

Article

A Methodological Approach to Assess the Effectiveness of Planning Tools to Address Locust Infestations in a Changing Climate Context: A Case Study in Sardinia (Italy)

Antonio Ledda ^{1,2,*} , Arturo Cocco ^{1,3} , Vittorio Serra ¹ , Giovanna Calia ¹ , Daniele Trogu ¹ and Andrea De Montis ¹ 

¹ Department of Agricultural Sciences, University of Sassari, Viale Italia 39a, 07100 Sassari, Italy; acocco@uniss.it (A.C.); vserra@uniss.it (V.S.); giovannacalia@live.it (G.C.); andreadm@uniss.it (A.D.M.)

² Dipartimento di Innovazione, University of Sassari, 07026 Olbia, Italy

³ Desertification Research Centre (NRD), University of Sassari, 07100 Sassari, Italy

* Correspondence: antonioledda@uniss.it; Tel.: +39-079-229240

Abstract

Locusts are recognized globally as one of the worst pests affecting human activities in the agricultural sector. From 2019 to 2024, a severe outbreak of the Moroccan locust (*Dociostaurus maroccanus*) occurred in Sardinia (Italy). We aim to propose a methodological approach and useful criteria for considering locust infestations risk in regional and/or subregional plans that affect land use and landscape. The idea is to integrate prevention strategies into planning practice, in the context of climate changes affecting the development and spread of insects, including locusts. As for the methodology, from an analysis of scientific literature, we have distilled five useful criteria for assessing whether spatial planning tools integrate locust-related issues. The criteria are intended as a scoreboard to highlight the strengths and weaknesses of the plans. We applied the five criteria to assess a regional and a municipal master plan adopted in Sardinia. The findings show that the regional plan received a positive evaluation while the municipal master plan did not meet any criteria. As countermeasures, we suggest that public administrations and planners integrate the criteria while designing planning tools affecting land use and land management.

Keywords: *Dociostaurus maroccanus*; prevention; spatial planning; assessment criteria



Academic Editors: João Pedro Monteiro, Eduardo Natividade-Jesus, Nuno Sousa and João Coutinho-Rodrigues

Received: 18 June 2026

Revised: 18 July 2026

Accepted: 21 July 2026

Published: 23 July 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

1. Introduction

According to the International Plant Protection Convention (IPPC), the effects of climate change on plant pests are still unclear, despite the vast scientific literature on climate change biology [1]. In this study, we mean plant pests (hereafter pests) as defined by the IPPC, i.e., “any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products” [1]. Locusts are included among the most destructive plant pests [2]. Although research gaps still exist, the IPPC pointed out that “in many cases climate change will result in increasing problems related to plant health in managed (e.g., agriculture, horticulture, forestry), semi-managed (e.g., national parks) and presumably also unmanaged ecosystems” [1]. Klein et al. [3] remarked that “locust outbreaks might occur more often in the future due to a combination of inefficient management, regional instabilities or conflicts, changing climate and environmental conditions, as well as agricultural and pastoral activities”.

Locusts are considered one of the worst pests humans are committed to address [4–7]. Scholars tend to agree that land-use change (e.g., agricultural abandonment) and climate change are among the causes that trigger outbreaks and affect the distribution of locusts [3]. The Moroccan locust (*Dociostaurus maroccanus* (Thunberg, 1815)) has proven to be harmful in several contexts, including Sardinia (Italy) [8,9], where a destructive outbreak of this species occurred from 2019 to 2024, destroying pastures and crops and covering approximately 60,000 hectares in 2022 [9].

Spatial planning has the potential to both address climate change [10] and pests [11]. For example, regarding spatial planning and pests, Hlásny and Haas [11] focused on bark beetle management. Bark beetle outbreaks have affected large European forest areas, which in turn have consequences for socio-economic issues and people's quality of life. In this context, spatial planning and zonation are considered requirements to promote efficient management.

Spatial planning can be defined in different ways [12] and its definition ranges from “the methods used largely by the public sector to influence the future distribution of activities in space [...]” [13] to “actions and interventions that are based on ‘critical thinking about space and place’ [...]”. It involves not only legislative and regulatory frameworks for the development and use of land, but also the institutional and social resources through which such frameworks are implemented, challenged and transformed” (Davoudi et al. [14]). Spatial planning is a crucial element in defining long-term sustainable strategies capable of guiding social, economic, and territorial development, both nationally and internationally [15]. Although there are differences between countries, three fundamental functions are generally common [16], as spatial planning: (i) offers a medium- to long-term strategy for territories, with the purpose of meeting shared objectives, promoting an integrated vision that encompasses diverse viewpoints of sectoral policies; (ii) constitutes an autonomous sector of government action, dedicated to land-use and physical development; and (iii) can also be understood as the planning of sectoral policies according to a variety of spatial scales. Spatial planning aims at sustainable development [17], has to address global challenges [18], contributes to the “development and safeguarding of territories to ensure the sustainable use of a habitat, which is clearly significantly influenced by climate change” [19], and has a potential role to both climate change mitigation and adaptation [20]. Spatial planning relies on advanced technological tools that, through constant data flows and simulations, allow for the exploration of different scenarios. In this context, geographic information system (GIS) methodologies are essential for assessing vulnerabilities, analyzing risks and impacts, and supporting complex decision-making processes [21].

According to Kumar and Geneletti [22], spatial planning encompasses two primary dimensions, i.e., it fosters “the community and institutional vision for future socio-ecological development under legal endorsements [and controls] land use change and spatial development of the local area through allocation of space for various activities” [22]. Spatial plans steer “the physical development of a city [and] provide guidance for land-use changes that affect ecological aspects such as land fragmentation, ecosystems, biodiversity, and other natural resources” [22].

Land use can affect locust outbreaks as in some countries in Africa [23]. In this regard, human activities (e.g., urban expansion) have effects on locust habitat [24]. Mallie et al. [25] remarked that rapid land-use and land-cover changes, and the degradation of shrublands and semi-arid rangelands, with seasonal flood events and irrigation expansion, are jointly responsible for creating “favorable conditions for desert locust breeding and proliferation” [25] in the Wabe Shebelle River Basin in Ethiopia. Cease et al. [26] list conditions that trigger locust outbreaks, such as precipitation, plant quality, and soil quality, which largely depends on land-use practices. Excessive livestock grazing is also responsible

for locust outbreaks, as it contributes to lowering the content of plant nitrogen [26]. For example, the Mongolian locust, *Oedaleus asiaticus* Bey-Bienko, prefers plants with a low protein content, which is due to a low nitrogen content [27]. Plans have been adopted to address locusts. As an example, the Republic of Kenya adopted the “Pest Management Plan (PMP) on locust control—contingency emergency recovery implementation plan (CERIP)” in 2020 [28], whose aims include the definition of procedures and methods for pest management planning, the design and execution of activities to be funded, and the establishment of monitoring and assessment systems for locust management practices across agro-ecosystems (see the plan for the full set of objectives). The Republic of Kenya has also implemented an “Emergency Locust Response Program” funded by the World Bank [29] to avoid desert locust—*Schistocerca gregaria* (Forskål 1775)—infestations through continuous monitoring and control, support households affected by infestations, and improve the early warning system. If we restrict the scope of our investigation to English-language documents (e.g., via Google search engine, query: Examples of “plans” or “programs” to address locusts, and similar combinations of keywords), there is a certain lack of regional or subregional plans that consider and address locust infestations.

Furthermore, although planning tools can steer land-use and land-use changes, we did not find any specific study regarding the role of such tools as an entry point to contribute to addressing locust outbreaks. Then, this is a research gap we aim to fill, although we are aware that this study may not provide the reader with fully exhaustive answers. The research question is: can we provide spatial planners with a minimum set of criteria that may be considered in planning tools to contribute to improving the fight against locust infestations?

As we speculate that spatial planning may contribute to improving the strategies to address locust infestations, and considering the lack of research on this topic, we propose a methodological approach based on useful criteria for addressing the issue of acridid infestation management in regional and/or subregional plans. As land-use management influences Moroccan locust population dynamics [3,9], the purpose is to promote the integration of concepts underlying these criteria into planning tools. This integration will guide practices toward prevention strategies, in the context of climate change resulting in more extreme weather events, which can affect the development and spread of pests, including locusts [9,30]. To do so, we developed an assessment system including criteria distilled from scientific literature and validated it for scrutinizing plans adopted in Sardinia (Italy).

The manuscript unfolds as follows. In Section 2, we describe the materials and methods. First, we distill from scientific literature criteria, which can be adopted to assess the performance of planning tools in terms of locust infestation management and prevention. Secondly, we define the score system, which has been inspired by previous research, and thirdly we set the sample of plans to be scrutinized. In Section 3, we present the findings. The results show that the regional plan received a positive evaluation while the municipal master plan scored very poorly against all the criteria. In Section 4, we discuss the findings in the context of the evidence emerging from previous international research, according to a comparative approach, and point out some critical considerations. Finally, in Section 5, we summarize the concluding remarks and point out the main limitations of this study.

