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Review

Barn Owls as a Nature-Based Solution for Pest Control: A Multinational Initiative Around the Mediterranean and Other Regions

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Abstract: Pest rodents cause extensive damage to crops worldwide. Up to 40% of global crop production is lost annually to pests and diseases, with rodents accounting for 15–30% of this loss amounting to billions of dollars each year. The current method of controlling rodent populations involves the extensive use of chemical rodenticides. While effective in the short term, these chemicals pose serious environmental and health risks, leading to secondary poisoning of non-target species and other long-term negative ecological consequences, underscoring the need to adopt more sustainable pest-control measures. Nature-Based Solutions (NbSs), on the other hand, are increasingly recognized for addressing environmental challenges such as climate change, biodiversity loss, and sustainable development, and they include actions that protect, sustainably manage, and restore ecosystems. In this context, Barn Owls (*Tyto alba*) are highly effective as a natural pest-rodent control agents in agro-ecosystems. The species has a wide distribution and adaptability to various environments, and its diet consists predominantly of small mammals, with rodents making up from 50–60% up to even 90–95% of the diet according to different geographical regions. Each Barn Owl family can consume thousands of rodents annually, creating a high potential to reduce crop damage and infestations. Deploying nest boxes in agricultural areas can significantly increase Barn Owl populations, ensuring continuous and effective rodent control. Limitations of this solution must also be taken into consideration such as predation on rodents and small mammals that are not pests, and possible competition with other nocturnal birds of prey. In the current paper, we aim to introduce the concept of owls as a NbS for pest rodent control and outline the main challenges, pitfalls, advantages, and disadvantages of implementing this solution in a new geographical region, and all the necessary in-between steps (scientific, societal, administrative, educational) that have to be followed for a successful implementation. So far, several countries have successfully implemented Barn Owl nest box schemes, with Israel and Cyprus achieving reduction in the use of pesticides by 45% and 58%, respectively, whereas the project is spreading to other Mediterranean countries (Jordan, Palestine Authority, Greece, Morocco, Spain), in palm plantations in Malaysia and USA, and in the vineyards of Napa Valley in California. The success of Barn Owl nest box programs relies on integrating scientific research, societal needs, supportive policy frameworks, and education. Barn Owl nest box programs are both bottom-up and top-down initiatives, in need of the participation of farmers and local communities to establish and deploy the Barn Owl solution. Continuous research is also necessary to explore systematically Barn owl trophic ecology, foraging and breeding ecology, interactions with agricultural landscape, and land uses in temporal and spatial scales, and challenges such as habitat suitability, availability of nesting sites, and regional ecological conditions must also be addressed.

Keywords: Barn Owls; *Tyto alba*; pest control; biological control; rodents; nature-based solution; Mediterranean

1. Introduction: The Pest-Rodents Global Problem and the Barn Owl as a NbS Solution

1.1. Background: Pest Rodents, a Global Problem for Agriculture, Economy, and Biodiversity

Pest rodents pose a significant challenge to global agriculture, causing extensive damage to crops and leading to substantial economic losses for farmers [1]. These pests can devastate entire fields, reducing yields and threatening food security worldwide [2]. A total range between 20% and 40% of global crop production is lost annually to plant pests and diseases, which includes damage caused by rodents [3–5]. Specifically, global destruction in agricultural production by rodents both in pre-harvest and post-harvest stages (field standing crops and in storage) reaches an average annual loss of 10–15%, which often increases above 30%, reaching even 80–90% of crop destruction in many cases (e.g., crops such as rice, cereals, corn, alfalfa, and more) [6–8]. This loss amounts to billions of dollars in economic damage each year. According to the Food and Agriculture Organization of the United Nations, a total loss of global crop production of 40% is equal to a total loss in the global economy of over USD 220 billion per year [9]. For instance, in Asia alone, the annual grain consumption by rodents could feed 200 million people [10,11].

