expert feedback on the task was positive; they remarked that once the scoring mechanism was made clear, the task could be performed without researcher assistance. The number of pairwise comparisons was found to be reasonable and not burdensome, although the method is certainly limited by the number of SWOT items included in the analysis. Techniques based on pairwise comparison demand a high level of cognitive effort from its participants, affecting the outcome quality [80] and making these methods hard to implement when many alternatives are available [81,82]. In this instance, only items indicated by the FGDs as most relevant were included to preserve exercise practicability and validity. Nonetheless, less relevant items may play an important role by decreasing or increasing the effects of others.

6. Conclusions

Beekeeping is a unique activity, able to support rural economies and communities without negative environmental consequences [6]. Honey bees guarantee society a mix of ecological functions and benefits by provisioning and supporting ecosystem services (agricultural production, food security, and biodiversity) [14,23]. Estimates of the economic value of pollinator ecosystem services over the past decade have risen and are still believed to be under-estimated [83]. As scientists have refined their contribution calculations, honey bee colonies have declined due to agricultural intensification and diseases, recently made worse by increasingly-evident climate change effects [40].

The situation demands conservation and land-use planning agenda to be strengthened to protect the provision of such services from anthropogenic actions [83]. Rural development measures within the post-2020 CAP can play a strategic role, as the maintenance of a viable beekeeping sector in rural areas is fundamental for the support of local economies and the flow of ecological services provided by honey bees. In an increasingly budget-constrained context [84], beekeeping policy should exploit key levers able to efficiently affect the entire system.

In this study, a simple mixed-method tool was trialled in which a pairwise comparison was added to a SWOT analysis-produced list of items. The SWOT analysis integrated with additional information, provides a framework by which policymakers can mould their needs and strategies to maintain or strengthen beekeeping farm viability and the capacity of the sector to contribute to sustainable rural development.

Study results challenged the belief that adverse climatic effects seem less severe and more manageable in protected areas versus intensive agricultural areas. In fact, from the two distinct beekeeper locations considered, a general need for better-targeted incentives, technical assistance, and extension was revealed. Such measures should not only cover the specific costs of climate change-related adaptation strategies, but also be more cost-effective to free beekeepers from self-reliance alone. Although the legal issues involved in the enforcement of competition law represent a constraint for implementation of the desired measures, the approach adopted in this study may contribute to define a 'strategic agenda' for the sector. That is to say, a list of needs and coherent actions adapted to the local context, wherein different types of measures could be classified into categories of support (e.g., permitted, permitted under conditions, and forbidden, based on the World Trade Organisation model). The technique used for prioritising the SWOT items allowed consideration of the mutual effects of the items, as they were dependent or explanatory variables. Limited by the number of pairwise comparisons, application of the method confirmed the relatively-low cognitive effort required to weight and rank SWOT items, as well as its suitability for quick and preliminary analysis by non-skilled evaluators, such as policy officers and practitioners.

Author Contributions: Conceptualisation, S.N. and M.V.; methodology, S.N.; formal analysis, S.N. and M.V.; investigation, S.N. and M.V.; data curation, S.N. and M.V.; writing—original draft preparation, S.N.; writing—review and editing, S.N., M.V. and C.F.; project administration, C.F.; funding acquisition, C.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was carried out with the financial support of "Parco Naturale Gesso e Stura" and "Unione di Comuni Colline di Langa e del Barolo" (Cuneo, Italy) within the framework of Interreg V-A France-Italy (Alcotra) "CClimaTT—Climate Change within Cross-Border Territories".

Institutional Review Board Statement: All experimental protocols were approved by the ad hoc committee of DISAFA (University of Torino).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Acknowledgments: The authors are grateful to the study area beekeepers, CClimaTT project staff, "Parco Naturale Gesso e Stura" (Cuneo, Italy), "Unione di Comuni Colline di Langa e del Barolo" (Cuneo, Italy), Seacoop Cooperative (Turin, Italy), and the association "La fabbrica dei suoni" (Cuneo, Italy). Special thanks are given to all involved stakeholders: Vincenzo Panettieri (Mediterranean Beekeepers Federation, Perugia, Italy), Roberto Reggiani (Associazione Apicoltori Reggio Parma, Reggio Emilia, Italy), Alberto Contessi (Osservatorio Nazionale Miele, Bologna, Italy), Ernesto Marengo (Società Agricola Cooperativa Piemonte Miele, Cuneo, Italy), Gaetana Mazzeo (Department of Agriculture, Food and Environment, Di3A, University of Catania, Italy), Ignazio Floris (Department of Agriculture, University of Sassari, Italy). Last, but not least, the authors thank Roberto Cagliero and Paola Ferrazzi for their precious and significant support of this work.

Conflicts of Interest: The authors declare no conflict of interest. Project funders had no role in the study design, collection, analyses, or interpretation of data, writing of the manuscript, or decision to publish the results.

Appendix A

Table A1. Pairwise comparison of the SWOT items by beekeeper association leaders.

		S		W		O		T			
		Strong Beekeeper Motivation	**Collaboration among Beekeepers**	**Lack of Time and Labour**	**Higher Management Costs**	**Recently Increased Retail Prices of Bee Products**	**Public and Consumer Interest**	**Reduced Strength of the Honey Bee Colonies**	**Insufficient And Mis-Targeted Public Support**	**Lower Honey Prices from Foreign Competitors**	**Algebraic Sum by Row**
S	Strong beekeeper motivation		2	−2	−2	2	2	−2	−2	−2	**−4**
	Collaboration among beekeepers	2		2	2	2	2	1	−2	−2	**7**
W	Lack of time and labour	0	−1		2	−2	−1	2	2	2	**4**
	Higher management costs	1	−1	2		0	0	2	2	2	**8**
O	Recently increased retail prices of bee products	0	0	0	−2		0	−2	0	−2	**−6**
	Public and consumer interest	1	0	0	0	0		2	0	0	**3**
T	Reduced strength of honey bee colonies	0	0	2	2	0	0		1	1	**6**
	Insufficient and mis-targeted public support	0	−1	1	2	−1	−1	0		2	**2**
	Lower honey prices from foreign competitors	−2	−1	2	2	2	−2	2	2		**5**
	Sum of the absolute values by column	**6**	**6**	**11**	**14**	**9**	**8**	**13**	**11**	**13**	

Table A2. Pairwise comparison of the SWOT items by honey market organization leaders.

		S		W		O		T			
		Strong Beekeeper Motivation	**Collaboration among Beekeepers**	**Lack Of Time and Labour**	**Higher Management Costs**	**Recently Increased Retail Prices of Bee Products**	**Public and Consumer Interest**	**Reduced Strength of the Honey Bee Colonies**	**Insufficient and Mis-Targeted Public Support**	**Lower Honey Prices from Foreign Competitors**	**Algebraic Sum by Row**
S	Strong beekeeper motivation		1	−1	−1	2	2	−1	−1	0	**1**
	Collaboration among beekeepers	2		2	0	0	0	0	1	0	**5**
W	Lack of time and labour	−2	−1		0	0	0	1	0	0	**−2**
	Higher management costs	−2	−1	0		−1	0	2	2	2	**2**
O	Recently increased retail prices of bee products	0	0	0	0		0	0	0	0	**0**
	Public and consumer interest	1	0	0	0	0		2	0	1	**4**
T	Reduced strength of honey bee colonies	−2	0	0	2	0	0		2	0	**2**
	Insufficient and mis-targeted public support	0	−2	0	2	−1	−1	0		0	**−2**
	Lower honey prices from foreign competitors	0	0	0	2	2	−1	0	1		**4**
	Sum of the absolute values by column	**9**	**5**	**3**	**7**	**6**	**4**	**6**	**7**	**3**	

Table A3. Pairwise comparison of the SWOT items by entomologists.

		S		W		O		T			
		Strong Beekeeper Motivation	**Collaboration among Beekeepers**	**Lack of Time and Labour**	**Higher Management Costs**	**Recently Increased Retail Prices of Bee Products**	**Public and Consumer Interest**	**Reduced Strength of the Honey Bee Colonies**	**Insufficient and Mis-Targeted Public Support**	**Lower Honey Prices from Foreign Competitors**	**Algebraic Sum by Row**
S	Strong beekeeper motivation		1	1	−1	2	2	0	0	0	**5**
	Collaboration among beekeepers	1		1	1	−2	0	1	1	0	**3**
W	Lack of time and labour	−1	−1		1	−1	−1	1	1	1	**0**
	Higher management costs	2	−2	1		−2	0	2	2	2	**5**
O	Recently increased retail prices of bee products	0	0	−1	−2		1	2	−1	0	**−1**
	Public and consumer interest	0	0	0	0	1		2	0	0	**3**
T	Reduced strength of honey bee colonies	1	1	2	−2	−2	0		1	2	**3**
	Insufficient and mis-targeted public support	−1	−2	0	1	−1	−1	1		1	**−2**
	Lower honey prices from foreign competitors	0	0	1	1	0	−1	1	1		**3**
	Sum of the absolute values by column	**6**	**7**	**7**	**9**	**11**	**6**	**10**	**7**	**6**	

References

1. Ritter, W.; Akratanakul, P. *Honey Bee Diseases and Pests: A Practical Guide*; FAO: Rome, Italy, 2006.
2. Estoque, R.C.; Murayama, Y. Suitability Analysis for Beekeeping Sites Integrating GIS & MCE Techniques. In *Spatial Analysis and Modeling in Geographical Transformation Process*; Springer: Dordrecht, The Netherlands, 2011. [CrossRef]
3. Damián, G.C. GIS-Based Optimal Localisation of Beekeeping in Rural Kenya. Master Thesis, Geographical Information Sciences Department of Physical Geography and Ecosystems Science, Lund University, Lund, Sweden, 2016.
4. Sari, F.; Ceylan, D.A.; Özcan, M.M.; Özcan, M.M. A comparison of multicriteria decision analysis techniques for determining beekeeping suitability. *Apidologie* **2020**, *51*, 481–498. [CrossRef]
5. Fedoriak, M.; Kulmanov, O.; Zhuk, A.; Shkrobanets, O.; Tymchuk, K.; Moskalyk, G.; Olendr, T.; Yamelynets, T.; Angelstam, P. Stakeholders' views on sustaining honey bee health and beekeeping: The roles of ecological and social system drivers. *Landsc. Ecol.* **2021**, *36*, 763–783. [CrossRef]
6. Bekić, B.; Jovanović, M. Beekeeping as a Factor of Danube Region Sustainable Development. In *International Scientific Conference Sustainable Agriculture and Rural Development in Terms of the Republic of Serbia Strategic Goals Realization within the Danube Region: Regional Specificities*; Institute of Agricultural Economics: Belgrade, Serbia, 2015; pp. 156–172, ISBN 978-86-6269-046-3.
7. Altunel, T.; Olmez, B. Beekeeping as a rural development alternative in Turkish northwest. *Appl. Ecol. Environ. Res.* **2019**, *17*, 6017–6029. [CrossRef]
8. Blanc, S.; Brun, F.; Di Vita, G.; Mosso, A. Traditional beekeeping in rural areas: Profitability analysis and feasibility of pollination services. *Qual. Access Success* **2018**, *19*, 72–79.
9. European Commission. Honey. Detailed Information on Honey Production, National Apiculture Programmes, Budget and Legal Bases. Available online: https://ec.europa.eu/info/food-farming-fisheries/animals-and-animal-products/animal-products/honey_en (accessed on 20 January 2021).
10. European Commission. EU Beekeeping Sector. National Apiculture Programmes 2020–2022. Available online: https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/animals_and_animal_products/documents/honey-apiculture-programmes-overview-2020-2022.pdf (accessed on 20 January 2021).
11. Chauzat, M.-P.; Cauquil, L.; Roy, L.; Franco, S.; Hendrikx, P.; Ribière-Chabert, M. Demographics of the European apicultural industry. *PLoS ONE* **2013**, *8*, e79018. [CrossRef]
12. Floris, I. Italian Apiculture, a Journey through History and Honey Diversity. Accademia Nazionale Italiana di Entomologia, Firenze, Italia. 2020. Available online: https://biodiversityassociation.org/it/wba-project/shop/tutti-i-prodotti/italian-apicuture/ (accessed on 20 January 2021).
13. European Commission. *Evaluation of Measures for the Apiculture Sector. Final Report*; DG Agriculture and Rural Development, Framework Contract No 30-CE-0219319/00-20; European Commission: Bruxelles, France, 2013; 170p.

14. IPBES. *The Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production*; Potts, S.G., Imperatriz-Fonseca, V.L., Ngo, H.T., Eds.; Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services: Bonn, Germany, 2016; p. 552.
15. Klein, A.M.; Boreux, V.; Fornoff, F.; Mupepele, A.C.; Pufal, G. Relevance of wild and managed bees for human well-being. *Curr. Opin. Insect Sci.* **2018**, *26*, 82–88. [CrossRef] [PubMed]
16. Klein, A.M.; Vaissière, B.E.; Cane, J.H.; Steffan-Dewenter, I.; Cunningham, S.A.; Kremen, C.; Tscharntke, T. Importance of pollinators in changing landscapes for world crops. *Proc. R. Soc. Lond. Ser. B* **2007**, *274*, 303–313. [CrossRef] [PubMed]
17. Gallai, N.; Salles, J.M.; Settele, J.; Vaissière, B.E. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecol. Econ.* **2009**, *68*, 810–821. [CrossRef]
18. Hein, L. The economic value of the pollination service, a review across scales. *Open Ecol. J.* **2009**, *2*, 74–82. [CrossRef]
19. Ollerton, J.; Winfree, R.; Tarrant, S. How many flowering plants are pollinated by animals? *Oikos* **2011**, *120*, 321–326. [CrossRef]
20. Wratten, S.D.; Gillespie, M.; Decourtye, A.; Mader, E.; Desneux, N. Pollinator habitat enhancement: Benefits to other ecosystem services. *Agric. Ecosyst. Environ.* **2012**, *159*, 112–122. [CrossRef]
21. Leonhardt, S.D.; Gallai, N.; Garibaldi, L.A.; Kuhlmann, M.; Klein, A.M. Economic gain, stability of pollination and bee diversity decrease from southern to northern Europe. *Basic Appl. Ecol.* **2013**, *14*, 461–471. [CrossRef]
22. Mazzeo, G.; Scavo, A.; Lo Monaco, A.; Longo, S.; Mauromicale, G. Insect pollinators improve seed production in globe artichoke (*Cynara cardunculus* var. *scolymus*). *Ann. Appl. Biol.* **2020**, *176*, 241–248. [CrossRef]
23. Potts, S.G.; Imperatriz-Fonseca, V.; Ngo, H.T.; Aizen, M.A.; Biesmeijer, J.C.; Breeze, T.D.; Dicks, L.V.; Garibaldi, L.A.; Hill, R.; Settele, J.; et al. Safeguarding pollinators and their values to human well-being. *Nature* **2016**, *540*, 220–229. [CrossRef] [PubMed]
24. Badiou-Bénéteau, A.; Benneveau, A.; Géret, F.; Delatte, H.; Becker, N.; Brunet, J.L.; Reynaud, B.; Belzunces, L.P. Honeybee biomarkers as promising tools to monitor environmental quality. *Environ. Int.* **2013**, *60*, 31–41. [CrossRef] [PubMed]
25. Bargańska, Z.; Ślebioda, M.; Namieśnik, J. Honey bees and their products: Bioindicators of environmental contamination. *Crit. Rev. Environ. Sci. Technol.* **2016**, *46*, 235–248. [CrossRef]
26. Potts, S.G.; Biesmeijer, J.C.; Kremen, C.; Neumann, P.; Schweiger, O.; Kunin, W.E. Global pollinator declines: Trends, impacts and drivers. *Trends Ecol. Evol.* **2010**, *25*, 345–353. [CrossRef]
27. Goulson, D.; Nicholls, E.; Botías, C.; Rotheray, E.L. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science* **2015**, *347*, 1255957. [CrossRef]
28. Flores, J.F.; Gil-Lebrero, S.; Gámiz, V.; Rodríguez, M.I.; Ortiz, M.A.; Quiles, F.J. Effect of the climate change on honey bee colonies in a temperate Mediterranean zone assessed through remote hive weight monitoring system in conjunction with exhaustive colonies assessment. *Sci. Total Environ.* **2019**, *653*, 1111–1119. [CrossRef] [PubMed]
29. Bänsch, S.; Tscharntke, T.; Ratnieks, F.L.W.; Härtel, S.; Westphal, C. Foraging of honey bees in agricultural landscapes with changing patterns of flower resources. *Agric. Ecosyst. Environ.* **2020**, *291*, 106792. [CrossRef]
30. Vercelli, M.; Croce, L.; Mancuso, T. An economic approach to assess the annual stock in beekeeping farms: The honey bee colony inventory tool. *Sustainability* **2020**, *12*, 9258. [CrossRef]
31. Le Conte, Y.; Navajas, M. Climate change: Impact on honey bee populations and diseases. *Rev. Sci. Tech. Off. Int. Epiz.* **2008**, *27*, 499–510.
32. Cornelissen, B.; Neumann, P.; Schweiger, O. Global warming promotes biological invasion of a honey bee pest. *Glob. Chang. Biol.* **2019**, *25*, 3642–3655. [CrossRef] [PubMed]
33. Nicholson, C.C.; Egan, P.A. Natural hazard threats to pollinators and pollination. *Glob. Chang. Biol.* **2020**, *26*, 380–391. [CrossRef] [PubMed]
34. Hegland, S.J.; Nielsen, A.; Lázaro, A.; Bjerknes, A.L.; Totland, Ø. How does climate warming affect plant-pollinator interactions? *Ecol. Lett.* **2009**, *12*, 184–195. [CrossRef]
35. Schweiger, O.; Biesmeijer, J.C.; Bommarco, R.; Hickler, T.; Hulme, P.E.; Klotz, S.; Kühn, I.; Moora, M.; Nielsen, A.; Ohlemüller, R.; et al. Multiple stressors on biotic interactions: How climate change and alien species interact to affect pollination. *Biol. Rev.* **2010**, *85*, 777–795. [CrossRef] [PubMed]
36. EU Pollinators Initiative. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. COM/2018/395 Final. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1528213737113&uri=CELEX:52018DC0395 (accessed on 20 January 2021).
37. Ismea. *Il Settore Apistico Nazionale*; Ismea: Rome, Italy, 2019; 24p.
38. Copa-Cogeca. Position Paper on the European Honey Market. Action Plan to Rectify the Alarming Situation. Brussels. February 2020. Available online: https://www.copa-cogeca.eu/downloadThread.aspx?threadID=2153212 (accessed on 17 April 2021).
39. ParaiÏso, A.A.; Sossou, A.; Iz-Haquou, D.; Yegbemey, N.H.; Sanni, A. Perceptions and adaptations of beekeepers and honey hunters to climate change: The case of the communes of Natitingou and Tanguieta in Northwest of Benin. *Afric. Crop Sci. J.* **2012**, *20*, 523–532.
40. Vercelli, M.; Novelli, S.; Ferrazzi, P.; Lentini, G.; Ferracini, C. A Qualitative Analysis of Beekeepers' Perceptions and Farm Management Adaptations to the Impact of Climate Change on Honey Bees. *Insects* **2021**, *12*, 228. [CrossRef]
41. European Union. SWOT (Strengths, Weakness, Opportunities, Threats). Available online: https://europa.eu/capacity4dev/evaluation_guidelines/wiki/swot-strenghts-weakness-opportunities-threats-0 (accessed on 20 January 2021).

42. Valentin, E.K. Away with SWOT analysis: Use defensive/offensive evaluation instead. *J. Appl. Bus. Res.* **2005**, *21*, 91–105. [CrossRef]
43. Khatir, M.V.; Akbarzadeh, Z. Elucidation of structural relationships of SWOT: A mixed method approach based on FMADM for formulating science and technology strategies. *Technol. Soc.* **2019**, *56*, 44–56. [CrossRef]
44. Kurttila, M.; Pesonen, M.; Kangas, J.; Kajanus, M. Utilizing the analytic hierarchy process (AHP) in SWOT analysis—A hybrid method and its application to a forest-certification case. *For. Pol. Econ.* **2000**, *1*, 41–52. [CrossRef]
45. Akbulak, C.; Cengiz, T. Determining ecotourism strategies using A'WOT hybrid method: Case study of Troia Historical National Park, Çanakkale, Turkey. *Int. J. Sustain. Dev. World Ecol.* **2014**, *21*, 380–388. [CrossRef]
46. Canto-Perello, J.; Curiel-Esparza, J.; Calvo, V. Strategic decision support system for utility tunnel's planning applying A'WOT method. *Tunn. Undergr. Space Technol.* **2016**, *55*, 146–152. [CrossRef]
47. Kişi, N. A Strategic Approach to Sustainable Tourism Development Using the A'WOT Hybrid Method: A Case Study of Zonguldak, Turkey. *Sustainability* **2019**, *11*, 964. [CrossRef]
48. Bottero, M.; D'Alpaos, C.; Marello, A. An Application of the A'WOT Analysis for the Management of Cultural Heritage Assets: The Case of the Historical Farmhouses in the Aglié Castle (Turin). *Sustainability* **2020**, *12*, 1071. [CrossRef]
49. Catron, J.; Stainback, G.A.; Dwivedi, P.; Lhotka, J.M. Bioenergy development in Kentucky: A SWOT-ANP analysis. *For. Pol. Econ.* **2013**, *28*, 38–43. [CrossRef]
50. Barati, A.A.; Kalantari, K.; Nazari, M.R.; Asadi, A. A hybrid method (ANP-SWOT) to formulate and choose strategic alternatives for development of rural cooperatives in Iran. *J. Agric. Sci. Technol.* **2017**, *19*, 757–769.
51. Starr, M.; Omkar, J.; Rodney, E.W.; Zou, C.B. Perceptions regarding active management of the Cross-timbers forest resources of Oklahoma, Texas, and Kansas: A SWOT-ANP analysis. *Land Use Pol.* **2019**, *81*, 523–530. [CrossRef]
52. Falcone, P.M. Tourism-based circular economy in Salento (South Italy): A SWOT-ANP analysis. *Soc. Sci.* **2019**, *8*, 216. [CrossRef]
53. Grošelj, P.; Hodges, D.G.; Stirn, L.Z. Participatory and multi-criteria analysis for forest (ecosystem) management: A case study of Pohorje, Slovenia. *For. Pol. Econ.* **2016**, *71*, 80–86. [CrossRef]
54. Barry, F.; Seck, D.; Faye, O.; Mbahin, N.; Diawara, I.; Camara, B.; Ciss, I.; Bakou, S.N.; Diouf, A. Beekeeping diagnostic in four production basins in Senegal: An analysis of opportunities and weaknesses. *Int. J. Biol. Chem. Sci.* **2018**, *12*, 1186–1198. [CrossRef]
55. Güngör, E. Determination of optimum management strategy for honey production forest lands using a'wot and conjoint analysis: A case study in turkey. *Appl. Ecol. Environ. Res.* **2018**, *16*, 3437–3459. [CrossRef]
56. European Commission. Rural Development. Protecting the Future of Rural Communities. Available online: https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/rural-development (accessed on 20 January 2021).
57. European Commission. EU Farm Policy Rules to be Further Simplified. Available online: https://ec.europa.eu/commission/presscorner/detail/en/IP_17_5242 (accessed on 20 January 2021).
58. OECD. *Agricultural Policy Monitoring and Evaluation 2018*; OECD Publishing: Paris, France, 2018; p. 204.
59. European Commission. Future of the Common Agricultural Policy. Available online: https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/future-cap_en (accessed on 20 January 2021).
60. Wilkinson, S. Focus group methodology: A review. *Int. J. Soc. Res. Methodol.* **1998**, *1*, 181–203. [CrossRef]
61. Bloor, M.; Frankland, J.; Thomas, M.; Robson, K. *Focus Groups in Social Research*; Sage Publications: London, UK, 2001; 120p.
62. Krueger, R.A.; Casey, M.A. *Focus Groups: A Practical Guide for Applied Research*; Sage Publications: Thousand Oaks, CA, USA, 2014; 280p.
63. Gibbs, A. Focus groups. *Soc. Res. Update* **1997**, *19*, 1–8.
64. Onwuegbuzie, A.J.; Dickinson, W.B.; Leech, N.L.; Zoran, A.G. A qualitative framework for collecting and analyzing data in focus group research. *Int. J. Qual. Meth.* **2009**, *8*, 1–21. [CrossRef]
65. Oprandi, N. *Focus Group: Breve Compendio Teorico-Pratico*; Emme&Erre Libri: Padova, Italy, 2001.
66. Stewart, D.W.; Shamdasani, P.N.; Rook, D.W. *Focus Groups*; Sage Publications: Thousand Oaks, CA, USA, 2007; 188p.
67. Gamble, J.; Thompson, A., Jr.; Peteraf, M. *Essentials of Strategic Management: The Quest for Competitive Advantage*; McGraw-Hill Education: New York, NY, USA, 2019; p. 864.
68. Bezzi, C. Rendiamo dinamica la SWOT. *Rass. Ital. Valutazione* **2005**, *31*, 7–15.
69. Bolli, M.; Cagliero, R.; Cisilino, F.; Cristiano, S.; Licciardo, L. *L'analisi SWOT per la Costruzione Delle Strategie Regionali e Nazionale Della PAC Post-2020. Working Document, Rete Rurale Nazionale 2014–2020*; Mipaaf: Roma, Italy, 2019; p. 54.
70. Jain, A.; Nandakumar, K.; Ross, A. Score normalization in multimodal biometric systems. *Patt. Recog.* **2005**, *38*, 2270–2285. [CrossRef]
71. McEldowney, J.; Kelly, P. *CAP Strategic Planning. Operationals Perspectives. EPRS-European Parliamentary Research Service*; European Union: Brussels, Belgium, 2019; p. 28.
72. Knierim, A.; Nowicki, P. SWOT analysis: Appraisal of a new tool in European rural development policies. *Outlook Agric.* **2010**, *39*, 65–72. [CrossRef]
73. Regione Piemonte. Testo Vigente del PSR 2014–2020. Available online: https://www.regione.piemonte.it/web/temi/fondi-progetti-europei/programma-sviluppo-rurale-feasr/gestione-attuazione-psr/testo-vigente-psr-2014-2020 (accessed on 1 March 2021).
74. Dyson, R.G. Strategic development and SWOT analysis at the University of Warwick. *Eur. J. Operat. Res.* **2004**, *152*, 631–640. [CrossRef]

75. Al-Araki, M. SWOT analysis revisited through PEAK-framework. *J. Intell. Fuzzy Syst.* **2013**, *25*, 615–625. [CrossRef]
76. Cosmina, M.; Gallenti, G.; Marangon, F.; Troiano, S. Reprint of "Attitudes towards honey among Italian consumers: A choice experiment approach". *Appetite* **2016**, *106*, 110–116. [CrossRef] [PubMed]
77. Kos Skubic, M.; Erjavec, K.; Klopčič, M. Consumer preferences regarding national and EU quality labels for cheese, ham and honey: The case of Slovenia. *Br. Food J.* **2018**, *120*, 650–664. [CrossRef]
78. Cisilino, F.; Licciardo, F. Il partenariato nel PSR 2014-20 del Friuli Venezia Giulia attraverso la SWOT relazionale partecipata. *Agriregionieuropa* **2014**, *39*, 77–79.
79. Licciardo, F.; Buscemi, V.; Solca, F. La valutazione del contesto di riferimento del PSR 2014-20 della Regione Sardegna attraverso la SWOT relazionale. In Proceedings of the Atti del Congresso, Associazione Nazionale di Valutazione XVIII Congresso Annuale, Genova, Italy, 17–18 April 2015. [CrossRef]
80. Maida, M.; Maier, K.; Obwegeser, N. Pairwise comparison techniques for preference elicitation: Using test-retest reliability as a quality indicator. In Proceedings of the International Conference on Information Resources Management (Conf-IRM 2012), Vienna, Austria, 21–23 May 2012; p. 65.
81. Vestola, M. *A Comparison of Nine Basic Techniques for Requirements Prioritization*; Helsinki University of Technology: Helsinki, Finland, 2010; pp. 1–8.
82. Cagliero, R.; Bellini, F.; Marcatto, F.; Novelli, S.; Monteleone, A.; Mazzocchi, G. Prioritising CAP Intervention Needs: An Improved Cumulative Voting Approach. *Sustainability* **2021**, *13*, 3997. [CrossRef]
83. Porto, R.G.; de Almeida, R.F.; Cruz-Neto, O.; Tabarelli, M.; Viana, B.F.; Peres, C.A.; Lopes, A.V. Pollination ecosystem services: A comprehensive review of economic values, research funding and policy actions. *Food Secur.* **2020**, *12*, 1–18. [CrossRef]
84. European Parliament. The History of the EU Budget. Available online: https://www.europarl.europa.eu/thinktank/en/document.html?reference=IPOL_IDA (accessed on 1 March 2021).

land

MDPI

Article

Co-Management of Protected Areas: A Governance System Analysis of Vatnajökull National Park, Iceland

Jon Geir Petursson [1,*] and Dadi Mar Kristofersson [2]

[1] Environment and Natural Resources, Faculties of Life and Environmental Sciences, and Sociology, Anthropology and Folkloristics, University of Iceland, 102 Reykjavik, Iceland
[2] Faculty of Economics, University of Iceland, 102 Reykjavik, Iceland; dmk@hi.is
* Correspondence: jgp@hi.is

Abstract: Land allocated to protected areas (PA) is expanding as are expectations about the services these areas deliver. There is a need to advance knowledge on PA governance systems, like co-management, recognising that there is no "one-size-fits-all" solution. We analyse the co-management governance system and performance of Vatnajökull National Park (VNP), Iceland. We adapt an analytical framework from the literature on environmental governance and analyse its governance system, hence actor roles, institutional arrangements and interactions. Our findings illustrate that the co-management structure was an outcome of political negotiations and a response to the lack of legitimacy of its predecessors; resulting in a tailor-made governance system set out in park-specific legislation. Although the performance is quite positive, being adaptive to changes, inclusive, promoting rural development and an appreciated facilitator of devolution and power-sharing, it has come with challenges. It has encountered problems delineating responsibilities among its actors, causing conflict and confusion; in settling conflicting localised issues close to local stakeholders, there have been capacity issues. We argue that the VNP co-management system is fit for its purpose, aligned with Icelandic land-use governance structures but in need of systematic improvements. There are important lessons as Iceland seeks to expand its PA estate and beyond, since the global community is setting ambitious policy goals to expand site-based conservation.