2. Materials and Methods

We aim at assessing how far locust infestations permeate a regional and a municipal master plan adopted in Sardinia. In this regard, content analysis proved to be adequate to scrutinize different types of documents [31–34]. As an example, Mascarenhas et al. [34] adopted a mix of qualitative and quantitative methods to scrutinize policy and guidance documents, while De Montis et al. [32] performed a comparative and qualitative approach

for scrutinizing strategic environmental assessment guidelines released in European administrations. In this study, we adopted a content analysis and followed De Montis et al. [35] who (i) distilled criteria from scientific literature, (ii) defined a score system, and (iii) set the sample of plans to be scrutinized, with the purpose of figuring out to what extent green infrastructures were introduced in a set of regional plans and programs. In the next subsections, we describe study area, target species (i.e., *Dociostaurus maroccanus*), assessment criteria, scoring system, and the sample of plans investigated.

2.1. Study Area

The study was conducted in Sardinia, the second largest island in the Mediterranean Sea (approximately 24,000 km²), located in the western Mediterranean Basin (Figure 1A). The island is characterized by a Mediterranean climate, with mild, relatively wet winters and hot, dry summers, and is predominantly classified as a Mediterranean pluviseasonal oceanic macrobioclimate [36,37]. Rainfall is concentrated mainly between October and May, with annual precipitation ranging from less than 400 mm in the driest coastal areas to more than 1300 mm in the inland mountains [38], whereas the summer months are typically dry.

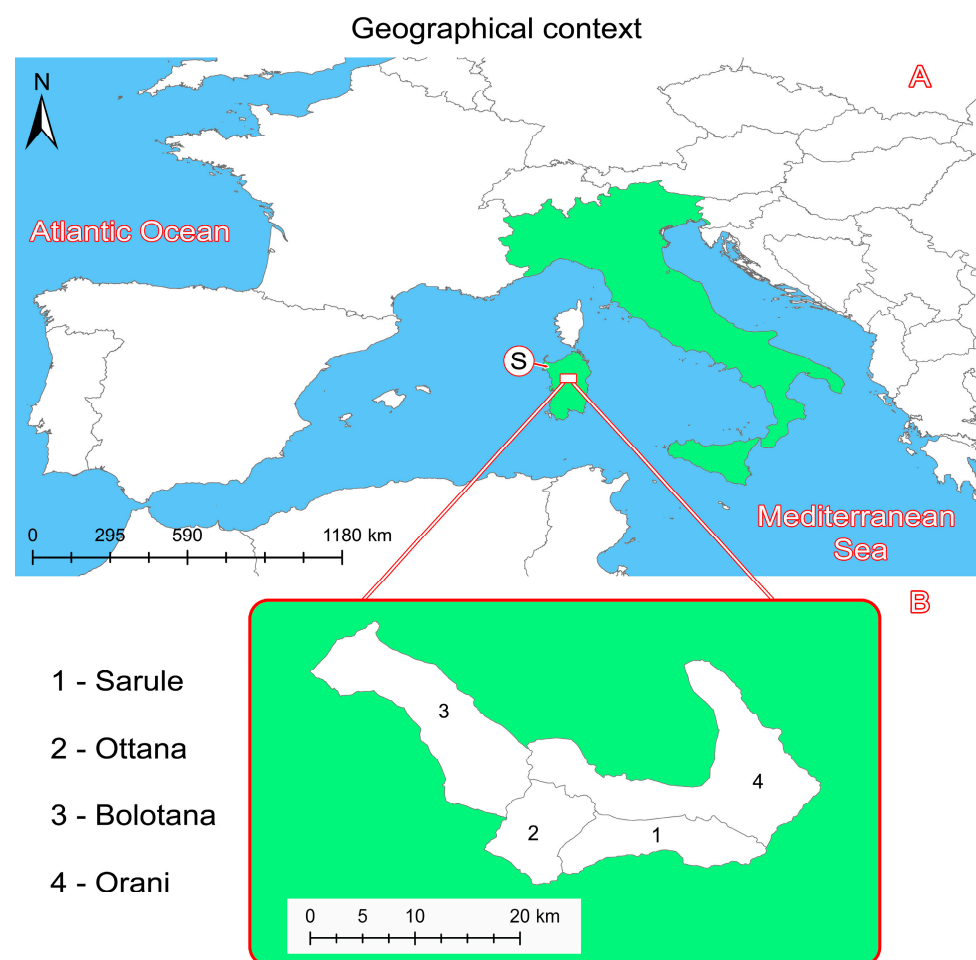


Figure 1. Geographical context. (A) Italy (in green), southern Europe; “S” means island of Sardinia. (B) The four municipalities (in white, borders in grey) investigated in this research: 1, Sarule; 2, Ottana; 3, Bolotana; 4, Orani.

The municipalities of Sarule, Ottana, Bolotana, Orani, located in the middle Tirso River valley, in central Sardinia (Figure 1B), were selected because they have experienced recurrent outbreaks of the Moroccan locust since the beginning of 1900. In the outbreak from 2019–2024, the four municipalities were the most severely affected by *Dociostaurus*

maroccanus on the entire island [9]. Mean annual temperature is approximately 17 °C, with marked seasonal variation, including summer temperatures exceeding 40 °C and winter temperatures occasionally falling below 0 °C, whereas mean annual precipitation is about 500 mm [37]. Soils are predominantly shallow, often with exposed bedrock, and have a sandy loam to loam texture, with alluvial deposits occurring along the Tirso River and its main tributaries. Land use is dominated by extensive livestock farming, with large areas of permanent pastures, often affected by overgrazing, interspersed with abandoned agricultural land and Mediterranean shrub communities. The area is highly susceptible to land degradation and desertification and is classified as “Fragile”, according to the Environmentally Sensitive Area Index (ESAI) [39]. Vegetation is typical of Mediterranean agro-pastoral ecosystems, including herbaceous grasslands, scattered oak woodlands, and Mediterranean shrub communities [40]. The combination of semi-arid climatic conditions, overgrazed pastures, abandoned farmland, and degraded open habitats creates favorable ecological conditions for the establishment and proliferation of the Moroccan locust.

2.2. Target Species

The Moroccan locust (Figure 2) is one of the most important species in terms of economic damage in the Mediterranean Basin, North Africa, the Middle East, the Caucasus, and Central Asia, where recurrent outbreaks periodically threaten agricultural production and pastoral systems [41]. The species is univoltine, completing one generation per year. Eggs are laid in compact, bare or sparsely vegetated soils, during summer. Overwintering occurs in the soil, and nymphs hatch in spring and pass through five instars before reaching adulthood in late spring or early summer. Adult females subsequently oviposit in suitable breeding sites, completing the annual life cycle [3].

Doclostaurus maroccanus exhibits density-dependent phase polyphenism, alternating between a solitary phase, in which individuals occur at low densities and cause limited damage, and a gregarious phase characterized by marked behavioral, physiological, and morphological changes. Under favorable environmental conditions and increasing population density, nymphs aggregate into marching bands and adults may form highly mobile swarms capable of dispersing over 50 km during their lifetime [3]. These outbreaks can rapidly expand across administrative boundaries, making coordinated management essential.

The species preferentially breeds in semi-arid environments characterized by open habitats, sparse vegetation, dominated by xerophytic *Poaceae* species, compact soils, and extensive grazing systems. Land abandonment, overgrazing, vegetation degradation, and favorable climatic conditions can increase habitat suitability and promote population outbreaks [9,42]. During gregarious outbreaks, swarms consume a wide variety of herbaceous vegetation, including natural pastures and cultivated crops, causing severe ecological and economic losses. Recent studies also suggest that ongoing climate change may further increase the frequency and spatial extent of outbreaks in several regions of Eurasia by creating increasingly favorable environmental conditions for the species [3].

Locust management in Sardinia has historically relied on control campaigns implemented during outbreak periods rather than on continuous prevention and early warning systems. Because major outbreaks recur at relatively long intervals (approximately every 15 years), surveillance and monitoring activities tend to decline after the emergency has ended. This pattern is consistent with the anti-locust cycle described by Gay et al. [43], whereby investments in monitoring and preventive management increase during severe outbreaks but progressively decrease afterwards, leaving territories insufficiently prepared when new outbreaks occur. During the most recent outbreak, the Autonomous Region of Sardinia adopted the Action Plan to Control and Manage Acridid Infestations [44] to

strengthen monitoring and coordinate control activities. However, a permanent monitoring network and an operational early warning system have not yet been established. This context further highlights the importance of integrating long-term prevention measures into spatial planning.

