

Article

Perceptions of the Effects of Livestock Farming on Biodiversity: Insights from a Study in the Galápagos Islands

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Abstract

Livestock farming is a key socioeconomic activity on Santa Cruz Island, Galápagos (Ecuador); however, its development within a fragile ecological context poses significant challenges for biodiversity conservation. This study analyzes the perceptions of livestock producers regarding the effects of livestock production on key components of biodiversity on Santa Cruz Island. It also examines the relationship between these perceptions and sociodemographic and productive variables, while identifying mitigation strategies from the perspective of local stakeholders. A structured survey was conducted with 92 producers, covering sociodemographic profiles, environmental perceptions, perceived effects on soil, water, and fauna, as well as mitigation strategies. Descriptive statistics, chi-square tests, and logistic regression were used to examine relationships between production characteristics and perceived impacts. The results indicate that producers primarily associate biodiversity decline with livestock expansion, intensification, and land-use change driven by deforestation. Producers with greater experience more frequently reported changes in native species, with significant associations between these perceptions and reported effects on water quality and soil degradation. Nevertheless, some cumulative environmental effects were inconsistently recognized, highlighting gaps in the understanding of island ecological dynamics. Regarding mitigation, 80% of respondents supported subsidies for sustainable practices, and 60% expressed willingness to receive training; in contrast, the implementation of these strategies could be limited by technical, economic, and institutional constraints. Overall, the results reflect heterogeneous perceptions of livestock-related impacts, highlighting the importance of incorporating local knowledge into the design of management strategies, while not replacing the need for direct ecological assessments.

Keywords: conservation strategies; insular ecosystems; land-use change; perception; livestock management; sustainable practices



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1. Introduction

Livestock farming is one of the main anthropogenic pressures on natural ecosystems worldwide, contributing to habitat transformation, biodiversity loss, and the disruption of key ecological processes [1–3]. Despite its importance in family-based and smallholder production systems linked to food security [4–7], the expansion of livestock production without adequate environmental management has intensified conflicts between agricultural production and biodiversity conservation, particularly in ecologically fragile regions such as the Galápagos Islands [8].

The Galápagos Islands represent one of the most sensitive socioecological systems worldwide due to their exceptional biological richness and high levels of endemism [9,10]. The archipelago preserves nearly 95% of its original flora and fauna, with remarkable endemism among reptiles, terrestrial invertebrates, algae, and birds [11]. Of the total terrestrial area, 96.7% is designated as protected land, while only 3.3% corresponds to human settlements, within which approximately 19,010 ha are used for agricultural and livestock activities [12]. Livestock production in these areas has been associated with deforestation, habitat degradation, and the introduction and spread of invasive species, one of the main threats to the archipelago's biodiversity [13–17].

Despite conservation efforts led by the Galápagos National Park, scientific understanding of the relationship between livestock practices and local biodiversity remains limited. Existing studies have primarily focused on emblematic species or invasive species management programs [8,18], while few have directly assessed the ecological effects of livestock production or identified practices capable of mitigating its impacts. Additionally, previous research has described family-based livestock systems without thoroughly evaluating their ecological implications, and comparative analyses between agricultural and protected areas report biodiversity differences without clarifying the mechanisms associated with livestock activities [19,20]. This gap constrains the development of management strategies aligned with conservation objectives.

In this context, it is essential to distinguish between measured ecological impacts and social perceptions of those impacts. Producers' perceptions do not constitute direct measurements of changes in biodiversity; rather, they reflect interpretations based on experience, local knowledge, and production conditions. Nevertheless, these perceptions are relevant for understanding decision-making processes and the adoption of production practices. Farmers' perceptions have increasingly been recognized as an important component of biodiversity conservation research [21,22]. Furthermore, given that biodiversity encompasses multiple levels (genetic, species, and ecosystem), this study focuses on producers' perceptions of observable components, particularly at the species and ecosystem levels (flora, fauna, and natural resources). To ensure a consistent understanding of the concept during data collection, the questionnaire included an operational definition of biodiversity as the "variety of plants, animals, and environmental conditions present on the farm and its surrounding areas" [23].

This study aims to: (a) analyze local producers' perceptions of livestock management practices and their relationship with biodiversity conservation within production units; and (b) identify mitigation strategies and sustainable practices implemented or considered feasible by producers to reduce negative impacts and promote more sustainable systems. In island socioecological systems such as the Galápagos, where ecological dynamics are highly sensitive to anthropogenic pressures and direct biophysical measurements are often logistically constrained or temporally limited, perception-based approaches provide a complementary and cost-effective source of information. Farmers' perceptions are not merely subjective opinions; they shape decision-making processes, influence the adoption of conservation-oriented practices, and reflect local ecological knowledge accumulated through long-term interaction with the environment [21,22]. Understanding how producers perceive the relationship between livestock production and biodiversity is therefore critical for designing management strategies that are both ecologically sound and socially feasible, as misalignment between scientific evidence and local perceptions can lead to resistance, non-compliance, or ineffective policy implementation [24,25].

Based on these objectives, the following research hypotheses are proposed: (a) local producers perceive that conventional livestock management practices generate significant negative impacts on biodiversity within production units; and (b) producers with greater

awareness of the effects of livestock production on biodiversity exhibit a higher willingness to implement mitigation strategies and sustainable practices. The findings are expected to contribute to the development of public policies and management strategies that prioritize biodiversity conservation in the Galápagos archipelago [26].

2. Materials and Methods

2.1. Study Area

The study was conducted on Santa Cruz Island, Galápagos Archipelago, Ecuador (Figure 1). The Galápagos Archipelago is one of the most volcanically active regions in the world. The climate is characterized by two main seasons: a warm season from January to May and a cooler season from June to December. Mean temperatures range between 21 and 26 °C, while annual precipitation varies widely from approximately 79.4 to 696 mm.

Soils are predominantly loamy to clay loam in texture, including silty loam types. Approximately 26% of the soils belong to the orders Alfisols, Entisols, and Inceptisols [27].