Keywords: co-management; protected areas; rural development; governance system; legitimacy; Vatnajökull National Park; Iceland

Citation: Petursson, J.G.; Kristofersson, D.M. Co-Management of Protected Areas: A Governance System Analysis of Vatnajökull National Park, Iceland. *Land* **2021**, *10*, 681. https://doi.org/10.3390/land10070681

Academic Editors: Mónica de Castro-Pardo, Joao C. Azevedo and Pascual Fernández

Received: 1 June 2021
Accepted: 25 June 2021
Published: 28 June 2021

1. Introduction

Land designated as protected areas (PA) has greatly increased globally during the past decades, with even more ambitious targets on the horizon. It is seen as a key instrument for the conservation of nature, with most nation states currently expanding their PA estates [1,2]. Concurrently, expectations about the delivery of multiple services from such areas, beyond purely conservation objectives, has evolved and expanded [3]. This requires suitable and effective governance approaches to PAs that can accommodate the different localities and socio-economic settings to operate within [4,5]. Co-management is an approach to govern natural resources that has gained wide attention, acting as a compromise between top-down and bottom-up approaches [6]. It can be defined as multi-level resource governance when the central government shares power and responsibility with other actors, typically including resources users, local government and often also the private sector and civil society [7]. The proponents of the co-management paradigm claim that it entails options for more socially inclusive and effective approaches, having promoted the approach as a strategy to mitigate conflicts, promote local rights, equity, legitimacy, and sustainability [8]. This may further resolve constraints between different levels of government, generating increased accountability upwards and increased legitimacy downwards [9,10]. Different forms of co-management have been applied across many natural resource contexts worldwide, like in fisheries, grazing, forestry, wildlife and PAs [11,12].

This study focuses on the application of co-management in the context of PA governance. PAs are important parts of national strategies to govern biodiversity and carbon resources, landscapes and multiple other environmental services, encompassing now more than 15% of the global terrestrial area [3]. PA governance has been subject to multiple challenges. For a long time, the key approach was based on top-down centralised models, often described by the metaphor of a "fortress" approach to governance [13]. This type of traditional top-down governance has been criticised for not delivering legitimate and efficient conservation and has frequently been a source of multiple social conflicts. There has therefore been an appeal for alternative governance strategies [14]. PA governance has been evolving over the past few decades towards more enabling contexts for conservation, seeking more socially inclusive and legitimate governance where co-management has become an influential approach [15,16], often as a part of national decentralisation agendas [17]. This has manifested in alternative strategies including co-management and direct community conservation strategies, seeing transfer of mandates and power-sharing agreements between actors at different governance levels [18]. Co-management has emerged from these transitions as an influential narrative of joint decision-making between central and local level actors, distinguished by the presence of some level of power-sharing and partnerships [6,16].

Simultaneously there has been a transition in expectations about the delivery of PAs and governance systems to accommodate that. For a long period in economic terms, PA were looked upon as "economic black holes" in the otherwise productive rural agricultural landscapes, including in Iceland [19]. The initial view was that such areas were mainly supposed to deliver strict conservation, leaving the interest in their existence mainly to conservationists and philanthropists outside of the economic rational. This economical notion has, however, been changing, with increased focus on the broad delivery of ecosystem services to society at large, perhaps most notably tourism, rural development and public goods such as carbon and water [3]. Concurrently, PAs are becoming increasingly recognised as important for the growing nature-based tourism sector, worldwide [20].

Summing up responses to these PA transitions has created a widespread call for alternative and innovative governance models that can meet the challenges of multiple delivery of both social and ecological criteria [21]. Co-management is there seen as one key alternative approach, providing a model for more inclusive governance and a vehicle for delivery of multiple ecosystem services.

The co-management approach has, however, been challenging to implement. Although current political trends tend to promote the approach, empirical findings on performance remain ambiguous about the degree of success and many studies have cautioned against seeing it as a panacea for advancing the legitimacy of governance [22,23]. It is also important that when instituting a co-management system, no standard or blueprint design exists, but rather it should be viewed as a call for innovative and tailor-made institutional solutions since local environment conditions, social settings, contexts and capacities vary [3,23,24]. These issues are also interdependent. Therefore, it is the design of the co-management system that will largely shape the governance outcomes.

Iceland constitutes a good case for the study of some of those PA transitions. Its protected area estate has been developing for a long period of time, currently encompassing ca. 1/4 of its lands under formal protection, including the large Vatnajökull National Park (VNP) [25]. The expectations towards delivery of services from the PAs have been changing. In addition to conserving nature, it is recognised for its capacity with regards to nature-based tourism as a driver of rural development.

This study aims to contribute to the debate on how to design inclusive governance systems for PAs. Its main objective is to advance the knowledge about the design and performance of the co-management approach to govern PAs. It is, therefore, not the scope of this study to assess directly the ecological conservation outcomes in the park. We develop an analytical framework to analyse the design and performance of a co-management resources governance system for PAs, using the case of VNP in Iceland, established in 2007 with a co-management approach to governance.

Our main research questions are as follows:

- How can a co-management governance system be designed for a large national park?
- What have been the main challenges impacting the performance of the co-management governance system?
- What are the key policy implications and how can they inform park governance and rural development?

2. Materials and Methods

2.1. Governance System Analytical Framework

This study is conceptually based on a governance system analysis framework to analyse the design and performance of PA co-management and related processes. It has theoretical underpinnings in institutional theory and elaborates its analytical framework from theories about the governance of environmental resources [26–28].

We understand co-management as a specific type of natural resources governance system, and for this study, as an approach to govern protected areas. Well-defined frameworks are available for the analysis of such governance systems to investigate their various components and interrelationships [29,30]. We employ a modified version of such a framework to guide our analyses of the co-management governance system in VNP (Figure 1). Importantly, there is no blueprint for the design of such co-management governance systems. Additionally, policy options are usually narrowed down as such systems do not emerge in a vacuum but are frequently shaped and re-shaped by historical institutional processes and legacies [31].

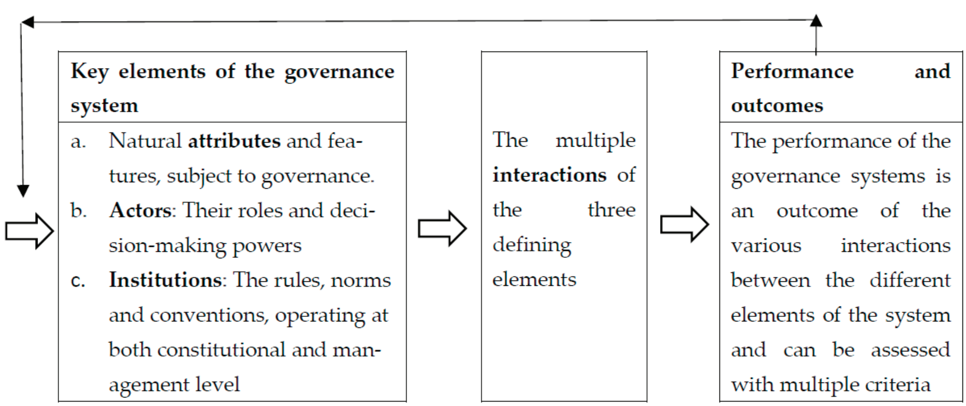


Figure 1. A natural resources governance system and its analytical elements (Adopted from Vatn, 2015).

The governance system framework is built on an understanding of its three main components and their interactions.

First, institutions are central when examining how humans relate to the environment and all humanly using natural resources can be understood to be embedded in complex, social-ecological systems [29]. Institutions in this context provide the set of rules, norms and conventions that guide and are being guided by, the human interactions with the environment [32]. Institutions are different from the organisations that constitute the actors that make policies, take decisions or are affected by decisions. Institutions are not static but subject to change and evolution [30]. Importantly, co-management can be viewed either as a model for new PAs or as an institutional change alternative to already existing PAs that have been governed under different approaches. The study of any governance system is therefore influenced by the history and legacy of the older systems, its power relations and conflict levels [31].

Second, the actors are those that have a role in the given governance system. They can broadly be differentiated according to capacities in the civil society, constituting economic or administrative actors that further operate at different levels. Core analytical issues concern actor agencies as defined by their power and resources, rights and responsibilities, and how these facets are derived from different sources. As power-sharing is an implicit objective of co-management, who gets what power and how actors exercise their power become an important analytical issue [11,33]. Power is, however, a highly contested term in all social analysis [34]. We follow the argument made by Giddens [35] that "power is the capacity to achieve outcomes", with the notion that to have resources is one thing but to use them and be effective is another [34].

Third, there are the attributes of the natural resources at stake. No national parks have the same natural resources and nor their socio-ecological relations are the same. This calls for an institutional framework that fits well with the physical attributes of the natural resources at stake [31].

2.2. Assessing Performance of a Governance System

Governance performance can be assessed in different ways, according to different criteria and at multiple levels [30]. For our study of the performance of the governance system, we employ two important criteria: legitimacy, both at the input and output levels and institutional fitness (Table 1).

Table 1. Criteria for the co-management governance system performance assessment.

Analytical Criteria		**Relative to Park Governance**
Legitimacy	Input level	Factors that shaped the park creation. Focus on participation and representation.
	Output level	Factors related to park operation. Focus on accountability and performance.
Institutional fitness	Fit	The fitness of the governance system to the physical attributes. Concerns mainly spatial fit, but is to a lesser degree temporal and functional.
	Interplay	The interplay with other institutions at both horizonal and vertical levels.

Legitimacy is an important analytical criterion for the evaluation of a governance system and its performance, understood here as something that goes beyond legality to incorporate justified authority [36]. We differentiate our understanding of legitimacy at the input-output level. At the input level, analysis focuses especially on the acceptability of decisions, participation and representation, whereas output legitimacy investigates governance outcomes and effectiveness [30].

PA establishment is essentially an institutional exercise, determining spatial demarcations of land and the establishment of management rules. Institutional fit is a concept covering the relationships in a governance system between involved institutions and the biophysical systems [31]. It refers to how well the institutional arrangements match the defining features of the perceived biophysical problems they address [37]. PA institutions, however, do not operate in a vacuum but are subject to multiple interplays with other land-use-related institutions, both at horizonal and vertical levels [38]. Therefore, how institutions fit and their interplay represent important evaluation criteria of PAs and their performance.

2.3. The Study Site and Its Governance Context

2.3.1. The Case: Vatnajökull National Park

This study takes the case of Vatnajökull National Park (VNP) that was created with legislation passing the Icelandic Parliament in 2007 that set foundation for issuing a by-law, that formally was enacted by the Minster in the 2008, formally establishing the park [39]. VNP was established via the merging of two existing national parks, Skaftafell NP founded in 1967 and Jökulsárgljúfur NP founded in 1973, and the addition of a large area encompassing the whole of the Vatnajökull Glacier and some of its surrounding landscapes. Since its establishment, it has gradually been expanded to its current size of approximately 14,700 km^2, constituting around 14% of Iceland's total land area (Figure 2). It is currently the largest national park in Europe, outside of Russia, and is classified as Category II with embedded Category Ib and VI areas according to the IUCN categorisation [39].

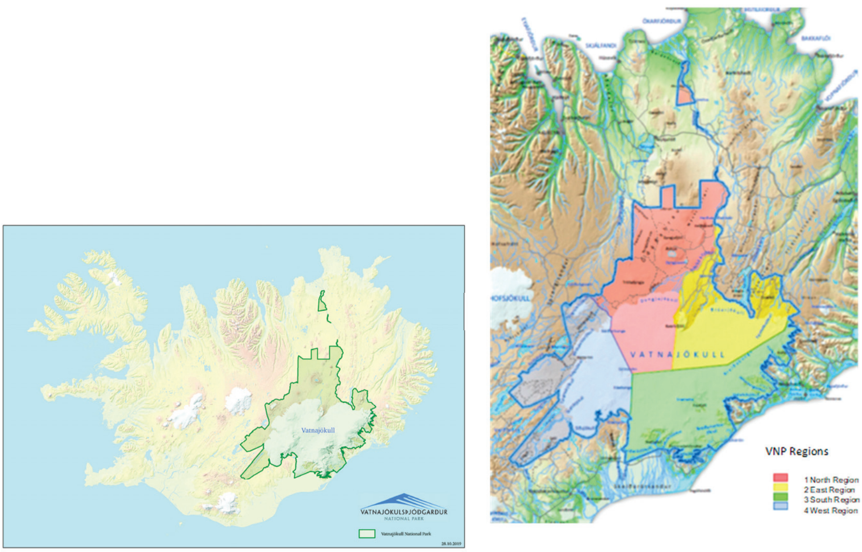


Figure 2. Maps of Vatnajökull National Park in Iceland and its four administrative regions (Source: Vatnajökull NP).

VNP includes the Vatnajökull Glacier ice cap that covers around more than half of the park. It represents an example of the shaping forces of nature, including the dividing tectonic plates of North America and Eurasia, and associated geological processes. Due to its globally unique geographical features, with volcanic activity and glacial forces occurring simultaneously, the park demonstrates the dynamic forces of nature, characteristics which led to it becoming a UNESCO World Heritage Site in 2019. This is well described in the foundation document for the UNESCO inscription [39].

The park exclusively includes uninhabited areas with no permanent human settlement within its boundaries in recent history. Some of the surrounding landscapes next to the park boundary are settled, especially in the southern part.

Tourism is by-far the biggest economic activity in the park and of significant importance at multiple levels. Visitor number in VNP have been high, with some of its most popular sites receiving around 1 million annual visitors in 2019.

2.3.2. Some Governance Factors Related to Area-Based Conservation in Iceland

PAs are a significant land-use category in Iceland with about 26.5% of the country area under legal protection in around 120 individual units [40]. The first protected area was established by law in 1930 but the largest area additions have occurred during the past few decades, especially VNP in 2007 [25]. We identify some land governance factors that matter and shape area-based conservation considerations in the country, especially with a focus on the central highlands.

Iceland is quite sparsely populated with around 360,000 inhabitants on 103,000 km^2 land area, equating to population density of only 3.5 person/km^2. Of these, around 60% of the population resides in the capital area and its immediate surroundings. Vast tracts of the central regions are uninhabited due to harsh conditions. Only around 1.2% of the land is under cultivation agriculture, either hayfields or croplands, although most other lands outside cultivation are subject to seasonal sheep grazing, one of the most common types of farming in Iceland. Nature-based tourism, which much occurs in PAs, expanded greatly from 2010–2019 and rose to become the country's biggest export earner and major rural development driver [41]. The economic potential of PAs as a land-use category are therefore increasingly recognised [42].

The country has two levels of government, central and local at the municipal level, the latter is currently formed of 69 units. Most aspects of general nature conservation and natural resource governance are the mandate of the central government, and the direct role of local governments is relatively limited. However, local governments, do have substantial power to influence most conservation and natural resources policies within their constituencies, due to their responsibility for spatial planning. In the context of PA establishment, the central government has never established a PA without seeking consent from the respective local government, regardless of its land tenure.

PAs are established according to two pathways in Iceland [25]. Most commonly, protected areas are designated according to the Nature Conservation Act. The act allows for different categories of PAs, including the designation of national parks. PAs established under the Nature Conservation Act allow the formation of consultation committees but do not, however, facilitate power-sharing co-management governance. However, some larger PAs have been established under site-specific legislation that can allow for a more tailor-made, flexible approach to governance.

Although a well-developed economy, the property rights concerning most lands in the central highlands have long been subject to ownership disputes, deadlocking land-use decisions in the region. The government initiated a major land reform process in 1998 with the establishment of a special governmental committee (Óbyggðanefnd) aiming to resolve these issues [43]. This has resulted in a protracted legal process, still ongoing, where most of the lands in the central highlands have to date been declared public lands (Þjóðlendur). This process has caused multiple conflicts but has now completed clarifying land-rights in most of the central highlands. This has had implications for PA considerations and any other land-use decisions as this has clarified land rights and responsibilities in the region.

The institutional attributes of the public lands also matter. According to Icelandic law, the management of public lands is subject to collaboration between the two tiers of government, the central and local. The overall authority is in the hands of the Prime Minister's office. In addition, certain groups of farmers are formally granted usufruct rights to some resources like grazing and fishing, commonly based on historical rights. PAs on public lands therefore already include co-management aspects concerning the respective roles of central and local government, and the usufruct rights of individual holders to some resources.

2.4. Data Sources

The qualitative data for this study are based on multiple sources, collected in phases from 2013 to date. This long period of data gathering has enabled a longitudinal analysis of the co-management system and how its governance has progressed. First, we conducted a systematic analysis of secondary data, for example, on the processes around the park's establishment, and its natural and cultural attributes. There is a major report on the park's unique natural attributes that was produced as a part of the UNESCO World Heritage Site application, leading to its inscription on the list [39]. We would also like to note some unpublished master's thesis from the University of Iceland on different aspects of VNP establishment [44,45]. Second, we collected multiple data as a part of a study commissioned by the Ministry for the Environment and Natural Resources in 2013, as members of an expert committee set up to formally assess the park's performance [46]. A web-based semi-structured questionnaire was sent to key actors in the VNP governance systems, asking about different aspects of the park governance (see its structure in Supplementary Material). We also conducted focus group meetings in the park's four administrative regions (in Skútustaðir (north); Egilsstaðir (east); Smyrlabjörg (south) and Kirkjubæjarklaustur (west)), organised with a structured discussion around selected questions and an open, more general discussion focusing on the current governance structures, perceptions and performance outcomes. The meetings were publicly announced and open to all. They were attended by a wide range of stakeholders, both local actors with a formal role in the co-management system, park staff and the general public. This was followed by in-depth interviews, conducted with a selected group of actors who have major responsibility for park governance. The third category of data derived from a series of interviews, beyond the 2013 assessment, was conducted with stakeholders in VNP management at all levels.

3. Results and Discussion

3.1. Historical and Political Legacies Shaping VNP Approach to Governance

There are multiple historical processes and political considerations that shaped the idea for the establishment of VNP and contributed and defined its approach to governance. Our interviews revealed that it was not merely an outcome of simple technical or rational, apolitical policy-making.

The driving forces behind the establishment of VNP are relatively well described, highlighting the dual perspectives of nature conservation and aspirations for rural development. They were also considerably influenced by the debate and trade-offs about the construction of the large Kárahnjúkar dam from 2003 to 2007 [39,44,45,47,48].

Our focus is, however, on the approach to governance selected and the role of co-management in VNP. We can identify some processes that were a recurrent theme during our interviews, concurrently driving VNP's establishment and shaping its governance approach.

The debates and controversies around the hydro-electric development in Kárahnjúkar were frequently raised. An outcome of this debate was a double-sided decision on conservation and development, hence, to build the large dam and establish the large park. After that became clear, the interviewees observed that, concurrently with the tri-lateral negotiations between the central government, local governments and other stakeholders on the park establishment, is was evident that it would not be possible without adopting a governance model that would enable local level actors to have a direct stake in the park's governance, especially within the local governments. Nor was fully devolving the authority to govern the park to the local governments seen as an option, partly due to the large numbers of municipalities in Iceland. The local governments have, via their legal mandates in spatial planning over their respective constituencies, a veto right on the establishment of protected areas. It was therefore quickly recognised that some sort of co-management with shared powers needed to be the way forward.

During the period of the park's establishment, the Obyggðanefnd (wilderness committee) had clarified the ownership of most of the lands that were suggested for inclusion in VNP, and this paved the way for the park's establishment and its initial spatial demarcation. Some areas considered to be included in the park were left out due to unsettled land ownership disputes but were reserved for potential inclusion later. As the property rights regime for public lands is already subject to co-management between central and local governments, this was conducive with the park's co-management considerations.

Lastly, the two former national parks, Skaftafell, founded in 1967, and Jökulsárgljúfur, founded in 1973, that were merged into VNP had been governed according to a centralised, top down governance approach (Figure 3). It was claimed that the two parks had suffered from a lack of legitimacy in the view of local actors, and the parks and park decision-making was therefore seen as distanced from the local communities and not connected to local government decision-making. This fed into the discussion around VNP and the need for a strong local voice for more inclusive park governance. This voice was stronger in the northern than the southern region and manifested clearly in the year 2004, when a large step towards the establishment of VNP was taken by expanding Skaftafell NP in the south to the whole of the southern part of Vatnajökull Glacier (Figure 3).

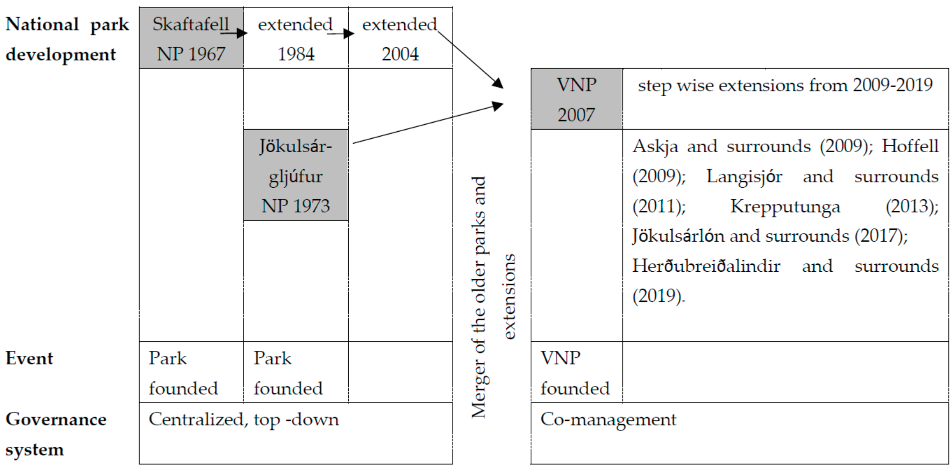


Figure 3. The development process of Vatnajökull National Park (VNP) and its predecessors.

According to our interviewees, these historical and political legacies jointly narrowed the policy options to materialise the central political will to establish the large VNP, closing down options to establish the park without sharing and devolving authority to local government actors. It was not a primary desire on the part of central government side at the outset of management discussions to share park governance responsibilities with others, however, this quickly became an unambiguous reality if the park was going to be established.

Once this became clear, the next task was designing a co-management system for the park that could be aligned with the general governance structures in Iceland, as no such legal framework or co-management system existed for PAs in the country.

We find that the process of establishing the park was aimed at designing an inclusive power-sharing governance system, generating a high degree of input legitimacy, which still has an impact on how the park is perceived today. This was manifested by all local governments in the park by their willingness to formally sign-up to the park's establishment, prior to the law passing through the Icelandic Parliament in 2007 which created the right to establish the park with a co-management approach to governance.

3.2. Institutions for Park Co-Management, Their Fit and Interplay

An important feature of the institutional framework for VNP is that it was established through park-specific legislation and not under the general Nature Conservation Act as most other protected areas in the country. The Nature Conservation Act does not recognise co-management as a governance system for PAs. This park-specific legislation allowed for tailor-made institutional solutions to meet the expectations and political bargaining that unfolded during the preparations for the establishment of the park. Many features in the legislation helped to guide the formation of the institutions of the co-management governance system. The legislation outlines four key objectives of VNP that its management must address:

(a) Conservation of nature and culture;
(b) Public access;
(c) Research and education;
(d) Regional economic development and sustainable use.

The park-specific legislation allowed for the establishment of an independent government agency that reports directly to the Minister. It has its own identity in the government annual budget and gives the VNP director full authority as a senior official. This, in essence, bypasses the Environment Agency, the agency that is otherwise responsible for PAs in the country. It also gives leverage to the devolved aspects of the co-management system, facilitating direct political attention and amplifying the possibility for park actors to lobby in the park interest.

The park-specific legislation enables the designing of roles for the various actors in the system and creation of multiple institutions related to park access and management. Many of these institutions are supposed to be designed and re-designed, bundled and delivered in the form of by-laws or strategic documents, and have direct backing in the park-specific legislation (Table 2).

Table 2. Main institutions, defining and guiding VNP governance.

Lead Document	Responsible Actors	Adoption and Amendment Power	Key Contents
Legislation	The Icelandic Parliament	By majority at the parliament	Outlines the overall objectives and the governance structure including role and mandates of key actors
By-law	The Minister	The minister can make changes, however, usually following consultation with the Park Board	Defines the park spatial boundaries. Sets out key rules
Management Plan (stjórnunar og verndaáætlun)	The Park Board	The management plan is produced by regional councils and the Park Board. The Minister signs and ratifies the Plan but his options to make changes are limited to issues that might conflict the park legislation	Give detailed account of how the park is supposed to be governed, sets out decisions on infrastructure and access rules
Commercial activity policy (atvinnustefna)	The Park Board	Produced by the regional councils and Park Board. Issued by the Park Board	Outlines VNP's policy on commercial operations within the park and instruments for their governance
Other rules, norms and conventions	The regional councils, Park Board and Director	Diverse Codes of conduct and Rules of procedures that apply to different administrative units within the co-management system. Amendment power by the respective units.	

The institutional bundles guiding the park's management have different decision-making levels that are central to understanding the power-sharing arrangements and devolution aspirations. Besides the legislation and by-laws that are institutional bundles operating at the constitutional level, the lead document for park management is its management plan. The legally anchored management plan is supposed to be the VNP's main platform and basis for policy-making and decision-making, produced with a bottom up approach that is inclusive of both internal (among park actors) and external stakeholder participation. The management plan is central in coordination and leverage of policy directions and decisions taken by park actors on the regional committees and its governing Board. Including a great level of detail and subject to regular updates, it sets the direction that the Park's director and its employees are supposed to follow and execute. We find that this is important for the efficiency of the co-management approach and there was a consensus among the interviewees in the semi-structured interviews that this was well-suited for fulfilling decentralised decision-making, generating legitimacy concerning the VNP's operations.

The large park is divided into four management regions, each with substantial autonomy. This was regarded as a necessity due to the very large size of the park, long distances and different regional perceptions towards the park. The regional boundaries follow the constituencies of the respective local governments: one local government in the southern region, two in the eastern, and three in the northern and western. The VNP's formal rules are uniform to all the regions but allow for considerable flexibility of application. This means that there can be considerable different regional priorities in VNP, which allows for regional identities to emerge, but further create a significant coordination challenges for the Park's Board, especially once it comes to allocating funding and budgets to the regions.

The institutions for park access and resource use are supposed to serve its multiple objectives of conservation, public access and economic development (Table 3). We found that the institutions were those mostly delivering their purpose effectivity, although there was evidence of some local disputes on resource access issues, which appeared to be driven by different actors values and interests than flaws in institutional properties.

Table 3. Main rules of access and resource use within the park.

Resources Use	Main Rules of Access	Manifestation
General access and recreation	Allowed	According to the Icelandic free right to roam (almannaréttur), all individuals are entitled to enter the park and wander.
Sheep grazing	Summer grazing is allowed for a given set of pastures under traditional uses	Farmers have legally protected long-term usufruct rights to grazing to most lands within the park boundary.
Hunting: reindeer	Allowed in defined areas according to the national reindeer hunting regime	Hunting licences are allotted by government annually. Some no-hunting zones within the park.
Hunting: birds	Generally allowed Prohibited in defined areas with the park	Subject to hunting licences issued by the government. Some no-hunting zones within the park.
Non-commercial fishing	Traditional rules prevail	Farmers groups keep the fishing rights they had before the park. Fishing licences.
Commercial Tourism *	Subject to permit from the park	The changes in the park legislation in 2016 made clauses of licencing for commercial tourism activities within the park.

* added with the legal amendments in 2016.

There was, however, one considerable matter lacking in the initial legislation establishing co-management of VNP. Once the park legislation was ratified and its legal instrument to regulate access, it did not differentiate the general individual right to roam and commercial tourism access or concession management. When the foundations for the park were negotiated, tourism was a relatively small sector but grew exponentially in Iceland from 2007–2019, with the number of annual foreign visitors expanding from around 450.000 in 2007 to around 2 million in 2019 [49]. Some of the VNP's more popular sites have been receiving around 1 million annual visitors. This has been among the greatest challenges for the park governance system, as many of its sites include the most popular natural features that tourists in Iceland aim to see. Concurrently, this growth sparked multiple economic opportunities for the neighbouring communities. The park's initial institutional framework simply lacked the necessary measures to regulate and guide commercial tourism, mitigating pressures and congestions. In 2013, an expert committee was founded to assess the VNP's performance, which was permitted by a clause in the establishment legislation from 2007 that requested reassessment of the co-management system. After a thorough study, the committee put forward recommendations that led to an amendment of the park legislation in 2015, establishing clauses of licencing for commercial tourism access. This change ensured that the institutional framework could regulate commercial tourism, occurring alongside a policy on commercial tourism, by-law and a set of contract and concession templates and rules. In this sense, the VNP's co-management governance system was quite responsive to an emerging challenge and capable of adapting. We find this to be a great strength of the system and an indicator of flexibility and responsiveness, as most land-use institutions in Iceland were badly prepared to handle the exponential increase in tourism. The pro-active approach by VNP has actually served as a model for other PAs in Iceland.

Once we assess the co-management system from the perspective of institutional fit, we find that the park-specific legislation and formal institutional framework that it shapes are well-fitting with the natural resources it is supposed to govern. Since its establishment, VNP has been subject to major extensions that have proven successful and embedded in the co-management institutions (Figure 3). Some issues of spatial misfit were raised in our interviews concerning the topic of landscape connectivity, mainly on the need to connect some of the shaping forces of nature in the park, such as lava field and glacier rivers that emanate from the park and perhaps should be a part of the park.

We identify, however, some challenges in institutional interplay, both within the VNP's governance system and with other institutions dealing with land-use issues that have both proven to be strengths and weaknesses of the co-management model.

The forces of vertical institutional interplay are evident in the provisions in the VNP's legislation that override the spatial planning mandate of the local governments and the role of the Prime Minister's Office in the management of public lands. This has truly been a seminal issue in leveraging the management plan of the park, giving it the status of the lead document for land-use decision-making within the park. Assessing vertical interplay within the park, the system has in general been efficient in coordinating the vertical interaction between the hierarchy of the bundles of institutions for its governance, mainly between the provisions of the legislation, by-laws and the management plan, all vested at different decision-making levels.

From the perspective of horizontal institutional interplay, we find it important that VNP is an autonomous government agency, separate from other PAs agencies in the country. This amplifies the VNP's status but on the other hand creates significant capacity concerns for its administration. We found this to be a common theme during our interviews, that VNP was lacking in administrate capacity on issues such as finance, law and technical capacity, which it needed from a government agency. This issue could be mitigated via a merger with other agencies or enhanced horizontal collaboration with other agencies.

Internally, the key forces of horizonal interplay have been apparent in the four autonomous regions, each with its unique features. The regional division was frequently mentioned as a great strength in bringing power down to local actors, but simultaneously is has created tensions around some issues, especially budget allocations and priorities in infrastructure development. The regions have also had to confront different legacies from the past, impacting the VPN's legitimacy, under different pressures from tourism and they have taken markedly different approaches on rural development opportunities. The perceptions among the local actors in the four regions towards the park are therefore quite different. This was made very clear during the stakeholder meetings in the different regions. This regional diversity is, however, not necessarily a weakness as there are many rural development success stories to tell, especially from the southern region that has been in the forefront at seizing opportunities related to the park, which has been well documented in other studies [42,50]. However, an important lesson is that although aspirations for rural development are articulated in the VNP's objectives, rural development does not come automatically. The VNP case illustrates clearly that it is dependent on the local actors to proactively seize the opportunities that the park provides. Under such circumstances, the park can become a great vehicle for regional economic development and job creation, as has been the case in its southern region.