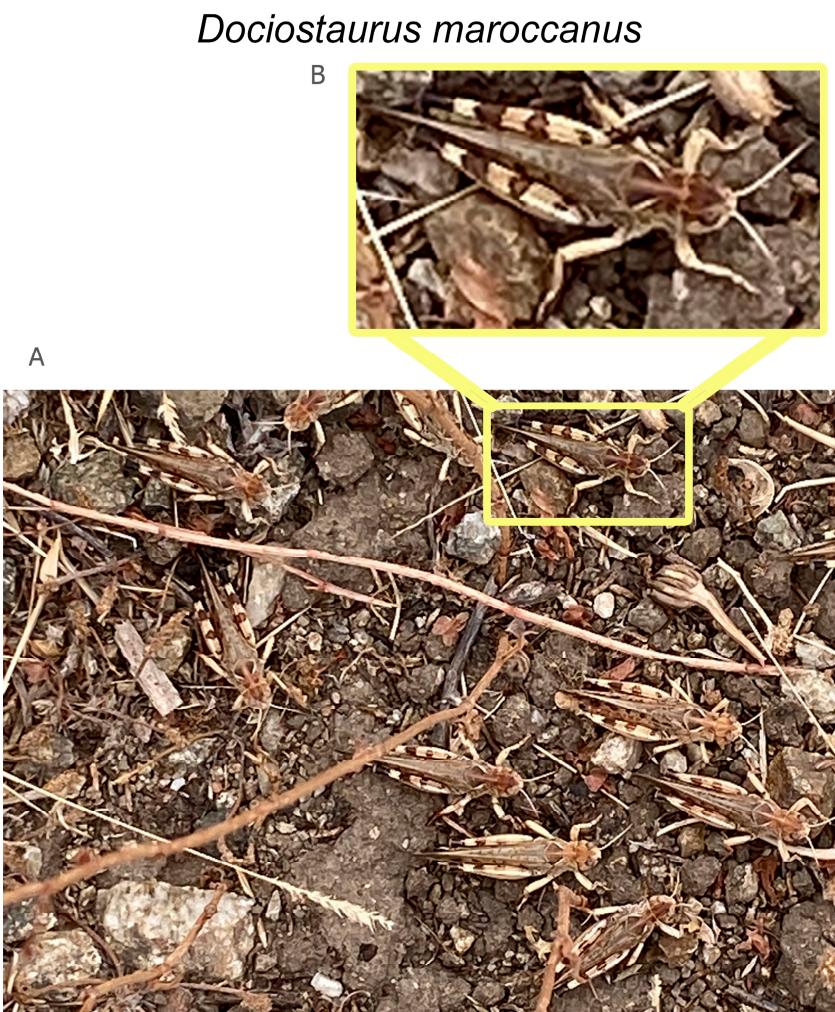


Figure 2. *Dociostaurus maroccanus*. (A) Gregarious adults. Photograph by the authors, previously published in Klein et al. [9], reused under the CC BY 4.0 license. (B) Focus on a locust.

2.3. Defining the Assessment Criteria

The method consisted of analysis and synthesis of scientific literature (Table 1). This activity was aimed at identifying useful criteria for the integration of prevention strategies for acridid infestations into planning tools.

Table 1. Keywords used.

Keywords	SCOPUS—Article (Article Title, Abstract, Keywords), Sort by Relevance	Web of Science (Web of Science Core Collection)—Article (Topic), Sort by Relevance	Google (Pages)
“locust” AND “spatial planning”	1	1	29
“ <i>Dociostaurus maroccanus</i> ” AND “spatial planning”	0	0	4
“ <i>Dociostaurus maroccanus</i> ” AND “plans”	0	1	28
“locusts” AND “plans”	69	2	38
“locusts” AND “programs”	237	19	36
“locusts” AND “prevention”	151	31	33

Source: SCOPUS, Web of Science, and Google Search: 15 June 2026.

The scientific foundation of this study is based on peer-reviewed journal articles (research articles and review articles), with the purpose of ensuring the highest possible quality of scientific sources. The selected set of articles was filtered to identify the publications most relevant to the objectives of the study. The filter consisted of reading the (i) title, (ii) abstract (and/or the content of the web page for Google results) and (iii) keywords of the journal articles, which allowed the authors to assess the pertinence of the study in relation to the research scope. Only the articles satisfying this initial eligibility assessment were subjected to content analysis. The content analysis was performed by the authors of this research, who have academic background in spatial and landscape planning and climate change adaptation governance. Furthermore, both the criteria and results were checked by an entomologist with expertise in locust infestations. The entomologist coauthored this research. Overall, six participants with different roles were involved. The research team consisted of two associate professors, a researcher, and three collaborators. All participants hold a PhD.

Twenty publications have been selected based on titles, abstracts and keywords. After reading the entire papers, eleven publications have been filtered out.

In the selected nine journal articles listed in Table 2, the following issues are discussed. Saha et al. [45] investigated the modeling of current and future potential desert locust distributions under climate change scenarios using the machine learning algorithm MaxEnt 3.4.1. According to the authors, potential invasion risk maps can contribute to resource-efficient management of the phenomenon. Peng et al. [6] focused on a review of studies on historical and recent locust infestations, introducing links to effects of climate change, food security, and mitigation strategies. The authors emphasize the role of global warming as a likely primary cause of locust infestations. The study highlights solutions for exploiting and preventing infestations. Regarding exploitation, locusts can be considered an excellent source of protein in livestock farming, as they can be used as feed for farm animals. Among control/prevention tools, useful solutions include the use of bacteria, fungi, poisonous plant species, and parasitic wasps, reforestation combined with late season crops such as soybeans (*Glycine max*) and alfalfa (*Medicago sativa*), and grazing strategies for livestock. Yao et al. [46] developed a WebGIS-based decision support system designed for locust control and prevention. This tool integrates real-time data synchronization strategies—based on the use of the Global Positioning System (GPS)—that are useful, for example, for tracking the location of the (i) personnel involved in infestation control and (ii) goods transport vehicles. In addition, it integrates a locust population estimation model to assess their spatial distribution. Cressman [47] presented an overview of the strategic importance of remote sensing in desert locust early warning system. Such a system is structured on three levels: at the field level, with field surveys where operators record and transmit—in real time and via satellite—observations on ecological conditions, locust populations, and control treatments; at the national level, where officials collect and correct data and, therefore, data are analyzed using a customized geographic information system (GIS) for preparing national locust bulletins; at the international level, where the Food and Agriculture Organization (FAO) receives data from national centers and imports it into a GIS platform. Such a platform allows for the querying, visualization, comparison, and mapping of (i) locust, (ii) ecological, (iii) rainfall, and (iv) historical data to assess the current scenario and forecast future developments. The author emphasizes the ability of the GIS to rapidly manage, analyze, and archive huge amounts of data, a feature that, combined with its effectiveness, is a key factor when dealing with insects that can pullulate exponentially in swarms able to move rapidly across continents. Remote sensing, which plays a fundamental role in identifying changes in locust habitats, also plays a key role in locust infestation management. Lecoq [48] emphasized the role of GPS technology as support to ground observation. The author notes a critical issue regarding the sustainability of preventive control systems in the world's poorest countries, which typically have limited financial resources to finance

intensive control campaigns and prevention activities. Lecoq [48] pointed out the need to allocate adequate funds and define emergency action plans for sustainable locust control. Showler et al. [49] focused on the desert locust and on three approaches for managing its infestations, which consist of reaction, pro-action, and outbreak prevention. The authors identify pro-action and prevention as two effective approaches to mitigating (pro-action) and preventing (prevention) the phenomenon to a certain extent. In addition to the need for adequate funding, improved and sustainable coordination among stakeholders at different levels is recognized as a requirement to prevent epidemics. Zhang et al. [50] reviewed the progress made and the areas where further improvements are needed in the management of locusts and grasshoppers. GIS, GPS, remote sensing, and information technology /computer science play a key role in preventive locust management. Among desirable improvements in the management of the phenomenon, unmanned aerial vehicles (UAVs) and drones could be very useful for the timely detection and treatment of locusts and grasshoppers. The need for continued financial support (nationally and internationally, when appropriate) is emphasized to implement control programs promptly. Lockwood et al. [51] investigated the sustainable management of locusts and grasshoppers and emphasized the key role of science. Indeed, a socially and economically viable approach to managing infestations, but lacking adequate technical and scientific considerations, risks being unsustainable. A sustainable management system should be based on multitasking (involving individuals in multiple, related pest management activities) and preventative (with focus on monitoring) strategies. Baraka et al. [52], citing studies by Lecoq [48] and Alemu and Neigh [53], recognized the role of GPS, GIS, and UAVs for land exploration in managing the desert locust. Nevertheless, potential technical failures in UAVs can raise safety concerns (e.g., interference with civil aviation routes and the risk of causing accidents) [52]. Based on the literature review, this paper proposes a synthesis of criteria that should be met into land and landscape management plans to address locust infestations (see Table 3).

Table 2. Scientific articles selected after screening.

	Titles	In Text Quotation	Journal
1	Modeling current and future potential distributions of desert locust <i>Schistocerca gregaria</i> (Forskål) under climate change scenarios using MaxEnt	Saha et al. [45]	<i>Journal of Asia-Pacific Biodiversity</i>
2	A review of historical and recent locust outbreaks: Links to global warming, food security and mitigation strategies	Peng et al. [6]	<i>Environmental Research</i>
3	A WebGIS-based decision support system for locust prevention and control in China	Yao et al. [46]	<i>Computers and Electronics in Agriculture</i>
4	Role of remote sensing in desert locust early warning	Cressman [47]	<i>Journal of Applied Remote Sensing</i>
5	Recent progress in Desert and Migratory Locust management in Africa. Are preventative actions possible?	Lecoq [48]	<i>Journal of Orthoptera Research</i>
6	Early Intervention against Desert Locusts: Current Proactive Approach and the Prospect of Sustainable Outbreak Prevention	Showler et al. [49]	<i>Agronomy</i>
7	Locust and grasshopper management	Zhang et al. [50]	<i>Annual Review of Entomology</i>
8	Can we make locust and grasshopper management sustainable?	Lockwood et al. [51]	<i>Journal of Orthoptera Research</i>
9	Threats of desert locust management to people and the environment	Baraka et al. [52]	<i>International Journal of Environmental Science and Technology</i>

Table 3. Criteria for the assessment of the plans.