The vegetation comprises a diverse set of ecosystems and species, including mangroves, shrubs, and succulent plants. Representative species include *Vachellia insulae-iacobi*, palo santo (*Bursera graveolens*), cactus (*Opuntia galapageia*), Cat's claw (*Zanthoxylum fagara*), ferns (*Elaphoglossum firmum*), and several epiphytic species. In the humid highlands, characteristic species include *Scalesia affinis*, *Miconia robinsoniana*, and guayabillo (*Psidium galapageium*) [17,27].

Human settlement and agricultural activities are restricted to four inhabited islands and areas outside the boundaries of the Galápagos National Park. Among these, San Cristóbal and Santa Cruz Islands have the largest extent of human-modified land. Approximately 11% of the total land surface is suitable for agriculture [27].

Livestock farming is concentrated in the parishes of Bellavista and Santa Rosa, where dual-purpose cattle systems (milk and meat production) predominate in small- and medium-scale family farming systems. Local (Creole) breeds and crossbreeds with improved tropical-adapted cattle are commonly used.

Management practices are predominantly extensive or semi-intensive, based on continuous grazing on introduced pastures, mainly *Cynodon dactylon* and *Paspalum conjugatum*, with low to moderate stocking rates. The level of technological adoption remains limited, with scarce implementation of sustainable practices such as rotational grazing or silvopastoral systems. Since 2017, approximately 75% of agricultural products consumed in the Galápagos have been imported from mainland Ecuador. Projections indicate that, under a business-as-usual scenario and without significant changes in food policies, this proportion could rise to nearly 95% by 2037 [28].

The climate is subtropical, with two well-defined seasons: a warm and rainy season from January to May, with temperatures ranging from 24 °C to 29 °C, and a cooler, dry season from June to December, with average temperatures between 18 °C and 20 °C [29]. The agricultural zone is located between 100 and 520 m a.s.l., where humidity and temperature conditions are favorable for agricultural and livestock activities [30].

On Santa Cruz Island, vegetation is distributed along altitudinal gradients ranging from arid coastal zones to humid highland ecosystems. Livestock farming is mainly concentrated in the upper part of the island, where pastures coexist with remnant forests of giant daisy trees (*Scalesia pedunculata*) and shrublands dominated by Galápagos miconia (*Miconia robinsoniana*). These areas, originally covered by endemic vegetation, have been progressively transformed into agricultural land, resulting in habitat fragmentation, loss of native vegetation cover, and displacement of native species [17].