Summing up, our analysis of the VNP's institutional framework reveals a quite solid co-management system to govern the large park, and the more recent changes have leveraged its operational capacity. We find, however, that the park-specific legislation, a key pillar in its co-management model, is partly a double-edged sword. It has been very beneficial for VNP, enabling a power-shared co-management structure around the park and leverage of its operative capacity. At the same time, it has proven to be very demanding to work with and requires political attention and willingness, capacity and resources not available for all PAs. It is therefore likely an unfeasible option for most co-management approaches except for very large parks that possess much prestige, like VNP truly does. As we find the co-management model conducive for efficient park management, able to cope and adapt to change, it should be more appropriate to establish a more general legislative framework that permits such governance approaches that could then be aligned and tailored to respective PAs, their attributes and services.

3.3. The Actor Structure, Their Roles and Powers

3.3.1. The Actor Structure, Power and Membership

We find that the institutional framework of the governance system is inclusive of many actors at different levels and it sets out and defines their different role and mandates. These actors represent both central government, local governments and civil society, however with different roles and power structures.

The co-management organisational structure of the park has essentially three key building blocks: the four Regional councils, the Park Board operating at the policy and decision-making level, and the Park Director and his team of staff, operating at a more executive level (Figure 4).

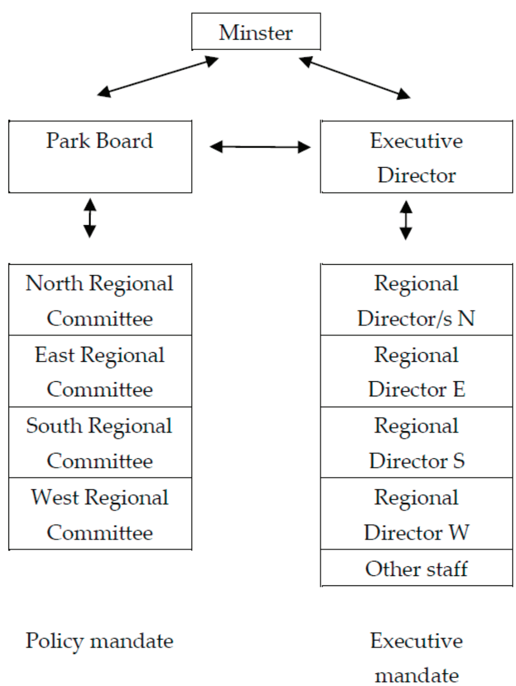


Figure 4. The organisational structure of the co-management system of VNP.

At the central government level, VNP's administration falls within the remit of the Ministry for the Environment and Natural Resources. The official funding for the park comes from the government's central budget via this ministry. It has a defined Park Board with seven representatives, including two representatives from the central government, four from local governments and one from environmental civil society. Representatives from recreation and tourism civil society have observer status at the Park Board. The Minister is given the role to appoint the Chairman of the Board and the Vice-Chair. The Minster further appoints the Executive Director after recommendations from the Park Board, who holds the status of a public official. The regional Park directors are also state employees, under the supervision of the Executive Director. They are, however recruited, after recommendations from the respective regional councils.

Within each regional council, the local governments have three representatives, one of whom constitutes the chair. The respective local government chairs in the four regional councils are nominated as the four local government members on the Park Board. The local governments are therefore given substantial formal power in the actor structure in the legislation, having the majority of the votes on the Park Board with four representatives out of seven and the majority on the regional councils.

The civil society has three representatives on each regional council, representing environment, and recreation and economic actors representing tourism. The civil society also has a member on the Park Board, representing the environmental sector, while the recreational sector and tourism sector has only a member without voting rights.

Although the co-management structure is inclusive of local governments and some civil society actors, we found some dissatisfaction around these membership arrangements. The membership concerns were mainly from the civil society actors that have full representation on the regional councils but only observer status at the Park Board. Moreover, farmers have rights to resources within the park but are not represented in its co-management structure.

We found these claims to be legitimate and they illustrate the membership challenge in a co-management system. It is not clear who should be invited and what powers each member should get in such system. In the case of VNP, farmers are partly dissatisfied by not being members of the regional councils and some civil society actors included on the regional councils are dissatisfied about not being full members of the Park Board. There is obviously no single blueprint for legitimate membership, but these are evidently key issues for any co-management park consideration as they can severely impact the legitimacy of its establishment and operations.

Co-management is essentially about power sharing. The formal actor structure reflects the aim of devolving power from the central to the local. The local governments have a chairman in all regional boards, three out of six members in the regional boards, and four out of seven votes in the Park Board.

Our respondents at all levels appreciated that the co-management model had truly and comprehensively shared power and devolved it to a local level and beyond central government. The system gives the local governments' actors the majority vote on the Park Board and the chair in all the regional councils. The civil society actors have got a formal decision-making power in the system and not only a consultative function as is commonly practiced in other PAs. Furthermore, the Minister is bound to formally endorse the management plan without having any amendment power, given it meets all the legal requirements, and this is seen as a key manifestation of the power sharing and devolution. There is also the notion that the park actors have in general been accountable to the powers devolved to them, an important issue to ensure the legitimacy of VNP's operations.

Another issue related to the actors and their power relations is the funding of VNP's operations. As it is an independent government authority, the bulk of its funding comes directly from the state budget, however, with a legal option for generation of its own incomes from services in the park. This has commonly been in a ratio of circa 80:20 annually with VNP's own incomes having grown in parallel with increased tourism. Funding the park has been subject to bargaining between the central and local governments, perhaps not a surprise given the general tug-of-war on funding between these two levels of government in Iceland on multiple issues. This commonly plays out in local governments asking for more resources than the central government is willing to release. Adding to this resentment is the commonly raised issue of unkept financial promises relating to VNP's establishment, frequently raised in the semi-structured interviews. As a part of their initial agreeing to the park and an important carrot for their acceptance of its establishment had been a generous offer by the central government to provide park infrastructure and jobs in the respective jurisdictions. This bargaining resulted in the locations for VNP's regional administrative centres being stated in the legislation, with a central government promise to provide sufficient financial capital for this purpose. The government promises for funding park infrastructure were, however, severely constrained almost immediately after VNP's establishment by the Iceland economic collapse in 2008, which was followed by the austerity plan and severe cuttings in all government spending. There is actually still a backlog in VNP's infrastructure development. The issue of park funding, both to secure sufficient funding and its internal allocation, is truly a significant challenge for their co-management system. The high level of funding coming directly from the state budget in VNP gives the central government actors great power to influence and steer, albeit not necessarily in a direct manner.

3.3.2. Actor Complexity and Role Ambiguity

At first glance, the actor structure of the governance system looks complex (Table 4). It should be kept in mind that the aspiration for being inclusive and sharing power calls for a more complex structure, at least compared to the more traditional top-down and authoritarian governance systems. It is, however, a challenge for designing a co-management system to ensure that actors responsibilities and their degree of authority are clear. During a smooth ride, this might not be an issue but upon entering more turbulent periods, this becomes a seminal issue.

Table 4. Key actors and their roles in governance of Vatnajökull NP.

Level	Actors	Description	Some Important Roles
Central	Ministry for the Environment and Natural Resources	VNP is an independent government authority, directly reporting to the Ministry	Appoints the Board Formalises Director's appointment according to the Board's recommendation Financial supervision relative to the state budget Overall responsibility
	Park Board	Seven board members. Two appointed by the minister, one from each of the four regional units, one from environment civil society. Also, two civil society actors have observer status.	Policy and decision-making Coordination of regional inputs and creation of the management plan Approve the budget and allocate to regions Harmonise the operation of the four regions
	Executive Director	The executive director of the park	Execute decisions and policy, set out in the management plan Daily management Staff Finance
Regional	Regional committees	The park is divided into four administrative regions: north, east, south and west.	Responsible for park management policy-making within each region Prepares regional sections of the overall park management plan
	Regional park managers	For each of the four management regions. Appointed after recommendation from the regional boards	Responsible for the management activities of individual regions
Local	Local governments	There are eight local governments that border the park	Have three members on the regional boards and four in the Park board
	Recreational NGOs	A group of NGOs engaged in recreation.	Members of the regional committee and observer at the Park Board
	Environmental NGOs	A group of NGOs engaged in conservation.	Members of the regional board and Park Board
	Tourism actors	The regional tourism societies	Members of the regional committee and observer at the Park Board

It was a recurrent theme from our respondents in the semi-structured interviews that the actor structure and the ambiguous definition of their roles and mandates were among the key challenges in VNP's system, although they appreciated its power-sharing aspect. Ambiguity in roles has then manifested differently and was jointly seen as impacting the output legitimacy of the park, undermining its effectiveness.

It was highlighted that during the first years of VNP's operation, this had been less of an issue as most actors were influenced by the high level of input legitimacy, and were thus comfortable with the park and being a part of its governance system. This, however, changed during the development of the park, both simply as time elapsed from its happy beginning but also when many decisions materialised, not least following the development of the first management plan. Many of the informal norms and conventions that had defined some of the coordination between the individual actors during the first years of operation were discarded. This ambiguity in actor roles has impacted the governance system's coordination and its conflict resolution capacity.

In general, the park actors agreed that the co-management system had been effective and capable of resolving the most conflicting issues. This was commonly raised during our semi-structured interviews, regional stakeholder meetings and other interviews. Interviewees appreciated that the devolved and inclusive structure was conducive for settling localised and conflicting issues. In addition, the process around development of the main steering document, the management plan was viewed as conducive to address, discuss and settle the most conflicting issues.

However, what was also raised was that some conflicting issues could become overwhelming and perhaps beyond the capacity of the co-management system to settle. A common theme was the conflict around motorised travel across the Vonarskarð highland landscape, where both the involved local governments and civil society actors have conflicting views on access. This single case of conflict had been impossible to settle with solutions deemed legitimate by the involved actors. That had therefore led to a loss of trust between the actors and amplified the ambiguity of a system wherein the final decision-making power is vested in the co-management system. Such conflicting cases can undermine the otherwise well-functioning co-management system. The obvious solution, we argue, would be to see some sort of independent reconciliation body established outside the park, where such disputes could be settled.

The issue of clarity in roles and degree of authority became a key issue for the park in 2018. It turned out to be overspending on its infrastructure development after significant increases in tourist numbers had led to a need for major investments. This was followed by a period of blame-game between the Park Board and Director on who had the necessary oversight, resulting in external evaluations including the National Audit Office [51]. In the end, the Minister replaced both the Park Director and Board Chairman. This episode clearly illustrated the importance of clarity on the degree of authority among the park actors in the co-management system. This was not an issue of any wrongdoings but rather a case of unclear roles.

This has been one of the key challenges for the VNP model and a key lesson for PA co-management. Although high input legitimacy and trust from the beginning can take a long time to cultivate, there is the necessity to ensure rigid delineation of actor roles and clarity about the degree of authority that each has in the power-shared system.

4. Conclusions and Implications for Policy

We find the co-management governance system of VNP to be a solid institutional framework for this large park which has been able tackle very high visitor numbers and emerging tourism pressures, illustrating its capacity to cope with the emerging changes. Our analysis revealed the key design features of the governance system and how the co-management approach has been instituted and manifests in decision-making. By using a governance system framework, we were able to identify the various governance challenges that shape its performance in multiple ways.

An important strength of the co-management system is that it facilitates the sharing of power, which is devolved from the central to the local, is inclusive to actors on multiple levels and is well integrated and aligned to the general land-use institutional framework. This has been made possible with park-specific legislation that has been the basis for the creation of multiple, innovative institutions for its coordination and interplay, both internally and externally. The legally binding and strong foundation in the VNP's management plan has proven to be essential to steer and coordinate park management. It is the strategic document for policy and decision-making that has become the glue that binds together and coordinates local, regional and national level interests. This was further leveraged with a high level of legitimacy at the input level, a key-issue which still presides more than a decade after VNP's inception. Some regions demonstrate well how rural development opportunities can be seized locally, something that, however, does not occur automatically, and there is a considerable regional variability in how such economic opportunities have been grasped. Its needs also to be recalled that the assessment provided in the study has a focus on the social aspects of the governance system but did not aim to assess the direct ecological conservation impacts.

The weaknesses of the co-management model relate to its complex actor structure and constraints in defining and delineating the roles and mandates of key actors. This has become especially demanding as the co-management model has redistributed power. Although trust, norms and conventions are important elements of coordination with the co-management system, roles and decision-making mandates need to be clearly defined and determined with respect to the many actors. Most conflicts have been settled within the governance system, but some local issues have become overwhelming for VNP's co-management system and difficult to settle. This calls for further work to align and adapt the co-management governance system. It has been a strength for VNP to have park-specific legislation and be leveraged as an independent government authority, but in comparison this is a weakness for the other parks that might not be offered such luxury. Being big is surely beneficial when considering tailormade institutional solutions to PAs.

PAs are a major land-use category and current expectations are that their coverage will continue to increase in the future. In Iceland, there are currently plans for expanding a NP model over large tracts of the Central Highlands in a proposed Highlands National Park and, globally, the coming CBD Post 2020—biodiversity goals will set out more ambitious targets for global, area-based conservation. This calls for further studies on governance system diversity and alternative models of governance. Our findings from this study have implications for the ongoing debate on alternative governance models for protected areas, although they also illustrate very well how co-management is context dependent and requires tailormade solutions. Our findings clearly demonstrate that co-management can result in a solid framework, but it does not come as a "one-size-fits-all" solution. This implies a need for diverse approaches for governance which are cognizant of the context and site-specific conditions that they operate within.

That might perhaps become one of the key obstacles for a large-scale rollout of such approaches, as policy-makers at different levels might not have the capacity, interest or available time and resources to develop such approaches, and they would therefore fail to secure the important input legitimacy, which has been among the key factors in VNP's relative success.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/land10070681/s1, Table S1: The guiding questions in the semi-structured interviews.

Author Contributions: Conceptualisation, data collection, writing, review and editing, J.G.P. and D.M.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Leclère, D.; Obersteiner, M.; Barrett, M.; Butchart, S.H.; Chaudhary, A.; De Palma, A.; DeClerck, F.A.; Di Marco, M.; Doelman, J.C.; Dürauer, M.; et al. Bending the curve of terrestrial biodiversity needs an integrated strategy. *Nature* **2020**, *585*, 551–556.
2. Ward, M.; Saura, S.; Williams, B.; Ramírez-Delgado, J.P.; Arafeh-Dalmau, N.; Allan, J.R.; Venter, O.; Dubois, G.; Watson, J.E. Just ten percent of the global terrestrial protected area network is structurally connected via intact land. *Nat. Commun.* **2020**, *11*, 4563. [CrossRef] [PubMed]
3. Watson, J.E.M.; Dudley, N.; Segan, D.B.; Hockings, M. The performance and potential of protected areas. *Nature* **2014**, *515*, 67–73. [CrossRef]
4. Borrini-Feyerabend, G.; Dudley, N.; Jaeger, T.; Lassen, B.; Pathak Broome, N.; Phillips, A.; Sandwith, T. *Governance of Protected Areas: From Understanding to Action*; IUCN: Gland, Switserland, 2013.
5. Eklund, J.; Cabeza, M. Quality of governance and effectiveness of protected areas: Crucial concepts for conservation planning. *Ann. N. Y. Acad. Sci.* **2017**, *1399*, 27–41. [CrossRef]
6. Carlsson, L.; Berkes, F. Co-management: Concepts and methodological implications. *J. Environ. Manag.* **2005**, *75*, 65–76. [CrossRef]
7. Fischer, A.; Wakjira, D.T.; Weldesemaet, Y.T.; Ashenafi, Z.T. On the interplay of actors in the co-management of natural resources—A dynamic perspective. *World Dev.* **2014**, *64*, 158–168. [CrossRef]
8. Borrini-Feyerabend, G.; Farvar, M.T.; Nguinguiri, J.C.; Ndangang, V.A. *Co-Management of Natural Resources: Organising, Negotiating and Learning-by-Doing*; GTZ and IUCN: Heidelberg, Germany, 2007.
9. Fedreheim, G.E.; Blanco, E. Co-management of protected areas to alleviate conservation conflicts: Experiences in norway. *Int. J. Commons* **2017**, *11*, 754–773. [CrossRef]
10. Hovik, S.; Hongslo, E. Balancing local interests and national conservation obligations in nature protection. The case of local management boards in norway. *J. Environ. Plann. Manag.* **2017**, *60*, 708–724. [CrossRef]
11. Plummer, R. The adaptive co-management process: An initial synthesis of representative models and influential variables. *Ecol. Soc.* **2009**, *14*, 24. [CrossRef]
12. Evans, L.; Cherrett, N.; Pemsl, D. Assessing the impact of fisheries co-management interventions in developing countries: A meta-analysis. *J. Environ. Manag.* **2011**, *92*, 1938–1949. [CrossRef]
13. Lockwood, M. Good governance for terrestrial protected areas: A framework, principles and performance outcomes. *J. Environ. Manag.* **2010**, *91*, 754–766. [CrossRef]
14. Petursson, J.G.; Vedeld, P. Rhetoric and reality in protected area governance: Institutional change under different conservation discourses in mount elgon national park, uganda. *Ecol. Econ.* **2017**, *131*, 166–177. [CrossRef]
15. Borrini, G.; Kothari, A.; Oviedo, G. *Indigenous and Local Communities and Protected Areas. Towards Equity and Enhanced Conservation*; IUCN: Gland, Switerland, 2004.
16. Cundill, G.; Thondhlana, G.; Sisitka, L.; Shackleton, S.; Blore, M. Land claims and the pursuit of co-management on four protected areas in south africa. *Land Use Policy* **2013**, *35*, 171–178. [CrossRef]
17. Ribot, J.C.; Agrawal, A.; Larson, A.M. Recentralizing while decentralizing: How national governments reappropriate forest resources. *World Dev.* **2006**, *34*, 1864–1886. [CrossRef]
18. Hutton, J.; Adams, W.M.; Murombedzi, J.C. Back to the barriers? Changing narratives in biodiversity conservation. *Forum Dev. Stud.* **2005**, *32*, 341–370. [CrossRef]
19. Child, B.A. Parks in transition: Adapting to a changing world. *Oryx* **2014**, *48*, 469–470. [CrossRef]
20. Spenceley, A. Tourism and protected areas: Comparing the 2003 and 2014 iucn world parks congress. *Tour. Hosp. Res.* **2017**, *17*, 8–23. [CrossRef]
21. Sandwith, T.; Enkerlin, E.; MacKinnon, K.; Allen, D.; Andrade, A.; Badman, T.; Brooks, T.; Bueno, P.; Campbell, K.; Ervin, J.; et al. The promise of sydney: An editorial essay. *Parks* **2013**, *20*, 7–18. [CrossRef]
22. Jentoft, S. Legitimacy and disappointment in fisheries management. *Mar. Policy* **2000**, *24*, 141–148. [CrossRef]
23. Berkes, F. Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *J. Environ. Manag.* **2009**, *90*, 1692–1702. [CrossRef]
24. Stenseke, M. Local participation in cultural landscape maintenance: Lessons from sweden. *Land Use Policy* **2009**, *26*, 214–223. [CrossRef]
25. Petursson, J.G.; Thorvardardottir, G.; Crofts, R. Developing iceland's protected areas: Taking stock and looking ahead. *Parks* **2016**, *22*, 13–24. [CrossRef]
26. Ostrom, E. *Governing the Commons: The Evolution of Institutions for Collective Action*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 1990; p. xviii. 280p.
27. Ostrom, E. *Understanding Institutional Diversity*; Princeton University Press: Princeton, NJ, USA, 2005.
28. Vatn, A. *Institutions and the Environment*; Edward Elgar: Cheltenham, UK, 2005.
29. Ostrom, E. A general framework for analyzing sustainability of social-ecological systems. *Science* **2009**, *325*, 419–422. [CrossRef] [PubMed]
30. Vatn, A. *Environmental Governance; Institutions, Policies and Actions*; Edward Elgar: Celtenham, UK, 2015.
31. Young, O.R. *The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale*; MIT Press: Cambridge, MA, USA, 2002.

32. Scott, W.R. *Institutions and Organizations*; Sage Publications: Newbury Park, CA, USA, 1995.
33. Pomeroy, R.S.; Berkes, F. Two to tango: The role of government in fisheries co-management. *Mar. Policy* **1997**, *21*, 465–480. [CrossRef]
34. Arts, B. *Non-State Actors in Global Governance: Three Faces of Power*; Max-Planck-Projektgruppe Recht der Gemeinschaftsgüter: Bonn, Germany, 2003.
35. Giddens, A. *The Constitution of Society: Outline of the Theory of Structuration*; Polity Press: Cambridge, UK, 1984; p. xxxvii, 402p.
36. Backstrand, K. Multi-stakeholder partnerships for sustainable development: Rethinking legitimacy, accountability and effectiveness. *Eur. Environ.* **2006**, *16*, 290–306. [CrossRef]
37. Brown, K. Integrating conservation and development: A case of institutional misfit. *Front. Ecol. Environ.* **2003**, *1*, 479–487. [CrossRef]
38. Vatn, A.; Vedeld, P. Fit, interplay, and scale: A diagnosis. *Ecol. Soc.* **2012**, *17*, 12. [CrossRef]
39. Baldursson, S.; Gudnason, J.; Hannesdottir, H.; Thordarson, T. *Nomination of Vatnajökull National Park for Inclusion in the World Heritage List*; Vatnajökull National Park: Reykjavik, Iceland, 2018.
40. Umhverfisstofnun. *The 2021 Annual Report of The Icelandic Environment Agency*; Iceland Environment Agency: Reykjavik, Iceland, 2021.
41. OECD. *"Iceland"*; OECD Publishing: Paris, France, 2020.
42. Siltanen, J. *Economic Impact of Iceland's Protected Areas and Nature-Based Tourism Sites*; Institute of Economic Studies: Reykjavik, Iceland, 2018.
43. Solnes, V. Administrative committee clarifying land ownership. The icelandic wasteland commission. *Nord. Adm. J.* **2017**, *94*, 59–74.
44. Gunnarsson, V. Orðræða um Stofnun Vatnajökulsþjóðgarðs. Ferðamennska, Sjálfbærni og Samfélag. Master's Thesis, Univerisity of Iceland, Reykjavík, Iceland, 2010.
45. Feingold, M. The Political Ecology of Protected Areas: The Case of Vatnajökull National Park. Master's Thesis, University of Iceland, Reykjavik, Iceland, 2021.
46. Petursson, J.G.; Ingolfsdottir, G.; Kristofersson, D.M. Endurskoðun á Stjórnfyrirkomulagi Vatnajökulsþjóðgarðs; Reykjavik, Iceland. 2013. Available online: https://rafhladan.is/bitstream/handle/10802/24252/vatnajokull_lokaskyrsla-180713.pdf?sequence=1 (accessed on 28 June 2021).
47. Benediktsson, K.; Thorvardardottir, G. Frozen opportunities? Local communities and the establishment of vatnajökull national park iceland. In *Mountains of Northern Europe: Conservation, Management, People and Nature*; Thompson, D.B.A., Price, M.F., Galbraith, C.A., Eds.; Scottish Heritage: Edinburgh, UK, 2005; pp. 333–347.
48. Gunnarsson, S.B. Vatnajökulsþjóðgarður (vatnajökull national park). *Glettingur* **2007**, *44*, 26–30.
49. Saeporsdottir, A.D.; Hall, C.M.; Wendt, M. Overtourism in iceland: Fantasy or reality? *Sustainability* **2020**, *12*, 7375. [CrossRef]
50. Ingólfsdóttir, A.I.; Árnason, T.; Siltanen, J.; Jóhannesson, H. *Náttúruvernd og Byggðaþróun: Hrif Verndarsvæða á Grannbyggðir*; Hagfræðistofnun Háskóla Íslands: Reykjavík, Iceland, 2019.
51. National Audit Office. *Vatnajökulsþjóðgarður. Ríkisendurskoðun, Skýrsla til Alþingis (Vatnajökull National Park. National Audit Office, Report to the Parliament)*; National Audit Office: Reykjavík, Iceland, 2019.

land

MDPI

Article

To What Extent Are Cattle Ranching Landholders Willing to Restore Ecosystem Services? Constructing a Micro-Scale PES Scheme in Southern Costa Rica

Iván Pérez-Rubio [1,*], Daniel Flores [2], Christian Vargas [3], Francisco Jiménez [4] and Iker Etxano [5,6,7]

1 Natural Management Resources, Universidad Estatal a Distancia (UNED), San José 474-2050, Costa Rica
2 Consultant in Technology, Strategy and Neuro-Innovation, San José 474-2050, Costa Rica; danielflorescr@gmail.com
3 Centro Nacional de Alta Tecnología (CeNAT)-Laboratorio PRIAS, San José 1174-1200, Costa Rica; cvargas@cenat.ac.cr
4 Gestión de Cuencas Hidrográficas, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba 30501, Costa Rica; fjimenez@catie.ac.cr
5 Department of Applied Economics I, Faculty of Social Sciences and Communication, University of the Basque Country (UPV/EHU), Sarriena s/n, 48949 Leioa, Spain; iker.etxano@ehu.eus
6 HEGOA, Institute for International Cooperation and Development Studies, University of the Basque Country (UPV/EHU), Avda. Lehendakari Agirre, 81, 48015 Bilbao, Spain
7 EKOPOL Research Group, Faculty of Social Sciences and Communication, University of the Basque Country (UPV/EHU), Sarriena s/n, 48940 Leioa, Spain
* Correspondence: ivan.perezr24@gmail.com; Tel.: +506-85154462

Citation: Pérez-Rubio, I.; Flores, D.; Vargas, C.; Jiménez, F.; Etxano, I. To What Extent Are Cattle Ranching Landholders Willing to Restore Ecosystem Services? Constructing a Micro-Scale PES Scheme in Southern Costa Rica. *Land* **2021**, *10*, 709. https://doi.org/10.3390/land10070709

Academic Editors: Mónica de Castro-Pardo, Joao C. Azevedo and Pascual Fernández

Received: 1 May 2021
Accepted: 4 June 2021
Published: 5 July 2021

Abstract: Deforestation and the unsustainable management of agricultural and livestock production systems in tropical mountain areas have caused fragmented and degraded landscapes. Payment for ecosystem services (PES) could be an effective policy instrument with which to reduce deforestation and restore disturbed ecosystems. The national-scale PES program in Costa Rica is recognized as being successful; however, its financial resources have been mostly dedicated to forest protection, and much less to reforestation projects. This paper aims to construct a micro-scale PES scheme by using primary data generated through spatial modeling and socio-economic and stated preference surveys (choice experiment) in southern Costa Rica. The results suggest that, on average, landholders would agree to implement restoration projects on their own private pasturelands if an appropriate holistic place-based approach was applied encompassing biophysical, social, economic, and institutional aspects. Willingness-to-accept values allow payments to be linked to cattle farmers' estimates of specific ecosystem services (ES) and land opportunity costs. The economic valuation of three ESs (erosion control, water availability, and biodiversity) allows construction of a layered payment scheme, which could encourage the development of a potential partnership between national and local institutions and NGOs as alternative buyers of ESs, reduce transaction costs, and improve household well-being.

Keywords: payment for ecosystem services; choice experiment; cattle ranching; land restoration; land tenure; Costa Rica

1. Introduction

Agriculture and livestock systems undoubtedly play a key role in supporting human well-being and livelihoods. However, anthropogenic pressure and associated land degradation result in a loss of biodiversity and a reduction in the variety and level of ecosystem services (ESs) [1–4]. Regarding mountain ecosystems, empirical research suggests that deforestation and forest degradation lead to depleted soil infiltration rates and water infiltration capacity [5]. The shift in the frequency distribution of erosion rates depends on the degree of human disturbance of the native vegetation [6,7], and the number of large floods increases strongly with accelerated deforestation [8–11]. Although in general terms the expansion of farmland has increased the value of some essential provisioning ESs and provided some economic benefits [12], it has also significantly affected human well-being [2,3,12], particularly in terms of the impact on land degradation [13]. This effect has been especially intense in tropical countries [14].

Restoration efforts aim at recovering the original characteristics of an ecosystem that was previously degraded, damaged, or destroyed by human intervention. It was suggested in [15] that ecological restoration increases biodiversity levels by an average of 44%. Empirical research demonstrates a significantly increasing trend in the ecosystem carbon sequestration service [16–18], erosion and flood control services [5,9,10,19,20], and landscape forest connectivity [21]. Restoration programs, followed by sustainable land-use management, can improve, both the provisioning of services, and people's well-being [2,3,15]. However, these multiple restoration goals can also diverge and conflict [3].

Restoration goals, strategies, and actions should be approached carefully, considering site-specific environmental conditions as a means for generating the expected ecological synergies. Furthermore, restoration strategies face the complex challenge of increasing the provisioning of services, such as food production, for an expanding population [22], while simultaneously conserving or enhancing biodiversity and other types of ES [2,23]. Science-based experience in some large-scale restoration projects (e.g., the Atlantic Forest Restoration Pact in Brazil) revealed that a successful restoration strategy needs to have a bottom-up decision-making approach, involving a range of stakeholders, including landowners, smallholders, nongovernment organizations, local government leaders, and indigenous and community groups [2,24–26].

To address all of these targets, restoration actions need the support of financial incentives, and most reforestation projects have shown net benefits, in both developed and developing countries [18,27,28]. Nonetheless, in broader terms, the efficiency of conservation and economic outcomes, often using cost-effectiveness as a proxy, should never outweigh the social equity dimensions and non-market value [29–31]. Ultimately, such financial incentives are usually instrumentalized in a subsidy-like approach, which means conditional cash payments aiming to compensate for the possible costs of alternative environmental land-use stewardship. These incentive mechanisms are conceptualized as payments for ecosystem services (PES) around the world. Even though they can show a wide range of specific characteristics, PES schemes have two fundamental attributes: voluntariness and additionality.

Unlike traditional command-and-control environmental policies, PES programs represent a novel paradigm by introducing a voluntary approach. Additionality in this context is commonly defined as the measured outcome of a policy or project, in addition to what might have occurred in the absence of a PES scheme [32]. However, this concept has been mostly applied in strictly environmental terms as "the net impact of the biophysical provision of ecosystem services, in comparison with the baseline scenario or hypothetical situation where the PES scheme is not in place" [33]. According to [34], environmental additionality is positively influenced by three factors: spatial targeting, payment differentiation, and strong conditionality.