Code	Criterion (CR)	References
CR01	The plan includes potential invasion risk map	[45]
CR02	... suggests the use of bacteria, fungi, poisonous plant species, wasps, mites, spiders and birds, reforestation interventions combined with late crops such as soybeans, alfalfa and fruit trees, grazing strategies for livestock to reduce the risk of infestations	[6]
CR03	... suggests solutions based on the use of GIS and/or WebGIS and/or remote sensing (in general) and drones to frame the territorial distribution of locusts and plan and implement control measures	[46–48,50,52]
CR04	... clarifies the sources of funding and the resources to be allocated each year for prevention campaigns	[48,49]
CR05	... has also been drafted based on scientific evidence.	[51]

2.4. Defining the Scoring System

The score system (Table 4) is inspired by Baker et al. [54], Cortinovis and Geneletti [55], and De Montis et al. [35]. We employed a qualitative and quantitative approach. In other words, we first assign the criteria a label (A, B, C, D, E) that summarizes our assessment and then we also transformed the qualitative score into a quantitative one. Especially on large samples of documents to be scrutinized, the quantitative assessment allows us to (i) numerically summarize the average performances, (ii) make numerical comparisons, (iii) calculate standard deviations, and (iv) obtain graphs. The method is designed to be applied to both small and large sets of plans.

Table 4. Score system.

Score		Motivation
Qualitative	Quantitative	
A—Excellent	1	The plan fully satisfies the criterion, as it provides every possible detail needed.
B—Good	0.75	... almost fully satisfies the criterion.
C—Acceptable	0.5	... partially satisfies the criterion as it provides some details.
D—Barely acceptable	0.25	... merely mentions the criterion and does not provide details.
E—Completely unsatisfactory	0	The plan does not consider the criterion at all.

In Table 4, in the first column, we assign a letter (A, B, ..., E) and in the second column a quantitative score (from 1 to 0) based on the reasons listed in the third column. The third column summarizes the rationale behind the score assigned to each criterion.

Each criterion was assigned a score from 0 (criterion not met) to 1 (fully met). Intermediate scores were assigned when the criterion was partially met. The assessment was performed by the authors of this research who are experts in spatial and landscape planning and climate change adaptation.

2.5. Defining the Sample of Plans to Be Scrutinized

In the second phase, we focused on the plans adopted in the Autonomous Region of Sardinia (Italy; Figure 1A). The regional and subregional plans were examined against the criteria listed in Table 3 to evaluate their performance in managing locust infestations. In this study, the Action Plan to Control and Manage Acridid Infestations in Sardinia [44] and plans adopted by municipalities located in areas particularly prone to infestations in recent years, before 2025 (Figure 1B; Table 5), were selected. As for the regional Action Plan, we also scrutinized the operational plan for phytosanitary actions (in Italian, Piano operativo degli interventi fitosanitari; [56]) and the guidelines for identifying measures to manage and counteract locust infestations in Sardinia (in Italian, Linee guida per l'individuazione delle misure di contenimento e di contrasto alla diffusione del fenomeno delle infestazioni acridiche in Sardegna; [57]) as these documents are listed on the same webpage as the Action Plan [44].

Table 5. Selected municipalities and adopted plans. PUC stands for “Piano Urbanistico Comunale”, the latest generation municipal master plan. PRG stands for “Piano Regolatore Generale”, namely the general regulatory plan, an old label of the Sardinian municipal master plan; PdF stands for “Programma di Fabbricazione”, namely a building program, a very old typology of municipal master plan.

Municipality	Spatial Tool Type ¹	Year (Update)	Plan Available Online
Bolotana	PUC	1995 (2008)	Yes
Orani	PRG	1983 (2008)	No
Ottana	PUC	2000 (2009)	No
Sarule	PdF	1975 (2011)	No

¹ Link: <https://www.sardegna.territorio.it/urbanistica/pianiurbanistici.html> (accessed on: 20 July 2026).

Municipal plans play an indirect—but potentially strategic—role in preventing locust and grasshopper infestations, through land-use management (for example, by regulating the use of agricultural areas falling within the so-called “E zones”) and ecosystem protection (for example, by protecting biodiversity and ecological networks, which helps preserve populations of natural enemies of locusts and avoids the creation of degraded monocultures that facilitate swarming). Furthermore, modern municipal plans should integrate climate change adaptation objectives and actions that, to some extent, contribute to influencing the locust lifecycle.

Only municipal master plans freely available online for download were considered.

Bolotana and Sarule are classified as “marginal municipalities” [58,59], and therefore already present significant critical issues that affect their development. The only plan available online as of 23 January 2025 was the municipal master plan (MMP) of Bolotana [60]. The MMP was adopted by City Council Resolution No. 54 of 6 June 1995 and approved by City Council Resolutions No. 82 of 28 September 1995 and No. 95 of 29 November 1995.

3. Results

This section summarizes the results obtained from the application of the method described in Section 2.

3.1. Scrutiny of the Regional Action Plan

The Autonomous Region of Sardinia has established a Territorial Unit for Phytosanitary Emergencies and adopted a plan (the so-called Action Plan) to control acridid infestations [44]. The Action Plan to Control and Manage Acridid Infestations (including the related documents [56,57]) was examined against the criteria listed in Table 3. The results are presented in Table 6.

Table 6. Evaluation of the Action Plan to Control and Manage Acridid Infestations in Sardinia.

Criterion (CR)	Description	Score	
		Qualitative	Quantitative
CR01	The plan includes potential invasion risk map	C	0.50
CR02	... suggests the use of bacteria, fungi, poisonous plant species, wasps, mites, spiders and birds, reforestation interventions combined with late crops such as soybeans, alfalfa and fruit trees, grazing strategies for livestock to reduce the risk of infestations	B	0.75
CR03	... suggests solutions based on the use of GIS and/or WebGIS and/or remote sensing (in general) and drones to frame the territorial distribution of locusts and plan and implement control measures	B	0.75
CR04	... clarifies the sources of funding and the resources to be allocated each year for prevention campaigns	B	0.75
CR05	... has also been drafted based on scientific evidence.	A	1.00
	Final score	1A, 3B, 1C	3.75 out of 5.00

Overall, the plan, which specifically addresses the issue of locust infestations, achieves a good score across all criteria. CR01 is partially met, because the plan includes maps of the areas affected by infestations of gregarious adult forms (in 2022). Considering all the actions reported in the plan (egg pod monitoring, nymph monitoring, natural enemy monitoring, georeferencing of infestation sites, assignment of an infestation probability class to each of the land-use categories, etc.), the maps referred to in CR01, even if not explicitly reported, would potentially be produced. CR02 is not fully met as the plan does not recommend the use of poisonous plant species, parasitic wasps, mites, spiders, and birds or grazing strategies for livestock to reduce the risk of infestations. However, it suggests a series of other measures, including the use of fungi and bacteria. As for CR03, the monitoring of oviposition in sample areas is planned according to the following protocol: (i) selection of macroareas with the highest probability of infestation, which involves the use of GIS support to identify potential breeding sites; (ii) selection of sampling areas, which includes monitoring via advanced technologies such as remote sensing and UAVs to map locust oviposition habitats and the environmental conditions that favor the transition from solitary to gregarious phases, through the use of red–green–blue (RGB), multispectral, and thermal imagery obtained from satellites. For the implementation of the plan (CR04), costs were estimated for the three-year period spanning August 2022 to July 2025, a timeframe within which the locust infestation was expected to be managed. The financial statement estimated costs amounting to 7,660,000 euros. According to the documentation, the Autonomous Region of Sardinia was expected to cover these projected costs; however, it remains unclear whether the region has effectively funded the entire amount. Regarding CR05, the regional funding (CR04) provided for the allocation of 300,000 euros to the Department of Agricultural Sciences, University of Sassari (Italy), which provided the scientific support required to implement the activities envisaged in the Action Plan. The Action Plan does not refer to the future effects of climate change. It only refers to meteorological data (rainfall, humidity, and temperature), with the aim of calculating the hydrothermal coefficient, the sum of growing degree days, and the hygrometric coefficient, which are usually used in relation to the insect's post-embryonic development stages.

3.2. Scrutiny of the Municipal Master Plan

The MMP of Bolotana was examined against the criteria listed in Table 3. The plan does not consider locust infestations at all: it does not meet any of the proposed assessment criteria or refer to the future effects of climate change. In Table 7, we report on the details of this scoring.

Table 7. Evaluation of the MMP of Bolotana.

Criterion (CR)	Description	Score	
		Qualitative	Quantitative
CR01	The plan includes potential invasion risk map	E	0.00
CR02	... suggests the use of bacteria, fungi, poisonous plant species, wasps, mites, spiders and birds, reforestation interventions combined with late crops such as soybeans, alfalfa and fruit trees, grazing strategies for livestock to reduce the risk of infestations	E	0.00
CR03	... suggests solutions based on the use of GIS and/or WebGIS and/or remote sensing (in general) and drones to frame the territorial distribution of locusts and plan and implement control measures	E	0.00
CR04	... clarifies the sources of funding and the resources to be allocated each year for prevention campaigns	E	0.00
CR05	... has also been drafted based on scientific evidence.	E	0.00
	Final score	5E	0.00 out of 5.00

4. Discussion

This study presented an assessment system based on five criteria for promoting the integration of issues related to acridid infestations into planning tools, thus guiding practices towards prevention strategies. The findings directly address the research question posed in Section 1, namely, can we provide spatial planners with a minimum set of criteria that may be considered in planning tools to contribute to improving the fight against locust infestations?. In this study, we addressed a research topic scarcely considered in scientific literature as we did not find any international research (in journal articles in English) whose focus was on a methodological approach to assess the effectiveness of planning tools to address locust infestations.