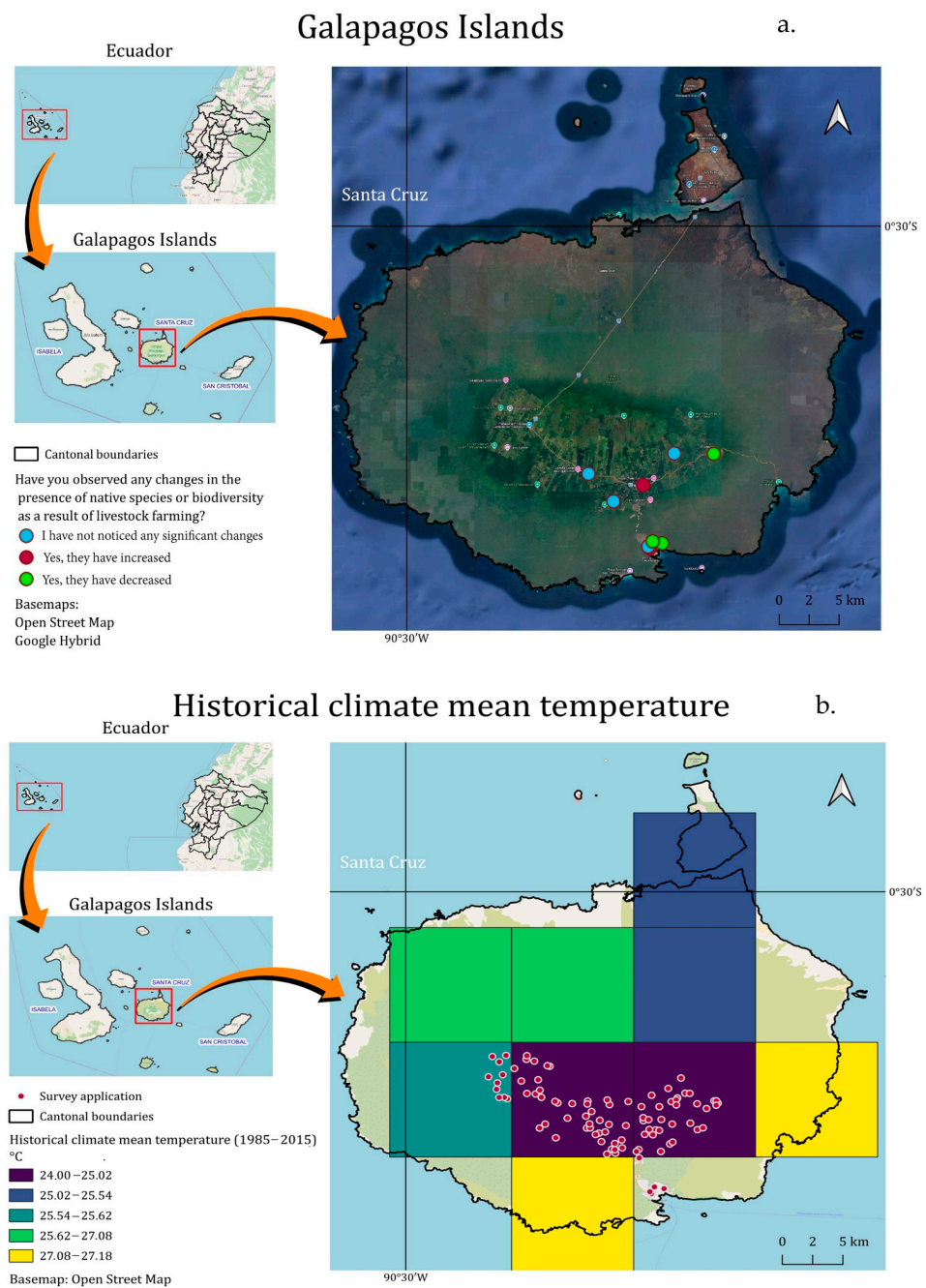


Figure 1. (a) Study area on Santa Cruz Island, Galápagos (Ecuador), showing the spatial distribution of livestock farms ($n = 92$) in the Bellavista and Santa Rosa parishes. Colored circles represent farmers' perceptions of changes in native species presence associated with livestock farming: blue = no significant changes observed, magenta = increase observed, and green = decrease observed. Black lines indicate cantonal boundaries. Scale bar: 0–5 km. Coordinate system: UTM Zone 15S (meters). Central coordinates: $0^{\circ}37' S$, $90^{\circ}22' W$. Settlements include Bellavista, Santa Rosa, Aguacatal, Camote, Cascajo, Guayabillos, Media Luna, Miramar, El Occidente, Salasaca, and El Carmen. Basemap sources: OpenStreetMap and Google Hybrid.

The introduction of forage grasses such as Bermuda grass (*Cynodon dactylon*) and sour paspalum (*Paspalum conjugatum*) has altered floristic composition and ecological dynamics, reducing biodiversity characteristic of humid ecosystems in the Galápagos Islands [31,32]. The study was conducted between April 2024 and February 2025 on Santa Cruz Island.

2.2. Study Design and Data Collection

Initially, 134 livestock producers registered in the official database of the Ministry of Agriculture and Livestock were considered [33]. Field verification identified inconsistencies, including inactive producers. For this study, inactive producers were defined as those who had ceased livestock activities for more than one year due to land-use change or abandonment of production. These cases were excluded to ensure data validity.

The final sample consisted of 92 active producers, exceeding the minimum required sample size ($n = 89$), estimated using the finite population formula (95% confidence level, 5% margin of error, $p = 0.5$). Although the study achieved high coverage of the target population (~70%), a non-probabilistic convenience sampling approach was applied due to field accessibility constraints.

Data were collected using a structured questionnaire implemented in KoboToolbox (available online: <https://www.kobotoolbox.org/>) [34,35]. The instrument included four sections: (1) sociodemographic characteristics, using closed categorical questions; (2) perceptions of biodiversity impacts, measured using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree); (3) perceived effects on soil, water, and fauna, using dichotomous and Likert-scale questions; and (4) mitigation strategies, using multiple-choice and open-ended questions.

The questionnaire was validated through expert review in agricultural production and biodiversity conservation, and piloted with a small group of producers to improve clarity and comprehension. Internal consistency was assessed using Cronbach's alpha coefficient, which indicated acceptable reliability ($\alpha > 0.70$).

Qualitative data from open-ended responses were analyzed using thematic content analysis, following an iterative coding process conducted independently by two researchers, achieving an inter-coder agreement of 87% (Table 1).

Table 1. Categories, subcategories, and themes of the survey questions.

Category	Subcategories	Question Topic
Perceptions of Livestock Farming Impacts on Biodiversity	Production Characteristics	Time dedicated to livestock Farming
	General Environmental Perception	Negative impact of livestock farming on biodiversity
	Biodiversity	Changes in native species presence
	Climate Change	Perceived local climate changes associated with livestock farming
	Temporal Dynamics	Comparison between past and current biodiversity
	Impact Factors	Main drivers of livestock farming impacts on biodiversity
	Livestock Expansion	Contribution of livestock expansion to habitat loss
	Livestock Practices	Practices most harmful to local flora and fauna
	Livestock Intensification	Effects of livestock intensification on biodiversity
	Livestock Management	Negative effects of poor livestock management
	Deforestation	Contribution of livestock-related deforestation to biodiversity Loss

Table 1. *Cont.*

Category	Subcategories	Question Topic
Effects on biodiversity	Perceived Environmental Deterioration	Level of concern about biodiversity Decline
	Soil and Biodiversity	Effects of livestock farming on soil quality
	Water and Biodiversity	Effects of livestock farming on water quality
Solutions to mitigate the impact on biodiversity	Sustainable Practices	Strategies to mitigate the environmental impacts of livestock farming
	Governance and Institutions	Mechanisms to promote sustainable livestock practices
	Training	Interest in training in sustainable livestock farming
	Environmental Regulation	Need for stricter government environmental regulations
	Environmental Incentives	Incentives to support biodiversity conservation

The study ensured informed consent from all participants, maintained confidentiality of responses, and used the collected data exclusively for academic and research purposes.

Given the limitations of the official registry of the Ministry of Agriculture and Livestock [33], particularly the presence of outdated or incomplete records, field verification was conducted to identify active livestock producers. Producers not formally registered but with verified and demonstrable experience in livestock activities were included through field-based identification procedures to improve the representativeness of the study population.

A Sankey diagram was used to visualize the relationships between perceived drivers and environmental impacts associated with livestock production practices. The diagram was constructed using survey data in which respondents identified associations between socioeconomic drivers and environmental outcomes.

Each link in the diagram represents the frequency with which a specific driver–impact relationship was reported. The width of each flow is proportional to the number of responses indicating that association. Nodes represent categories of drivers and environmental impacts, and node values (*n*) correspond to the total number of responses per category. Multiple responses per participant were allowed.

2.3. Data Analysis

Quantitative data were analyzed using descriptive statistics, including frequencies and percentages. Binary logistic regression was applied to assess the relationship between sociodemographic variables and the perception of the negative impact of livestock farming on biodiversity.

Model fit was evaluated using the Hosmer–Lemeshow goodness-of-fit test (chi-square, $\chi^2 = 6.373$, *df* = 8, *p* = 0.606), indicating an acceptable model fit. Additional indicators included the −2 Log Likelihood statistic (112.369) and the Nagelkerke pseudo-*R*². Multicollinearity was assessed using the Variance Inflation Factor (VIF), with all predictor variables showing values below 5 (range: 1.075–1.501), indicating no evidence of severe multicollinearity.