Accepting the existence of a polarized academic discussion surrounding efficiency versus equity, this debate has accomplished an expansion of the capabilities, dimensions, and limits of Wunder's pioneering conceptualization of PES [35]. Therefore, other attributes such as economic fairness and personal well-being should be taken into account. For example, given a compensation criterion approach, payments should compensate landholders for lost benefits related to the provision of environmental services and be differentiated according to the cost of such provision. Their willingness to accept (WTA) compensation for the services they provide is largely determined by the degree to which their livelihood depends on the land covered by the program. This, in turn, affects the opportunity cost of supplying the services. In addition, WTA is also a function of the potential on-farm benefits derived from the promoted land use change [33].

The pioneering nationwide PES program in Costa Rica is mostly recognized with regard to the conservation of remaining forests. In fact, from its inception in 1997 until 2018, almost 90% of the land covered was for strict forest protection (over one million hectares), while payments for reforestation were received for about 70,000 hectares [36]. Several studies have evaluated the impact of the program on reducing deforestation rates [37–39], on the effects on poverty and equity [40–42], and on the overall efficiency [42–44]. However, there is little scientific evidence about the preference of landholders for enrolling in a PES arrangement for reforestation purposes on their own property. There is also scarce information about the links between payments, land opportunity costs, and landholders' economic valuation of ES.

In this study, a micro-scale PES scheme is assessed with the support of a GIS-based spatial dataset in the Claro River sub-watershed (southern Costa Rica). Discrete choice modeling was carried out to elicit the preferences of landholders at the site regarding alternative restoration options, giving several ESs as attributes in the choice set. Choice experiments (CEs) are often used to examine human-induced changes in an ecosystem, represented by a set of attributes for which people can establish their preferences [45]. Closely related to this study, CEs have been applied as a method to investigate the preferences of farmers for participating in environmental incentive-based mechanisms in developing countries [46–53]. Most of them focused on analyzing the factors that can influence potential enrolment in hypothetical PES contracts, and just a few include the perception of the benefits of ecosystem services [49,52]. Unlike other studies, ours includes a place-based approach that complements the economic analysis from a micro-scale perspective.

This research was aimed at investigating some of the main shortcomings of the national PES program in Costa Rica reported by researchers and scholars, in terms of the lack of a spatial targeting approach, landholder WTA, and opportunity cost data. Specifically, this paper tries to respond to four questions: (1) Are landholders in the Claro River sub-watershed willing to implement reforestation projects by reducing cattle grazing pasture areas? (2) What is the minimum level of willingness to accept compensating payment to join a hypothetical PES program? (3) To what extent do current payments for reforestation reflect current land opportunity costs? (4) Could the estimated landholders' marginal economic valuation of determined ES could be endogenized into a micro-scale PES scheme?

2. An Overview of the Nationwide PES Program in Costa Rica

Costa-Rica's national-scale PES program emerged in 1995 from a convergence of various factors that led to the 1995 Forestry Law reform, which entailed a necessary increased level of restrictions on legal tree extraction. The program bundles together the provision of four main ESs: carbon sequestration, biodiversity protection, water regulation, and landscape beauty. It provides direct cash payments to private landowners for different types of five-year contracts: forest protection, reforestation, sustainable forest management, and agroforestry [42]. The National Forestry Fund (FONAFIFO) is the institutional mediator responsible for administrating the PES program. This mediating role can be described as the process by which the beneficiaries of the program give their acquired rights to the ES to FONAFIFO, which then sells them to potential buyers [54].

The program continues to be one of the most advanced in terms of experimentation in governance [55]; however, its environmental effects have often been questioned. Empirical studies suggest it has a minimal impact on reducing deforestation rates [37–39]. With respect to the socio-economic outcomes, apart from indigenous territories, most of the payments are captured by relatively wealthy landowners [41,56]. According to [40], there is no evidence of improvements in tangible household well-being, and it also does not appear to have benefited participants in terms of better means of living. The program does not have an explicit social component, despite it being a government-led initiative [36].

With respect to the policy criterion of conditionality, FONAFIFO established a pragmatic approach, where the extension of forest land is used as a proxy for ES [42]. Furthermore, and beyond the relative or even minimal impact on reducing deforestation rates, the outcome of the program in terms of additionality would require constructing a baseline dataset and conducting a systematic modeling analysis in the absence of a program for each PES contract. It was noted in [57] that a PES may result in more additionality if it is properly reoriented towards enhancing landscape restoration.

Additionality is positively influenced by spatial targeting; therefore, a land-use approach would allow FONAFIFO to allocate the optimal resources in order to prioritize and maximize the spatial provision of ES. Several studies [57–59] strongly recommend using a landscape approach, along with socio-economic and ecological indicators, for a more intensive and adequate assumption of an additionality principle in the national policy priorities. Moreover, the key factor for ensuring that a PES scheme is effective relies on the extent of the alignment of payments received by landholders with the additional enhancement of ES over the status quo scenario [60].

The decision on final levels of payments to be provided by nationwide public programs is usually arbitrary and will inevitably be influenced by administrative resolutions based on the available budget [42]; in fact, actual payments for reforestation still reflect levels prior to the program's introduction, and payments for forest protection were initially established on the then current renting price of pastureland. Current incentives are based approximately on national averages of the opportunity costs of forgone cattle pasture [58]. However, in theoretical terms, the payment level should reflect two important factors: (1) the estimated value of the ES provided by the forest, and (2) the opportunity cost for the landowner associated with participating.

Another debated subject highlighted by scholars regarding the Costa Rican PES scheme is the strong dependence on fixed payments [55,57,59], regardless of the spatial variability in the provision of environmental services or the cost of the required management practices to different landholders [54]. The method of accounting is determined by bundling the four officially selected ESs (carbon sequestration, landscape beauty, biodiversity conservation, and water protection). In this way, each piece of land, regardless of its particular ES value, receives a fixed payment. More recently, payment levels for forest protection have introduced differentiation for areas that are hydrologic hotspots. In addition, the reforestation category distinguishes four modalities: reforestation with fast-growing species, medium-growing species, native species, and natural regeneration. As an alternative to bundling, the layering of ecosystem services refers to separating payments for each site-specific ES to be provided in a packaged scheme [61].

There are also significant shortcomings in the PES design, and several improvements have been suggested, focusing on the development of differentiated payments that would reflect different opportunity costs. Considering that this type of design might be technically difficult, auctions have been encouraged [59] as a means of revealing opportunity costs [42], although implementing them would necessarily be costly. Another alternative for revealing opportunity costs, as well as eliciting landholders' preference for enrolment and level of WTA, is through a CE approach.

In addition, the diverse range of factors promoting or preventing landowner participation in the PES program have also been examined. According to [62], the Costa Rican case illustrates that participation is led by landowners and is greatly influenced by their capacity to cover transaction, legal, and information costs, and to satisfy land tenure requirements. However, one of the stricter institutional requirements of FONAFIFO, which limits access to enrolment in the program, is the lack of legal property titles among smaller landholders [42]. It was found in [63] that a combination of poor environmental conditions for agriculture and the opportunity cost calculus of landowners drives the decision to enroll in the program.

One more important constraint, often highlighted in theoretical and empirical studies, is the high transaction costs. PES contracts commonly incur two types of transaction costs: (1) those assumed by FONAFIFO that might discourage, even by legal means, the participation of smallholders [43]; and (2) those inevitably assumed by the eventual beneficiaries, which will necessarily affect their initial interest in participating in the program [64]. The costs assumed by beneficiaries are the greatest barrier to participation by the most vulnerable in developing countries [64–66]. Transaction costs include all expenses for contract establishment and maintenance (e.g., travel expenses, information gathering, the design of a management plan, and external monitoring). According to [67], estimates of transaction costs borne by participants vary from 12 to 18% of the total payments.

Beyond the national program, there are two remarkable experiences with local PESs in Costa Rica. On the one hand, the Heredia watershed payment scheme, managed by an ad hoc public enterprise and partially funded by a private corporation, provides payments to landowners to avoid land degradation of the area upstream of the watershed, where water sources are located. Although this scheme incorporates an explicit place-based approach, focusing on the provision of hydrological services within a watershed, it fails in not taking an additionality approach or adding other types of ES [68]. On the other hand, the RISEMP project scheme, sponsored by the World Bank and the Global Environment Facility (GEF) and coordinated by the Center for Tropical Agriculture, Research and Education (CATIE), facilitates payments to livestock producers conditioned on the adoption of silvopastoral practices. This project succeeds in at least two aspects: (1) it introduces a differentiated payment scheme reflecting differences in the intensity of silvopastoral efforts, and (2) it layers two ESs (biodiversity and carbon sequestration) [69,70].

3. Materials and Methods

3.1. Description of the Study Area

The study area is the Claro River sub-watershed, located in the Fila Cruces mountain range (8°40′–8°47′30″ N and 82°57′30″–83°4′30″ W) in southern Costa Rica (Figure 1). The area has a humid tropical climate, with mean annual precipitation of 4000–6000 mm. Its altitude lies between 60 and 1650 m.a.s.l. and it covers a total area of 10,081 km^2. It is an ecosystem with a very steeply sloped topography, characterized by biological connectivity and high ecological endemism [71]. This territory has been threatened by deforestation and fragmentation processes, in which land is mainly occupied by extensive livestock and subsistence agriculture [71–74]. These human activities are also causing severe alteration of the hydrological balance, the effects of which result in erosion and a high risk of landslides, floods [75], and sedimentation into the Golfo Dulce, affecting the coral reefs [76–79].

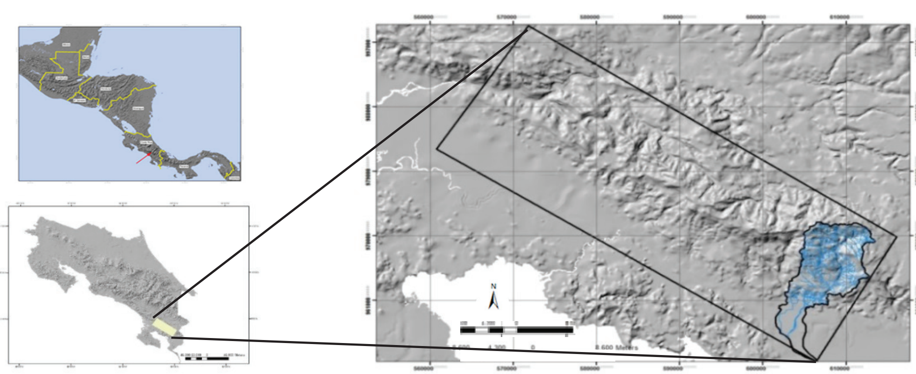


Figure 1. Geographic location of Claro River sub-watershed. Clearer figure in the Supplementary Materials.

3.2. GIS Erosion Susceptibility Assessment

The Claro River sub-watershed is especially affected by intense fragmentation in its upper part, which is also characterized by steep slopes. This disturbance has caused a great number of erosive events, including severe landslides. During the rainy season, floods are common in the lower lands affecting Rio Claro town. Actions that have been taken to avoid persistent flooding have focused on the construction of temporary levees (Figure 2). An empirical geological study recommended the implementation of reforestation policies due to highly overexploited terrain, mostly on steeply sloping land used as pasture and at high risk of landslides [75].

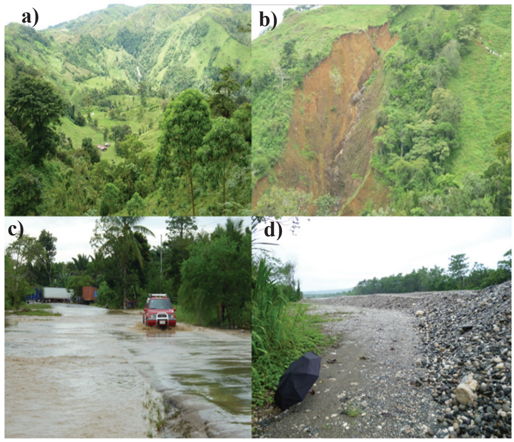


Figure 2. Environmental vulnerability caused by erosion in the Claro River sub-watershed: (**a**) drastic land-use change in livestock production on steeply sloping terrain located in the upper sub-watershed; (**b**) severe landslides also occur in the upper sub-watershed; (**c**) frequent floods affect lowlands close to Rio Claro town; (**d**) temporary levees are built to prevent floods in the town.

As part of an integrated assessment approach, employing primary data, an erosion susceptibility map was generated by using artificial neural networks [80]. It reveals severe alteration of the ecosystem in terms of the probability of occurrence of erosion events, especially in the upper sub-watershed (Figure 3). Empirical results suggest a strong spatial correlation between the erosion susceptibility index and land use and land cover data. The highest index values were reached in pasturelands and disturbed forests, and the lowest values in natural forest areas [80,81].

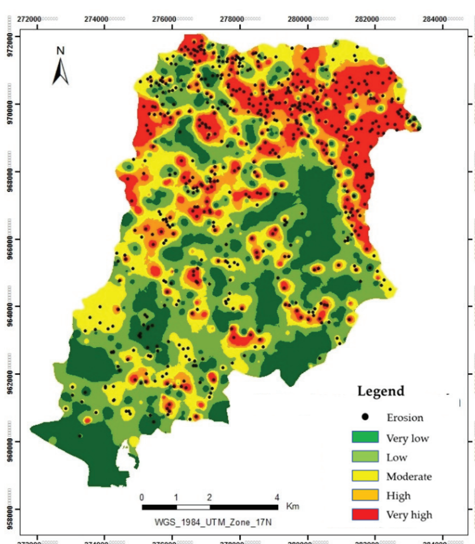


Figure 3. Erosion susceptibility map (Pérez-Rubio et al., 2021).

Research and restoration projects have been carried out over the past decade on abandoned and degraded agricultural and pasture lands near the upper sub-watershed of the river. Different restoration strategies have been tested, such as natural regeneration, applied nucleation/island tree planting, and plantation. Designing a cost-effective restoration strategy requires experience and knowledge from testing alternative treatments and knowledge of the adaptive dynamics of the plant species and the site characteristics, as well as the pre-defined ecological goal to be achieved [24,82]. The specific landscape and the biophysical and microclimatic conditions of the area, along with the low seed dispersal, aggressive exotic vegetation, and soil degradation represent strong limitations to natural regeneration for optimum forest recovery [83]. Results demonstrate that an active restoration strategy based on applied nucleation is the most cost-effective method compared to plantation in order to rapidly establish canopy cover and restore large areas [84–86].

3.3. Choice Experiment

3.3.1. Theoretical Approach

A choice experiment is a stated preference technique based on demand, welfare, and consumer theory [87], and the random utility model (RUM) developed by [88]. This study employed a choice experiment (CE) model to elicit individual landholders' preferences for adopting active ecological restoration measures in relation to their current cattle grazing land stewardship. This methodology relies on the assumption of the expected rational behavior of the subjects. Their choices among hypothetical alternatives should reveal the order of their preferences. A CE can offer several advantages over other non-market valuation methods, such as contingent valuation, including the ability to evaluate potential combinations of program characteristics [50], greater statistical efficiency, and better control of the collinearity of experimental stimuli among attributes [89].

However, the hypothetical nature of decision making in a choice experiment raises questions concerning three potential sources of bias. The first has to do with the respondents having a real understanding of the meaning and scope of the experiment, where bias may result from a lack of incentive to truthfully reveal their own preferences [53]. For this reason, conducting the experiment requires a prior induction exercise involving the use of charts and images to facilitate the identification of attributes and careful construction of the valuation scenario. Including cheap talk scripts, such as those developed by [90], has also been found to reduce hypothetical bias [91,92]. Second, the respondents may reveal a certain degree of caution or uncertainty about their preferences relative to their perception of institutional constraints when implementing the proposed environmental policies [93]. A third source of potential bias is in the underlying incentive for respondents to accommodate their choices to the researcher's view, thus the experiment may be affected by a lack of truthfulness [53].

3.3.2. Experimental Design and Data Collection

The CE model was designed by presenting choice sets to each respondent with two generic active restoration policies, with each alternative encompassing environmental attributes and their associated levels reflecting the expected impacts. The environmental attributes selected for valuation were three ESs: erosion control (ERO), water availability (WATER), and biodiversity (BIO). Table 1 shows the attributes and levels considered in this study. They aim at capturing in percentages the expected future level of provision of each ES. These values were obtained through consultation with experts. In addition, a fourth attribute represents the selected proportion of pastureland dedicated to the implementation of restoration actions (AREA). A maximum level of 50% was established, allowing livestock production in the remaining pastureland. Finally, the payment attribute (PAY) is defined as the minimum compensating payment that the farmer would be willing to accept to implement a restoration project in pastureland. Payment values are reported in Costa Rican colones. The proposed selection of attributes allows us to assess the relative importance of ESs to individual landholders' choices regarding restoration initiatives.

Table 1. Description of attributes and levels.

Attribute	Attribute Levels
Erosion control (ERO)	25, 35, 65%
Water availability (WATER)	15, 30, 60%
Biodiversity (BIO)	20, 30, 40%
Area (AREA)	15, 25, 50%
Payment (PAY)	100,000 CRC/ha/year
	150,000 CRC/ha/year
	200,000 CRC/ha/year
	250,000 CRC/ha/year

1USD = 557.34 CRC (October 2017).

The attributes and levels were combined using an orthogonal main effects design [47,49,94], which generated a fractional factorial design of 16 choice sets from the full factorial of 43 × 41 possible combinations [95–97]. Each choice set consisted of two generic alternatives (A and B), along with a status quo option describing the current grazing livestock production. The choice sets were not assigned in blocks, as is commonly done in practice, due to the limited sample size in the Claro River sub-watershed. The total number of observations was 496 (a total dataset of 82 respondents generated 492 observations in [48]).

The fieldwork was carried out between November 2017 and April 2018. A total of 31 landholders dedicated to livestock activity and located in the Claro River sub-watershed area were finally interviewed out of the estimated census data of 38 properties, based on the data offered by the local San Vito cattle farmers' chamber. The questionnaire (available on request) comprised two parts. The first part consists of respondent characteristics such as demographics, socioeconomic factors, and experience with natural resource management and environmental conservation. The second part presents the choice questions, including descriptions of the situations and a series of alternative soil management arrangements, for which respondents were asked to indicate their preference. Choice cards were used to elicit preferences, an example of which is shown in Figure 4.

3.3.3. Theory and Econometric Analysis

Following this model, people are assumed to choose the option that results in maximum utility for their daily decision-making. Thus, if individual n faces m mutually exclusive alternatives, the utility that the individual obtains from alternative j U_{nj} can be formalized as follows:

$$U_{nj} = V_{nj} + \varepsilon_{nj} \quad (1)$$

where V_{nj} is the observable part of utility (deterministic component) and ε_{nj} is the non-observable part (random component).

The observed utility component for individual n is assumed to be a linear additive function of x_{njk} variables for $k = 1, \ldots, K$ attributes that describe every alternative j, each weighted with a coefficient β_{njk}:

$$V_{nj} = \sum_{k=1}^{K} x_{njk}\beta_{njk} \quad (2)$$

The stochastic component of utility ε_{nj} is assumed to be independent and identically distributed (IID) with a type I extreme value (Gumbel) distribution [88], so that the parameters of Equation (2) can be estimated by means of multinomial logit (MNL) regression. However, the MNL model has two relevant drawbacks. First, as a consequence of the IID property, the model relies on the assumption that choices are consistent with the independent and irrelevant alternatives (IIA) property. This axiom states that the ratio of the probabilities of choosing one alternative over another (given that both alternatives have a non-zero probability of choice) is unaffected by the presence or absence of changes in the choice set [98]. The IIA property is usually checked by the test proposed in [99].

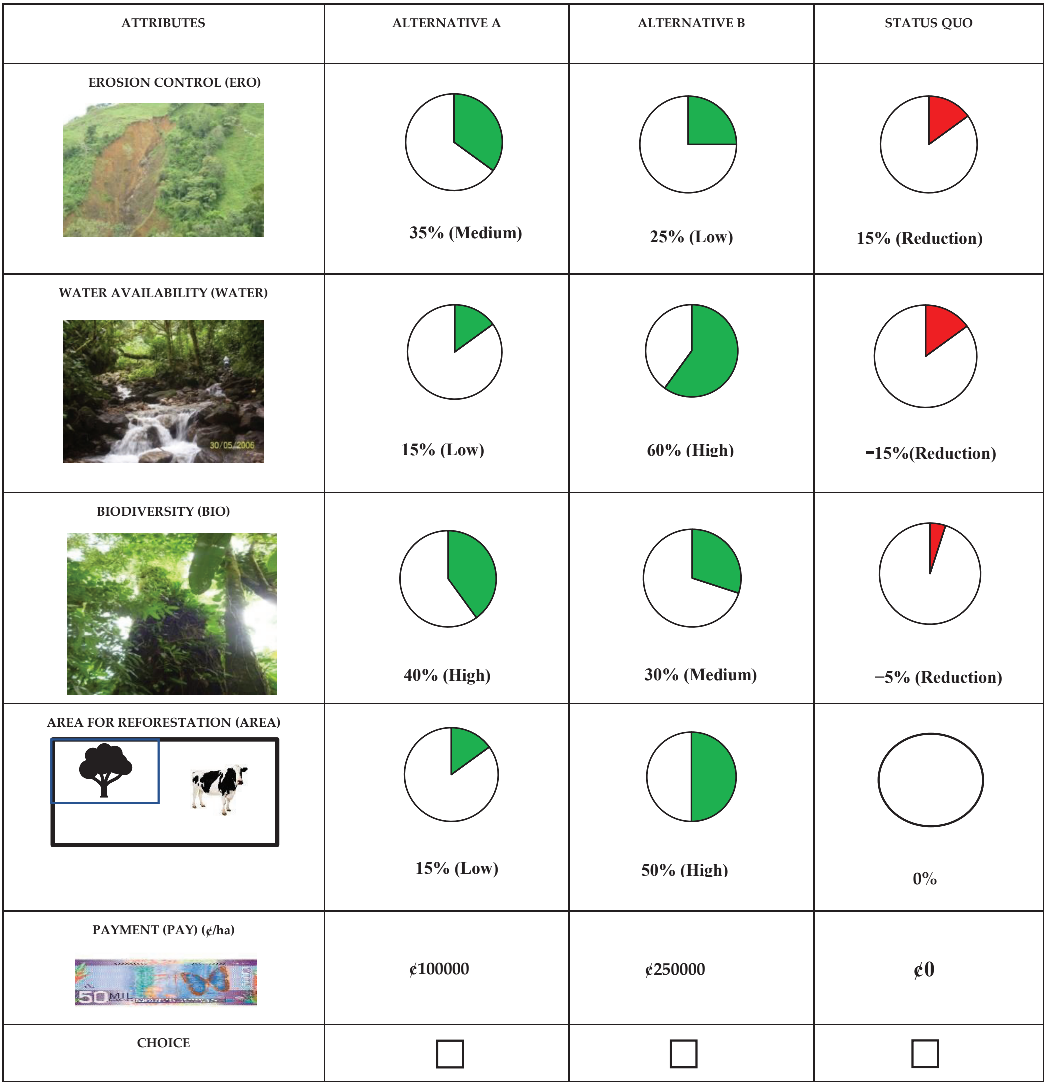


Figure 4. Example of a choice card. This card is an English translation of choice card 1 in the survey.

Second, the MLN model relies on an assumption of homogeneous preferences across respondents. Assuming the presence of taste variations, some degree of preference heterogeneity is required to be incorporated into the model: (i) observed heterogeneity, by allowing for interactions between socioeconomic characteristics and attributes of the alternatives or constant terms; or (ii) unobserved heterogeneity, by estimating coefficients over a continuous distribution rather than as a point estimate [45].

$$U_{nj} = \overline{\beta} x_{nj} + \widetilde{\beta_n} x_{nj} + \varepsilon_{nj} \quad (3)$$

Thus, each individual coefficient vector β is the sum of population mean $\overline{\beta}$ and individual deviation $\widetilde{\beta_n}$. The stochastic part of utility, $\widetilde{\beta_i} x_{nj} + \varepsilon_{nj}$, is correlated between alternatives, which means that the model does not exhibit the IIA property. If the error terms are IID type I extreme values, the model obtained is a random parameter logit (RPL). An RPL model allows parameters to vary randomly across individuals (but not across choice situations), providing a continuous distribution of preferences [100]. The model can include alternative specific constants (ASCs) for the status quo or for the restoration alternatives and interactions between the ASCs and respondent-specific characteristics (covariates) in order to improve the model fit [101], so that Equation (3) is rewritten as Equation (4):

$$U_{nj} = ASC_j + \overline{\beta}x_{nj} + \widetilde{\beta_n}x_{nj} + \alpha_{jm}ASC_j \ * S_{mn} + \delta_{nm}\ x_{nj} \ * S_{nm} + +\varepsilon_{nj} \quad (4)$$

where ASC_j is the alternative specific constant for alternative *j*, α_{jm} is the vector of coefficients of the interactions between the ASC and the *m*th socioeconomic characteristic of individual *n* (S_{mn}), and δ_{nm} is the vector of coefficients of interactions between the attributes and the *m*th socioeconomic characteristic of individual *n*. The ASC captures the average influence on the utility of unobserved factors that are correlated to alternative *j*. Many authors recommend including ASC terms [102,103], and their use is favored in the current state of art, although there are case studies in the literature that exclude ASCs [104–106]. It has been argued that ASCs are important in order for interpreting individual preferences [107]. Including ASCs helps to reduce inaccuracies due to violation of the assumption of IIA [103], and excluding them could result in biased attribute parameter estimates, since the remainder of the model would attempt to capture both observed and unobserved effects [102].

In this study, ASC was considered to be a random variable and was assigned to be correlated to the status quo alternative. In this sense, the parameter was coded zero for generic alternatives A and B, and one for the status quo option. If the sign of its estimated value is positive, respondents would, on average, prefer the status quo over the alternatives, and vice versa. The socioeconomic and attitudinal factors of respondent characteristics can be also included through interactions with the alternative specific constants, in order to improve the model fit. Furthermore, to test for the influence of socio-demographic variables on choices, interaction terms of ASC and other attributes were also generated.

Another alternative method for assessing the presence of unobserved heterogeneity in the model is to identify potential segments or subgroups across respondents who share preferences and socio-economic characteristics [100]. The latent class (LC) model can be considered a semi-parametric version of the RPL, where parameters are distributed discretely with a finite set of values. The model does not require additional assumptions regarding the distribution of β; instead, it assumes the existence of a given number of classes that are not observable by the analyst, as well as which individuals belong to which class. Membership of a particular class or segment for each individual is estimated through a latent membership likelihood function that depends on the socio-economic characteristics of the individual and not the characteristics of the program's attributes. The relevance of the LC model over the RPL is in the capturing of further information regarding the presence of differentiated classes, which could be useful in policy design [50]. Even if unobserved heterogeneity is accounted for in both RPL or LC methods, the model may fail to explain the source of heterogeneity [52].

Both RPL and LC models were estimated with R.3.4.2 [108] using the GMNL package [109]. The log-likelihoods were simulated using 200 shuffled Halton draws in a quasi-Monte Carlo maximum likelihood simulation. Model selection was based on the lowest Akaike information criterion (AIC). An iterative process was used, in which interaction variables (i.e., socio-demographic variables) were subtracted one by one, starting with the least statistically significant, and comparing the model to the previous one based on AIC. When only statistically significant interaction variables remained, the first ones to be dropped were progressively re-added and the model was re-evaluated for improvements to AIC, regardless of statistical significance.

4. Results

4.1. Descriptive Statistics of Respondent Characteristics

Based on the field survey, the majority of interviewed households were entirely dedicated to cattle ranching (74%) and the others to dual purpose cattle ranching, for both meat and milk production. Specifically, the revenue of ranching holdings is generated from the sale of animals, while in dual-purpose farming income is obtained from a combination of selling animals (occasionally) and milk (including its use in cheese production).

Table 2 shows a summary of descriptive statistics for the survey respondents. About 74% of the respondents were male, and the respondents' average age was over 49. It is relevant to highlight that the female respondents were mainly young women, fully involved in farming duties. About 36% of the households had their place of residence in nearby towns and villages of San Vito, Concepción, Aguabuena, and Rio Claro. These correspond to the wealthiest households, which own the largest land parcels and the most livestock units. Some of residents were professionals or perform alternative jobs in the towns. Out of the total survey population, only 25% had property rights, a proportion in agreement with the data collected in nearby Osa Peninsula [42]. As mentioned above, this is one of the main constraints on having access to credit and PES schemes, especially for the reforestation category.

Table 2. Characteristics of survey households.

Respondent Characteristics	Value (std. dev)
Average age (years)	49.36 (14.86)
Female respondents (%)	25.8
Households with place of residence outside land parcel (%)	36
Property rights (%)	25
Average size of pasturelands (ha)	38.16 (37.78)
Average size of forests (ha)	29.06 (18.27)
Average total number of cattle units	28.13 (20.21)
Cattle farming model (ranching) (%)	74

The average size of the pasture area within the total land parcel was reported to be about 38 hectares, although the high value of standard deviation (~37 ha) reveals a wide range of pastureland area across the properties, with an average number of cattle units of about 28. The vast majority of land parcels contain fragments of forest cover, either primary, secondary, or riparian, with an average size of about 30 hectares. This feature indicates a concern for the environment and a perception of forest benefits. There is no spatial evidence in the last decade of the clearing of forests for agriculture or livestock purposes [80].

4.2. Random Parameter Logit Model

The estimation results of the RPL models, both with and without respondent characteristics, are reported in Table 3. The values of the AIC statistic for both models reveal an improvement in the degree of goodness-of-fit for the model with covariates. Therefore, the latter was considered for further analysis. The selected respondent characteristics or covariates were those that reached the highest statistical significance. Two random parameters for attributes (ASC and AREA) were included and specified as normally distributed. The model also contains interaction effects between random variables and covariates. The payment attribute is fixed and measured in present value terms so that meaningful estimates of WTA can be calculated [46].

The status quo parameter (ASC) is negative, implying that, on average, most of the landholders were interested and willing to participate in a restoration initiative over the status quo option. As expected, an almost equal distribution of choices was found between the two hypothetical, generic restoration alternatives presented to the respondents. The first alternative was chosen in 36.5% of cases and the second in 35.7% of cases, confirming the absence of selection bias in the hypothetical alternatives due to design error [52].

Table 3. Results of random parameter logit models.