We demonstrate that it is possible to define a minimum set of scientifically grounded criteria that can be used to assess whether planning tools adequately incorporate measures for the prevention and management of locust infestations. The application of the assessment system to the Sardinian case study further shows that these criteria are operational and capable of identifying both strengths and critical gaps in existing planning instruments. Below we discuss the novelty of the findings in the scientific panorama and how the set of criteria may contribute to introducing locust outbreak considerations into plans closely related to spatial planning issues.

4.1. Regional Action Plan

Positive aspects and some critical issues emerge. At the regional level, the Action Plan to Control and Manage Acridid Infestations received a positive evaluation against the five criteria. The plan addresses locust infestations and includes maps of the areas affected by infestations of gregarious adult forms (CR01 partially met), which is not a map

of potential invasion risk [45]. However, considering all the adopted actions reported in the plan, a map of potential invasion risk could be produced. Maps assisting management actions against locust outbreaks may support governments in tracking locust swarms, forecasting locust outbreaks, and preventing further locust infestations [61]. The regional plan suggests the use of bacteria and fungi (and other solutions not included in the set of evaluation criteria) to reduce the risk of infestations [6] (CR02). This is important as entomopathogens can be effective in the biological control of locusts [62,63]. Protecting the habitats and biotopes of locust natural enemies (e.g., fungi, bacteria, parasitoids, predators, birds) is crucial, considering their role in maintaining the ecological balance [64]. However, in some cases, additional studies are needed to assess the long-term effects of bacteria on non-target organisms as well as on the environment (e.g., see Muhammad et al. [63]). The Action Plan indicates solutions based on the use of GIS and drones to map the spatial distribution of locusts [46–48,50,52] (CR03). The plan defines a sampling protocol for monitoring the oviposition in breeding areas, via GIS, remote sensing, and UAS. Locust infestation risk assessment can be improved with data acquired through remote sensing and related technologies [65]. Preventive management actions in breeding areas would benefit from this data [65]. The plan clarifies the funding sources and the amount to be allocated annually to prevention campaigns [48,49] (CR04). This is a critical element, as locust control depends on several factors, including financing and political will, which are defined as “structural bottlenecks” by Panopoulou and Tsagkarakis [8]. Effective locust management requires stable funding mechanisms for prevention [8]. Finally, the Action Plan was drafted in collaboration with universities ([51]; CR05), i.e., the University of Sassari. In this regard, Word Ries et al. [66] emphasized that the translation of fundamental research concerning locusts into successful monitoring and control relies on “interactive feedback and collaboration between scientists, locust control teams, and affected communities” [66]. Word Ries et al. [66] also provided an extensive overview on the role of universities and researchers in the field of locust management. Although the regional Action Plan achieved a good score, this does not mean that the plan is perfect but rather that it is consistent with a set of elements that need to be considered to address and/or prevent locust infestations.

4.2. Municipal Master Plan

As for the MMP of Bolotana, critical aspects concern the consideration of acridid infestations. The MMP currently lacks references to acridid infestations. In Italy, an MMP represents the main instrument through which a municipality regulates the development and use of its territory. Zoning defines residential areas, industrial areas, commercial areas, agricultural areas, natural and environmental protection areas, and areas intended for public services. Although an MMP is not intended as a tool to address locust infestations, it may contribute to addressing the phenomenon in terms of prevention. In other words, the MMP regulates the use of agricultural land through regulations. For these areas, the MMP could incorporate guidance or normative documents, suggestions and advice from entomologists, biologists, and agronomists, as well as other experts with documented experience in controlling locust infestations, to promote prevention. The locust thrives in areas with sparse—or in some cases completely absent—vegetation, dominated by *Poa bulbosa*, where the soil appears compacted by livestock overgrazing [56]; the MMP may provide farmers with guidance or a local management plan for preventing outbreaks. Furthermore, the MMP may promote the reduction of agricultural land fragmentation and pulverization, which often lead to land abandonment and the subsequent establishment of shrublands and forests, with a progressive and irretrievable loss of land value (e.g., in Lombardy, Italy; CREA [67]). Land fragmentation means “when there are several small land plots, all belonging to a single owner and that do not form a single acreage but distinct

allotments, interspersed with land plots pertaining to third parties” (Chessa [68] quoted by Asciuto et al. [69]), while pulverization means “the division of land property in such small parts that cannot guarantee a sufficient income to the farmer, who is therefore compelled to neglect his property and to find a job elsewhere in order to support his income” (Chessa [68] quoted by Asciuto et al. [69]). Pulverization of agricultural land constitutes a distinctive and persistent feature of Italian land property organization, which mainly depends on the right of succession [69]. As a countermeasure, for example, the MMP of Sassari (Sardinia, Italy) promotes projects for stemming the pulverization in its peri-urban area [70]. Such projects are intended to be developed under the umbrella concept of the Municipal Agricultural Park (in Italian, Parco Agricolo Comunale) and include the reduction of settlements in rural areas, emphasizing the agricultural purpose of the plots of land [70], which is compatible with the need for defragmentation and de-pulverization.

The Autonomous Region of Sardinia might provide guidelines for drafting a municipal locust management plan and each municipality could determine technically and economically sustainable activities to include them in such a municipal plan, according to its context-specific characteristics. Something similar has been done by the Emilia-Romagna region (Italy), which has released guidelines for drafting a municipal mosquito management plan.

As a final reminder, it should be kept in mind that locust outbreaks are not limited to the boundaries of specific municipalities. Moroccan locusts may travel more than 50 km during their lifespan [41], making infestations a supra-municipal issue that requires coordination beyond administrative borders. Consequently, effective prevention and control strategies should be planned and implemented at a broader territorial scale, promoting information sharing, synchronized monitoring activities, and coordinated interventions among neighboring municipalities. Therefore, municipalities affected—or expected to be affected—by infestations should implement shared and coordinated strategies and measures. Although municipal master plans primarily regulate land use within the administrative boundaries of individual municipalities, they may promote inter-municipal cooperation by incorporating common management objectives, referring to regional guidelines, and encouraging coordinated actions through agreements with neighboring municipalities and the Autonomous Region of Sardinia. This area-wide approach has already been adopted in transboundary locust management programs coordinated and supported by the FAO in Central Asia, where cooperation among different jurisdictions is considered essential for effective monitoring, early warning, and control of locust populations [71]. However, it is worth mentioning that many Sardinian municipalities are classified as “marginal areas”, i.e., “as contexts rich in natural resources that are characterized by a lack of infrastructure, are significantly far away from essential services, and suffer from sociodemographic and economic difficulties, such as depopulation, unemployment, and low incomes” [59]. In this context, small municipalities may face a shortage of adequate resources to address locusts and need to be supported by regional, national, and European institutions. From a practical perspective, effective prevention also depends on the active involvement of local communities, particularly farmers and livestock breeders. Successful prevention also requires the maintenance of local expertise, continuous surveillance, and effective communication among researchers, plant protection services, public authorities, and land managers, as the loss of institutional knowledge between outbreaks can compromise preparedness for future infestations; preventive measures should include avoiding prolonged overgrazing, limiting land abandonment where feasible, monitoring potential breeding sites during the oviposition and hatching periods, and promptly reporting early signs of locust aggregation to the competent authorities [9,43,48,50]. At the municipal level, coordinated land management, regular surveillance of historically infested areas,

and cooperation among neighboring municipalities should complement regional monitoring programs [43]. These actions are considerably more effective and less costly when implemented before populations reach the gregarious phase [43].

4.3. Climate Change Consideration in the Plans

The plans scrutinized in this study did not address the effects of climate change on locusts. This is relevant to this research as climate “change experts predict more extreme weather including droughts, floods and cyclones. Whereas locust numbers decrease during droughts, locust outbreaks often follow floods and cyclones. If not controlled, these outbreaks can lead to plagues” [72]. In general, we recommend that the Autonomous Region of Sardinia and the municipalities particularly affected by locust infestations update their plans considering the adoption of both the National Climate Change Adaptation Strategy and Plan and the Sardinian Regional Adaptation Strategy. Some adaptation measures based on the use of nature-based solutions could help mitigate locust infestations (see, for example, CR02 regarding reforestation interventions combined with late season crops).

4.4. Validation of the Criteria

Finally, the emphasis is on the minimum set of criteria we provide to spatial planners and/or practitioners interested in locust infestations. We have sought to advance research with a small contribution, with emphasis on the proposal of assessment criteria that can be used to both evaluate the quality of plans *ex post* (i.e., after adoption) and integrate key aspects of locust infestation prevention *ex ante* (i.e., within the context of the planning process, from the early stages). This is the main original contribution of this research as no previous study proposed and applied assessment criteria (assessment framework) on plans with the purpose of investigating their performance in terms of locust outbreak prevention.

To the best of our knowledge, this is the first study to translate current knowledge on locust ecology, monitoring, and management into a structured assessment framework specifically designed for spatial planning. Previous studies have mainly focused on locust biology, remote sensing, ecological modeling, early warning systems, or pest management techniques [3,8,42,46]. In contrast, our approach bridges entomology and planning tools (or planning tools closely related to spatial planning issues as the regional Action Plan) by proposing a practical set of planning criteria that can be systematically applied to evaluate regional and subregional plans. This methodological contribution may also be adapted to other regions affected by *Dociostaurus maroccanus* or similar locust species.