Rodents such as rats, mice, and voles are notorious for their ability to rapidly reproduce and adapt to various environments, including agricultural landscapes. They damage crops by feeding on seeds, stems, and roots, and they also cause significant harm to stored foods, livestock feed, and farm structures [2,8]. The impact of rodent infestations is not limited to direct consumption of crops but also includes secondary effects such as contamination and spread of diseases, further exacerbating food insecurity [12,13].

The current and most applicable method of controlling agricultural pest rodent populations involves the extensive use of chemical rodenticides. While effective in killing rodents as a “short-term” solution during population outbreaks, they do not offer a “long-term-stability” solution [14]. In addition, these substances pose serious environmental and health risks [15–18]. Commonly used rodenticide substances, such as brodifacoum, bromadiolone, and difenacoum, are anticoagulants that cause internal bleeding in rodents [19]. However, these toxic chemicals often result in secondary poisoning of non-target species when predators like raptors and others consume rodents that have ingested rodenticides [19–21]. Secondary poisoning can also affect domestic animals and humans, ultimately disrupting the health and survival of various species and the ecological balance [19]. Studies have shown that rodenticides can accumulate in the food chain, leading to long-term ecological consequences and apex predator deaths [20,21]. The presence of rodenticides in predatory birds and mammals has been widely documented, highlighting the pervasive nature of this problem [19]. This reduction in biodiversity can have cascading effects, ultimately impacting ecosystem services that are vital for human well-being and agricultural productivity and highlighting the need to adopt alternative, more sustainable strategies to cope with the rodent problem.

1.2. Nature-Based Solutions (NbSs): Facing Future Global Environmental Challenges with Different Strategies and the Importance of NbSs in Agricultural Management

Nature-Based Solutions (NbSs) are increasingly being recognized as essential for addressing various global challenges, including climate change, biodiversity loss, and sustainable development [22–24]. NbSs encompass actions that protect, sustainably manage, and restore natural or modified ecosystems, boosting natural solutions that provide environmental, social, and economic benefits. The importance of NbSs is emphasized by several major international organizations and initiatives.

The UN promotes NbSs through initiatives like the UN Decade on Ecosystem Restoration (2021–2030), which aims to prevent, halt, and reverse the degradation of ecosystems worldwide [25–27], emphasizing the role of NbSs in achieving Sustainable Development Goals (SDGs).

The FAO integrates NbSs into agricultural practices to safeguard natural resources and ensure food security [28,29]. By focusing on ecosystem functioning, the FAO promotes practices such as agroforestry, organic farming, and water conservation, which contribute to resilient and sustainable agrifood systems [28,29]. The EU has also embedded NbSs in its policy frameworks, particularly through the European Green Deal and the EU Biodiversity Strategy for 2030 [30–32]. These policies aim to transform Europe into a climate-neutral continent by 2050, emphasizing the role of NbSs in mitigating climate change, protecting biodiversity, and enhancing ecosystem services.

As global populations rise, climate change impacts intensify, and biodiversity loss is accelerated due to land use changes; thus, sustainable agricultural practices become essential for ensuring food security, protecting biodiversity, and mitigating negative effects [33,34].

NbSs leverage natural processes to enhance ecosystem services, such as soil health, water regulation, and pest control [35–37]. For instance, wetlands act as natural sponges that reduce the risk of floods [38], green roofs and walls insulate buildings and reduce the urban heat island effect [39], mangroves protect coastal areas as natural barriers against storm surges and sea-level rise [40], and, in agriculture, specific techniques like regenerative agriculture, permaculture, and natural pest control reduce the need for chemical inputs, enhance soil health, and increase biodiversity on farms [41]. These practices improve resilience and maintain healthy ecosystems.

In addition to environmental benefits, NbSs also provide economic advantages [42–45]. By reducing the need for costly chemical pesticides, farmers can lower production costs and enhance long-term agricultural productivity. Moreover, NbSs can create new job opportunities in rural areas, contributing to sustainable rural development [46]. Adopting NbSs in agriculture aligns with global policy frameworks like the European Green Deal and the UN's Sustainable Development Goals, which advocate for sustainable and resilient agricultural practices.