Variables and Interaction Effects	RPL without Covariates (Model 1)	RPL with Covariates (Model 2)
ASC (for status quo alternative)	−0.090 (0.898)	−1.949 (0.819) *
Erosion control (ERO)	0.019 (0.004) ***	0.019 (0.004) ***
Water availability (WATER)	0.017 (0.004) ***	0.017 (0.004) ***
Biodiversity (BIO)	0.003 (0.009)	0.003 (0.009)
Area (AREA)	−0.070 (0.024) **	−0.077 (0.034) *
Payment (PAY)	0.014 (0.001) ***	0.014 (0.001) ***
ASC × Dual purpose	-	3.211 (0.731) ***
ASC × Pastureland size	.	0.022 (0.008) **
Area × Dual purpose	-	−0.114 (0.057) *
Standard deviation		
ASC	3.521(1.118) **	0.131 (0.711)
Area	0.109 (0.020) ***	0.156 (0.025) ***
AIC	600.508	587.37
Log likelihood	−292.25	−282.69
Number of observations	496	496

Standard errors in parentheses. * Significant at $p < 0.1$, ** significant at $p < 0.05$, *** significant at $p < 0.01$.

The positive signs and statistical significance of the coefficient estimates for the ES attributes (apart from BIO) indicate a higher likelihood that a landholder would participate in a restoration program. The erosion control (ERO) and water availability (WATER) attributes show high statistical significance and a similar coefficient magnitude, with ERO slightly more preferred than WATER. The negative sign of the AREA attribute, which describes the maximum portion of pastureland that farmers would be willing to convert to reforestation, indicates that the greater its value, the lower its utility to respondents. This sign is expected, indicating that households obtain a regular income from livestock production.

The incorporation and accounting of unobserved preference heterogeneity among respondents by allowing model parameters to vary randomly across individuals is partially explained by the presence of statistically significant estimates of their standard deviations [110] registered by the ASC (in the model without covariates) and AREA random parameters. In order to explore possible sources of heterogeneity, several interactions among the attributes and socioeconomic characteristics of the respondents were tried, but only the ones depicted in Table 3 were found to be significant. The interaction between ASC and the dual-purpose scheme shows a positive sign, which may indicate that farmers working under this scheme are less likely to participate in a restoration program. In addition, the interaction between ASC and pastureland size reveals that the larger the size, the higher the probability that the current situation (status quo) would be chosen ($p < 0.05$).

The implication of the negative sign for the interaction between the AREA attribute and the dual-purpose scheme is that landholders using this scheme are more likely to set aside a smaller proportion of pastureland for reforestation purposes. The significance and negative sign of ASC indicates that the utility for respondents is higher for the two hypothetical, generic environmental alternatives than the status quo option when everything else is held constant. In other words, the majority of respondents showed a strong preference for improving the status quo scenario beyond what was depicted by the proposed attributes shown on the choice cards [111].

4.3. Latent Class Logit Model

In contrast to RPL, the LC model allows for the detection of groups with homogenous behavior within the sample of respondents. Hence, the model assumes that the landholders' preferences are similar within classes and different between them. The choice of the optimal number of segments with heterogeneous preferences was based on the AIC statistics, although as suggested in [112], it is better determined through the Bayesian information criterion (BIC). In addition, it was recommended in [102] to assess the values of statistical significance, signs and magnitude of estimated parameters, and cautiously observe the socioeconomic characteristics of the target population [113].

Applying all of these criteria in this study resulted in two groups showing a clearly differentiated behavioral status. ASC was coded as for the RPL model. Table 4 reports the parameter estimates for each class and the class membership predicted function based on the socioeconomic covariates.

Table 4. Results of latent class model estimates.

Attributes	Class 1	Class 2
ASC (for status quo alternative)	1.964 (1.012)	−1.638 (0.564) **
Erosion control (ERO)	0.146 (0.221)	0.288 (0.075) ***
Water availability (WATER)	0.013 (0.252)	0.337 (0.082) ***
Biodiversity (BIO)	−0.048 (0.204)	−0.020 (0.084)
Area (AREA)	−2.131 (0.336) ***	−0.168 (0.085)
Payment (PAY)	1.244 (0.213) ***	0.280 (0.073) ***
Membership equation		
Intercept		4.794 (0.638) ***
Pastureland size		0.017 (0.003) ***
Forest land size		0.141 (0.028) ***
Dual purpose		−2.696 (0.295) ***
Age		−0.182 (0.023) ***
Average membership probability	38.70	61.29
AIC	669.42	
Log likelihood	−317.71	
Number of observations	496	

Standard errors in parentheses. ** significant at $p < 0.05$, *** significant at $p < 0.01$.

According to the results of the LC model estimates, 38.7% of the respondents belong to class 1 and the remaining 61.29% to class 2. The respondents in class 1 did not make their choices depending on the ES attributes, as the estimated coefficients were not statistically significant. Furthermore, they seemed to express a strong preference for maintaining the largest portion dedicated to pastureland, as shown by the magnitude and significantly negative value of the AREA coefficient. In addition, class 1 displays a higher sensitivity to the payment attribute compared with class 2. In summary, the profile of respondents in class 1 demonstrates a relatively reluctant attitude towards the proposed restoration alternatives. In contrast, the pattern of preferences of class 2 indicates that these individuals have an explicit environmental concern, as shown by the significantly positive values of the ES attributes and the significance and negative sign of ASC. In addition, this class is less sensitive to payment levels. In sum, class 2 is defined by similar average preferences as found in the RPL model.

The estimated coefficients of the membership equation provide information about the sources of preference heterogeneity across both classes. The membership function coefficients for class 1 are normalized to zero, in order to be able to identify the remaining coefficients, hence the membership equation for class 2 has to be evaluated relative to class 1. The positive sign of the pastureland size variable indicates that individuals who have larger pasturelands are more likely to belong to class 2. This result is reasonable, given the fact that landholders with larger properties are more likely to implement restauration initiatives, compared with households that have smaller land parcels, and therefore a higher dependency on land-use resources. The majority of these households are involved in dual-purpose activities, and their land parcels have a smaller average size than those involved solely in cattle ranching. This interpretation is consistent with the significance and negative sign of the dual-purpose variable, which indicates that households using this farming regime are more likely to belong to class 1. The positive sign of the forest size variable implies that landholders with larger parcels of forest are more likely to belong to class 2. With regard to the age variable, younger people are more in favor of implementing restoration initiatives than older people.

4.4. Marginal Value of Attributes and Welfare Change

As a result of the logit transformation of the econometric calculation of the utility function, the coefficient estimates can be interpreted as the relative contribution of a unit change in a particular attribute to the probability that a given choice is made while holding everything else constant. In theory, willingness-to-pay (WTP) estimates are determined by calculating the ratio of an attribute's marginal utility to the marginal utility of income [114]. The estimated coefficient on the payment attribute β_{nj} generated by both RPL and LC models can be interpreted as the marginal utility of income [45]. For linear attribute parameters, the marginal willingness to pay (mWTP) equals the negative ratio of the respective attribute coefficient β_{nj} and the coefficient of the payment attribute β_{nj}.

$$WTP_n = -\frac{\partial U/\partial \beta_{nj}}{\partial U/\partial \beta_{np}} = \frac{-\beta_{nj}}{\beta_{np}} \tag{5}$$

This study assumes the payment attribute to be fixed and not randomly distributed, so the parameters and distributions for WTA compensation can be easily estimated [101,104,115,116]. In addition, the payment vehicle is defined as a compensation amount, so that the denominator of Equation (5) will be positive, and therefore the corresponding ratio or "implicit price" indicates a WTA compensation amount.

In order to examine a broader meaning of mWTA estimates, a common method is to calculate the marginal individual welfare changes or compensating surplus (CS) related to different policy scenarios by using the formula provided in [114]:

$$CS = -\frac{(U_0 - U_1)}{\beta_{np}} \tag{6}$$

where U_0 indicates utility at the status quo, U_1 indicates the utility of a determined policy scenario, and β_{np} is the parameter estimate of income. For this calculation, it is assumed that the utility is linear and separable into attributes.

The WTA estimates were calculated for the different attributes of the model by using Equation (5) from RPL models, both with and without covariates, and are reported in Table 5. The values are measured in CRC/ha/year for a unit increase in attribute level. The monetary values reveal few differences among the ecosystem service attributes, but a remarkable difference in the ASC attribute. The two RPL model estimates denote similar differences between their respective coefficients (see Table 3). In this case, the ASC attribute was previously defined as a random variable with a normal distribution, and as the payment level is fixed, the respective WTA amount will also be normally distributed, which accounts for statistically significant standard deviations across the respondents. The preference heterogeneity among respondents is reflected by a significant difference in WTA estimates [116].

Table 5. Marginal willingness to accept, in CRC 1000 per hectare per year, in 2017.

Attributes	RPL Model without Covariates	RPL Model with Covariates
ERO	1.419 (0.747, 2.091) ***	1.413 (0.738, 2.088) ***
WATER	1.212 (0.599, 1.825) ***	1.222 (0.606, 1.837) ***
AREA	−4.990 (−8.509, −1.470) **	−5.519 (−10.460, −0.579) *
ASC	−6.433 (−132.413, 119.545)	−139.183 (-269.097, −9.269) *

95% confidence interval in parentheses. * Significant at $p < 0.1$, ** significant at $p < 0.05$, *** significant at $p < 0.01$. USD 1 = CRC 557.34 (October 2017).

The positive sign of the marginal rate of substitution for the environmental attributes indicates that, with everything else being equal, respondents would be better off on average with an increase in the levels of those attributes. For a 1% improvement in the provision of ERO, farmers on average would be willing to pay a premium of 1413 CRC/ha/year (approximately 2.54 USD/ha/year). Similarly, for a 1% improvement in the provision of WATER, farmers on average would be willing to pay 1222 CRC/ha/year (approximately 2.17 USD/ha/year). All of these monetary values can also be interpreted in terms of existing and future bequest values, representing the economic importance that landholders assign to the enhancement of ecosystem services for present and future generations.

The marginal rate of substitution for the AREA attribute represents a significant feature. In this case, as noted above, AREA refers to the maximum portion of pastureland that landholders would be willing to give up in order to implement restoration initiatives. Hence, for a 1% increase in the portion of pasture area for restoration purposes, landholders on average would be willing to accept at least CRC 5227 (approximately USD 9.38) per hectare per year (RPL model without covariates) and CRC 5519 (approximately USD 9.90) per hectare per year (RPL model with covariates). The ASC monetary value suggests a baseline payment to consider participating in a restoration initiative (irrespective of the attributes considered in the model).

The welfare values of potential restoration scenarios were estimated by applying Equation (6) with the results of the RPL model with covariates. Three hypothetical policy scenarios were evaluated, reflecting the different degrees of implementation and environmental effects of the restoration strategies (strong, medium, and weak). Table 6 reports the attribute levels and compensating surplus estimates for each scenario. The status quo scenario is related to the current grazing livestock and the attribute levels are set to zero, so that the potential negative environmental impact is not considered for comparison purposes. The negative sign of the compensating surplus (CS) estimates implies, in practical terms, the requirement of an additional incentive payment for landholders to implement these restoration scenarios. These monetary values indicate a welfare change due to the proposed policy scenarios, taking into consideration both the utility associated with the attributes and the exclusion of the value associated with the baseline payment.

Table 6. Compensating surplus (CS) for different restoration scenarios, in 1000 CRC per hectare per year, in 2017.

Scenario	Levels of Attributes				Compensating Surplus	
	ERO	**WATER**	**BIO**	**AREA**	**Mean**	**Confidence Interval**
Strong restoration (I)	65%	60%	40%	50%	−100.086	(−612.950, 412.776)
Medium restoration (II)	35%	30%	30%	25%	−43.835	(−315.233, 227.562)
Weak restoration (III)	25%	15%	20%	15%	−23.777	(−190.041, 142.486)

95% confidence interval in parentheses. USD 1 = CRC 557.34 (October 2017).

The welfare value results shown in Table 6 correspond to the mean amount of money that an individual landholder would be additionally compensated for implementing the restoration policy initiative as described for each scenario. Thus, the estimated annual compensating surplus that each household would receive is an average of CRC 100,086 (approximately USD 179.57) for scenario I, CRC 43,835 (approximately USD 78.65) for scenario II and CRC 23,777 (approximately USD 42.62) for scenario III. All of these values would be conditioned on compliance with the change in the additionality provision of ES.

4.5. Opportunity Costs and Nationwide PES Scheme in Costa Rica

To test the validity of these results, the opportunity costs of implementing restoration alternatives should be considered. The opportunity cost of an activity is theoretically defined as the highest profit forgone by not putting the land under an available alternative. In this case study, cattle ranching is not just the main land-use economic activity amongst surveyed households; moreover, it is hard to find alternative high-value crops given the low soil productivity and the other special biophysical conditions of the area. Empirical studies [117,118] report that about three-quarters of areas under PES schemes have soils that do not allow agricultural use. Alternative land uses such as urbanization and tourism are currently very far from being realistic and suitable options. Hence, the opportunity costs were calculated for cattle ranching and dual purpose (meat and dairy), with estimated average annual household benefits of about 175,876.14 and 338,925 CRC/ha/year, respectively. Although net present values should be calculated in order to properly consider these opportunity costs, since this study is only concerned with comparing programs, only the on-going year of payments is considered.

With regard to the national PES scheme in Costa Rica, there is a wide range of payments depending in the restoration category (Table 7). For instance, for a reforestation plan with fast-growing species (e.g., *Vochysia guatemalensis*), the payment established for 2017 was CRC 643,107 per hectare for a 5-year period (an average of approximately CRC 128,621 per hectare and per year) by executive order R-541-2016-MINAE. The only plan capable of fully compensating the opportunity costs for the considered year is reforestation with native species.

Table 7. Costa Rican PES program reforestation payment levels and categories for 2017.

Categories	Hectare/Contract (CRC)	Annual Average Payment per Hectare	First Year Payment per Hectare
Reforestation with fast-growing species	643,107	128,621.4	321,553.5
Reforestation with medium-growing species	757,634	151,526.8	378,817
Reforestation with native species	1,136,451	227,290.2	568,225.5
Natural regeneration	109,106	21,821.2	21,821.2

USD 1 = CRC 557.34 (October 2017).

5. Discussion

5.1. Targeting of Ecosystem Services as a Place-Based Approach

The first research question of this study was how to assess the extent to which cattle ranching landholders located in the Claro River sub-watershed would be willing to implement restoration projects within their properties through a hypothetical PES scheme. This question was raised based on the results obtained from primary data through a GIS-based spatial assessment, which demonstrated the presence of high levels of erosion susceptibility in the upper sub-watershed and a strong spatial correlation with cattle rangelands [80,81]. The selection of the erosion control (ERO) attribute along with two other ESs (water availability and biodiversity) in the CE model allowed us to elicit the respondents' preferences for them in order. The ERO coefficient was shown to be positive and have the highest statistical significance, hence it shows that people prioritize restoration strategies focused on reversing land degradation and erosion risks. The WATER attribute estimate is also statistically significant (in contrast with the BIO attribute), with a magnitude very close to ERO. This means that landholders would prefer reforestation actions that would simultaneously enhance and ensure the delivery of water.

A common concern among researchers and environmental practitioners is the uncertain environmental effectiveness of nationwide PES schemes. The lack of a spatial targeting approach and the short-term nature of the programs are cited among the main concerns [42,58,119]. Although the current Costa Rican PES scheme policy framework favors those applicants whose properties are located within a pre-established national biological corridor, the employment of national-scale secondary spatial data necessarily fails to address an effective place-based approach to target specific ESs.

In this case study, GIS-based erosion susceptibility data allows a spatially related allocation of payments. A micro-scale approach to the PES scheme would imply a double gain in terms of cost-effectiveness. First, a pre-determined ecosystem-based spatial targeting approach would allow the allocation of financial resources to areas more likely to enhance specific ESs. Primary SIG-based data and newly developed machine learning modeling techniques facilitate the spatial allocation of prioritized hotspots. Second, a micro-scale mapping assessment is essential for allocating specific restoration practices to tackle land degradation. In this sense, further research is strongly recommended to expand the GIS-based spatial assessment in the same location to quantify a wider range of ESs (e.g., water availability, biodiversity conservation, carbon sequestration).

5.2. Willingness to Restore Ecosystem Services under a PES Scheme

The first step in targeting the restoration of ecosystem services through a PES scheme relies on the active involvement of a large proportion of the potential providers. Following a place-based approach, in this case study, this commitment lies with the cattle farmers. The overall results of RPL and LC estimates suggest a strong preference among average landholders for the implementation of restoration initiatives, with the necessary support of a designed, constructed PES scheme. This result is consistent with the findings of previous case studies assessing the willingness to accept PES schemes in rural areas in Mexico and Nicaragua [46–48,50].

However, in this case study, about a third of the respondents clearly opted to maintain their current livestock production, without any land-use changes in their pastureland parcels. Most of the dual-purpose farmers preferred to maintain the status quo, although this choice does not necessarily assume an overall negative environmental opinion.

Two distinctive systems of livestock production were found. On the one hand, larger holdings, mainly located in the upper watershed, are involved in a cattle ranching-only scheme, based on selling and buying male bovines. The landholders' families live in nearby urban settlements and usually generate extra off-farm income. Most of the holdings were reported to have less than one animal per hectare, so the revenue per hectare is low. Aside from the low productivity, the poor soil nutrient availability [120] and climatic conditions [121] also limit the implementation of alternative commodity crops. On the other hand, households under dual-purpose schemes are mainly characterized by small-scale family-based production of milk and cheese. The revenue per hectare is significantly higher than in the other cattle scheme thanks to the profitable sales of milk and artisanal cheese.

Therefore, the notable divergence in landholders' stated choices, reflected in these two distinct systems of livestock production, can be explained by the differences in their land opportunity costs. This deductive conclusion is closely aligned to existing case studies in Mexico, Costa Rica, and other Central American countries [46–48,56,63,68]. Furthermore, it is possible to infer that the average low land opportunity costs and current low meat prices at local markets could also eventually explain the choice of some respondents for restoration alternatives.

To examine the extent to which landholders would potentially be eager to implement restoration actions on their properties under a PES scheme, individual marginal willingness to accept (WTA) estimates and implicit prices were calculated (see Table 5). Observing the monetary value of the ASC, landholders on average would require 139,183 CRC/ha/year (approximately 249.72 USD/ha/year) as a baseline payment to enter the overall program. To determine internal validity, this amount can be contrasted with the estimated land opportunity costs for cattle ranching farmers (about 175,876.14 CRC/ha/year). Assuming that the monetary value of the ASC is normally distributed, it is possible to infer with reasonable confidence that the observed WTA estimates are within a realistic range.

According to our results, apart from the strategy of reforestation with native species, the amount of current fixed payments under the Costa Rican PES scheme seems to be insufficient to fully compensate the average income received by cattle ranching landholders. In this hypothetical scenario, transaction and operational costs are not considered, otherwise these would be necessarily assumed by landholders and, as a consequence, could nearly outweigh the whole compensation payment.

Therefore, landholders' participation in a potential PES scheme could only be effective if an external intermediary institution were willing to assume at least the expected high direct operational costs of implementing reforestation projects. Transaction costs could be considerably reduced if economies of scale were gained by bundling individual contracts into a unique global contract. In this sense, given the fact that a discrete CE is basically designed as an individual decision-making approach, the capability of a community-based scheme could change the opinion of some initially reluctant landholders [53]. Thus, future research should address the design and testing of alternative methodologies that could contribute to the search for collective decisions by potential beneficiaries, which would result in an efficient use of available public resources.

Despite the small sample size, we consider these results to be reasonably representative of the current state of cattle ranching landholders in mountain areas of southern Costa Rica. However, it would not be accurate to claim external validity outside this area. The preferences stated by the respondents must be contextualized in their own temporal and spatial scale. Taking into account the shortcomings of this case study, we demonstrate that even for a specific site with low land opportunity costs, it would be hard for the current national PSE scheme for reforestation to fulfil the preferences of landholders.

5.3. Evaluating a Layered Payment Scheme

The Costa Rican PES program includes the ability to enroll a PES scheme under a wide range of reforestation categories, allowing significant variation in PES levels (see Table 7). This remarkable advantage implicitly captures latent layered payments that reflect differentiated ESs. In this sense, a reforestation strategy with native species may reflect a biodiversity-targeted approach. However, a baseline spatial dataset is essential to quantify the added net impact, in terms of enhanced provision of ES derived by the implementation of reforestation actions. This case study in particular provides GIS-based spatial hotspot data regarding erosion susceptibility modeling. Further spatial modeling research is required to provide a baseline dataset regarding water supply or water quality ES.

We consider that the main contribution of this case study consists of incorporating an ES additionality approach into a small-scale PES scheme. It is argued in [122] that in order for a PES scheme to be efficient, the actions and derived services paid for are additional to the status quo, and according to [60] this is a prerequisite for achieving effectiveness. In this sense, we investigated landholders' willingness to accomplish reforestation actions, which imply land-use changes to their properties, in exchange for compensating payments conditioned on the enhancement of specific ESs. Hence, we designed a CE model by defining attributes related to the provision of erosion control, water availability, and biodiversity. The latter was not statistically significant in the econometric analysis and therefore was not included in further calculations.

Turning to the attributes valued the highest by the landholders, their estimated marginal WTA measures indicate the required additional payment for enhancing erosion control (2.54 USD/ha/year) and water availability (approximately 2.17 USD/ha/year). In order to construct a PES scheme with these findings, there are two alternative strategies: the traditional bundling, as used by the Costa Rican PES scheme, which consists of grouping both ESs together in a single package, or layering, by which payments are made separately for each ES within the same scheme framework.

We consider that the layering approach implies a further improvement step, considering the following: (1) With the support of baseline spatial datasets, trade-offs and overlapping effects between the additional enhancement provision of ES can be reduced by diverting the optimal resources to the required site-specific restoration actions [61]. (2) This approach would favor the construction of "networked" or multi-level governance, which refers to the creation of ad hoc horizontal partnerships of institutions and social actors to manage the PES scheme, ideally based on bottom-up, collective decision-making [61]. As an example, an erosion control scheme could be collectively funded by government institutions, regarding agriculture and livestock production or risk management, and social actors, such as local chambers of producers, in parallel with a scheme targeting local water companies by introducing a tariff to pay for water availability and quality. (3) Layering ecosystem services would benefit landholders by having additional payments conditioned on the enhanced delivery of ES.

6. Conclusions

This paper reports empirical research findings from a CE model integrated with support from GIS-based spatial data, to explore how landholders around the Claro River sub-watershed evaluate the option of restoring the region's ES. The environmental spatial assessment and existing research evidence demonstrate high levels of erosion susceptibility in the upper sub-watershed, which leads to land degradation, with impacts on multiple ESs such as livestock yield, water availability, and biodiversity loss.

The overall CE results indicate that landholders under a cattle ranching regime are mostly willing to adopt drastic environmentally sound land-use changes if optimal incentive payments are provided through a PES scheme. CE also allows us to examine the presence and potential sources of behavioral heterogeneity across respondents and to estimate their willingness to accept (WTA) the implementation of restoration practices on their pasturelands. The larger the pasturelands and associated lower productivity, the more likely they will enroll in a PES scheme. In contrast, landholders under a dual-purpose farming scheme are clearly averse to changing their current small-scale mode of production.

Based on the results from this study, households explicitly recognize the benefits gained by first reducing the risks of soil erosion and land degradation, followed by securing water availability. The estimated levels of WTA these ESs capture the economic relevance that people attribute to securing present and future provision. However, in order to implement restoration projects, the estimated average individual WTA compensation levels for landholders, which are closely correlated to their opportunity costs, are strongly affected by the size of their pasturelands. These WTA estimates are a long way from fully offsetting the current payments offered by the Costa Rican PES program, even if a potential intermediary entity were to assume the expected high operational and transaction costs. Moreover, the lack of land tenure rights among most of the landholders would undermine access to the program.

Beyond these results, this case study assesses the potential benefits of a micro-scale layered PES scheme based on a spatial targeting approach and landholders' willingness to accept payments to provide their most highly valued ecosystem services. This novel proposal could overcome the main shortcomings of the national PES scheme. However, the results must be carefully framed in the current temporal and spatial scales of the studied area and the small size of the surveyed population. Therefore, it is difficult to assume external validity for other sites in Costa Rica.

Some necessary policy implications should be addressed in order to undertake a micro-scale PES scheme. First, appropriate policy frameworks and institutional arrangements should be considered to draft flexible payment schemes closely aligned to a spatial targeting approach, in order to measure the additionality of differentiated ESs. Second, the development of "networked" or multi-level governance could improve access to alternative financial mechanisms, to complement the budget-fixed bounds of the nationwide PES program and play an intermediary role in assuming the expected high direct operational and transaction costs. Third, the implementation of secured land tenancy rights will be an inevitable and essential policy.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/land10070709/s1, Figure S1: Gographical location of the Claro River sub-watershed in southern Costa Rica.

Author Contributions: Conceptualization, I.P.-R.; methodology, I.P.-R.; software, I.P.-R. and D.F.; validation, D.F., C.V., F.J. and I.E.; formal analysis, D.F., C.V. and I.E.; investigation, I.P.-R.; resources, I.P.-R., D.F. and C.V.; data curation, I.P.-R., D.F. and C.V.; writing—original draft preparation, I.P.-R.; writing—review and editing, I.P.-R.; visualization, D.F., C.V., F.J. and I.E.; supervision, I.E.; project administration, D.F. and C.V.; funding acquisition, I.P.-R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Fondo de Becas CeNAT-CONARE, Costa Rica, https://cenat.ac.cr/ (accessed on 28 April 2021). The publication process was partly financed by the EKOPOL Research group, recognized by the Basque Government (IT-1365-19).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: We appreciate the support from the local residents, local institutions and scholars. We would also like to thank the two anonymous reviewers for their comments and suggestions. Special thanks go to the PRIAS-CENAT laboratory personnel for technical and logistic support during this research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Barral, M.P.; Benayas, J.M.R.; Meli, P.; Maceira, N.O. Quantifying the impacts of ecological restoration on biodiversity and ecosystem services in agroecosystems: A global meta-analysis. *Agric. Ecosyst. Environ.* **2015**, *202*, 223–231. [CrossRef]
2. Brancalion, P.H.S.; Niamir, A.; Broadbent, E.; Crouzeilles, R.; Barros, F.S.M.; Zambrano, A.M.A.; Baccini, A.; Aronson, J.; Goetz, S.; Reid, J.L.; et al. Global restoration opportunities in tropical rainforest landscapes. *Sci. Adv.* **2019**, *5*. [CrossRef] [PubMed]
3. Navarro, L.M.; Marques, A.; Proença, V.; Ceaușu, S.; Gonçalves, B.; Capinha, C.; Fernandez, M.; Geldmann, J.; Pereira, H.M. Restoring degraded land: Contributing to Aichi Targets 14, 15, and beyond. *Curr. Opin. Environ. Sustain.* **2017**, *29*, 207–214. [CrossRef]
4. Benayas, J.M.R.; Bullock, J.M. Restoration of Biodiversity and Ecosystem Services on Agricultural Land. *Ecosystems* **2012**, *15*, 883–899. [CrossRef]
5. Watson, J.E.M.; Evans, T.; Venter, O.; Williams, B.; Tulloch, A.; Stewart, C.; Thompson, I.; Ray, J.C.; Murray, K.; Salazar, A.; et al. The exceptional value of intact forest ecosystems. *Nat. Ecol. Evol.* **2018**, *2*, 599–610. [CrossRef] [PubMed]
6. Vanacker, V.; Bellin, N.; Molina, A.; Kubik, P.W. Erosion regulation as a function of human disturbances to vegetation cover: A conceptual model. *Landsc. Ecol.* **2014**, *29*, 293–309. [CrossRef]
7. Viles, H.A.; Naylor, L.A.; Carter, N.E.A.; Chaput, D. Biogeomorphological disturbance regimes: Progress in linking ecological and geomorphological systems. *Earth Surf. Process. Landf.* **2008**, *33*, 1419–1435. [CrossRef]
8. Calder, I.R. Forests and hydrological services: Reconciling public and science perceptions. *Land Use Water Resour. Res.* **2002**, *2*. [CrossRef]
9. Brookhuis, B.; Hein, L. The value of the flood control service of tropical forests: A case study for Trinidad. *For. Policy Econ.* **2016**, *62*, 118–124. [CrossRef]
10. Bruijnzeel, L. Hydrological functions of tropical forests: Not seeing the soil for the trees? *Agric. Ecosyst. Environ.* **2004**, *104*, 185–228. [CrossRef]
11. Farley, K.A.; Jobbagy, E.G.; Jackson, R.B. Effects of afforestation on water yield: A global synthesis with implications for policy. *Glob. Chang. Biol.* **2005**, *11*, 1565–1576. [CrossRef]
12. Wang, X.; Dong, X.; Liu, H.; Wei, H.; Fan, W.; Lu, N.; Xu, Z.; Ren, J.; Xing, K. Linking land use change, ecosystem services and human well-being: A case study of the Manas River Basin of Xinjiang, China. *Ecosyst. Serv.* **2017**, *27*, 113–123. [CrossRef]
13. IPBES. *Summary for Policymakers of the Assessment Report on Land Degradation and Restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*; Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services: Bonn, Germany, 2018; p. 44.
14. Kaimowitz, D.; Sheil, D. Conserving What and for Whom? Why Conservation Should Help Meet Basic Human Needs in the Tropics. *Biotropica* **2007**, *39*, 567–574. [CrossRef]
15. Benayas, J.M.R.; Newton, A.C.; Diaz, A.; Bullock, J.M. Enhancement of Biodiversity and Ecosystem Services by Ecological Restoration: A Meta-Analysis. *Science* **2009**, *325*, 1121–1124. [CrossRef] [PubMed]
16. Feng, X.; Fu, B.; Lu, N.; Zeng, Y.; Wu, B. How ecological restoration alters ecosystem services: An analysis of carbon sequestration in China's Loess Plateau. *Sci. Rep.* **2013**, *3*, 2846. [CrossRef] [PubMed]
17. Fonseca, W.; Alice, F.E.; Rey-Benayas, J.M. Carbon accumulation in aboveground and belowground biomass and soil of different age native forest plantations in the humid tropical lowlands of Costa Rica. *New For.* **2011**, *43*, 197–211. [CrossRef]
18. Huang, L.; Shao, Q.; Liu, J. Forest restoration to achieve both ecological and economic progress, Poyang Lake basin, China. *Ecol. Eng.* **2012**, *44*, 53–60. [CrossRef]
19. Bosch, J.; Hewlett, J. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *J. Hydrol.* **1982**, *55*, 3–23. [CrossRef]
20. Van Dijk, A.I.J.M.; Van Noordwijk, M.; Calder, I.R.; Bruijnzeel, S.L.A.; Schellekens, J.; Chappell, N.A. Forest–flood relation still tenuous—Comment on 'Global evidence that deforestation amplifies flood risk and severity in the developing world'. *Glob. Chang. Biol.* **2009**, *15*, 110–115. [CrossRef]
21. Arroyo-Rodríguez, V.; Pineda, E.; Escobar, F.; Benítez-Malvido, J. Value of Small Patches in the Conservation of Plant-Species Diversity in Highly Fragmented Rainforest. *Conserv. Biol.* **2009**, *23*, 729–739. [CrossRef]