On the other hand, the methodological approach is not new, because the use of plan assessment frameworks is well established in other fields of research [35,73–77]. Such an assessment approach adds transparency to the evaluation [76]. In this regard, we tested a scientifically sound methodological approach to a new research topic and proved its applicability.

5. Conclusions

As scientific literature has scarcely addressed this topic, we aimed to provide spatial planners with a minimum set of criteria that may be considered in planning tools to contribute to improving rational and integrated management of locust infestations. We focused on finding a minimum set of criteria that should be satisfied by plans that have a leading role in the development and management of territories that may be affected by locust outbreaks. Thus, we identified five criteria and validated them by scrutinizing a regional and a subregional plan closely related to spatial planning issues. The main findings show that, although four out of five criteria are not fully met, the regional Action Plan shows good performances as it: includes maps of the areas affected by infestations of

gregarious adult forms that can be integrated to obtain a map of potential invasion risk; suggests the use of bacteria and fungi to reduce the risk of infestations; indicates solutions based on the use of GIS and drones to map the spatial distribution of locusts; clarifies the funding sources and the amount to be allocated annually to prevention campaigns; was drafted in collaboration with universities, i.e., the University of Sassari (Italy). On the other hand, the MMP examined in this research currently lacks integration of considerations concerning locust infestation. None of the plans refer to climate change.

In terms of practical implications, the regional Action Plan already provided those responsible for locust outbreak management with well-founded scientific measures, if we consider the current state of the art. As for the MMP, it is not intended as a tool to address locust infestations. Thus, it is not surprising that it does not address the issue. However, the MMP has effect on land-use and land-use changes, which in turn can play a role in locust outbreaks. In this regard, the five criteria proposed in this study might be part of updates of the MMP. Future updates to the MMP should at least take locust infestations into account and integrate ad hoc guidance (e.g., in the form of an annex) to address the phenomenon at the local level, in addition to the framework of actions already recommended by the Autonomous Region of Sardinia through the Action Plan to Control and Manage Acridid Infestations.

This study can contribute to locust outbreak prevention by providing public administrations with a minimum set of criteria, derived from scientific literature, which can be integrated into regional and municipal planning tools (or planning tools closely related to spatial planning issues such as the regional Action Plan). By combining entomological knowledge and a planning assessment framework, the proposed methodology provides a practical tool aimed at supporting planners and decision-makers in integrating long-term prevention strategies into territorial governance. However, this study has several limitations that need to be addressed in future research.

First, it is quite difficult to find similar research and compare the findings as scientific literature does not offer many studies dealing with the same topic (spatial planning and locust infestations). The study is rooted in an international scientific basis but its comparison with other studies may be difficult.

Second, the proposed criteria have a solid theoretical framework and should be further validated through practical experience and real-world applications. In fact, the inclusion of a measure in a plan does not necessarily imply its full implementation, as financial resources, technical capacity, administrative constraints, and political commitment may affect the extent to which planned actions are effectively carried out. Additionally, all criteria were given equal weight (i.e., criteria with mutually relative importance), a rather simplistic approach. Experts in locust management, who have different cultural backgrounds, should be involved in defining the weights of each criterion.

Third, the sample of plans scrutinized is quite small and therefore the significance of the findings is not representative of the full set of plans adopted in Sardinia by municipalities that are potentially targeted by locust outbreaks. Furthermore, future research should also consider regional action plans adopted by other Mediterranean European regions affected by the same plague to investigate common critical issues and exportable solutions/best practices.

Fourth, as for distilling the criteria, we focused on a subset of publications (journal articles in English), and other key factors included in conference papers and book chapters and publications released in other languages might have been overlooked.

Fifth, we did not investigate if the plans integrate implicit measures to address the effects of climate change, which can contribute to promoting locust outbreaks. This is relevant to future updates of the plans, in light also of the European, Italian, and Sardinian

strategies for adaptation to climate change. Furthermore, we assessed the plans against the set of criteria without considering implicit actions that may contribute to addressing locust outbreaks.

In future research, we intend to address these limitations, focusing on three aspects: (i) improving the assessment framework by introducing weights for each criterion based on interviews with specialists from other disciplines. We aim at involving entomologists, biologists, and agronomists, as well as other experts with documented experience in controlling locust infestations, to promote prevention. This will be relevant to assign weights to the criteria according to a bottom-up approach. Moreover, (ii) we assessed the plans against the set of criteria without considering implicit actions that may contribute to addressing locust outbreaks. Then, in a 2.0 version of this study, we aim at also investigating this issue (i.e., if the plans include implicit measures/actions useful for mitigating or avoiding locust outbreaks). The final aspect (iii) concerns the scrutiny of other plans, programs and projects, adopted in Mediterranean contexts, to verify whether and how preventive measures against locust infestations have been introduced.

Author Contributions: Conceptualization, A.L.; methodology, A.L.; validation, A.C., V.S. and G.C.; formal analysis, A.L.; investigation, A.L., A.C., V.S., G.C., D.T. and A.D.M.; data curation, A.L., V.S. and G.C.; writing—original draft preparation, A.L.; writing—review and editing, A.L., A.C., D.T. and A.D.M.; supervision, A.L., A.C. and A.D.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research is supported by the project titled “Studio dei fattori predisponenti le infestazioni acridiche in Sardegna e sviluppo di sistemi di monitoraggio e controllo innovativi e sostenibili”, bando interno per la ricerca collaborativa tra ateneo di Sassari e ateneo di Cagliari (internal call for collaborative research between the University of Sassari and the University of Cagliari, Italy)—DM737/2021 risorse 2022–2023, funded by the European Union NextGenerationEU.

Data Availability Statement: Data can be retrieved from the references.

Conflicts of Interest: The authors declare no conflicts 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.

Abbreviations

The following abbreviations are used in this manuscript:

CR	Criterion
e.g.,	Exempli Gratia (Latin for “for example”)
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GPS	Global Positioning System
i.e.,	Id Est (Latin for “that is”)
IPPC	International Plant Protection Convention
ISC	International Science Council
MMP	Municipal Master Plan
PdF	Programma di Fabbricazione (in English, Building Program)
PRG	Piano Regolatore Generale (in English, General Regulatory Plan)
PUC	Piano Urbanistico Comunale (in English, Municipal Master Plan)
RGB	Red–Green–Blue
UNDRR	United Nations Office for Disaster Risk Reduction
UAVs	Unmanned Aerial Vehicles