Chi-square (χ^2) tests were conducted to examine associations between categorical variables. Effect sizes were estimated using Cramér's V statistic. The assumptions of the chi-square test, particularly expected cell frequencies, were verified prior to analysis. When assumptions were not fully met, results were interpreted with caution.

To reduce the risk of type I error, no adjustments for multiple comparisons (e.g., Bonferroni correction) were applied; therefore, statistically significant associations ($p < 0.05$) were considered exploratory.

Qualitative data from open-ended questions were analyzed using content analysis. An iterative coding process was applied to identify thematic categories, grouping producers' perceptions, perceived constraints, and proposed mitigation strategies.

All statistical analyses were performed using IBM SPSS Statistics, version 26.0 (IBM Corp., Armonk, NY, USA) [35].

3. Results

The results presented correspond to perceptions reported by livestock producers and do not constitute direct measurements of ecological or biophysical conditions.

3.1. Sociodemographic Characterization of Producers

The sociodemographic characterization of the participants showed that 76.07% of respondents were adults between 36 and 70 years of age, whereas less than 15% were younger than 16 or older than 70 years. This distribution indicates a predominance of individuals of economically active age with substantial experience in productive activities and natural resource management within the territory.

Regarding educational attainment, 40% of participants reported having completed secondary education, while 32% had attained higher education or postgraduate qualifications. In contrast, only 1% reported having no formal education. These findings suggest a relatively favorable educational profile among the surveyed population.

Concerning primary occupation, approximately 87% of respondents reported being engaged in agricultural and livestock production activities, whereas the remaining 13% were involved in other economic sectors or did not respond to this question. The predominance of agricultural producers indicates that the perceptions captured in this study largely reflect the views of individuals whose livelihoods are closely linked to natural resources and local environmental conditions.

The agricultural zone of Santa Cruz Island covers approximately 100 km² and is bordered by the Galápagos National Park (Table 2). The results of the logistic regression model indicated that none of the evaluated independent variables showed a statistically significant association with the dependent variable: "Do you consider that livestock farming has a negative impact on biodiversity?" (Yes/No) (Table 2).

Table 2. Binary logistic regression results for the sociodemographic variables of livestock producers on Santa Cruz Island.

	B	Standard Error	Wald	df	Sig.	Exp(B)
Gender	0.441	0.483	0.834	1	0.361	1.555
Age	0.197	0.295	0.444	1	0.505	1.218
Education Level	0.320	0.290	1.219	1	0.270	1.378
Years in Livestock Farming	0.093	0.326	0.82	1	0.775	1.098
Economic Activity	1.265	0.954	1.758	1	0.185	3.544

The table presents the coefficients of the binary logistic regression model (B), standard error, Wald statistic, degrees of freedom (df), significance level (Sig.), and odds ratios [Exp(B)] for the sociodemographic variables of livestock producers on Santa Cruz Island. A value of $p < 0.05$ was considered statistically significant.

Although variables such as educational level, time dedicated to livestock farming, and economic activity showed positive trends in their relationship with the outcome variable, the statistical evidence was insufficient to confirm significant effects. In particular, economic activity presented the largest relative magnitude of association among the predictors considered; however, this relationship did not reach statistical significance ($p > 0.05$). No causal inferences can be drawn from these associations. The lack of statistical significance may be attributed to limited statistical power due to sample size ($n = 92$) and/or the asymmetric distribution of the dependent variable.

The lack of statistically significant predictors in the logistic regression model may be attributed to the relatively small sample size ($n = 92$), which limits statistical power to detect modest associations. Additionally, the dependent variable exhibited an asymmetric distribution, with the majority of respondents perceiving negative impacts. Unobserved variables not included in the model may also explain part of the variability in perceptions.

3.2. Perceptions of the Impact of Livestock Farming on Biodiversity

Chi-square analysis revealed a statistically significant association between time dedicated to livestock farming and perceived changes in native species, indicating that perceptions of biodiversity change vary according to years of experience in livestock activities (Table 3). In contrast, no significant association was observed between time dedicated to livestock farming and perceptions of the overall negative impact of the activity. Similarly, no significant relationship was identified between perceptions of the negative impact of livestock farming and the identification of the main factor affecting biodiversity, suggesting heterogeneity in the criteria used by respondents to attribute environmental impacts.

Table 3. Livestock practices and their relationship with biodiversity variables on Santa Cruz Island.

Analyzed Relationship	χ^2	gl	p	Cramér's v
Time Dedicated to Livestock Farming ↔ Negative Impact of Livestock Farming	2.154	3	0.541	0.87
Time Dedicated to Livestock Farming ↔ Changes in Native Species	44.208	12	<0.001	0.312
Negative Impact of Livestock Farming ↔ Main Impact Factor	2.242	5	0.815	0.068
Livestock Expansion ↔ Biodiversity	100.982	8	<0.001	0.468
Livestock Intensification ↔ Biodiversity Decline	69.937	12	<0.001	0.389
Poor Livestock Practices ↔ Biodiversity Decline	18.292	12	0.107	0.199
Deforestation ↔ Primary Impact Factor	44.051	20	<0.001	0.312

The table presents the chi-square statistic (χ^2), degrees of freedom (df), and significance level (p) for the analyzed relationships between productive and environmental impact variables. Statistical significance was considered at $p < 0.05$. Cramér's V values were interpreted as follows: 0.10–0.30 indicates a weak association, 0.30–0.50 a moderate association, and values greater than 0.50 a strong association.

Statistically significant associations were observed between livestock expansion and biodiversity change, as well as between livestock intensification and biodiversity decline, indicating that both processes are perceived as key drivers of biodiversity loss. In contrast, the relationship between poor livestock practices and biodiversity decline was not statistically significant. Finally, a significant association was found between deforestation and the main perceived factor affecting biodiversity, highlighting its central role in respondents' perceptions of environmental impacts associated with livestock farming (Table 3).