22. Food and Agriculture Organization (FAO). The Resource Outlook to 2050: By How Much Do Land, Water and Crop Yields Need to Increase by 2050. Available online: http://ftp.fao.org/docrep/fao/012/ak971e/ak971e00.pdf. (accessed on 24 March 2018).
23. Kiers, E.T.; Leakey, R.R.B.; Izac, A.-M.; Heinemann, J.A.; Rosenthal, E.; Nathan, D.; Jiggins, J. ECOLOGY: Agriculture at a Crossroads. *Science* **2008**, *320*, 320–321. [CrossRef] [PubMed]
24. Holl, K.D. Research Directions in Tropical Forest Restoration. *Ann. Mo. Bot. Gard.* **2017**, *102*, 237–250. [CrossRef]
25. Jones, H.P. Impact of Ecological Restoration on Ecosystem Services. In *Encyclopedia of Biodiversity*; Elsevier: Amsterdam, The Netherlands, 2013; pp. 199–208.
26. Reed, M.S.; Buenemann, M.; Atlhopheng, J.; Akhtar-Schuster, M.; Bachmann, F.; Bastin, G.; Bigas, H.; Chanda, R.; Dougill, A.; Essahli, W.; et al. Cross-scale monitoring and assessment of land degradation and sustainable land management: A methodological framework for knowledge management. *Land Degrad. Dev.* **2011**, *22*, 261–271. [CrossRef]
27. DE Groot, R.S.; Blignaut, J.; VAN DER Ploeg, S.; Aronson, J.; Elmqvist, T.; Farley, J. Benefits of Investing in Ecosystem Restoration. *Conserv. Biol.* **2013**, *27*, 1286–1293. [CrossRef] [PubMed]
28. Mekuria, W.; Veldkamp, E.; Tilahun, M.; Olschewski, R. Economic valuation of land restoration: The case of exclosures established on communal grazing lands in Tigray, Ethiopia. *Land Degrad. Dev.* **2011**, *22*, 334–344. [CrossRef]
29. Corbera, E.; Pascual, U. Ecosystem Services: Heed Social Goals. *Science* **2012**, *335*, 655–656. [CrossRef] [PubMed]
30. Muradian, R.; Arsel, M.; Pellegrini, L.; Adaman, F.; Aguilar, B.; Agarwal, B.; Corbera, E.; De Blas, D.E.; Farley, J.; Froger, G.; et al. Payments for ecosystem services and the fatal attraction of win-win solutions. *Conserv. Lett.* **2013**, *6*, 274–279. [CrossRef]
31. Pascual, U.; Phelps, J.; Garmendia, E.; Brown, K.; Corbera, E.; Martin, A.; Gomez-Baggethun, E.; Muradian, R. Social Equity Matters in Payments for Ecosystem Services. *Bioscience* **2014**, *64*, 1027–1036. [CrossRef]
32. Shrestha, R.; Timilsnia, G. The additionality criterion for identifying clean development mechanism projects under the Kyoto Protocol. *Energy Policy* **2002**, *30*, 73–79. [CrossRef]
33. Pascual, U.; Muradian, R.; Rodríguez, L.C.; Duraiappah, A. Exploring the links between equity and efficiency in payments for environmental services: A conceptual approach. *Ecol. Econ.* **2010**, *69*, 1237–1244. [CrossRef]
34. Ezzine-De-Blas, D.; Wunder, S.; Ruiz-Pérez, M.; Moreno-Sanchez, R.D.P. Global Patterns in the Implementation of Payments for Environmental Services. *PLoS ONE* **2016**, *11*, e0149847. [CrossRef] [PubMed]
35. Wunder, S. Payments for Environmental Services: Some Nuts and Bolts. CIFOR Occasional Paper. Available online: http://www.cifor.org/publications/pdf_files/OccPapers/OP-42.pdf (accessed on 20 April 2021).
36. Porras, I.; Chacón-Cascante, A. Costa Rica's Payments for Ecosystem Services Programme. In *Ecosystems, Poverty Alleviation and Conditional Transfers*; International Institute for Environment and Development: London, UK, 2018; p. 59.
37. Robalino, J.; Pfaf, A.; Sánchez-Azofeifa, A.; Alpízar, F.; León, C.; Rodríguez, C.M. *Deforestation Impacts of Environmental Services Payments—Costa Rica's PSA Programme 2000–2005*; Environment for Development: Washington, WA, USA, 2005; p. 20.
38. Robalino, J.; Pfaff, A.; Villalobos, L. Assessing the impact of institutional design of payments for environmental services: The Costa Rican experience. In *Ecosystem Services from Agriculture and Agroforestry: Measurement and Payments*; Earthscan: Oxford, UK, 2011.
39. Sánchez-Azofeifa, A.; Pfaff, A.; Robalino, J.; Boomhower, J. Costa Rica's Payment for Environmental Services Program: Intention, implementation, and impact. *Conserv. Biol.* **2007**, *21*, 1165–1173. [CrossRef] [PubMed]
40. Arriagada, R.A.; Sills, E.O.; Ferraro, P.; Pattanayak, S.K. Do Payments Pay Off? Evidence from Participation in Costa Rica's PES Program. *PLoS ONE* **2015**, *10*, e0131544. [CrossRef]
41. Lansing, D.M. Understanding Smallholder Participation in Payments for Ecosystem Services: The Case of Costa Rica. *Hum. Ecol.* **2017**, *45*, 77–87. [CrossRef]
42. Porras, I.; Barton, D.N.; Miranda, M.; Chacón-Cascante, A. *Learning from 20 Years of Payments for Ecosystem Services in Costa Rica*; International Institute for Environment and Development: London, UK, 2013; p. 76.
43. Legrand, T.; Froger, G.; Le Coq, J.-F. Institutional performance of Payments for Environmental Services: An analysis of the Costa Rican Program. *For. Policy Econ.* **2013**, *37*, 115–123. [CrossRef]
44. Arriagada, R.A.; Ferraro, P.; Sills, E.O.; Pattanayak, S.K.; Cordero-Sancho, S. Do Payments for Environmental Services Affect Forest Cover? A Farm-Level Evaluation from Costa Rica. *Land Econ.* **2012**, *88*, 382–399. [CrossRef]
45. Hoyos, D. The state of the art of environmental valuation with discrete choice experiments. *Ecol. Econ.* **2010**, *69*, 1595–1603. [CrossRef]
46. Baker, K.; Baylis, K.; Bull, G.; Barichello, R. Are non-market values important to smallholders' afforestation decisions? A psychometric segmentation and its implications for afforestation programs. *For. Policy Econ.* **2019**, *100*, 1–13. [CrossRef]
47. Torres, A.B.; Macmillan, D.C.; Skutsch, M.; Lovett, J.C. Payments for ecosystem services and rural development: Landowners' preferences and potential participation in western Mexico. *Ecosyst. Serv.* **2013**, *6*, 72–81. [CrossRef]
48. Costedoat, S.; Koetse, M.; Corbera, E.; Ezzine-De-Blas, D. Cash only? Unveiling preferences for a PES contract through a choice experiment in Chiapas, Mexico. *Land Use Policy* **2016**, *58*, 302–317. [CrossRef]
49. Diafas, I.; Barkmann, J.; Mburu, J. Measurement of Bequest Value Using a Non-monetary Payment in a Choice Experiment—The Case of Improving Forest Ecosystem Services for the Benefit of Local Communities in Rural Kenya. *Ecol. Econ.* **2017**, *140*, 157–165. [CrossRef]
50. Kaczan, D.; Swallow, B.M.; Adamowicz, W. Designing a payments for ecosystem services (PES) program to reduce deforestation in Tanzania: An assessment of payment approaches. *Ecol. Econ.* **2013**, *95*, 20–30. [CrossRef]

51. Lliso, B.; Pascual, U.; Engel, S.; Mariel, P. Payments for ecosystem services or collective stewardship of Mother Earth? Applying deliberative valuation in an indigenous community in Colombia. *Ecol. Econ.* **2020**, *169*, 106499. [CrossRef]
52. Tarfasa, S.; Balana, B.B.; Tefera, T.; Woldeamanuel, T.; Moges, A.; Dinato, M.; Black, H. Modeling Smallholder Farmers' Preferences for Soil Management Measures: A Case Study from South Ethiopia. *Ecol. Econ.* **2018**, *145*, 410–419. [CrossRef]
53. Vorlaufer, T.; Falk, T.; Dufhues, T.; Kirk, M. Payments for ecosystem services and agricultural intensification: Evidence from a choice experiment on deforestation in Zambia. *Ecol. Econ.* **2017**, *141*, 95–105. [CrossRef]
54. Pagiola, S. Payments for environmental services in Costa Rica. *Ecol. Econ.* **2008**, *65*, 712–724. [CrossRef]
55. Matulis, B.S. Persistent Neo-liberalization in PES: Taxes, Tariffs, and the World Bank in Costa Rica. *Conserv. Soc.* **2017**, *15*, 147–156. [CrossRef]
56. Zbinden, S.; Lee, D.R. Paying for Environmental Services: An Analysis of Participation in Costa Rica's PSA Program. *World Dev.* **2005**, *33*, 255–272. [CrossRef]
57. Sierra, R.; Russman, E. On the efficiency of environmental service payments: A forest conservation assessment in the Osa Peninsula, Costa Rica. *Ecol. Econ.* **2006**, *59*, 131–141. [CrossRef]
58. Barton, D.; Faith, D.; Rusch, G.; Acevedo, H.; Paniagua, L.; Castro, M. Environmental service payments: Evaluating biodiversity conservation trade-offs and cost-efficiency in the Osa Conservation Area, Costa Rica. *J. Environ. Manag.* **2009**, *90*, 901–911. [CrossRef] [PubMed]
59. Daniels, A.E.; Bagstad, K.; Esposito, V.; Moulaert, A.; Rodriguez, C.M. Understanding the impacts of Costa Rica's PES: Are we asking the right questions? *Ecol. Econ.* **2010**, *69*, 2116–2126. [CrossRef]
60. Vedel, S.E.; Jacobsen, J.B.; Thorsen, B.J. Forest owners' willingness to accept contracts for ecosystem service provision is sensitive to additionality. *Ecol. Econ.* **2015**, *113*, 15–24. [CrossRef]
61. Reed, M.S.; Allen, K.; Dougill, A.J.; Evans, K.L.; Kenter, J.O.; Hoy, J.; McNab, D.; Stead, S.M.; Twyman, C.; Scott, A.S.; et al. A place-based approach to payments for ecosystem services. *Glob. Environ. Chang.* **2017**, *43*, 92–106. [CrossRef]
62. Estrada, N.; Declerck, F. Payment for ecosystem services for energy, biodiversity conservation, and poverty reduction in Costa Rica. In *Integrating Ecology and Poverty Reduction: The Application of Ecology in Development Solutions*; Springer: New York, NY, USA, 2011.
63. Arriagada, R.; Sills, E.O.; Pattanayak, S.K.; Ferraro, P.J. Combining Qualitative and Quantitative Methods to Evaluate Participation in Costa Rica's Program of Payments for Environmental Services. *J. Sustain. For.* **2009**, *28*, 343–367. [CrossRef]
64. Pagiola, S.; Arcenas, A.; Platais, G. Can Payments for Environmental Services Help Reduce Poverty? An Exploration of the Issues and the Evidence to Date from Latin America. *World Dev.* **2005**, *33*, 237–253. [CrossRef]
65. Grieg-Gran, M.; Porras, I.; Wunder, S. How can market mechanisms for forest environmental services help the poor? Preliminary lessons from Latin America. *World Dev.* **2005**, *33*, 1511–1527. [CrossRef]
66. Villanueva, C.; Ibrahim, M.; Casasola, F.; Sepúlveda, C. Ecological indexing as a tool for the Payments for Ecosystem Services in agricultural landscapes: The experience of the GEF-Silvopastoral project in Costa Rica, Nicaragua and Colombia'. In *Ecosystem Services from Agriculture and Agroforestry: Measurement and Payments*; Earthscan: Oxford, UK, 2011.
67. Miranda, M.; Porras, I.; Moreno, L. *The Social Impacts of Payments for Environmental Services in Costa Rica: A Quantitative Field Survey and Analysis of the Virilla Watershed*; Markets for Environmental Services: London, UK, 2003.
68. Kosoy, N.; Martinez-Tuna, M.; Muradian, R.; Martinez-Alier, J. Payments for environmental services in watersheds: Insights from a comparative study of three cases in Central America. *Ecol. Econ.* **2007**, *61*, 446–455. [CrossRef]
69. Garbach, K.; Lubell, M.; DeClerck, F.A. Payment for Ecosystem Services: The roles of positive incentives and information sharing in stimulating adoption of silvopastoral conservation practices. *Agric. Ecosyst. Environ.* **2012**, *156*, 27–36. [CrossRef]
70. Rasch, S.; Wünscher, T.; Casasola, F.; Ibrahim, M.; Storm, H. Permanence of PES and the role of social context in the Regional Integrated Silvo-pastoral Ecosystem Management Project in Costa Rica. *Ecol. Econ.* **2021**, *185*, 107027. [CrossRef]
71. ProDUS. *Diagnóstico: Plan Regulador Cantonal de Golfito*; Universidad de Costa Rica: San José, Costa Rica, 2007; p. 658.
72. TNC. *Evaluación Ecológica, Socio-Económica, Institucional del Sector de Fila Cruces, Golfito, Costa Rica*; Universidad Nacional: Heredia, Costa Rica, 2008; p. 159.
73. Höbinger, T.; Schindler, S.; Seaman, B.S.; Wrbka, T.; Weissenhofer, A. Impact of oil palm plantations on the structure of the agroforestry mosaic of La Gamba, southern Costa Rica: Potential implications for biodiversity. *Agrofor. Syst.* **2011**, *85*, 367–381. [CrossRef]
74. SINAC. Grúas II: Propuesta de ordenamiento territorial para la conservación de la biodiversidad en Costa Rica. In *Análisis de Vacíos en la Representatividad e Integridad de la Biodiversidad Terrestre*; Universidad de Costa Rica: San José, Costa Rica, 2007; p. 100.
75. Andreas, M.; Allan, A. Incorporating geology and geomorphology in land management decisions in developing countries: A case study in Southern Costa Rica. *Geomorphology* **2007**, *87*, 68–89. [CrossRef]
76. Cortés, J. The coral reefs of Golfo Dulce, Costa Rica. In *Distribution and Community Structure*; National Museum of Natural History Smithsonian Institution: Washington, WA, USA, 1990; p. 37.
77. Cortés, J. *Los Arrecifes Coralinos del Golfo Dulce, Aspectos Ecológicos*; Universidad de Costa Rica: San José, Costa Rica, 1992; p. 8.
78. Quesada, A.; Cortés, J. Los ecosistemas marinos del Pacífico sur de Costa Rica: Estado del conocimiento y perspectivas de manejo. *Rev. Biol. Trop.* **2006**, *54*, 101–145.
79. Umaña, G. *Characterization of Some Golfo Dulce Drainage, River Basin (Costa Rica)*; Universidad de Costa Rica: San José, Costa Rica, 1998; p. 11.

80. Pérez-Rubio, I.; Flores, D.; Vargas, C.; Mende, A.; Jiménez, F. Análisis comparativo de susceptibilidad de erosión y evaluación de incertidumbre en la subcuenca del Río Claro, Costa Rica. *Rev. Cienc. Ambient.* **2021**, *55*, 271–293. [CrossRef]
81. Pérez-Rubio, I.; Mende, A. Análisis espacial de susceptibilidad de erosión en una cuenca hidrográfica del trópico húmedo de Costa Rica. *Rev. Cienc. Ambient.* **2017**, *52*, 1–26. [CrossRef]
82. Holl, K.D.; Zahawi, R.A.; Cole, R.J.; Ostertag, R.; Cordell, S. Planting Seedlings in Tree Islands Versus Plantations as a Large-Scale Tropical Forest Restoration Strategy. *Restor. Ecol.* **2010**, *19*, 470–479. [CrossRef]
83. Holl, K.D. Factors Limiting Tropical Rain Forest Regeneration in Abandoned Pasture: Seed Rain, Seed Germination, Microclimate, and Soil1. *Biotropica* **1999**, *31*, 229–242. [CrossRef]
84. Cole, R.; Holl, K.; Keene, C.; Zahawi, R. Direct seeding of late-successional trees to restore tropical montane forest. *For. Ecol. Manag.* **2011**, *261*, 1590–1597. [CrossRef]
85. Holl, K.D.; Reid, J.L.; Chaves-Fallas, J.M.; Oviedo-Brenes, F.; Zahawi, R.A. Local tropical forest restoration strategies affect tree recruitment more strongly than does landscape forest cover. *J. Appl. Ecol.* **2016**, *54*, 1091–1099. [CrossRef]
86. Zahawi, R.A.; Holl, K.D.; Cole, R.J.; Reid, J.L. Testing applied nucleation as a strategy to facilitate tropical forest recovery. *J. Appl. Ecol.* **2012**, *50*, 88–96. [CrossRef]
87. Lancaster, K.T. A New Approach to Consumer Theory. *J. Political Econ.* **1966**, *74*, 132–157. [CrossRef]
88. McFadden, D. Conditional Logit Analysis of Qualitative Choice Behaviour. In *Frontiers in Econometrics*; Zarembka, P., Ed.; Academic Press: New York, NY, USA, 1974.
89. Holmes, T.P.; Adamowicz, W.L. *Attribute-Based Methods, a Primer on Nonmarket Valuation*; Springer: New York, NY, USA, 2003; pp. 171–219.
90. Cummings, R.G.; Taylor, L.O. Unbiased Value Estimates for Environmental Goods: A Cheap Talk Design for the Contingent Valuation Method. *Am. Econ. Rev.* **1999**, *89*, 649–665. [CrossRef]
91. Landry, C.E.; List, J.A. Using Ex Ante Approaches to Obtain Credible Signals for Value in Contingent Markets: Evidence from the Field. *Am. J. Agric. Econ.* **2007**, *89*, 420–429. [CrossRef]
92. Mozumder, P.; Berrens, R.P. Investigating hypothetical bias: Induced-value tests of the referendum voting mechanism with uncertainty. *Appl. Econ. Lett.* **2007**, *14*, 705–709. [CrossRef]
93. Biénabe, E.; Hearne, R.R. Public preferences for biodiversity conservation and scenic beauty within a framework of environmental services payments. *For. Policy Econ.* **2006**, *9*, 335–348. [CrossRef]
94. Lee, C.-L.; Wang, C.-H.; Sriarkarin, S. Evaluating the Public's Preferences toward Sustainable Planning under Climate and Land Use Change in Forest Parks. *Sustainability* **2019**, *11*, 3149. [CrossRef]
95. Burgess, L. Discrete Choice Experiments. Department of Mathematical Sciences, University of Technology, Sydney. Available online: http://crsu.science.uts.edu.au/choice/ (accessed on 22 April 2021).
96. Louviere, J.J. *Analyzing Individual Decision Making: Metric Conjoint Analysis*; SAGE Publications: Newbury Park, CA, USA, 1988.
97. Pearmain, D.; Swanson, J.; Kroes, E.; Bradley, M. *Stated Preference Techniques: A Guide to Practice*; Steer Davies Gleave and Hague Consulting Group: London, UK, 1991.
98. Louviere, J.J.; Hensher, D.A.; Swait, J.D. *Stated Choice Methods: Analysis and Application*; Cambridge University Press: Cambridge, UK, 2000.
99. Hausman, J.; McFadden, D. Specification Tests for the Multinomial Logit Model. *Econometrica* **1984**, *52*, 1219. [CrossRef]
100. Boxall, P.C.; Adamowicz, W.L. Understanding Heterogeneous Preferences in Random Utility Models: A Latent Class Approach. *Environ. Resour. Econ.* **2002**, *23*, 421–446. [CrossRef]
101. Revelt, D.; Train, K. Mixed Logit with Repeated Choices: Households' Choices of Appliance Efficiency Level. *Rev. Econ. Stat.* **1998**, *80*, 647–657. [CrossRef]
102. Adamowicz, W.; Boxall, P.; Williams, M.; Louviere, J. Stated Preference Approaches for Measuring Passive Use Values: Choice Experiments and Contingent Valuation. *Am. J. Agric. Econ.* **1998**, *80*, 64–75. [CrossRef]
103. Blamey, R.; Bennett, J.; Louviere, J.; Morrison, M.; Rolfe, J. A test of policy labels in environmental choice modelling studies. *Ecol. Econ.* **2000**, *32*, 269–286. [CrossRef]
104. Bujosa, A.; Riera, A.; Hicks, R.L. Combining Discrete and Continuous Representations of Preference Heterogeneity: A Latent Class Approach. *Environ. Resour. Econ.* **2010**, *47*, 477–493. [CrossRef]
105. Dissanayake, S.T.M.; Ando, A.W. Valuing Grassland Restoration: Proximity to Substitutes and Trade-offs among Conservation Attributes. *Land Econ.* **2014**, *90*, 237–259. [CrossRef]
106. Ruto, E.; Garrod, G. Investigating farmers' preferences for the design of agri-environment schemes: A choice experiment approach. *J. Environ. Plan. Manag.* **2009**, *52*, 631–647. [CrossRef]
107. Morrison, M.; Bennett, J.; Blamey, R.; Louviere, J. Choice Modeling and Tests of Benefit Transfer. *Am. J. Agric. Econ.* **2002**, *84*, 161–170. [CrossRef]
108. R Core Team. *R: A Language and Environment for Statistical Computing Computer Program, Version 3.6.1*; R Foundation for Statistical Computing: Vienna, Austria, 2019.
109. Sarrias, M.; Daziano, R. *gmnl: Multinomial Logit Models with Random Parameters: R Package Version 1.1-3*; R Foundation for Statistical Computing: Vienna, Austria, 2017.
110. Mariel, P.; Hoyos, D.; Meyerhoff, J. Stated or inferred attribute non-attendance? A simulation approach. *Econ. Agrar. Recur. Nat.* **2013**, *13*, 51–67. [CrossRef]

111. Rajmis, S.; Barkmann, J.; Marggraf, R. User community preferences for climate change mitigation and adaptation measures around Hainich National Park, Germany. *Clim. Res.* **2009**, *40*, 61–73. [CrossRef]
112. Greene, W.H.; Hensher, D.A. A latent class model for discrete choice analysis: Contrasts with mixed logit. *Transp. Res. Part B Methodol.* **2003**, *37*, 681–698. [CrossRef]
113. Scarpa, R.; Thiene, M. Destination Choice Models for Rock Climbing in the Northeastern Alps: A Latent-Class Approach Based on Intensity of Preferences. *Land Econ.* **2005**, *81*, 426–444. [CrossRef]
114. Hanemann, W.M. Discrete/continuous models of consumer demand. *Econometrica* **1984**, *52*, 541–561. [CrossRef]
115. Croissant, Y. *Estimation of Multinomial Logit Models in R: The mlogit Packages: R Package Version 0.2-2*; R Foundation for Statistical Computing: Vienna, Austria, 2012.
116. Espinosa-Goded, M.; Barreiro-Hurle, J.; Ruto, E. What Do Farmers Want from Agri-Environmental Scheme Design? A Choice Experiment Approach. *J. Agric. Econ.* **2010**, *61*, 259–273. [CrossRef]
117. Hartshorn, G.; Ferraro, P.; Spergel, B.; Sills, E. *Evaluation of the World Bank—GEF Ecomercados Project in Costa Rica*; NC State University: Raleigh, NC, USA, 2005.
118. Ortiz, E.; Borge, C.; Sage, L. *Impacto del Programa de Pago de Servicios Ambientales en Costa Rica Como Medio de Reducción de la Pobreza en Medios Rurales*; Unidad Regional de Asistencia Técnica (RUTA): San José, Costa Rica, 2003; p. 62.
119. Wünscher, T.; Engel, S.; Wunder, S. Spatial targeting of payments for environmental services: A tool for boosting conservation benefits. *Ecol. Econ.* **2008**, *65*, 822–833. [CrossRef]
120. Celentano, D.; Zahawi, R.A.; Finegan, B.; Ostertag, R.; Cole, R.J.; Holl, K.D. Litterfall Dynamics Under Different Tropical Forest Restoration Strategies in Costa Rica. *Biotropica* **2010**, *43*, 279–287. [CrossRef]
121. Cole, R.J.; Holl, K.D.; Zahawi, R.A. Seed rain under tree islands planted to restore degraded lands in a tropical agricultural landscape. *Ecol. Appl.* **2010**, *20*, 1255–1269. [CrossRef] [PubMed]
122. Wunder, S.; Engel, S.; Pagiola, S. Taking stock: A comparative analysis of payments for environmental services programs in developed and developing countries. *Ecol. Econ.* **2008**, *65*, 834–852. [CrossRef]

land

Article

Examining Linkages among Livelihood Strategies, Ecosystem Services, and Social Well-Being to Improve National Park Management

Siyuan He [1,*], Louise Gallagher [2] and Qingwen Min [1,3]

[1] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; minqw@igsnrr.ac.cn
[2] Institute for Environmental Sciences, University of Geneva, 1205 Geneva, Switzerland; louise.gallagher@unige.ch
[3] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China
* Correspondence: hesy@igsnrr.ac.cn; Tel.: +86-10-6488-9810

Abstract: This research examines perceptions of ecosystem services (ES) and social well-being in the Wuyishan National Park, China. This study analyses the importance of and linkages between them based on the impact of new designation of protected areas on this social-ecological system. Realisation of rural well-being is critical to park-people relations in populated protected areas, and effective resolution is needed to achieve positive conservation outcomes. We conducted 372 structured interviews with community members with different livelihood strategies. Key findings from the research include: (1) the importance of provisioning (e.g., tea, rice, timber) and cultural ES (e.g., local culture, eco-tourism) is related to both current livelihood necessity and future development pursuit. (2) The perceived material well-being is higher than spiritual well-being, and high social well-being is closely related to high-income groups and those that think highly of cultural services, i.e., those engaged in non-agricultural activities (e.g., tourism) and tea cultivation. (3) Cultural values are better preserved in tea and rice cultivation and tourism, but in general, they are not incorporated to improve social well-being. The results suggest that Protected area (PA) management of local communities must seek cultural valorisation for differentiated livelihood strategies for rural people's sustainable livelihood and stability of the social-ecological system.

Keywords: ecosystem services; social well-being; livelihood strategies; cultural values; community development; national park

Citation: He, S.; Gallagher, L.; Min, Q. Examining Linkages among Livelihood Strategies, Ecosystem Services, and Social Well-Being to Improve National Park Management. *Land* **2021**, *10*, 823. https://doi.org/10.3390/land10080823

Academic Editors: Mónica de Castro-Pardo, Joao C. Azevedo and Pascual Fernández

Received: 29 June 2021
Accepted: 29 July 2021
Published: 6 August 2021

1. Introduction

Ensuring the well-being of rural people in and around protected areas (PAs) is an important prerequisite for local community support to PA management and participation in the sustainable use of natural resources and biodiversity conservation [1]. In human–nature interactions, a variety of ecosystem services are produced and flow to local communities, benefiting them in financial or non-financial forms and promoting their overall well-being. However, protected areas, conservation set-asides can also involve the loss of access to natural resources, conflict over their preservation and utilisation, and unequal impacts to different resource users [2–6]. In this context, the well-being of the local rural people is becoming a critical facet for conservation practitioners and managers to understand with a social-ecological systems perspective when designing or evaluating impacts of conservation interventions [7–10].

Since the Millennium Ecosystem Assessment [11], the relationship between ecosystem services and human well-being (ES-HWB) has been widely studied around the world in an effort to foster effective governance in biodiversity conservation and sustainable development. At the cross-country level, research confirms a significant general relationship between the provision of ecosystem services and human well-being [12–14]. At a local to regional scale, various studies have revealed the nonlinear, dynamic, and diverse relationship between a variety of ecosystem services and human well-being both spatially and temporally [15–18]. However, protection and enhancement of ecosystem services is a relatively new goal for PAs in China compared to well-established biodiversity conservation priorities [19,20]. In the global conservation context, assessing human perceptions of natural capital, ecosystem services, or nature-generated benefits, have proven instrumental for designing and adapting conservation strategies for PAs, in that local communities' perception of their landscapes and management practices can directly affect the process of legitimacy for conservation governance or social acceptance, thus the stability of the social-ecological system [21–23]. Int is increasingly accepted that understanding and considering local livelihood practices and benefits, often embedded in local and traditional knowledge and interactions with ecosystems, might improve the efficacy of community participation in conservation and ultimately the resilience of the social-ecological system in PAs [5,10,24,25]. Yet, little is known about the multiple ways in which local people relate to, perceive, and value ecosystem services and related human well-being.

Past research on the relationship between ecosystem services and human well-being (ES-HWB) in China has largely focused on the comprehensive efficacy of conservation policies encompassing integrated ecology and poverty alleviation projects, ecological restoration projects, and eco-compensation programs in underdeveloped and ecologically fragile regions [26]. This is because enhancing ecosystem services and improving human well-being is a win–win target for these national and regional policies and projects [27]. For example, some policy studies of ecological poverty alleviation and ecological engineering have assessed temporal and spatial changes of ecosystem functions and services (directly and indirectly), using economic parameters to represent the objective well-being of farmers [28,29]. Other studies have identified spatial and temporal patterns of interaction between ecosystem services value and economic income well-being, revealing sustainable and unsustainable regional development modes [17,30].

Replying to criticisms of the ES approach as materially-oriented, overemphasising services that can be monetised and assuming rational behaviours (i.e., assumptions that individuals maximise their own gains without considering collective well-being), some studies have evaluated policy efficacy through analysing stakeholders' perception of ecosystem services and human well-being. For example, research analysed stakeholders' perception of the importance of ecosystem services and degree of improvement after policy implementation, assessed rural people's perception and ecosystem services dynamics and satisfaction of well-being of many aspects, revealing that human well-being can be affected by provisioning, regulating and cultural services, and the supply-demand match state [31–34]. Overally, research on the efficacy of eco-compensation mainly focuses on the changes of ecosystem functions and services before and after the implementation of the policy regarding ecological outcomes, and addressing rural livelihood dynamics as human well-being [35–38]; however, the contribution of ecosystem services enhancement to human well-being is seldom analysed with an integrated efficacy approach that fully reflects ES-HWB relationships.