1.3. Barn Owls: A Nature-Based Solution (NbS) Against Pest Rodents in Agriculture

Barn Owls are one of the most widely distributed avian species, found on every continent except Antarctica [47]. Their ability to thrive in diverse environments, from temperate regions to tropical landscapes, and notably across the Mediterranean Basin, makes them particularly suitable for various agricultural settings [48,49]. This adaptability, along with various ecological and biological adaptations of the species as explained in Materials and Methods, ensures that Barn Owl-based pest control programs can be implemented globally, including in Mediterranean agricultural systems, adapting effectively to local conditions and agricultural practices.

In the current paper, we aim to introduce the concept of owls as a NbS for pest rodent control and outline the main challenges, pitfalls, advantages, and disadvantages in implementing this solution in a new geographical region, and all the necessary in-between steps (scientific, societal, administrative, educational) that have to be followed for a successful implementation. As such, we present, hereafter, the following discrete sections: (i) Biological and ecological traits of the Barn Owl that enable the species to perform as the most effective pest-rodent control agent in agroecosystems worldwide; (ii) Scientific axes upon which research must be realized and data/protocols that must be compiled; (iii) Societal engagement in a two-via concept: engagement of local authorities, municipalities, regional governments, and, when possible, respective central government authorities, as well as engagement of directly interested stakeholders, the farmers, and agricultural associations; (iv) Educational challenges and awareness actions and their importance in the broad public acceptance of the Barn Owl as a natural pest control agent, and in modifying the psychological perception of Barn Owls. By addressing these objectives, the current paper aims to provide a scalable and replicable model for natural pest-rodent control that can be adopted in other regions facing similar agricultural challenges. Finally, with the current paper, we aim to demonstrate to the global extended network of researchers and conservationists the work we have realized so far and the goals achieved across the participating countries, and to share knowledge, resources, and best practices.

2. State of the Art: National Barn Owl Projects in the World and Their Results So Far—International Collaboration

2.1. The Barn Owl Project in Israel

Historically, farmers in Israel used highly toxic pesticides to combat rodents. These chemicals caused severe ecological damage, impacting migratory birds from Europe and Western Asia, soil, water, and human populations [50,51]. In addition, the decline in raptor populations, which are natural predators of rodents, was significant. In 1981, a collaborative effort involving researchers from Tel Aviv University, the Hebrew University of Jerusalem, and Society for the Protection of Nature in Israel (SPNI) personnel sought to implement biological pest control using Barn Owls in the Hula Valley [50,51]. This initial attempt faced significant challenges (including damage to the nesting boxes and pesticide misuse), leading to its failure.

In 1983, the project shifted to Kibbutz Sde Eliyahu “https://kibbutzulpan.org/kibbutz-ulpan-sde-eliyahu/, (accessed on 15 October 2024)”, a communal farm near the Jordanian border in the Great Rift Valley known for its bio-organic agriculture. Researchers installed 14 nest boxes for Barn Owls around the orchards and plantations. Despite initial setbacks, local Barn Owls eventually populated the nest boxes, initiating natural rodent control in crops like dates and pomegranates. In 1990, farmers expanded the use of nest boxes around orchards and plantations in Sde Eliyahu to field crops and alfalfa, further supporting Barn Owl populations and Barn Owl predation upon pest rodents. A meeting in 1998 between government authorities and agricultural associations led to the adoption of the Sde Eliyahu model in the Beit She’an Valley as well, with farmers agreeing to use biological control methods and install additional nest boxes.

In 2002, a significant reduction in vole population in Beit She’an Valley was noted most possibly due to the increased use of nest boxes by the Barn Owls, whereas in January 2009, a contract was signed between the Ministry of Agriculture and Rural Development, the Ministry of Environmental Protection, and the SPNI “https://natureisrael.org/ (accessed on 15 October 2024)” to advance the national project using raptors as biological control agents in agriculture. The University of Lausanne/Switzerland UNIL “https://barnowl-research.ch/en (accessed on 15 October 2024)” has been supporting and guiding the Israeli Barn Owl project since 2009. Originally piloted at Kibbutz Sde Eliyahu, this project has expanded significantly since its declaration as a national project in 2008 [50,51].