3.3. Effects on Biodiversity

Statistically significant associations were identified between the perception of biodiversity decline and the perceived effects of livestock farming on water pollution and water quality (Table 4). A significant relationship was also observed between perceived

biodiversity decline and the effects of livestock farming on soil and biodiversity, indicating consistency in producers' perceptions of the environmental impacts associated with livestock activities.

Table 4. Environmental perception, time in livestock farming, and environmental impact variables on Santa Cruz Island.

Analyzed Relationship	χ^2	gl	<i>p</i>	Cramér's <i>v</i>
Perceived Biodiversity Decline ↔ Water Pollution/Quality	17.108	3	<0.001	0.305
Perceived Biodiversity Decline ↔ Effects on Soil and Biodiversity	184.000	6	<0.001	1.000 *
Effects on Soil and Biodiversity ↔ Water Pollution/Quality	11.180	2	0.004	0.247
Time in Livestock Farming ↔ Perceived Biodiversity Decline	22.174	9	0.008	0.245
Time in Livestock Farming ↔ Effects on Soil	7.128	6	0.309	0.138
Time in Livestock Farming ↔ Water Pollution	3.883	3	0.274	0.145

The table reports the chi-square statistic (χ^2), degrees of freedom (df), and significance level (*p*) for the analyzed relationships. Statistical significance was considered at *p* < 0.05. Values of *p* < 0.001 are reported accordingly in the table. * Cramér's V value of 1.000 indicates a perfect association resulting from the specific structure of the cross-tabulation; this result should be interpreted with caution given the sample size. A value of *p* < 0.05 was considered statistically significant.

Similarly, a significant association was found between perceived effects on soil and biodiversity and water pollution and water quality, suggesting that producers link soil degradation with impacts on water resources. Regarding productive characteristics, time dedicated to livestock farming was significantly associated with the perception of biodiversity decline, indicating that this perception varies according to years of experience in livestock activities. However, no significant associations were observed between time dedicated to livestock farming and perceptions of effects on soil and biodiversity, nor with water pollution and water quality.

To quantitatively assess reported perceptual heterogeneity among producers, subgroup analyses were conducted based on years of livestock experience (≤ 10 years, *n* = 27; 11–20 years, *n* = 16; >20 years, *n* = 49) and farm size (small: ≤ 10 ha, *n* = 43; medium: 11–50 ha, *n* = 28; large: >50 ha, *n* = 21). Table 5 reports the proportion of respondents within each subgroup who identified specific drivers as the main factor affecting biodiversity, as well as those who perceived soil degradation and water pollution as consequences of livestock farming.

The results reveal descriptive heterogeneity. Regarding the main perceived impact factor, deforestation was identified by 61.2% of producers with >20 years of experience, compared to 51.9% of those with ≤ 10 years. Conversely, livestock expansion was more frequently cited by less experienced producers (33.3% vs. 26.5%). Regarding environmental effects, perceptions of soil degradation varied by farm size, with higher proportions among small-scale producers (62.8%) compared to medium- (46.4%) and large-scale producers (42.9%). In contrast, perceptions of water pollution were relatively consistent across groups (56.3–69.4%). Although chi-square tests were not statistically significant, these subgroup patterns suggest that perceptual heterogeneity may be structured by productive experience and farm scale rather than being randomly distributed.

To visualize the main perceived relationships between livestock-related drivers and environmental impacts, a Sankey diagram was constructed based on survey responses (Figure 2). Each flow reflects the frequency with which respondents linked a specific driver

(e.g., “lack of training”) to an environmental outcome (e.g., “habitat loss”), with these connections reflecting subjective interpretations rather than biophysical causality. Accordingly, the terms “perceived associations” or “reported relationships” are used throughout the interpretation of this figure instead of “causal effects.”

Table 5. Subgroup differences in perceptions of impact drivers and environmental effects among livestock producers on Santa Cruz Island (n = 92).

Subgroup	Deforestation as Main Driver (%)	Livestock Expansion as Main Driver (%)	Perceived Soil Degradation (%)	Perceived Water Pollution (%)
Years of experience				
≤10 years	51.9% (14)	33.3% (9)	51.9% (14)	63.0% (17)
11–20 years	50.0% (8)	31.3% (5)	43.8% (7)	56.3% (9)
>20 years	61.2% (30)	26.5% (13)	55.1% (27)	69.4% (34)
χ^2 (p-value)	0.659 (0.719)	0.399 (0.819)	0.601 (0.740)	0.865 (0.649)
Cramér’s V	0.085	0.066	0.081	0.097
Farm scale (ha)				
Small (≤10 ha)	55.8% (24)	25.6% (11)	62.8% (27)	67.4% (29)
Medium (11–50 ha)	57.1% (16)	35.7% (10)	46.4% (13)	60.7% (17)
Large (>50 ha)	57.1% (12)	33.3% (7)	42.9% (9)	66.7% (14)
χ^2 (p-value)	0.013 (0.994)	0.810 (0.667)	2.560 (0.278)	0.390 (0.823)
Cramér’s V	0.012	0.094	0.167	0.065

Note: Percentages indicate the proportion of producers within each subgroup who selected each item. Multiple responses per participant were allowed for drivers; therefore, percentages for drivers do not sum to 100. Chi-square tests were performed for each comparison; due to multiple comparisons (n = 8), p-values should be interpreted as exploratory. Cramér’s V values: 0.10–0.30 = weak association, 0.30–0.50 = moderate association based on [36]. The value of $p < 0.05$ was considered statistically significant.

It is important to emphasize that the Sankey diagram (Figure 2) visualizes perceived associations reported by producers, rather than empirical causal relationships. The flows represent the frequency with which respondents linked a given driver to an environmental outcome; in contrast, these connections reflect subjective interpretations rather than biophysical causality. Therefore, throughout the interpretation of this figure, the term “perceived associations” or “reported relationships” is used instead of “causal effects.”