While the need for integrating benefit-sharing and community participation into protected area management has been recognised [39,40], empirical evidence explaining the rural perception of ecosystem services, well-being, and their interaction remains scarce in China [18,33,34]. A small portion of research has focused on PAs or an ecosystem under certain management rules from the perspective of stakeholder perception, revealing rural people's motivation and decision-making mechanism to obtaining certain ecosystem services for well-being, thus to help policy design with effective conservation incentives. For example, studies were carried out in community sacred forest, agroecosystem and wetland to assess rural people's perception of ecosystem services and their satisfaction of current supply, identifying key factors and extending to analyse their conservation willingness [41–43].

In summary, current research on ecosystem services and human well-being mainly has a posterior perspective, focusing on policy efficacy assessment. Besides, well-being assessments are often conducted with economic indicators for objective well-being, but little is known about comprehensive well-being, especially subjective well-being which is reflective of social-cultural effects. Furthermore, livelihood strategies are more taken as an indicator of well-being, instead of a social-economic factor to represent the notion of social complexity in the idea of "community" [44], where diverse social and experiences of different groups may need context-specific approaches to the management of PAs. The end result is that accurate policy evaluations are a challenge, robust policy recommendations hard to make. There is a lack of baseline research to support and inspire new policy design.

A careful understanding of the linkages between ES and human well-being may offer insights that can improve the design of PA conservation interventions, and the governance processes needed to achieve positive outcomes of nature conservation, livelihood development, and well-being improvement [20,45]. During China's optimisation of protected area systems and national park establishment, securing ecosystem services for local well-being as well is becoming a common understanding which urges empirical research into PA's social-ecological systems [19,20].

This study aimed to address this gap by delineating triple elements of PA's social-ecological system, i.e., livelihood strategies, ecosystem services, and human well-being, among the rural residents living within and around the national park pilot of Mt. Wuyi (Wuyishan), China. Our work was guided by the following four objectives:

1. To examine perceptions of: (i) ecosystem services importance; (ii) traditional culture inheritance; (iii) material and spiritual well-being;
2. To assess a series of demographic, industrial, and cultural factors that describe the respondents and are expected to explain human well-being perceptions, and;
3. To determine how livelihood strategies, ecosystem services, and human well-being intertwine;
4. To provide insights about the implication of the results for rural livelihood sustainability under the management of PAs.

We statistically tested assumptions that are derived from the first three objectives, and then discussed how the dynamic interplay among livelihood, ES, and human well-being can be harnessed to enhance governance for conservation and rural livelihood development.

2. Material and Methods

2.1. Study Area

This research was conducted in the Wuyishan National Park pilot located in the northwest of Fujian Province in Southeast China (Figure 1). It has a total area of 1001.41 km^2 aimed mainly at conserving the subtropical forest ecosystem. At present, there are about 3000 people living inside of the park and about 20,000 people adjacent to the park boundary, belonging to 29 villages. The major income of 80% of these rural households is from tea production in the lower slope of forest and spotted rocky hills, followed by bamboo industry, migrant labour income, and other ways of life. Tea planting has a history of thousands of years to have started in the Song Dynasty and flourished in Ming and Qing Dynasties. In the recent 40 years of human-nature interaction, implementation of conservation policies represented by the designation of the national nature reserve (1979), national scenic spots (1983), and world heritage site (1998) has, on the one hand, fully recognised the biological relevance and ecosystem service value, and deeply impacted rural people's land management and attitude of nature conservation, thus affected their perception of ecosystems, on the other hand [5].

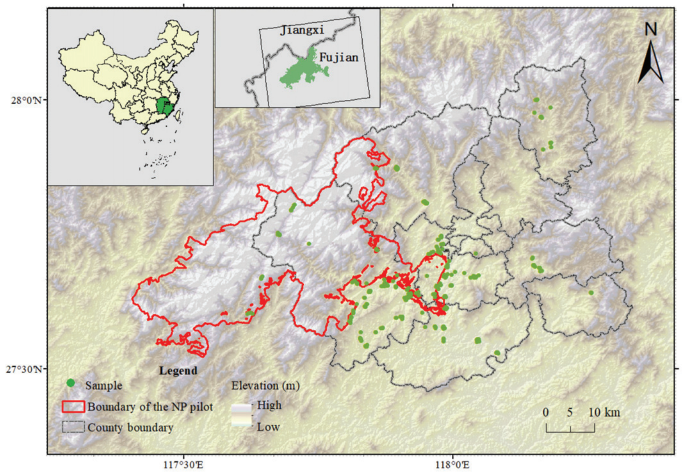


Figure 1. The map of the city of Wuyishan and the location of the National Park Pilot.

Therefore, this case is typical for this social-ecological approach with its consistent and diverse conservation interventions to reflect a context-based and case-specific condition, and the methods and results can inform a wider set of conditions where small scale rural communities are engaged in conservation interventions, both under policy reform as China, and other conditions.

2.2. Data Collection

We hypothesised that in Wuyishan, where great natural and cultural value exists, local rural residents highly depend on these values to form livelihood strategies (building on [5,46]), and certain traditional knowledge, technologies, and belief have been recognised and inherited (building on [5]). We expected that households with different livelihood strategies would perceive ecosystem services and well-being differently and relevant to livelihood activities. Finally, we expected that three groups of factors, including household demographic characteristics, industrial characteristics, and cultural inheritance, would affect different residents' perceptions of well-being.

A structured questionnaire was used in the study by trained volunteers to conduct interviews with selected households. Sample selection is based on the population of administrative villages, livelihood strategies, and family income level. Households engaged in different livelihoods as a major income were selected according to both population data and the introduction of the administrative village leader, who had very good knowledge of family income distribution in the villages. Snowball sampling was also used as a supplement to lead recommendations to ensure full coverage of households of different livelihoods and income levels. In total, 372 households were interviewed. The questionnaire had four parts. The first part is basic information, those including demographic information of the interviewee such as gender, age, head of household or not and educational level; household information such as length of residence, annual household income, family population, size of the labour force, number of migrant workers, ratios of income from production, wages and welfare; livelihood features such as major livelihood activity of income, and two measures of the production chain: the source of related techniques and product destination.

The second part is a list of 15 ecosystem services (ESs) of the Wuyishan national park pilot for interviewees to select and rank. These ecosystem services were selected from previous studies [5], preliminary fieldwork, and expert interviews. They were divided into provisioning, regulating, and cultural services based on the Millennium Ecosystem Assessment [11], and illustration is provided to help to understand each of the ecosystem services. Interviewees were asked to choose five of the most important ESs and score them from 5 to 1 according to their importance. Those not chosen were given 0. For each ES, their weight score is calculated according to $\sum_{i=1}^{n=6} S_i \times f_i$, where S_i is a single score from 0 to 5 and f_i is the frequency of that score given by all the interviewees.

The third part is a cultural inheritance evaluation form including two specific descriptions. The first is the degree of understanding and mastering of traditional knowledge and technology and the second is the degree of understanding and practicing customs. A five-point Likert scale was used for the interviewee to describe the degree of cultural inheritance as 1: very little, 2: a little, 3: average, 4: much, 5: very much. A score of 1 to 5 was also given to the degree from the lowest to the highest.

The last part is a social well-being evaluation form. Usually, human well-being is regarded as the antonym of poverty, and it covers a spectrum from basic material needs to elements that are required to meet high-quality living standards, as well as elements that matter to personal development, such as freedom, choice, health, good social relations, security, etc. [11,47]. Thus, well-being is a comprehensive evaluation of people's living in certain living context and moral values [11]. A strong positive relationship exists between the sense of happiness and richness before income reaches a certain level [48], therefore, income-related indices are often used in well-being evaluation in less-developed regions as an objective indicator to represent the local priority for basic physiological and security needs. As many policies aim to reach multiple objectives in promoting human well-being, many studies focus on human perception of social, economic, cultural, and environmental outcomes to form subjective indicators to represent comprehensive happiness. The concept of social well-being, or the three-dimensional well-being is also widely accepted in social science and development scholarship [49]. Material well-being is grounded in tangible terms (e.g., physical resources, financial resources, assets, shelter), relational well-being includes social relations, access to public goods, personal relationships, and attitudes in life, and subjective well-being encloses intangible terms of individual perceptions (e.g., of material, social, and human position), cultural values (e.g., ideologies, beliefs), aspirations, and happiness. Considering the importance of income as an objective indicator and the essential material well-being for subsistence, and comprehensiveness of subjective indicators, as well as research feasibility, this research borrowed the concept of social well-being, and reduced multiple elements of human well-being in the MEA to two major aspects, material well-being representing livelihood security, encompassing physical aspects such as basic material for life, health and security similar to the definition in social well-being, and spiritual well-being concerning mental fulfillment, encompassing social and cultural aspects such as good social relations and their value base, and freedom and choice, thus a combination of relational and subjective well-being. These meanings were explained to interviewees to evaluate two descriptions of "I am satisfied with my material living standard" and "I feel fulfilled in my daily life" by a five-point Likert scale of 1: strongly disagree, 2: disagree, 3: neutral, 4: agree, 5: strongly agree. A score of 1 to 5 was also given to the answer from "strongly disagree" to "strongly agree".

2.3. Data Analysis

The data were organised and analysed in SPSS (Statistical Product and Service Solutions, Version 22). Descriptive statistics were used to analyse the basic information and all the evaluation data. Nonparametric correlation analysis was used to detect the trade-offs and synergies of perceived important ecosystem services and the relation between ecosystem services and well-being perception.

One-Way ANOVA was used to analyse farmers' understanding of traditions and their perception of well-being regarding their different livelihood activities. First, the homogeneity of data variance was detected. Data of material well-being had homogeneity of variance, and the least significant difference method (LSD) was used to analyse the significance of differences among livelihood groups. For the other three series of data without homogeneity of variance, Kruskal–Wallis test, a nonparametric method was used.

The data of well-being perception and its potential impact factors were mainly discrete data of ordered and unordered categorical variables, which were not suitable for ordinary linear regression. Therefore, the best scale regression (CATREG) was used. In this model, both dependent and independent variables can be categorical variables. The original variables were transformed using nonlinear mothed and the model iteratively sought the best fit for an optimised linear equation model. Demographic characteristics (X_1-X_8, X_{10}-X_{12}), industrial characteristics (X_9, X_{13}-X_{14}), and cultural inheritance (X_{15}-X_{16}) were taken as three major groups of explanatory variables, and their impact directions were hypothesised and tested with CATREG (Table 1).

Table 1. Variables and the prediction of impacts of explanatory variables.

Variables	Type of Variables	Assignment	Direction
Y Perception of Well-Being	Ordered Categorical	1: strongly disagree, 2: disagree, 3: neutral, 4: agree, 5: strongly agree	
X_1 Gender	Unordered Categorical	1: Male; 2: Female	?
X_2 Age	Numerical	Real age	?
X_3 Education	Ordered categorical	1: Primary; 2: Junior; 3: Senior; 4: College; 5: Graduate	?
X_4 length of residence	Numerical	Number of years for the household to reside	?
X_5 Family population	Numerical	Number of registered people in the household	-
X_6 Ratio of labour force	Numerical	The ratio of labour force to the family population	+
X_7 Ratio of migrant workers	Numerical	The ratio of people working outside of hometown to the family population	+
X_8 Annual household income	Ordered categorical	1: <5000; 2: 5000–10,000; 3: 10,000–50,000; 4: 50,000–100,000; 5: 100,000–500,000; 6: 500,0000–1,000,000; 7: >1,000,000	+
X_9 Major livelihood activity	Unordered categorical	1: Tea cultivation; 2: Rice cultivation; 3: Forestry; 4: other agricultural activities; 5: Tourism operation; 6: Other non-agricultural business	?
X_{10} Ratio of income from production/operation	Numerical	Ratio of household income from production and operation to the total income	+
X_{11} Ratio of income from wages	Numerical	Ratio of fixed wage from government sectors, institutions or companies to the total income	+
X_{12} Ratio of income from welfare	Numerical	Ratio of social security income such as pension to the total income	-
X_{13} Source of technologies for livelihood	Unordered categorical	1: Family legacy; 2: Neighbor communication; 3: Government training; 4: other sources; 5: no technology needed	?
X_{14} Product destination	Unordered categorical	1: For family consumption; 2: For sale; 3: Both; 4: No material product	?
X_{15} Degree of understanding and mastering of traditional knowledge and technology	Ordered categorical	1: very little, 2: a little, 3: average, 4: much, 5: very much.	+
X_{16} Degree of understanding and practicing customs	Ordered categorical	1: very little, 2: a little, 3: average, 4: much, 5: very much.	+

3. Results

3.1. Demographic and Livelihood Features

Demographic and livelihood features of respondents are list in Table 2. The majority of interviewees were male and more than 70% of the respondents were household heads. People aged from 40 to 59 and having finished junior high school and below took part the most in the age and educational level groups. Nearly 75% of the respondents have lived in local communities for at least 40 years. More than half of the families were mainly engaged in tea planting, followed by rice planting, forestry, other agricultural and non-agricultural industries. The largest family size was five people, and 60% of families had at least half of their members as the main labour force. Less than 30% of families had migrant workers. 43% of families had an annual income between 100,000 and 500,000 yuan (ca. 15,000 and 75,000 dollars).

Table 2. Demographic characteristics of respondents and their households.

Factor	Variables	Sample Size	%	Factor	Variables	Sample Size	%
Gender	1 Male	308	82.80	Family population	1 <3	62	16.67
	2 Female	64	17.20		2 4–6	248	66.67
Household head	1 Yes	275	73.92		3 7–9	47	12.63
	2 No	97	26.08		4 >10	15	4.03
Age	1 <18	0	0	Ratio of labour force	1 <1/3	60	16.13
	2 18–24	3	0.81		2 1/3–1/2	89	23.92
	3 25–39	52	13.98		3 1/2–2/3	130	34.95
	4 40–59	251	67.47		4 >2/3	93	25.00
	5 >60	66	17.74	Ratio of migrant workers	1 0	276	74.19
Education	1 Primary	110	29.57		2 0.1–0.3	60	16.13
	2 Junior	181	48.66		3 0.3–0.5	25	6.72
	3 Senior	63	16.94		4 >0.5	11	2.96
	4 College	16	4.30	Annual household income	1<5000	2	0.54
	5 Graduate	1	0.27		2 5000–10,000	8	2.15
Length of Residence	1 <20	18	4.84		3 10,000–50,000	81	21.77
	2 20–30	27	7.26		4 50,000–100,000	69	18.55
	3 30–40	49	13.17		5 100,000–500,000	161	43.28
	4 40–50	121	32.53		6 500,0000–1,000,000	23	6.18
	5 >50	157	42.20		7 >1,000,000	28	7.53
Major livelihood activity	1 Tea cultivation;	217	58.33				
	2 Rice cultivation	69	18.55				
	3 Forestry	13	3.49				
	4 Other agricultural activities	24	6.45				
	5 Tourism management	23	6.18				
	6 Other non-agricultural business	26	6.99				
				Total sample		372	

There were some differences in demographic features among households with different livelihood strategies (Figure 2). The proportion of households living more than 40 years locally was higher in households engaged in agriculture and forestry than those engaged in non-agricultural activities. A big family with more than 10 members only existed in tea and rice cultivation families. Households engaged in forestry tended to have a lower ratio of workforce, while those engaged in other agricultural activities had a higher proportion of migrant workers.

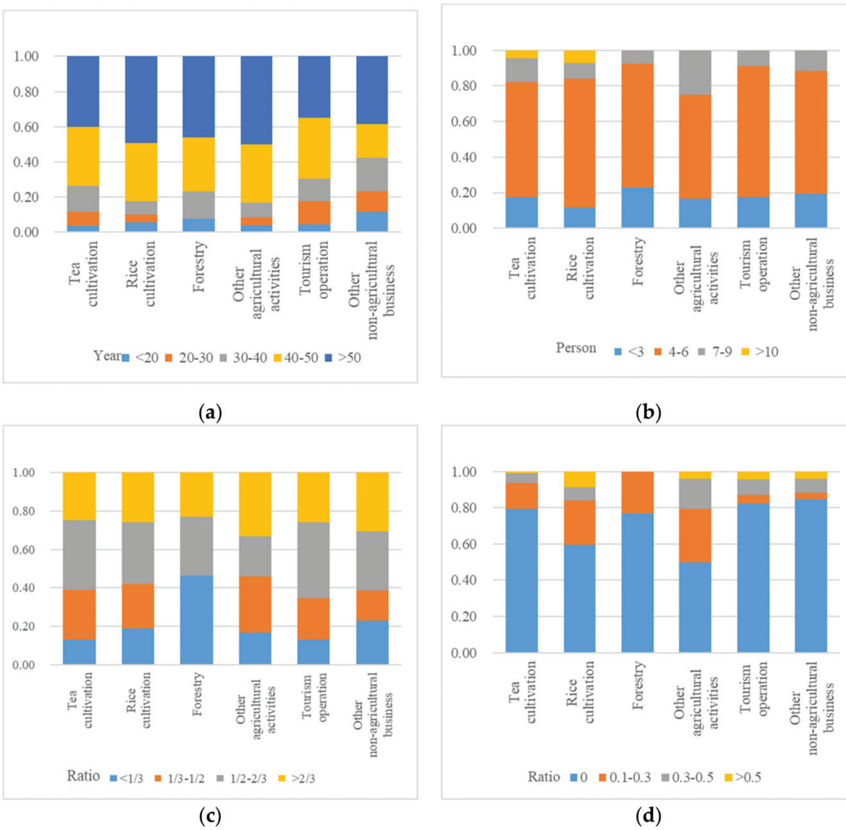
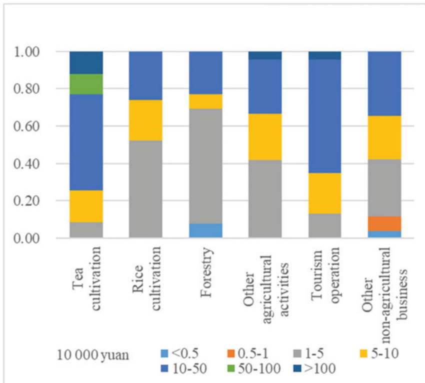
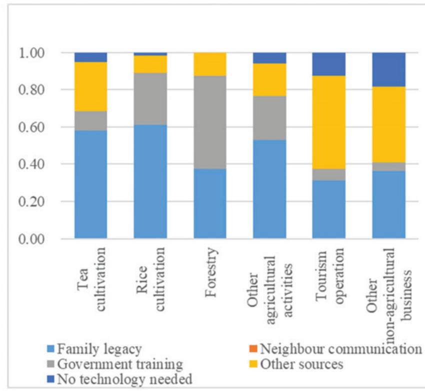


Figure 2. Distribution of some features of households engaged in different livelihood activities. Columns show the proportion of each category for the feature:length of residence (**a**), family population, (**b**) labour conditions: labour ratio (**c**), migrant worker ratio (**d**).

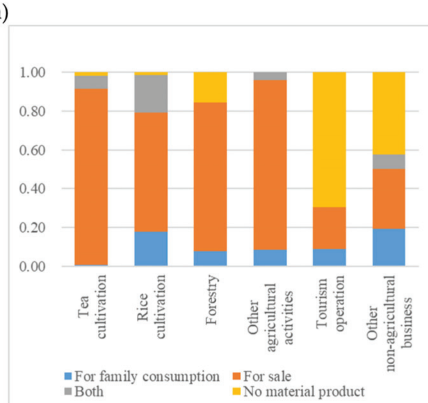
The annual income and features of the production chain reflected by technology sources and product destination also differed among families with different livelihoods (Figure 3). All the agro/forestry-related families except tea farmers tended to have a low- and middle-income of less than 50,000 yuan, while tea and non-agricultural activities seemed to raise more households to middle-and high-income families of more than 100,000 yuan a year. From the perspective of technology sources, family inheritance and neighbourhood communication were taken as the main sources, while households engaged in non-agricultural industries had a much higher proportion in "other" sources. As for the product destination, only rice cultivation families had a slightly higher proportion of self-consumption.



(a)



(b)



(c)

Figure 3. Annual income and two industrial features of different livelihood activities. Columns show the proportion of each category for the feature: annual household income (**a**), technology source (**b**), and product destination (**c**).

3.2. Assessment of Ecosystem Services among Households with Different Livelihoods

In general, the perceived importance of ecosystem services by all the rural households presented trade-offs (Figure 4), i.e., one ES was important, while the other was not when there is a significant negative correlation between the weighted scores of ES importance as perceived. Trade-off existed between provisioning services (except for tea or apiculture) and most cultural services (except for scientific research or environmental education), provisioning services and some regulating services, and between regulating services and most cultural services (except for scientific research). Synergies, which means that interviewees like or dislike two or more ESs at the same time when a significant positive correlation emerges between two weighted scores of ES importance, existed within provisioning services between timber and apiculture/non-timber forest products (NTFP), between provisioning services (rice) and regulating services (soil regulation), and within regulating services between soil regulation and climate regulation.

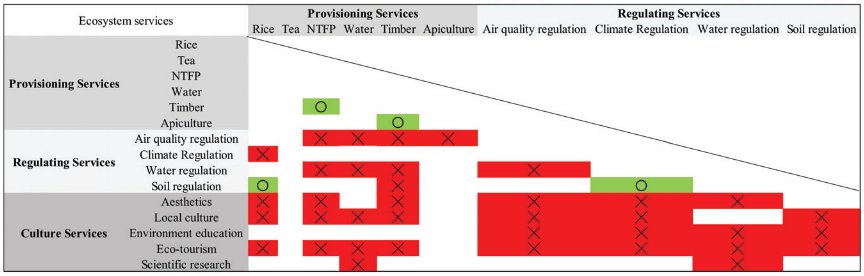


Figure 4. Significant trade-off and synergy of the perceived importance of ecosystem services.

In general, an accumulated score of perceived importance of ecosystem services by all the groups showed that freshwater, eco-tourism, local culture, air quality regulation, and tea ranked in the top five, while scientific research ranked the last as perceived by all the respondents from different ways of life (Figure 5). The coefficient of variation of single scores showed that rural people's assessment of the importance of tea and freshwater was highly convergent (CV < 0.15), and that of eco-tourism, water regulation, air quality regulation, and climate regulation was also similar (CV < 0.36) among respondents, regardless of livelihood strategies.

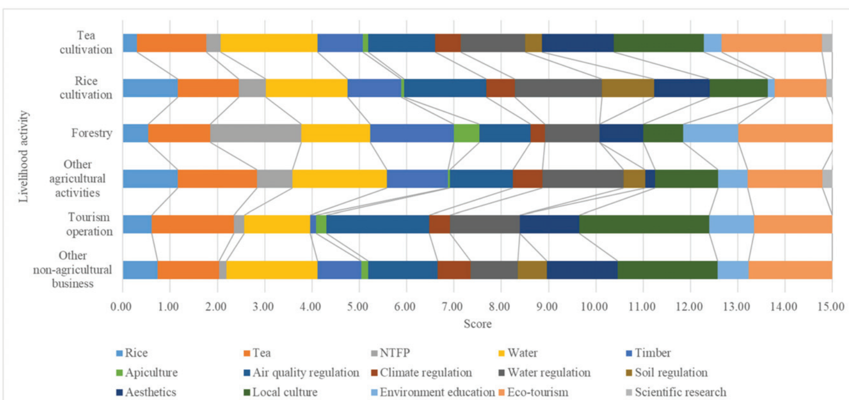


Figure 5. Importance of ecosystem services assessed by households of different livelihood strategies.

Livelihood strategies affected people's assessment of ecosystem services. Respondents engaged in different livelihood activities prioritised different ESs. Except for freshwater, the absolute high importance was given to tea, rice, NTFP, and timber among all the provisioning services, respectively, for those engaged in tea cultivation, rice cultivation, and forestry. For those taking other agricultural activities, tea, rice, and timber are also important. For those engaged with non-agricultural activities, the absolute importance of provisioning services was relatively low, while local culture and eco-tourism of cultural services were perceived mostly important in the absolute score.

Regulating services showed relative importance within people taking on different livelihood activities. Air quality regulation was highly valued by people engaged in tourism operation, and water regulation was relatively important to all the agricultural-related groups. Soil regulation was the most important to rice production families.

Some cultural services also showed relative importance among different groups. Aesthetics was supposed very important to people engaged in tea cultivation and non-agricultural activities, while environmental education was relatively important in the eye of people engaged in forestry.

Finally, there were both similarities and differences in the perception among people engaged in different livelihood activities. Correlation analysis showed that the most significant similarity in perception exists between tea farmers and people taking non-agricultural activities (0.947, 0.767), paddy farmers and other farmers (0.754), tourism operators, and those managing other non-agricultural businesses (0.827). For the first pairs, the similarity mainly existed in their perception of the importance of regulating and cultural services. For the second pair, provisioning services. For the third pair, cultural services. While the difference in perception mainly existed between people engaged in forestry and other groups except those engaged in agriculture other than tea and rice cultivation.

3.3. Well-Being Perception of Households Engaged in Different Livelihoods

Rural people benefit from ecosystem services in terms of types, quantity, and quality, thus obtaining well-being, including basic material for a good life, health, good social relations, security, and freedom and choice. A simplified perception evaluation of material and spiritual well-being showed that people with different livelihood strategies perceived well-being differently (Figure 6). In general, satisfaction with material well-being was higher than that of spiritual well-being. Specifically, satisfaction with material and spiritual well-being changed proportionally among people engaged in all kinds of agricultural activities (Figure 6a). Non-agriculture-related people had a much higher satisfaction of material well-being. People engaged in forestry perceived a relatively higher satisfaction of spiritual well-being; however, their satisfaction of material well-being is below an average score of 3 (Figure 6b). The highest satisfaction of material well-being existed in people engaged in all the non-agricultural activities. This difference was significant among people ($F = 8.906$, $p < 0.001$), mainly between forestry and all the other livelihoods, and between rice cultivation and groups of all the non-agricultural activities and tea cultivation. Satisfaction with spiritual well-being scored no more than the average of 3 among all the people (Figure 6c). Relatively speaking, it was the lowest for rice cultivation people and highest for tourism operation people. The between-group difference was also significant, representing mainly by the difference between rice cultivation and the two groups of tea cultivation and tourism operation, and between non-agricultural activities and two groups of tea cultivation and tourism operation.

Spearman's correlation analysis showed that the assessment of the importance of ecosystem services was related to the perception of social well-being. The higher the perceived importance of rice and timber in the provisioning services, the lower the satisfaction of material well-being ($p < 0.01$). The higher the perceived importance of local culture and scientific research, the higher the satisfaction of material well-being ($p < 0.05$). Those taking apiculture in provisioning services as important tended to have high satisfaction of spiritual well-being, while a negative correlation existed between soil regulation and spiritual well-being. Taking the two aspects of well-being as a whole, perception of the importance of rice and tea significantly affected social well-being in a negative and positive way, respectively. Regulating services did not affect social well-being. The perceived high importance of eco-tourism in culture services also significantly resulted in better social well-being.

Considering different livelihoods, people engaged in all the non-agricultural activities thought highly of local culture and also were much satisfied with material well-being. Those managing tea plantations and forestry highly valued eco-tourism and had relatively high satisfaction of spiritual well-being.

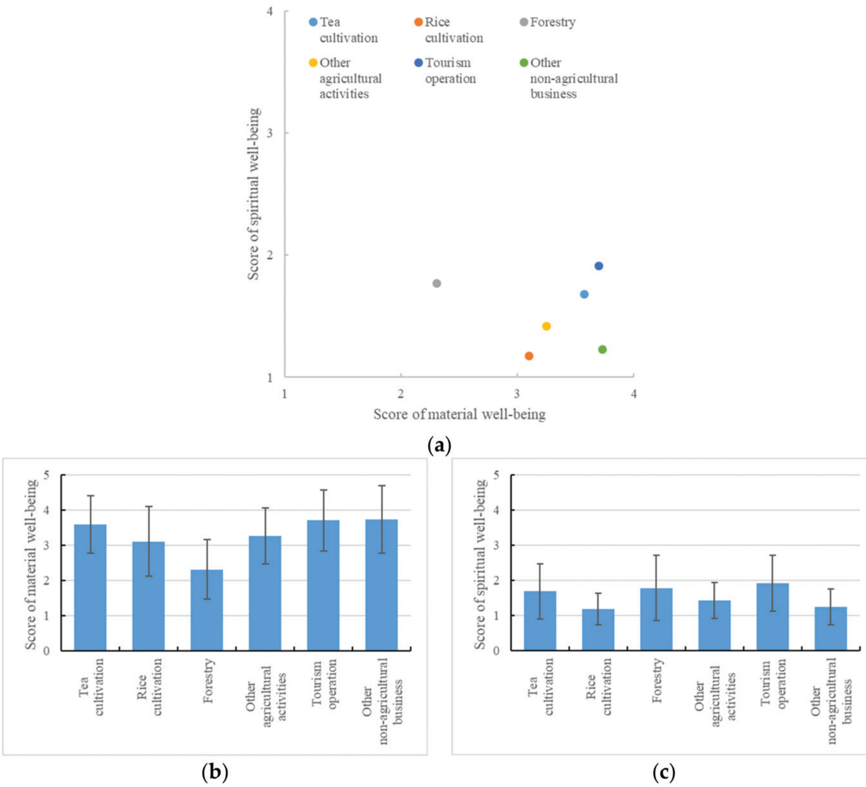


Figure 6. Perception of well-being among households of different livelihood strategies. The relationship between material well-being and spiritual well-being (**a**); scores of material well-being (**b**); scores of spiritual well-being (**c**).

3.4. Cultural Inheritance Affected by Households Engaged in Different Livelihoods

Cultural inheritance evaluation from the degree of understanding and mastering of traditional knowledge and technology and the degree of understanding and practicing customs showed that most of the respondents thought that their understanding and mastering of traditional culture was rather weak (Figure 7). Those engaged in tourism operations and rice cultivation had a relatively high mastery of traditional knowledge and technology, and those carrying out other non-agricultural activities mastered the least. Traditional customs were relatively better understood and practiced by people engaged in tourism operation and tea cultivation, and the least understood or practiced by people taking all the other agricultural and forestry activities. The degree of mastering of the two factors was consistent in tea farmers and tourism operation families. The degree of mastering of knowledge and technology was higher than that of customs for people taking all the other agricultural and forestry activities, and the opposite was true for people taking non-agricultural activities.