References

1. IPPC Secretariat. *Scientific Review of the Impact of Climate Change on Plant Pests. A Global Challenge to Prevent and Mitigate Plant-Pest Risks in Agriculture, Forestry and Ecosystems*, 1st ed.; FAO on Behalf of the IPPC Secretariat: Rome, Italy, 2021.
2. United Nations Office for Disaster Risk Reduction (UNDRR); International Science Council (ISC). UNDRR–ISC Hazard Information Profiles—2025 Update: BI0402 Locust Upsurge United Nations Office for Disaster Risk Reduction; International Science Council. Available online: <https://www.undrr.org/terms/hips/BI0402> (accessed on 8 June 2026).
3. Klein, I.; Devkota, R.S.; Ciplak, B.; Gapparov, F.; Nurjonov, F.; Cocco, A.; Floris, I.; Eisfelder, C.; Lazar, M.; Raissova, N.; et al. Climate Change May Promote Locust Outbreaks in Eurasia—Future of *Dociostaurus maroccanus* by Ecological Modelling. *Agronomy* **2026**, *16*, 749. [CrossRef]
4. Li, S.; Feng, S.; Ullah, H.; Tu, X.; Zhang, Z. IPM—Biological and Integrated Management of Desert Locust. *J. Integr. Agric.* **2022**, *21*, 3467–3487. [CrossRef]
5. Retkute, R.; Hinton, R.G.K.; Cressman, K.; Gilligan, C.A. Regional Differences in Control Operations during the 2019–2021 Desert Locust Upsurge. *Agronomy* **2021**, *11*, 2529. [CrossRef]
6. Peng, W.; Ma, N.L.; Zhang, D.; Zhou, Q.; Yue, X.; Khoo, S.C.; Yang, H.; Guan, R.; Chen, H.; Zhang, X.; et al. A Review of Historical and Recent Locust Outbreaks: Links to Global Warming, Food Security and Mitigation Strategies. *Environ. Res.* **2020**, *191*, 110046. [CrossRef] [PubMed]
7. Dobson, H.M. *Desert Locust Guidelines: 4. Control*, 2nd ed.; FAO: Rome, Italy, 2001.
8. Panopoulou, C.; Tsagkarakis, A. From Surveillance to Sustainable Control: A Global Review of Strategies for Locust Management. *Agronomy* **2025**, *15*, 2268. [CrossRef]
9. Klein, I.; Cocco, A.; Uereyen, S.; Mannu, R.; Floris, I.; Oppelt, N.; Kuenzer, C. Outbreak of Moroccan Locust in Sardinia (Italy): A Remote Sensing Perspective. *Remote Sens.* **2022**, *14*, 6050. [CrossRef]
10. de Groot-Reichwein, M.A.M.; Goosen, H.; van Steekelenburg, M.G.N. Climate Proofing the Zuidplaspolder: A Guiding Model Approach to Climate Adaptation. *Reg. Env. Change* **2014**, *14*, 909–918. [CrossRef]
11. Hlásny, T.; Haas, J. Managing Bark Beetle Outbreaks in the 21st Century. Policy Brief 2023. Available online: <https://foresteurope.org/wp-content/uploads/2023/07/Policy-brief-Managing-bark-beetle-outbreaks-in-the-21st-century.pdf> (accessed on 8 June 2026).
12. Morphet, J. *Effective Practice in Spatial Planning*; Routledge: London, UK, 2010.
13. European Commission: Directorate-General for Regional and Urban Policy. *The EU Compendium of Spatial Planning Systems and Policies*; Office for Official Publications of the European Communities: Luxembourg, 1997.
14. Davoudi, S.; Crawford, J.; Mehmood, A. (Eds.) *Planning for Climate Change: Strategies for Mitigation and Adaptation for Spatial Planners*; Routledge: London, UK, 2010.
15. United Nations. *Spatial Planning: Key Instrument for Development and Effective Governance with Special Reference to Countries in Transition*; UN: Geneva, Switzerland, 2008.
16. OECD. *Towards a New Role for Spatial Planning*; OECD: Paris, France, 2001.
17. Zhang, J.; Wang, Q.; Xia, Y.; Furuya, K. Knowledge Map of Spatial Planning and Sustainable Development: A Visual Analysis Using CiteSpace. *Land* **2022**, *11*, 331. [CrossRef]
18. Marucci, A.; Fiorini, L. Ecological Connectivity Guides Spatial Planning. In *Nature-Positive Cities: Adaptive Spatial Planning in Italy for an Ecological Urban Transition*; De Toni, A., Arcidiacono, A., Ronchi, S., Eds.; Springer Nature: Cham, Switzerland, 2026; pp. 49–59.
19. Bundschuh-Rieseneder, F.; Tischler, M.; Happacher, E. Spatial Planning. In *Climate Change Integration in the Multilevel Governance of Italy and Austria*; Brill Nijhoff: Leiden, The Netherlands, 2022; pp. 145–162.
20. Parks, L.; Bertuzzi, N. Introduction Climate Change Integration in the Multilevel Governance of Italy and Austria. In *Climate Change Integration in the Multilevel Governance of Italy and Austria*; Brill Nijhoff: Leiden, The Netherlands, 2022; pp. 1–22.
21. Ministry of Enterprises and Made in Italy. Innovative Approaches to Territorial Safety Planning Promoted by CTE SICURA [Nuovi Approcci Alla Pianificazione per La Sicurezza Territoriale Promossi Dalla CTE SICURA]. Available online: <https://portalecte.mimit.gov.it/index.php/cte/38-laquila/52-blog/139-nuovi-approcci-alla-pianificazione-per-la-sicurezza-territoriale-promossi-dalla-cte-sicura> (accessed on 8 June 2026).
22. Kumar, P.; Geneletti, D. How Are Climate Change Concerns Addressed by Spatial Plans? An Evaluation Framework, and an Application to Indian Cities. *Land Use Policy* **2015**, *42*, 210–226. [CrossRef]
23. Farrow, R.A. Effects of Changing Land Use on Outbreaks of Tropical Migratory Locust, *Locusta migratoria migratorioides* (R. & F.). *Int. J. Trop. Insect Sci.* **1987**, *8*, 969–975. [CrossRef]
24. Zhao, L.; Huang, W.; Chen, J.; Dong, Y.; Ren, B.; Geng, Y. Land Use/Cover Changes in the Oriental Migratory Locust Area of China: Implications for Ecological Control and Monitoring of Locust Area. *Agric. Ecosyst. Environ.* **2020**, *303*, 107110. [CrossRef]

25. Mallie, D.T.; Demissie, S.T.; Beza, S.A.; Erena, S.H.; Dejene, S.W. Predicting the Impact of Climate Change on Desert Locust (*Schistocerca gregaria*) Breeding Areas Using an Ensemble Model: A Case Study of the Wabe Shebelle River Basin, Ethiopia. *Environ. Chall.* **2025**, *21*, 101365. [CrossRef]
26. Cease, A.J.; Elser, J.J.; Fenichel, E.P.; Hadrich, J.C.; Harrison, J.F.; Robinson, B.E. Living with Locusts: Connecting Soil Nitrogen, Locust Outbreaks, Livelihoods, and Livestock Markets. *BioScience* **2015**, *65*, 551–558. [CrossRef]
27. Cease, A.J.; Elser, J.J.; Ford, C.F.; Hao, S.; Kang, L.; Harrison, J.F. Heavy Livestock Grazing Promotes Locust Outbreaks by Lowering Plant Nitrogen Content. *Science* **2012**, *335*, 467–469. [CrossRef] [PubMed]
28. Republic of Kenya. Pest Management Plan (PMP) on Locust Control Contingency Emergency Recovery Implementation Plan (CERIP) 2020. Available online: <https://documents1.worldbank.org/curated/en/226761584947023230/pdf/Pest-Management-Plan-on-Locust-Control-Contingency-Emergency-Recovery-Implementation-Plan.pdf> (accessed on 8 June 2026).
29. Republic of Kenya. Emergency Locust Response Program 2020. Available online: <https://elrp.go.ke/background> (accessed on 8 June 2026).
30. Global Center on Adaptation. Italy Braces Itself for More Locust Swarms. Available online: <https://gca.org/italy-braces-itself-for-more-locust-swarms/#:~:text=More%20extreme%20weather%20driven%20by,species%20native%20to%20southern%20Europe> (accessed on 8 June 2026).
31. White, L.; Noble, B.F. Strategic Environmental Assessment for Sustainability: A Review of a Decade of Academic Research. *Environ. Impact Assess. Rev.* **2013**, *42*, 60–66. [CrossRef]
32. De Montis, A.; Ledda, A.; Caschili, S. Overcoming Implementation Barriers: A Method for Designing Strategic Environmental Assessment Guidelines. *Environ. Impact Assess. Rev.* **2016**, *61*, 78–87. [CrossRef]
33. Fischer, T.B. Reviewing the Quality of Strategic Environmental Assessment Reports for English Spatial Plan Core Strategies. *Environ. Impact Assess. Rev.* **2010**, *30*, 62–69. [CrossRef]
34. Mascarenhas, A.; Ramos, T.B.; Haase, D.; Santos, R. Ecosystem Services in Spatial Planning and Strategic Environmental Assessment—A European and Portuguese Profile. *Land Use Policy* **2015**, *48*, 158–169. [CrossRef]
35. De Montis, A.; Ledda, A.; Calia, G. Integrating Green Infrastructures in Spatial Planning: A Scrutiny of Regional Tools in Sardinia, Italy. *Eur. Plan. Stud.* **2022**, *30*, 251–268. [CrossRef]
36. Rivas-Martínez, S.; Rivas-Sáenz, S.; Penas, A. Worldwide Bioclimatic Classification System. *Glob. Geobot.* **2011**, *1*, 1–634. [CrossRef]
37. Canu, S.; Rosati, L.; Fiori, M.; Motroni, A.; Filigheddu, R.; Farris, E. Bioclimate Map of Sardinia (Italy). *J. Maps* **2015**, *11*, 711–718. [CrossRef]
38. Secci, D.; Patriche, C.V.; Ursu, A.; Sfică, L. Spatial Interpolation of Mean Annual Precipitations in Sardinia. A Comparative Analysis of Several Methods. *Geogr. Tech.* **2010**, *1*, 67–75.
39. Motroni, A.; Canu, S.; Bianco, G.; Loj, G. *Carta Delle Aree Sensibili Alla Desertificazione (Environmentally Sensitive Areas to Desertification, ESAs)*; Servizio Agrometeorologico Regionale Per La Sardegna: Sassari, Italy, 2004.
40. Capra, G.F.; Vacca, S.; Cabula, E.; Grilli, E.; Buondonno, A. Human-Altered and Human-Transported Soils in an Italian Industrial District. *Soil Sci. Soc. Am. J.* **2012**, *76*, 1828–1841. [CrossRef]
41. Latchininsky, A.V. Moroccan Locust *Dociostaurus Maroccanus* (Thunberg, 1815): A Faunistic Rarity or an Important Economic Pest? *J. Insect Conserv.* **1998**, *2*, 167–178. [CrossRef]
42. Khairov, K.S.; Lazutkaite, E.; Latchininsky, A.V. Distribution, Population Dynamics, and Management of Moroccan Locust *Dociostaurus Maroccanus* (Thunberg, 1815) (Orthoptera, Acrididae) in Tajikistan. *Insects* **2024**, *15*, 684. [CrossRef] [PubMed]
43. Gay, P.-E.; Lecoq, M.; Piou, C. Improving Preventive Locust Management: Insights from a Multi-Agent Model. *Pest Manag. Sci.* **2018**, *74*, 46–58. [CrossRef] [PubMed]
44. Autonomous Region of Sardinia. Action Plan to Control and Manage Acridid Infestations in Sardinia [Lotta Alle Cavallette. Piano di Azione e Documenti Sul Contrasto All'invasione di Cavallette]. Available online: <https://www.agenzialaore.it/index.php?xsl=2933&s=457877&v=2&c=96060&t=1> (accessed on 8 June 2026).
45. Saha, A.; Rahman, S.; Alam, S. Modeling Current and Future Potential Distributions of Desert Locust *Schistocerca gregaria* (Forskål) under Climate Change Scenarios Using MaxEnt. *J. Asia-Pac. Biodivers.* **2021**, *14*, 399–409. [CrossRef]
46. Yao, X.; Zhu, D.; Yun, W.; Peng, F.; Li, L. A WebGIS-Based Decision Support System for Locust Prevention and Control in China. *Comput. Electron. Agric.* **2017**, *140*, 148–158. [CrossRef]
47. Cressman, K. Role of Remote Sensing in Desert Locust Early Warning. *J. Appl. Remote Sens.* **2013**, *7*, 075098. [CrossRef]
48. Lecoq, M. Recent Progress in Desert and Migratory Locust Management in Africa. Are Preventative Actions Possible? *J. Orthoptera Res.* **2001**, *10*, 277–291. [CrossRef]
49. Showler, A.T.; Ebbe, M.A.O.B.; Lecoq, M.; Maeno, K.O. Early Intervention against Desert Locusts: Current Proactive Approach and the Prospect of Sustainable Outbreak Prevention. *Agronomy* **2021**, *11*, 312. [CrossRef]
50. Zhang, L.; Lecoq, M.; Latchininsky, A.; Hunter, D. Locust and Grasshopper Management. *Annu. Rev. Entomol.* **2019**, *64*, 15–34. [CrossRef] [PubMed]