The number of Barn Owl nest boxes has grown from 730 in 2008 to approximately 5000 today (Figure 1), with the vast majority financed by the farmers themselves, covering the whole agricultural territory of Israel [51]. Today, the application of rodenticides in Israel at the national level has been reduced by 45%, as recorded by the Ministry of Agriculture (Figure 2). The decrease in rodenticide use nationally could also be partially due to additional factors besides the Barn Owl nest boxes, such as growing awareness, lower reporting rates, and poor rodent years.

Figure 1. Map of installed Barn Owl nest boxes (>5000) in 2024 in the national territory of Israel. Each nest box is indicated with a green rectangular spot.

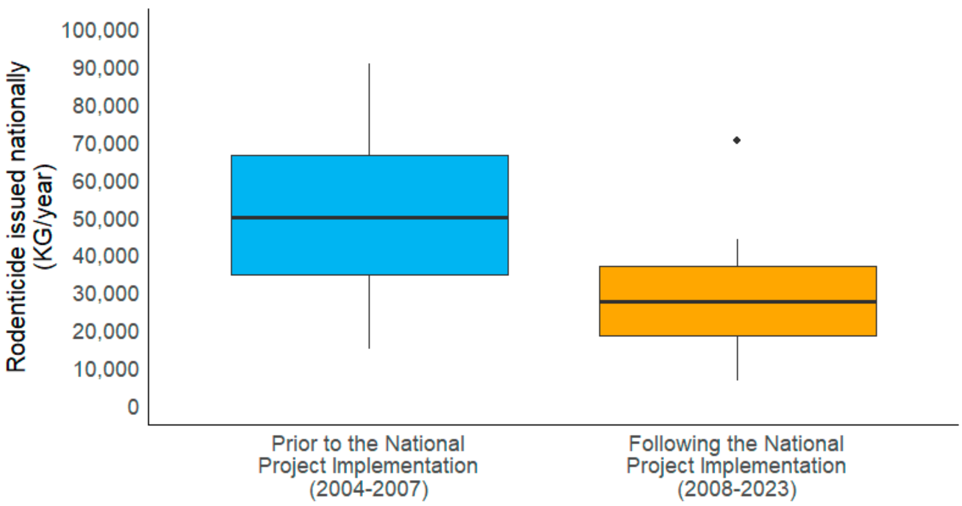

Figure 2. Boxplots indicating the annual amounts in kgs of 1080 rodenticides used in the national agricultural territory of Israel. The blue box plot demonstrates annual rodenticide use from 2004 to 2007. The orange box plot indicates annual rodenticide volume use from 2008 to 2023—after starting the Barn Owl project (source: Ministry of Agriculture of Israel, Dr. Yoav Motro).

The Israeli project is organized into 10 geographical regions, each managed by a regional coordinator responsible in each region for maintaining ongoing contact with farmers throughout the year and, along with a monitoring assistant, overseeing box monitoring during the breeding season. The project is led by the Ministry of Agriculture in cooperation with Tel Aviv University.

2.2. The Barn Owl Project in Jordan

The Barn Owl project was established in Jordan in December 2002 [51,52]. The leading group to initiate the project was the Amman Center for Peace and Development (ACPD). Nest boxes were installed progressively on the basis of one box per 30 acres to cover a 135 km length along the Jordan Valley. A total of 250 nest boxes have been installed so far in Jordan, out of which 176 are installed in the northern part of Jordan Valley and 46 in the southern part, whereas 30 more are now installed to upland farms of the Jerash area (Figure 3).