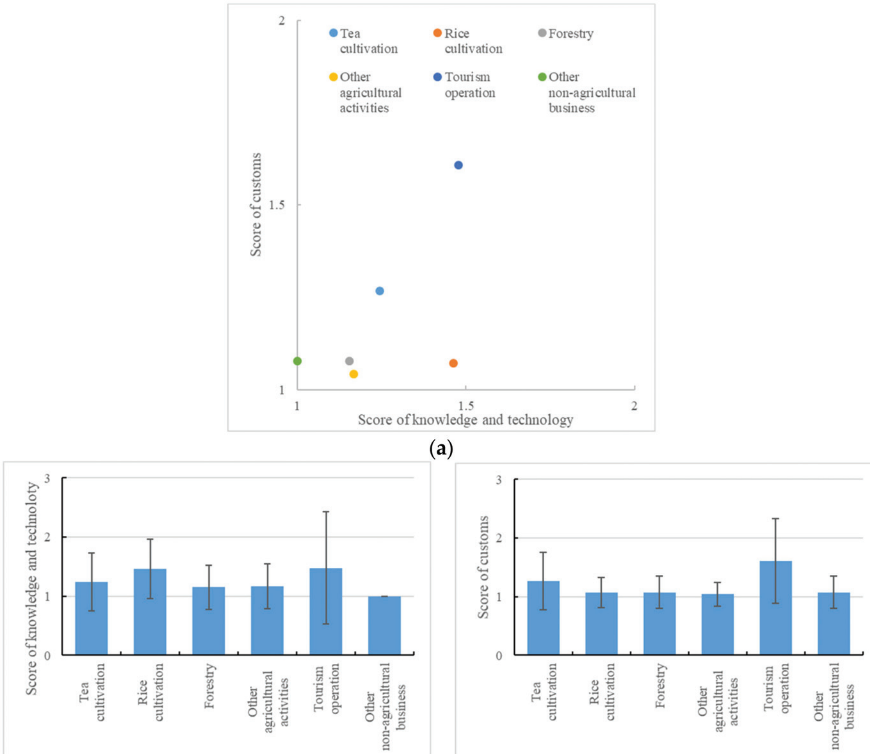


Figure 7. Recognition of traditional culture among households of different livelihood strategies. The relationship between the two factors of cultural inheritance (**a**); understanding and mastering traditional knowledge and technology (**b**); understanding and practicing customs (**c**).

Although the degree of cultural inheritance was generally low, the difference among livelihood activities was significant ($p < 0.001$). The difference in mastering traditional knowledge and technology was mainly between the respondents engaged in rice cultivation and other non-agricultural operation (Figure 7b). The difference in the understanding and practice of customs mainly existed between people engaged in tourism operations and other livelihoods (Figure 7c).

3.5. Well-Being Perception Affected by Demographic, Livelihood, and Cultural Inheritance

Household demographic characteristics, industrial characteristics, and cultural inheritance were all taken as impacting factors on the perception of well-being. After all the variables were analysed using the optimal scaling regression, insignificant variables and those incurring collinearity were eliminated or adjusted, resulted in two interpretation models. In both models, culture inheritance was not considered significant in affecting rural people's perception of well-being (Tables 3 and 4).

Table 3. Model parameters to predict impacts on material well-being.

Variable	Coefficient	Sig.	Importance
Livelihood activity	0.301	0.000	0.372
Ratio of income from welfare	−0.227	0.081	0.261
Annual household income	0.171	0.002	0.219
Product destination	0.185	0.024	0.114
Source of technologies for livelihood	0.102	0.012	0.034

Table 4. Model parameters to predict impacts on spiritual well-being.

Variable	Coefficient	Sig.	Importance
Livelihood activity	0.322	0.000	0.590
Annual household income	0.138	0.000	0.173
Ratio of income from welfare	0.141	0.003	0.105
Source of technologies for livelihood	0.119	0.000	0.081
Product destination	0.117	0.002	0.051

For both the material and spiritual well-being perception, demographic factors including the annual household income and the proportion of welfare income had a significant impact. Industrial characteristics, including technology source, the product destination, and livelihood strategies, all had significant influence. Based on the standardised coefficient and importance value, livelihood strategy was the most important variable in both models. The proportion of welfare income was secondly important to impact the perception of material well-being and so was annual household income to impact the perception of spiritual well-being.

4. Discussion

While ES and rural economic development are widely studied in terms of conservation policy efficacy [30], there is a need for studies on the interplay among livelihood activities, ES, and human well-being in protected areas under construction to inform decision-makers and conservation practitioners. This study highlights well-being facets based on perceptions that emerged during in-person interviews with community members. The results suggest that the perception of ecosystem services and well-being of rural people are strongly affected by the differences between livelihood strategies and the social-ecological context realities, and illustrate the complex role of cultural elements in experiencing and assessing these differences. This is significant because cultural values are commonly recognised as important in ES researches but they are often disconnected from well-being measures of both material and spiritual varieties in previous analyses.

The results of the assessment of the importance of diverse ecosystem services in the Wuyishan area reveals two key points. First, rural people's recognition of ecosystem services is closely related to their livelihood activities (Figure 8). They attach much value to natural capital, natural processes, and cultural capital on which their livelihoods depend, especially provisioning and cultural services. This is similar to previous research that local residents pay more attention to primary ecosystem services that can be directly enjoyed [4,50,51]. It is expected that direct provisioning services were important for subsistence, but the results also showed that some regulating services, which are critical elements supporting agricultural systems, were also identified, indicating that local people perceive their surroundings as a whole. This strong dependence of community livelihood on the types and conditions of local resources reflects a current livelihood situation. By contrast, the second point is that rural people's assessment gives a hint to their expectation of future livelihood in this specific social-ecological context. In Wuyishan area, local residents thought highly of some cultural services which have potentially added values but at the moment not directly related to the current livelihood (Figure 8). Cultural services which were prioritised regardless of livelihood strategies, such as eco-tourism by forestry related people, can be explained from two aspects. On the one hand, Wuyishan area is always supposed to be a region with rich traditional cultural resources that are well preserved as a cultural heritage site. Many community members have a place-based sense of locality that informs their identity, which is a vital component in the perception of cultural services [4,5,52]. This cultural inheritance is partly reflected in the decades of residence time, the low proportion of migrant workers, and the confirmation of technology with local origins. The importance of these features is also verified in some cultural landscapes [42,53,54]. On the other hand, agricultural and forestry practitioners who depend on material output seek higher added-value industrial activities under PA management. This trend of ecological and cultural valorisation in protected area is becoming common [55–57] and is also hinted by the results that middle-and high-income families that tend to engage in tourism operating. Moreover, tea farmers and tourism operators prioritised eco-tourism and tea, respectively, indicating their expectation of livelihood diversification based on the combination of provisioning and culture services, which can be conservation-compatible. This type of association is supposed to be a typical ES bundle that leads to integrated social well-being [44].

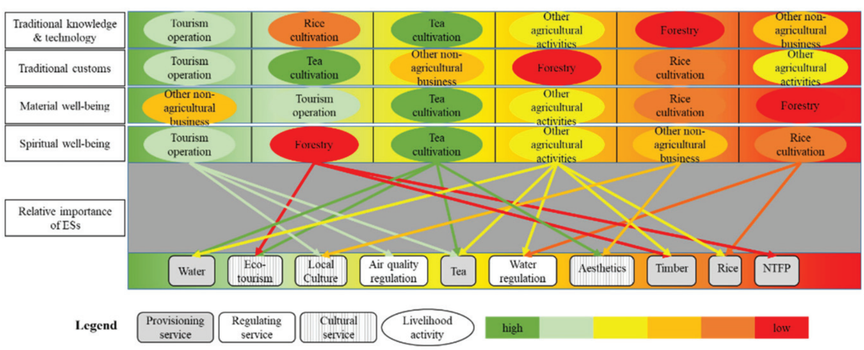


Figure 8. Illustration of the linkages among cultural inheritance, livelihood strategies, ecosystem services, and social well-being. The spectrum from green to red represents the decreasing value of certain variables. The colourful oval represents livelihood activity with certain average incomes illustrated by the colour from the spectrum. The relative importance of the 10 ESs ordered by their scores are illustrated with arrow lines with respect to livelihood activities.

Rural people's perception of well-being showed an imbalance, in that their satisfaction of material well-being was much stronger than that of spiritual well-being, which is similar to the research in another mountainous area of China [33]. However, contrary to the proposed hypothesis, that the rich traditional cultural value of Wuyishan is emphasised in the literature and discussed in the general context, was not really or fully inherited by rural people. Both traditional knowledge/technology and customs were not well understood or practiced. Only in rice and tea cultivation and tourism management were some traditions passed on. The loss of cultural heritage may affect the perception of spiritual well-being [33], but it also shows that cultural changes are taking place rapidly and continuously, and the protection of cultural heritage and cultural self-confidence in protected areas is becoming a problem faced by rural communities. It is found that people engaged in tourism operations had higher spiritual satisfaction and they said that this way of life brings them to the front of a wide range of people and opens their eyes to the outside world. They get much pleasure through communication and information exchange. At present, although cultural valorisation is partly realised, such as in the production of tea with geographical certification, for other traditional agricultural and forestry products, the liquidity of the attached ecological and cultural value is still low. The results reveal that community members with a stronger sense of material well-being were engaged in non-agricultural operations or tea cultivation, all with higher income benefited from cultural valorisation.

Contrary to the hypothesis, culture inheritance was not a significant factor affecting well-being perception; however, the current models have weak explanatory power indicating that the measurement of both the cultural inheritance and well-being may be simplified. Research shows that cultural inheritance helps maintain landscape, functions, and products of a traditional agricultural system [58,59]. The perception of cultural services also confirms the influence of the social-ecological context on the recognition of intangible values. Thus, it is necessary to further explore the culture's role in affecting human well-being in protected areas. The research showed that the material well-being and spiritual well-being of the residents in Wuyishan area are closely related to livelihood strategies and industrial characteristics. This reveals that on the one hand, there may be a weakening of satisfaction of spiritual well-being due to lack of cultural consciousness; on the other hand, there is not only strengthening of satisfaction of material well-being through economic benefit, but also high spiritual well-being brought by the stability of livelihood ensured by income, technology, market conditions, etc. (Table 4). The overall stability of a social-ecological system is affected by resource users' behaviours under policy changes [60,61]. It is obvious that livelihood strategies affect rural people's assessment of ecosystem services and well-being, and these judgements of the human–nature relations will influence the behavior choice of community residents, thus finally leading to a new protected area–community people relationships. To be effective in the long-term, governance of national parks must understand the bundle of tangible and intangible values, and find a solution to boost them for material and spiritual well-being. In our case, those with forestry and other agricultural activities should be given additional attention to help get access to cultural resources and secure crucial livelihood resources. Other community members included, a value-adding process starting from conservation of cultural values may help in the long-term nature conservation as well as cultural inheritance.

Insights from this research lead to three points that could help build a healthy park-people relation through the maintenance of sustainable and fair livelihood development. (1) Survey and restoration of traditional culture are necessary. A better understanding of traditional culture, higher income and, a higher degree of perceived well-being by people engaged in tourism operation and tea cultivation indicate that traditional culture can bring higher economic added value under certain conditions. Identifying cultural values conforms to the current recognition and expectation of rural livelihood by local people. This is especially helpful for traditional agricultural and forestry practitioners to achieve the multi-functionality of land use to increase income, and to protect and inherit local culture at the same time. (2) Traditional agricultural systems should be protected, activated, and utilised. Rice cultivation families had relatively high mastering of traditional knowledge and skills, low income, a high proportion of migrant workers, and the lowest satisfaction of well-being, making them the most unstable group in the social-ecological system. Therefore, rice paddies as a conservation-compatible livelihood activity is yet to achieve lucrative and sustainable income to support nature conservation. (3) Community perception and preference should be respected and coordinated to protected area management. Despite the variety of ecosystem services taken as important, general trade-offs occur between provisioning and other services. This dichotomy of material benefit and other benefits hinders rural people from fully understanding the realisation of human well-being from both the natural and cultural capital. Therefore, from the perspective of community capacity building, rural people must search for the possibility of transforming ecological and cultural values into economic values.

5. Conclusions

This study provides qualitative and quantitative evidence that local people living near PAs have vastly different perceptions regarding the provision of ESs and well-being. In this typical social-ecological system, ecosystems provide a variety of ecosystem services for rural people for a very long time to form different livelihood strategies. At the same time, traditional culture is supposed to pass on to secure the sustainability of livelihoods.

The qualitative analysis shows that local people perceive several different ecosystem services as important benefits from Wuyishan national park, and the similarity and difference in perceptions across the sample related to their dependence on natural capital for current livelihood and also to their expectations of higher value-added products in future livelihood development. Our results call for increased attention to cultural services and their intangible values because they are widely recognised by natural resource-dependent people and suggest ways in which incentives could be designed for the improved valorisation of cultural values.

Our study demonstrates that people's satisfaction with material well-being is higher than that of spiritual well-being where livelihood activities depend on ESs. People who value provisioning services tend to have lower satisfaction of well-being; those who value cultural services feel the opposite. Our study further indicates that rural people's inheritance of traditional knowledge, technology, and customs is not enough to directly impact on well-being perception. By contrast, prominent factors such as livelihood activities, household income conditions, and characteristics of the production chain have a significant effect. This result raises the further research necessity of understanding whether and how traditional culture matters to rural livelihood in terms of maintaining profitable, productive systems under PA management. Interestingly, tea as a provisioning service tends to bring high satisfaction of both material and spiritual well-being. So does eco-tourism. These results suggest interesting future research avenues on the possibility and methods of realising improvements in both material values and value of cultural services as embedded through agricultural products and tourism services.

Finally, we suggest that ecosystem services and rural people's well-being are important indicators for both formulating protected area management policies and evaluating its management effects. Satisfying diverse local needs of ecosystem services and securing human well-being are prerequisites for different local groups to accept and participate in nature conservation and also one of the goals of national park management. From the perspective of the social-ecological system, the benefit perception and sharing mechanism of the local community affects the robustness and resilience of the system through affecting their resource management behaviours, thus determines the sustainable utilisation of natural resources and the effective protection of ecological values.

Author Contributions: Conceptualisation and methodology, S.H. and L.G.; investigation, data collection and writing, S.H. and Q.M.; review and editing, S.H., L.G. and Q.M.; funding acquisition, L.G. and S.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Natural Science Foundation of China (42001194) and Luc Hoffmann Institute Fellowship.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Acknowledgments: The authors were grateful to the research interns from several domestic universities and local NGOs for their involvement in the household survey and preliminary analysis. The authors would like to thank all the anonymous interviewees who contributed their time and knowledge to this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Andrade, G.S.; Rhodes, J.R. Protected areas and local communities: An inevitable partnership toward successful conservation strategies? *Ecol. Soc.* **2012**, *17*, 14. [CrossRef]
2. Willemen, L.; Drakou, E.G.; Dunbar, M.B.; Mayaux, P.; Egoh, B.N. Safeguarding ecosystem services and livelihoods: Understanding the impact of conservation strategies on benefit flows to society. *Ecosyst. Serv.* **2013**, *4*, 95–103. [CrossRef]
3. Agarwala, M.; Atkinson, G.; Fry, B.P.; Homewood, K.; Mourato, S.; Rowcliffe, J.M.; Wallace, G.; Milner-Gulland, E.J. Assessing the relationship between human well-being and ecosystem services: A review of frameworks. *Conserv. Soc.* **2014**, *12*, 437–449. [CrossRef]
4. Amin, A.; Zaehringer, J.G.; Schwilch, G.; Koné, I. People, protected areas and ecosystem services: A qualitative and quantitative analysis of local people's perception and preferences in Côte d'I voire. *Nat. Resour. Forum* **2016**, *39*, 97–109. [CrossRef]
5. He, S.; Gallagher, L.; Su, Y.; Wang, L.; Cheng, H. Identification and assessment of ecosystem services for protected area planning: A case in rural communities of Wuyishan national park pilot. *Ecosyst. Serv.* **2018**, *31*, 169–180. [CrossRef]
6. Huq, N.; Pedroso, R.; Bruns, A.; Ribbe, L.; Huq, S. Changing dynamics of livelihood dependence on ecosystem services at temporal and spatial scales: An assessment in the southern wetland areas of Bangladesh. *Ecol. Indic.* **2020**, *110*, 105855. [CrossRef]
7. Daw, T.M.; Brown, K.; Rosendo, S.; Pomeroy, R. Applying the ecosystem services concept to poverty alleviation: The need to disaggregate human well-being. *Environ. Conserv.* **2011**, *38*, 370–379. [CrossRef]
8. Wu, J. Landscape sustainability science: Ecosystem services and human well-being in changing landscapes. *Landsc. Ecol.* **2013**, *28*, 999–1023. [CrossRef]
9. Kari, S.; Korhonen-Kurki, K. Framing local outcomes of biodiversity conservation through ecosystem services: A case study from Ranomafana, Madagascar. *Ecosyst. Serv.* **2013**, *3*, e32–e39. [CrossRef]
10. Cebrián-Piqueras, M.A.; Filyushkina, A.; Johnson, D.N.; Lo, V.B.; López-Rodríguez, M.D.; March, H.; Oteros-Rozas, E.; Peppler-Lisbach, C.; Quintas-Soriano, C.; Raymond, C.M.; et al. Scientific and local ecological knowledge, shaping perceptions towards protected areas and related ecosystem services. *Landsc. Ecol.* **2020**, *35*, 2549–2567. [CrossRef]
11. MA (Millennium Ecosystem Assessment). *Ecosystems and Human Wellbeing: The Assessment Series (Four Volumes and Summary)*; Island Press: Washington, DC, USA, 2005.
12. Engelbrecht, H.J. Natural capital, subjective well-being, and the new welfare economics of sustainability: Some evidence from cross-country regressions. *Ecol. Econ.* **2009**, *69*, 380–388. [CrossRef]
13. Yang, W.; Dietz, T.; Kramer, D.B.; Ouyang, Z.; Liu, J. An integrated approach to understanding the linkages between ecosystem services and human well-being. *Ecosyst. Health Sustain.* **2015**, *1*, 1–12. [CrossRef]
14. Daw, T.M.; Hicks, C.C.; Brown, K.; Chaigneau, T.; Januchowski-Hartley, F.; Cheung, W.; Rosendo, S.; Crona, B.; Coulthard, S.; Sandbrook, C.; et al. Elasticity in ecosystem services: Exploring the variable relationship between ecosystems and human well-being. *Ecol. Soc.* **2016**, *21*, 11. [CrossRef]
15. Berbés-Blázquez, M. A participatory assessment of ecosystem services and human wellbeing in rural Costa Rica using photo-voice. *Environ. Manag.* **2012**, *49*, 862–875. [CrossRef] [PubMed]
16. Hossain, M.S.; Dearing, J.A.; Rahman, M.M.; Salehin, M. Recent changes in ecosystem services and human well-being in the Bangladesh coastal zone. *Reg. Environ. Chang.* **2016**, *16*, 429–443. [CrossRef]
17. Zhang, J.; Deng, W.; Zhu, C.; Zhao, Y. Spatial Relationship and Its Dynamic Features of Ecosystem Services and Human Wellbeing in the Upper Reaches of Minjiang River. *Mt. Res.* **2017**, *35*, 388–398. (In Chinese)
18. Wang, B.; Tang, H.; Zhang, Q.; Cui, F. Exploring Connections among Ecosystem Services Supply, Demand and Human Well-Being in a Mountain-Basin System, China. *Int. J. Environ. Res. Public Health* **2020**, *17*, 5309. [CrossRef]
19. Xu, W.; Xiao, Y.; Zhang, J.; Yang, W.; Zhang, L.; Hull, V.; Wang, Z.; Zheng, H.; Liu, J.; Polasky, S.; et al. Strengthening protected areas for biodiversity and ecosystem services in China. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 1601–1606. [CrossRef]
20. He, S.; Su, Y.; Wang, L.; Gallagher, L.; Cheng, H. Taking an ecosystem services approach for a new national park system in China. *Resour. Conserv. Recycl.* **2018**, *137*, 136–144. [CrossRef]
21. Bennett N, J. Using perceptions as evidence to improve conservation and environmental management. *Conserv. Biol.* **2016**, *30*, 582–592. [CrossRef]
22. Tengö, M.; Hill, R.; Malmer, P.; Raymon, C.M.; Spiernburg, M.; Danielsen, F.; Elmqvist, T.; Folke, C. Weaving knowledge systems in IPBES, CBD and beyond—Lessons learned for sustainability. *Curr. Opin. Environ. Sustain.* **2017**, *26*, 17–25. [CrossRef]
23. Abukari, H.; Mwalyosi, R.B. Local communities' perceptions about the impact of protected areas on livelihoods and community development. *Glob. Ecol. Conserv.* **2020**, *22*, e00909. [CrossRef]
24. Gómez-Baggethun, E.; Reyes-García, V.; Olsson, P.; Montes, C. Traditional ecological knowledge and community resilience to environmental extremes: A case study in Doñana, SW Spain. *Glob. Environ. Chang.* **2012**, *22*, 640–650. [CrossRef]
25. Jones, P.J.S.; Qiu, W.; De Santo, E.M. Governing marine protected areas: Social–ecological resilience through institutional diversity. *Mar. Policy* **2013**, *41*, 5–13. [CrossRef]
26. Ouyang, Z.Y.; Zheng, H.; Xiao, Y.; Polasky, S.; Liu, J.; Xu, W.; Wang, Q.; Zhang, L.; Xiao, Y.; Rao, E.; et al. Improvements in ecosystem services from investments in natural capital. *Science* **2016**, *352*, 1455–1459. [CrossRef] [PubMed]
27. Zheng, H.; Robinson, B.E.; Liang, Y.C.; Polasky, S.; Ma, D.C.; Wang, F.C.; Ruckelshaus, M.; Ouyang, Z.Y.; Daily, G.C. Benefits, costs, and livelihood implications of a regional payment for ecosystem service program. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 16681–16686. [CrossRef]

28. Fang, Y.; Qin, D.; Ding, Y. Impact of grassland ecosystem manual intervention on economic welfare-a case of the source region of the Yellow River. *Resour. Environ. Yangtze Basin* **2010**, *9*, 1099–1105. (In Chinese)
29. Wei, W.; Wang, B.; Niu, X. The ecosystem services characteristics and its impacts on farmers' well-being for grain for green project in northern desertification areas. *J. Inn. Mong. Agric. Univ. Nat. Sci. Ed.* **2017**, *38*, 20–26. (In Chinese)
30. Wang, X.; Dong, X.; Liu, H.; Wei, H.; Fan, W.; Lu, N.; Xu, Z.; Ren, J.; Xing, K. Linking land use change, ecosystem services and human well-being: A case study of the Manas River Basin of Xinjiang, China. *Ecosyst. Serv.* **2017**, *27*, 113–123. [CrossRef]
31. Aini, A.; Halik, U.; Aishan, T.; Betz, F.; Abulizi, A.; Zhang, Q. Analysis of Stakeholders′ Cognition on Desert Riparian Forest Ecosystem Services in the Lower Reaches of Tarim River, China. *Res. Soil Water Conserv.* **2016**, *23*, 205–209. (In Chinese)
32. Li, N.; Cao, G.; He, B.; Lou, G. On the Relationship Between the Change in Farmer Wellbeing and Ecosystem Services: A Case Study of Wuling-Qinba Contiguous Destitute Areas in Chongqing. *J. Southwest Univ. Nat. Sci. Ed.* **2017**, *39*, 136–142. (In Chinese)
33. Wang, B.; Tang, H.; Xu, Y. Integrating ecosystem services and human well-being into management practices: Insights from a mountain-basin area, China. *Ecosyst. Serv.* **2017**, *27*, 58–69. [CrossRef]
34. Wei, H.; Liu, H.; Xu, Z.; Ren, J.; Lu, N.; Fan, W.; Zhang, P.; Dong, X. Linking ecosystem services supply, social demand and human well-being in a typical mountain–oasis–desert area, Xinjiang, China. *Ecosyst. Serv.* **2018**, *31*, 44–57. [CrossRef]
35. Su, F.; Shang, H. The impact of ecological compensation patters on livelihood strategy of farmers in Zhangye. *J. Arid Land Resour. Environ.* **2013**, *27*, 58–63. (In Chinese)
36. Zhao, X.; Zhang, L.; Jiang, J.; Hou, C. The impact of ecological compensation on the farmers' livelihood: A case study of Huanghe River Water Supply Areas of Gannan. *Geogr. Res.* **2013**, *32*, 531–542. (In Chinese)
37. Lu, C.X.; Yu, F.Q.; Liu X, J.; Dhruba Bijaya, G.C. Responses of ecosystems to ecological compensation in a key ecological function Area of the Loess Plateau. *J. Resour. Ecol.* **2015**, *6*, 369–374.
38. Cheng, S.H.; Ahlroth, S.; Onder, S.; Shyamsundar, P.; Garside, R.; Kristjanson, P.; McKinnon, M.C.; Miller, D.C. What is the evidence for the contribution of forests to poverty alleviation? A systematic map protocol. *Environ. Evid.* **2017**, *6*, 10. [CrossRef]
39. Wang, Q.; Yamamoto, H. Local Residents' Perception, Attitude and Participation Regarding Nature Reserves of China: Case Study of Beijing Area. *J. For. Plan.* **2009**, *14*, 67–77. [CrossRef]
40. Liu, J.; Ouyang, Z.; Miao, H. Environmental attitudes of stakeholders and their perceptions regarding protected area-community conflicts: A case study in China. *J. Environ. Manag.* **2010**, *91*, 2254–2262. [CrossRef]
41. He, J.; Shu, X.; Yu, X. Surveys and Analysis of Farmers' Perception about Wetland Ecosystem Services in Poyang Lake. *Resour. Sci.* **2010**, *32*, 776–781. (In Chinese)
42. Gao, H.; Ouyang, Z.; Zheng, H.; Bluemling, B. Perception and attitudes of local people concerning ecosystem services of culturally protected forests. *Acta Ecol. Sin.* **2013**, *33*, 756–763. (In Chinese)
43. Yang, S.; Zhao, W.; Pereira, P.; Liu, Y. Socio-cultural valuation of rural and urban perception on ecosystem services and human well-being in Yanhe watershed of China. *J. Environ. Manag.* **2019**, *251*, 109615. [CrossRef]
44. Chan, C.; Armitage, D.; Alexander, S.M.; Campbell, D. Examining linkages between ecosystem services and social wellbeing to improve governance for coastal conservation in Jamaica. *Ecosyst. Serv.* **2019**, *39*, 100997. [CrossRef]
45. Garrido, P.; Elbakidze, M.; Angelstam, P.; Plieninger, T.; Pulido, F.; Moreno, G. Stakeholder perspectives of wood-pasture ecosystem services: A case study from Iberian dehesas. *Land Use Policy* **2017**, *60*, 324–333. [CrossRef]
46. Chen, B.X.; Qiu, Z.M. Community attitudes toward ecotourism development and environmental conservation in nature reserve: A case of Fujian Wuyishan National Nature Reserve, China. *J. Mt. Sci.* **2017**, *14*, 1405–1418. [CrossRef]
47. Mooney, H.A.; Ehrlich, P.R. Ecosystem services: A fragmentary history. In *Nature's Services: Societal Dependence on Natural Ecosystems*; Daily, G.E., Ed.; Island Press: Washington, DC, USA, 1997; pp. 11–19.
48. Easterlin, R.A. Explaining happiness. *Proc. Natl. Acad. Sci. USA* **2003**, *100*, 11176–11183. [CrossRef] [PubMed]
49. Coulthard, S. What does the debate around social wellbeing have to offer sustainable fisheries? *Curr. Opin. Environ. Sustain.* **2012**, *4*, 358–363. [CrossRef]
50. Robinson, B.E.; Zheng, H.; Peng, W. Disaggregating livelihood dependence on ecosystem services to inform land management. *Ecosyst. Serv.* **2019**, *36*, 100902. [CrossRef]
51. Mikusiński, G.; Niedziałkowski, K. Perceived importance of ecosystem services in the Białowieża Forest for local communities–Does proximity matter? *Land Use Policy* **2020**, *97*, 104667. [CrossRef]
52. White, S.C. Analysing wellbeing: A framework for development. *Dev. Pract.* **2010**, *20*, 158–172. [CrossRef]
53. Jiao, Y.; Li, X.; Liang, L.; Takeuchi, K.; Okuro, T.; Zhang, D.; Sun, L. Indigenous ecological knowledge and natural resource management in the cultural landscape of China's Hani Terraces. *Ecol. Res.* **2012**, *27*, 247–263. [CrossRef]
54. Castonguay, A.C.; Burkhard, B.; Müller, F.; Horgan, F.G.; Settele, J. Resilience and adaptability of rice terrace socialecological systems: A case study of a local community's perception in Banaue, Philippines. *Ecol. Soc.* **2016**, *21*, 15. [CrossRef]
55. Gross, L.H.; Erickson, J.D.; Méndez, V.E. Supporting rural livelihoods and ecosystem services conservation in the Pico Duarte Coffee Region of the Dominican Republic. *Agroecol. Sustain. Food Syst.* **2014**, *38*, 1078–1107. [CrossRef]
56. Kumar, H.; Pandey, B.W.; Anand, S. Analyzing the Impacts of forest Ecosystem Services on Livelihood Security and Sustainability: A Case Study of Jim Corbett National Park in Uttarakhand. *Int. J. Geoherit. Parks* **2019**, *7*, 45–55. [CrossRef]
57. Hong, N.T.; Saizen, I. Forest ecosystem services and local communities: Towards a possible solution to reduce forest dependence in Bach Ma National Park, Vietnam. *Hum. Ecol.* **2019**, *47*, 465–476. [CrossRef]

58. Colquhoun, S.; Dockery, A.M. The link between Indigenous culture and wellbeing: Qualitative evidence for Australian Aboriginal peoples. *CLMR Discuss. Paper Ser.* **2012**, *18*, 161–176.
59. Zhang, Y.; Min, Q.; Zhang, C.; He, L.; Zhang, S.; Yang, L.; Tian, M.; Xiong, Y. Traditional culture as an important power for maintaining agricultural landscapes in cultural heritage sites: A case study of the Hani terraces. *J. Cult. Herit.* **2017**, *25*, 170–179. [CrossRef]
60. Deng, H.; Chen, Z.; Cao, H.; Shen, Y.; Wang, Y.; Shan, P. Perceptions and attitudes of local residents on a nature reserve: A case study in Baimaxueshan National Nature Reserve. *Int. J. Sustain. Dev. World Ecol.* **2015**, *22*, 165–170. [CrossRef]
61. Abukari, H.; Mwalyosi, R.B. Comparing conservation attitudes of Park-adjacent communities: The case of Mole National park in Ghana and Tarangire National Park in Tanzania. *Trop. Conserv. Sci.* **2018**, *11*, 1940082918802757. [CrossRef]

MDPI
St. Alban-Anlage 66
4052 Basel
Switzerland
Tel. +41 61 683 77 34
Fax +41 61 302 89 18
www.mdpi.com

Land Editorial Office
E-mail: land@mdpi.com
www.mdpi.com/journal/land

MDPI
St. Alban-Anlage 66
4052 Basel
Switzerland

Tel: +41 61 683 77 34
Fax: +41 61 302 89 18

www.mdpi.com

ISBN 978-3-0365-2294-4