51. Lockwood, J.A.; Showler, A.T.; Latchininsky, A.V. Can We Make Locust and Grasshopper Management Sustainable? *J. Orthoptera Res.* **2001**, *10*, 315–329. [CrossRef]
52. Baraka, G.E.; Sirera, A.; Ong'amo, G. Threats of Desert Locust Management to People and the Environment in Kenya. *Int. J. Environ. Sci. Technol.* **2025**, *22*, 3505–3520. [CrossRef]
53. Alemu, W.G.; Neigh, C.S.R. Desert Locust Cropland Damage Differentiated from Drought, with Multi-Source Remote Sensing in Ethiopia. *Remote Sens.* **2022**, *14*, 1723. [CrossRef]
54. Baker, I.; Peterson, A.; Brown, G.; McAlpine, C. Local Government Response to the Impacts of Climate Change: An Evaluation of Local Climate Adaptation Plans. *Landsc. Urban Plan.* **2012**, *107*, 127–136. [CrossRef]
55. Cortinovis, C.; Geneletti, D. Ecosystem Services in Urban Plans: What Is There, and What Is Still Needed for Better Decisions. *Land Use Policy* **2018**, *70*, 298–312. [CrossRef]
56. Autonomous Region of Sardinia. Operational Plan for Phytosanitary Actions [Piano Operativo Degli Interventi Fitosanitari. Agenzia Laore]. Available online: https://www.agenzia-laore.it/documenti/14_43_20230411104111.pdf (accessed on 8 June 2026).
57. Autonomous Region of Sardinia. Guidelines for Identifying Measures to Manage and Counteract Locust Infestations in Sardinia [Linee Guida per l'individuazione Delle Misure Di Contenimento e Di Contrasto Alla Diffusione Del Fenomeno Delle Infestazioni Acridiche in Sardegna]. Available online: <https://delibere.regione.sardegna.it/delibera/58151> (accessed on 8 June 2026).
58. Agenzia per la Coesione Territoriale. Support Fund for Marginalized Municipalities [Fondo Di Sostegno Ai Comuni Marginali 2021–2023. L'elenco Dei Comuni Ammessi al Riparto Del Fondo Con La Relativa Quota Di Contributo]. Available online: https://web.archive.org/web/20250402195102/https://www.agenziacoesione.gov.it/news_istituzionali/fondo-di-sostegno-ai-comuni-marginali-2021-2023/ (accessed on 20 July 2026).
59. De Montis, A.; Ledda, A.; Serra, V.; Calia, G. Green Infrastructure and Adaptation to Climate Change in Marginal Areas: A Reference Scheme for Implementation Guidelines in Italy. *Sustainability* **2024**, *16*, 8641. [CrossRef]
60. Comune di Bolotana. Pianificazione e Governo Del Territorio 1995. Available online: <https://servizi.comune.bolotana.nu.it/portale/trasparenza/trasparenzaamministrativadocs.aspx?R=1&CP=141> (accessed on 20 July 2026).
61. United Nations. SERVIR Produces Maps to Support Efforts Against Locust Outbreak in Eastern Africa. Available online: <https://www.un-spider.org/news-and-events/news/servir-produces-maps-support-efforts-against-locust-outbreak-eastern-africa> (accessed on 8 June 2026).
62. Muhammad, J.; Fathy, Z.; Moussa, S. Entomopathogenic Bacteria *Photobacterium luminescens* as Natural Enemy against the African Migratory Locust, *Locusta migratoria Migratorioides* (Reiche & Fairmaire, 1849) (Orthoptera: Acrididae). *Egypt. J. Biol. Pest Control* **2022**, *32*, 92. [CrossRef]
63. Muhammad, J.; Fathy, Z.; Moussa, S. Biological Control of *Schistocerca gregaria* and *Locusta migratoria Migratorioides* Using Entomopathogenic Bacteria. *Sci. Rep.* **2025**, *15*, 4601. [CrossRef] [PubMed]
64. Yasin, M.; Khan, A.; Qayyum, M.A.; Yousuf, H.M.B.; Mehfooz, A.; Hunter, D. Biological Control of Locusts and Grasshoppers: A Review. *J. Orthoptera Res.* **2024**, *33*, 289–304. [CrossRef]
65. Gebregiorgis, D.; Asrat, A.; Birhane, E.; Tiwari, C.; Kiage, L.M.; Ramisetty-Mikler, S.; Kallam, S.; Kabengi, N.; Gebrekirstos, A.; Wanjiru, S.; et al. Critical Gaps in the Global Fight against Locust Outbreaks and Addressing Emerging Challenges. *npj Sustain. Agric.* **2025**, *3*, 29. [CrossRef]
66. Word Ries, M.; Adriaansen, C.; Aldobai, S.; Berry, K.; Bal, A.B.; Catenaccio, M.C.; Cigliano, M.M.; Cullen, D.A.; Deveson, T.; Diongue, A.; et al. Global Perspectives and Transdisciplinary Opportunities for Locust and Grasshopper Pest Management and Research. *J. Orthoptera Res.* **2024**, *33*, 169–216. [CrossRef]
67. CREA. Indagine Sul Mercato Fondiario in Italia. L'andamento Delle Quotazioni Dei Terreni Agricoli. RAPPORTO 2024. 2025. Available online: <https://www.crea.gov.it/documents/68457/0/CREA-PB++Rapporto+PR+2024.pdf/27ada155-40fc-c33e-316e-8079673c2743?t=1761913560930> (accessed on 20 July 2026).
68. Chessa, F. *La Produzione Agraria e Le Forme Della Proprietà Fondiaria*; G. Giappichelli Editore: Turin, Italy, 1941.
69. Asciuto, A.; Borsellino, V.; D'Acquisto, M.; Di Franco, C.P.; Di Gesaro, M.; Schimmenti, E. Land Consolidation Policies in Sicily and Their Effects on Its Farmland. *Qual. Access Success* **2014**, *15*, 79–85.
70. Comune di Sassari. *Sassari Piano Urbanistico Comunale. Relazione Di Progetto*; Comune di Sassari: Sassari, Italy, 2012.
71. FAO. *Technical Guidance on Desert Locust—Early Warning System and Sustainable Management of Transboundary Pests, with Special Reference to Desert Locust (Schistocerca gregaria [Forskål]) in South Asia*; FAO: Rome, Italy, 2022.
72. FAO. Climate Change and Desert Locust. Available online: <https://www.fao.org/locust-watch/activities/climate-change/climate-change-and-desert-locust/en> (accessed on 8 June 2026).
73. Ledda, A.; Di Cesare, E.A.; Satta, G.; Cocco, G.; De Montis, A. Integrating Adaptation to Climate Change in Regional Plans and Programmes: The Role of Strategic Environmental Assessment. *Environ. Impact Assess. Rev.* **2021**, *91*, 106655. [CrossRef]
74. Ledda, A.; Kubacka, M.; Calia, G.; Bródka, S.; Serra, V.; De Montis, A. Italy vs. Poland: A Comparative Analysis of Regional Planning System Attitudes toward Adaptation to Climate Changes and Green Infrastructures. *Sustainability* **2023**, *15*, 2536. [CrossRef]

75. Nadruz, V.D.N.; Gallardo, A.L.C.F.; Montaña, M.; Ramos, H.R.; Ruiz, M.S. Identifying the Missing Link between Climate Change Policies and Sectoral/Regional Planning Supported by Strategic Environmental Assessment in Emergent Economies: Lessons from Brazil. *Renew. Sustain. Energy Rev.* **2018**, *88*, 46–53. [[CrossRef](#)]
76. Wende, W.; Bond, A.; Bobylev, N.; Stratmann, L. Climate Change Mitigation and Adaptation in Strategic Environmental Assessment. *Environ. Impact Assess. Rev.* **2012**, *32*, 88–93. [[CrossRef](#)]
77. Posas, P.J. Climate Change in SEA: Learning from English Local Spatial Planning Experience. *Impact Assess. Proj. Apprais.* **2011**, *29*, 289–302. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.