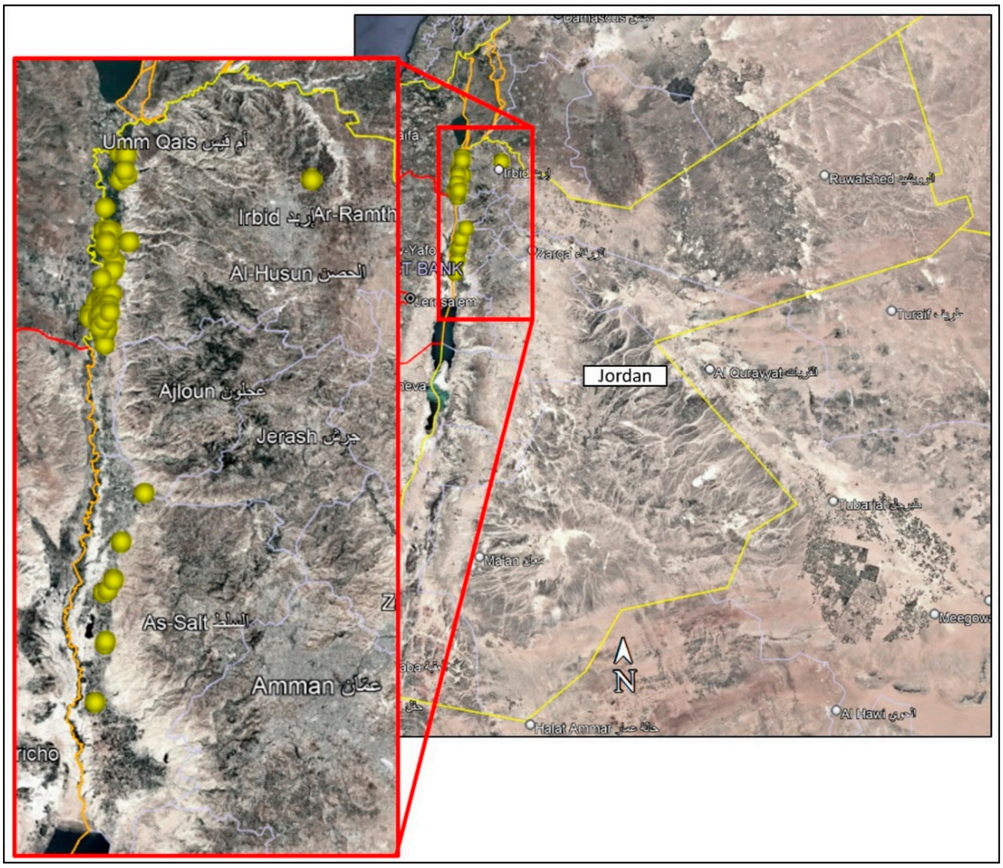

Figure 3. Map of 250 installed Barn Owl nest boxes in the national territory of Jordan. Each nest box is indicated with a yellow dot.

Progressively UNIL collaborated with SPNI and ACPD and has been supporting the Jordan Barn Owl project since 2009 [51,52]. In addition, the Ministry of Agriculture (MOA) and the National Agricultural Research Center (NARC) of Jordan have also been supporting the project. Up to the date, a total of 210 farmers have been involved officially in the Jordan Barn Owl project. Although annual monitoring takes place to record the Barn Owl occupation of the nest boxes and breeding success rates, no monitoring has been realized so far for the decrease in rodenticide usage by the farmers.