The Sankey diagram illustrates the frequency of perceived associations between drivers identified by producers and the environmental impacts of livestock farming on biodiversity. Structural factors, such as lack of training and limited economic resources, are closely associated with habitat loss and the introduction of exotic species, highlighting constraints in the adoption of sustainable practices. Producer disengagement also emerges as an important determinant, being linked to soil and water pollution as well as resource competition, which suggests that, beyond material limitations, sociocultural and governance barriers hinder the implementation of conservation strategies. Finally, lack of technology shows fewer connections but is directly associated with temperature change through inefficient production practices that increase emissions and ecosystem pressure.

Beyond its descriptive function, the Sankey diagram enables the identification of dominant perceived linkages between socioeconomic drivers and environmental impacts, revealing patterns of attribution among producers. This contributes to an understanding of how environmental causality is socially constructed and helps identify priority areas for intervention based on locally perceived drivers.

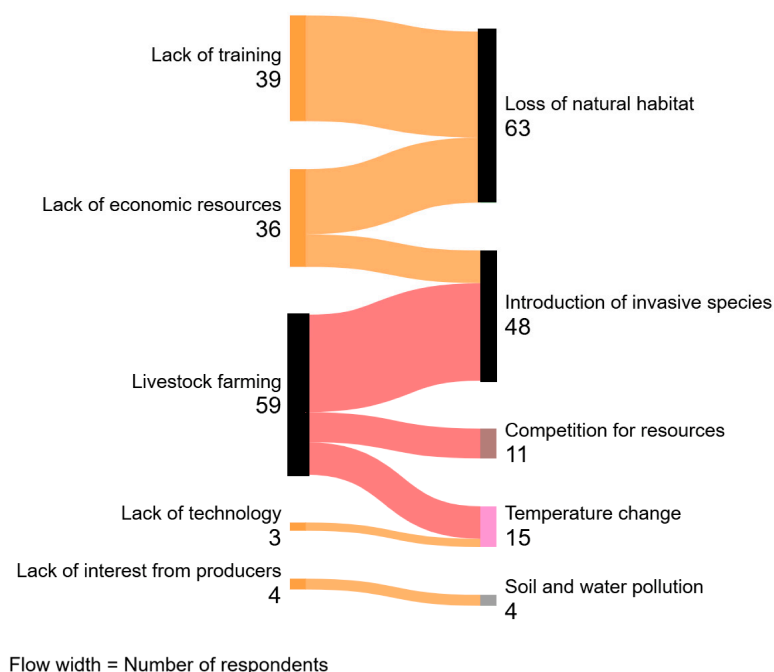


Figure 2. Perceived associations between drivers and environmental impacts of livestock farming as reported by producers on Santa Cruz Island. Sankey diagram illustrates perceived associations between drivers and environmental impacts related to livestock farming on Santa Cruz Island. Node values (n) indicate the total number of responses per category, and multiple responses per participant were allowed. The flows represent the number of respondents who selected each association. Importantly, this diagram visualizes perceived associations reported by producers and does not represent empirical causal relationships. These relationships should be interpreted as descriptive frequencies of subjective linkages rather than evidence of biophysical causality.

3.4. Mitigation Strategies and Sustainable Practices

The analysis of preferences revealed a strong inclination toward subsidies for sustainable practices (80%), highlighting the potential role of economic incentives in promoting the adoption of environmentally friendly management strategies (Figure 3). Training and technical assistance (60%) also emerged as a highly preferred area, suggesting that producers are receptive to acquiring knowledge and skills to implement more sustainable practices.

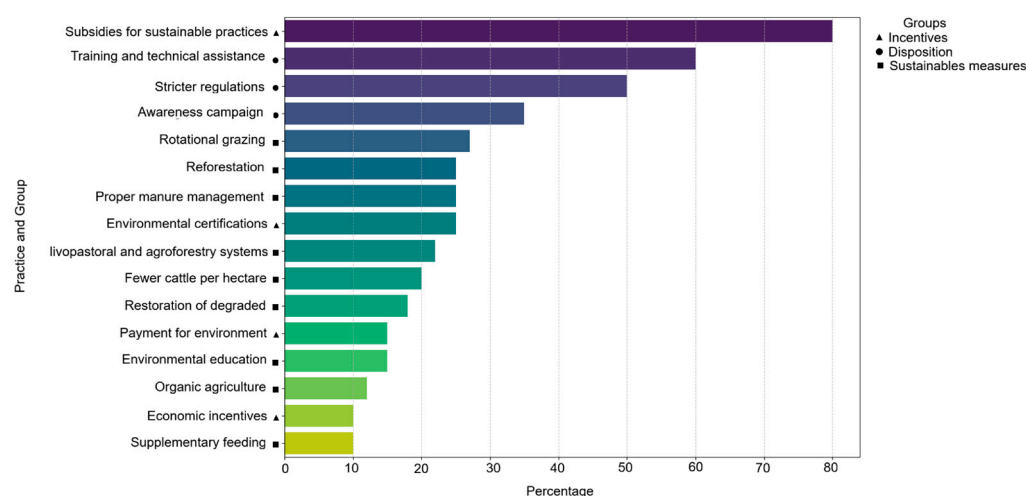


Figure 3. Producers' perceptions of sustainable livestock practices ranked by percentage. Percentages represent the proportion of responses obtained from producers on Santa Cruz Island, and colors indicate different category groups.

Regarding management measures, rotational grazing (27%) and reforestation (25%) showed the highest levels of implementation or willingness to adopt, indicating that these practices are relatively more accepted or feasible within the local context. In contrast, general economic incentives and practices such as organic farming exhibited lower response rates, suggesting the need for further investigation into the barriers limiting their adoption.

With respect to local production systems, producers recognized that livestock farming, although limited in scale, contributes to the supply of animal protein for both the resident population and the tourism sector, thereby reducing dependence on imported food from the mainland.

4. Discussion

All results presented in this section are based on producers' perceptions and should not be interpreted as direct ecological measurements. Consequently, references to "effects," "impacts," "drivers," or "relationships" reflect perceived associations reported by respondents rather than empirically verified causal links. These findings provide valuable insights into local knowledge and stakeholder perspectives, but they do not constitute evidence of ecological processes or cause-and-effect relationships.