2.3. The Barn Owl Project in Cyprus

In Cyprus, the Barn Owl project was initiated by the Game and Fauna Service "GFS—https://gws.moi.gov.cy/ (accessed on 15 October 2024)" in 1995. The GFS started placing nesting boxes for Barn Owls in Larnaca district as part of a pilot project to get GFS staff involved in wider conservation projects besides "strict" game management practices. In 2003–2004, GFS presented through the Department of Agriculture the nesting box scheme to the United Nations Development Program (UNOPS). UNOPS got interested as an alternative for controlling rodents instead of using rodenticides. Then, in cooperation with UNOPS 200, such boxes were constructed and placed in all districts: Nicosia, Larnaca, Famagusta, Limassol, and Paphos. GFS has expanded its network to numbers exceeding 800 nest boxes nowadays. The Forestry Department (DF) was also installing nesting boxes in the 1990s, but only in forestry managed land. For BirdLife Cyprus (BLC) "https://birdlifecyprus.org/ (accessed on 15 October 2024)", the project started in 2014 and involved various national authorities. In the initial years of the project for BLC, 2014–2018, the efforts were mostly with individual interested farmers all across Cyprus, while also organizing workshops and meeting policy-makers. In 2018, a working group was formed and discussions began for a National Action Plan (NAP) in Cyprus to bring all the efforts of the different departments into one coordinated effort (DF, GFS, BLC, Department of Agriculture (DA)). From 2019 onwards, the working group's efforts became more targeted and focused on whole communities rather than individual farmers. Contacts were made with municipalities and organized farmer groups. Local hunting clubs were also involved, and more recently, the Cyprus Hunting Federation (CHF) collaborated as well with the GFS. Although in the past, the Department of Agriculture was training hunting clubs on how to install rodenticides in the countryside, with the Barn Owl project, hunters (members of interested clubs) gradually started to learn how to install Barn Owl nest boxes and how project partners can monitor these boxes together. At the moment, a total of 1328 Barn Owl nest boxes are installed and operating in the national territory of Cyprus (Figure 4, Table 1).

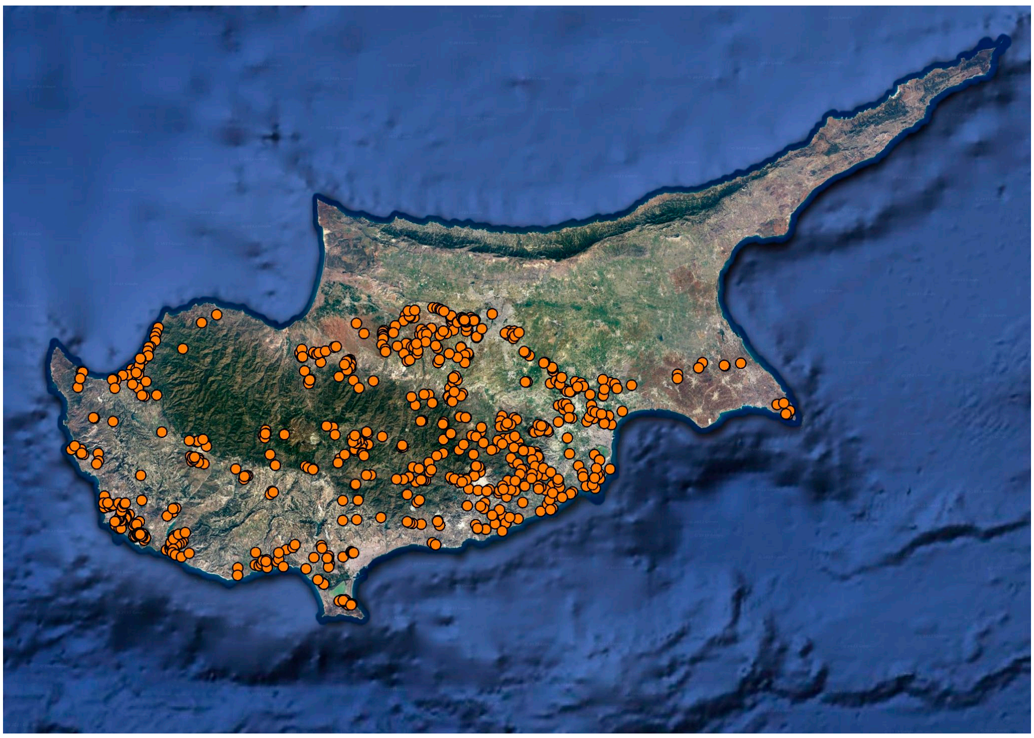

Figure 4. Map of installed and mapped Barn Owl nest boxes in 2024 in the national territory of Cyprus. The map includes a total of 738 gps-recorded and mapped Barn Owl nest boxes; the remaining 590 nest box localities will be mapped in the forthcoming period. Each nest box is indicated with a yellow dot.