The sociodemographic composition of the sample may have influenced the environmental perceptions documented in this study. The predominance of adults aged 36–70 years with extensive agricultural experience likely contributed to consistent observations of long-term environmental change; however, younger perspectives may be underrepresented. In addition, the relatively high educational level of respondents may have increased awareness of environmental issues, potentially underrepresenting perceptions from populations with lower formal education. Moreover, the strong predominance of agricultural and livestock producers suggests that responses were mainly shaped by individuals whose livelihoods depend directly on natural resources. This occupational structure may introduce a systematic bias toward concerns related to productivity, soil quality, water availability, and climate variability, while underrepresenting non-agricultural perspectives. Therefore, caution is required when extrapolating these findings beyond the studied population.

The results indicate that livestock production is perceived as being associated with environmental degradation; nevertheless, this relationship is not uniformly recognized among stakeholders. Biodiversity loss is mainly associated with visible processes such as livestock expansion, intensification, and land-use change linked to deforestation. In contrast, impacts such as soil degradation and water pollution are less frequently identified, revealing gaps in the understanding of cumulative environmental effects. At the same time, producers also perceive an inverse relationship, whereby native fauna may negatively affect agricultural production. For instance, the small ground finch has been reported as affecting farms [37], and 52.6% of farmers in Galápagos have perceived terrestrial birds as a nuisance [3]. These findings highlight the need for approaches that reconcile conservation and production [38], particularly in Santa Cruz Island, where tourism is the main economic activity and local food production faces structural constraints and rising demand.

Although there is general recognition of the importance of conservation, this awareness does not always translate into management actions, consistent with previous studies in the Galápagos [39,40]. This pattern reflects a predominantly utilitarian view of the environment among some residents, where economic development is often prioritized over conservation objectives.

The results reflect perception-based interpretations rather than direct ecological measurements. Although farmers' perceptions do not always align with biophysical evidence, they remain essential for understanding socioecological systems [24], as they directly influence management decisions and adaptation strategies. Accordingly, all interpretations are

framed within a perception-based analytical approach. Similar studies show that climate change perceptions influence adaptive capacity and production strategies [40], and that environmental attitudes affect the adoption of conservation practices [25].

Sociodemographic variables such as age, education, and ethnicity were not significantly associated with perceived environmental impacts ($p > 0.05$). Although some descriptive trends were observed in the logistic regression model (Table 2), they should not be interpreted as statistically meaningful relationships. The lack of significance may be related to limited statistical power ($n = 92$) and the asymmetric distribution of the dependent variable (81.5% perceived negative impacts).

This finding suggests that ecological knowledge does not necessarily increase with greater exposure to livestock farming, a pattern consistent with studies reporting fragmented environmental perceptions in rural communities [22,41,42]. In contrast to the present findings, several studies have shown that higher educational attainment is associated with greater environmental awareness, improved environmental performance, and an enhanced capacity to interpret information relevant to natural resource management [43]. Similarly, in livestock production systems, education has been identified as a factor that strengthens environmental awareness and increases producers' willingness to adopt conservation-oriented management practices [44]. The absence of this relationship in the present study may be explained by the relative homogeneity of the sample or by the predominance of experiential knowledge over formal education.

The study population on Santa Cruz Island is characterized by an aging demographic structure and predominantly basic to intermediate educational attainment. This profile is consistent with previous studies of small- and medium-scale livestock systems, where the limited participation of younger generations and restricted access to technical training constrain the adoption of productive innovations [3,45]. In the ecologically sensitive insular context of the Galápagos, these characteristics are particularly relevant because they may limit the sector's capacity to adapt to environmental challenges and evolving regulatory requirements.

Time dedicated to livestock farming was significantly associated with perceptions of changes in native species, suggesting that accumulated experience enhances awareness of ecological transformations. Similarly, livestock expansion and intensification were strongly associated with perceived biodiversity decline, consistent with studies documenting land conversion into pasture as a key driver of environmental change in insular systems [3,13]. Historical evidence for Santa Cruz confirms that livestock expansion has contributed to deforestation, invasive species introduction, and landscape simplification [14,16,46], which aligns with producers' perceptions.

However, dependence on livestock farming does not necessarily translate into comprehensive environmental awareness. Instead, producers tend to recognize only certain visible impacts (e.g., deforestation and invasive species), while cumulative processes are less frequently identified. This fragmented perception is consistent with studies reporting limited systemic understanding of socioecological systems in rural contexts [47].

This gap may also be linked to limited access to spatially explicit tools. Studies in the Galápagos have shown that participatory mapping using drone imagery shifts farmers' perceptions from immediate features toward landscape-scale processes and long-term land-use dynamics [48]. This suggests that the use of geospatial tools could help bridge the gap between perceived and actual environmental change.

From a territorial perspective, these findings should be interpreted within the broader context of land-use change and landscape fragmentation in Santa Cruz Island. Recent analyses show that agricultural land is undergoing transitions driven by crop specialization, labor dynamics, market orientation, and technical access [49]. Integrating remote sensing

and participatory approaches would allow a more robust comparison between perceived and observed landscape changes, as demonstrated in previous studies [48].

Producers expressed favorable attitudes toward sustainable practices, particularly subsidies, rotational grazing, and reforestation. Nonetheless, adoption is constrained by structural factors, including limited training, economic barriers, and institutional fragmentation. This indicates that transitions toward sustainability require integrated interventions addressing both technical and socioeconomic dimensions.

Implementation Constraints for Sustainable Livestock Practices

Economic constraints remain significant. Although 80% of respondents supported subsidies for sustainable practices, the long-term financial viability of such programs remains uncertain. Given the dependence of the Galápagos economy on tourism and external funding [36], producers with limited resources may struggle to co-finance sustainable investments even under subsidy schemes. In addition, increasing dependence on food imports may further reduce incentives for local production investment [28].

Technical constraints are also critical, as lack of training and technical assistance was identified as a major limitation. This aligns with previous studies highlighting restricted access to technical capacity in small-scale livestock systems in the Galápagos [3,45]. Effective implementation therefore requires continuous on-site support rather than isolated training interventions.

Institutional constraints arise from the complex governance structure of the archipelago, where most land is under protected status and agricultural activities are spatially restricted [11]. This regulatory configuration can generate coordination challenges between conservation and production sectors, as well as perceptions of institutional instability.

Proposed actionable strategies. Based on the constraints identified from producers' perceptions, we propose the following context-specific interventions:

1. Pilot integrated silvopastoral systems in collaboration with the Galápagos National Park Directorate, using a participatory co-design approach involving producers in native tree planting and pasture management. This recommendation aligns with producers' expressed interest in reforestation (25%, Figure 3) and silvopastoral systems.
2. Establish community-based technical service stations staffed by locally trained para-extensionists. Given that 60% of respondents expressed willingness to receive training (Figure 3), this approach would involve training selected producers as peer advisors, reducing dependence on external specialists and strengthening knowledge exchange within farming communities.
3. Develop a cross-institutional working group for sustainable livestock management, including representatives from the Ministry of Agriculture, the Galápagos National Park Directorate, and producer associations. This platform could address coordination challenges associated with protected area governance [11] and fragmented agricultural registry systems [32].

These recommendations are not exhaustive but provide a concrete pathway for translating producers' willingness to adopt sustainable practices into effective long-term conservation outcomes.

The findings of this study can be contextualized within previous research conducted in the Galápagos archipelago. Study [3] reported that 52.6% of farmers perceived terrestrial birds as a nuisance, with one producer explicitly reporting crop damage caused by the Galápagos mockingbird. This aligns with our observation that producers primarily identify visible and direct impacts of livestock farming (e.g., deforestation and habitat loss), whereas cumulative effects (e.g., soil degradation and water pollution) are less frequently recognized. The consistency between our perception-based findings and those of [3] suggests that

experiential knowledge shapes environmental awareness in relatively consistent ways across different agricultural contexts within the archipelago.

Regarding land-use change, study [17] documented historical deforestation and pasture expansion on Santa Cruz Island using remote sensing, showing that livestock areas expanded by approximately 23% between 2000 and 2018. Our results complement these biophysical measurements by revealing producers' perceptions of the same processes: 57.9% of respondents identified deforestation as the main driver of biodiversity loss, and livestock expansion was significantly associated with perceived biodiversity decline ($\chi^2 = 100.982$, $p < 0.001$). This convergence between perceived and observed land-use change strengthens the validity of local ecological knowledge as a complementary source of information for conservation planning.

The unique governance context of the Galápagos, where 96.7% of the terrestrial area is designated as protected land and agricultural activities are restricted to only 3.3% of the archipelago [11], shapes producers' environmental perceptions in ways that differ from mainland contexts. The high support for subsidies (80%) observed in this study likely reflects expectations of external compensation for working within a conservation-dominated landscape, as well as economic constraints associated with limited land availability. Similarly, the expressed willingness to receive training (60%) may be influenced by the perception that sustainable practices are required by the Galápagos National Park rather than voluntarily adopted. These governance-driven perceptions have direct implications for policy design: incentive programs must be economically sustainable and institutionally coordinated to avoid creating dependency or unrealistic expectations among producers.

Overall, the results highlight the coexistence of a livestock system that contributes to local livelihoods with heterogeneous perceptions of its environmental impacts. This duality underscores the need for integrated territorial management approaches that link production systems and conservation objectives.

This study presents several important limitations. The sampling approach employed corresponds to a non-probabilistic convenience sampling design; therefore, the results are representative only of the group of producers surveyed on Santa Cruz Island and cannot be generalized to the entire island population or to other inhabited islands of the archipelago, such as Isabela and San Cristóbal. In addition, this sampling strategy may introduce selection bias, as participant inclusion was based primarily on accessibility and availability criteria.

Future research should increase sample size and adopt probabilistic sampling designs to improve statistical representativeness, reduce potential bias, and enhance the generalizability of findings at a broader regional scale within the Galápagos archipelago. Furthermore, future studies should incorporate ecological indicators, longitudinal monitoring, and spatial analyses to objectively assess the impacts of livestock farming on biodiversity, as well as the effectiveness of mitigation strategies.

5. Conclusions

This study examined livestock producers' perceptions of the impacts of livestock farming on biodiversity components on Santa Cruz Island, Galápagos, based exclusively on responses from 92 surveyed producers. The findings are strictly representative of this sample and cannot be generalized to other inhabited islands of the archipelago (Isabela and San Cristóbal) or to the wider Galápagos population. Within this scope, three main conclusions emerge. First, producers more readily identified direct and visible impacts such as livestock expansion, intensification, and deforestation as drivers of biodiversity loss, whereas indirect or cumulative effects, including soil degradation and water quality decline,

were less consistently perceived. This indicates a partial understanding of ecological processes, primarily focused on observable components of environmental change.

Second, years of experience in livestock farming was the only variable significantly associated with perceptions of changes in native species, highlighting the importance of experiential knowledge in interpreting environmental transformations. In contrast, sociodemographic variables such as age, education level, and economic activity showed no statistically significant associations with perceptions of negative environmental impacts, although observed trends suggest potential relationships that require further investigation with larger and more representative samples.

Third, although a generally favorable disposition toward the adoption of sustainable practices was observed (e.g., 80% supported subsidies and 60% expressed willingness to receive training), this study assessed perceived willingness rather than actual implementation or effectiveness. The adoption of such practices remains constrained by economic, technical, and institutional factors.

Overall, the proposed hypotheses are only partially supported. While producers recognize certain negative impacts of livestock farming, these perceptions are heterogeneous and do not fully capture the multidimensional nature of biodiversity and ecosystem processes. These findings highlight that local perceptions constitute a valuable input for understanding socioecological dynamics and informing decision-making in productive systems. At the same time, their scope is limited to the social domain. Future research should therefore complement perception-based approaches with ecological field measurements, longitudinal monitoring, and spatial analyses to provide a more comprehensive evaluation of livestock impacts on biodiversity in the Galápagos archipelago.

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