Table 1. Cumulative number of Barn Owl nest boxes installed from 2020 to 2024. The occupation rate of nest boxes by Barn Owls is sampled only in a number of nest boxes each year. The total kgs of rodenticides that were issued for usage from the Ministry of Agriculture in Cyprus for the same period (2020–2024) are also recorded.

Year of Barn Owl Nest Box Installment	Cumulative Total Number of Barn Owl Nest Boxes Installed in Cyprus National Territory	Number of Confirmed Occupied Barn Owl Nest Boxes	Total Thousands of kgs of Rodenticides Issued Each Year in Cyprus National Territory from the Ministry of Agriculture
2020	450	no available data for all nest boxes	201,150 kg
2021	1124	79% (sample of only 200 nest boxes across Cyprus—not all boxes were monitored)	190,050 kg
2022	1328	20% (sample of only 200 nest boxes across Cyprus—not all boxes were monitored)	106,525 kg
2023–2024	1328	46% (sample of only 200 nest boxes across Cyprus—not all boxes were monitored)	118,500 kg

Similarly to Israel, the decrease in rodenticide use nationally could also be partially due to additional factors to the Barn Owl nest boxes, such as growing awareness, lower reporting rates, and poor rodent years.

The current structure of the NAP is a collaboration between representatives from the DA, the DF, BLC, the GFS, and the Veterinary Services of the Ministry of Agriculture, Natural Resources and Environment (VS). This working group was formed in 2018 under the Ministry of Agriculture and Rural Development, and the NAP document was finalized and translated into English and Greek in 2020. Since 2021, the working group has been operating under funding from the Ministry of Agriculture and Rural Development. This funding is allocated after consultation with the working group, based on what actions are deemed necessary each year. Since 2021, the budget has been allocated into four categories. These are monitoring and research, equipment, raising awareness and outreach, and construction of nesting boxes. Each partner is also supporting the project through their own resources and capacity.

2.4. The Barn Owl Project in Greece

The Barn Owl project in Greece was initiated with a pilot project from the Civil Society Organization (CSO) "TYTO—Association for the Management and Conservation of Biodiversity in Agricultural Ecosystems" "https://www.tyto.org.gr (accessed on 15 October 2024)". TYTO installed the first 100 Barn Owl nest boxes in 2019 in the Thessaly plains, the largest and most intensively exploited agroecosystem of Greece. The 2019 pilot project was funded initially by the Hellenic Agricultural Organization DEMETER, and then by the CSO Pelargos. From 2019 up to 2023, these 100 nest boxes were monitored annually by TYTO personnel. In 2023, the actions of TYTO bore fruit. After an unofficial two-year collaboration with the Directorate of Agricultural Economy and Veterinary Services of the Region of Thessaly, the collaboration led to an official 4-year contract, which was signed between the Region of Thessaly and TYTO. Within the context of that contract, 190 more Barn Owl nest boxes were installed in the region of Thessaly. A total of nine different municipalities participated in the project, and as of July 2023, a total of 290 Barn Owl nest boxes had been installed and operating in nine different municipalities of the Region of Thessaly (Table 2, Figure 5).

Table 2. Municipalities of the Region of Thessaly in central Greece that participate in the Barn Owl project along with the total extension of agricultural land within each municipality jurisdiction that has annual recurring problems of crop destruction from pest rodents. The total number of Barn Owl nest boxes in each discrete municipality is also presented.

Municipalities Engaged in the Barn Owl Project in Thessaly, Greece	Agricultural Land with Annual Recurring Problems of Crop Destruction from Pest Rodents (sq.km)	Barn Owl Nest Boxes Installed in 2019	Barn Owl Nest Boxes Installed in 2023	Total Barn Owl Nest Boxes Installed and Operating in Thessaly in 2024
Kileler	160	53	20	73
Farsala	160	25	28	53
Riga Feraiou	137	19	20	39
Larisa	110	5	30	35
Sofades	57	0	20	20
Tempi	142	0	20	20
Elassona	75	0	20	20
Tirnavos	64	0	20	20
Agia	7	0	10	10
Total	**911**	**102**	**188**	**290**

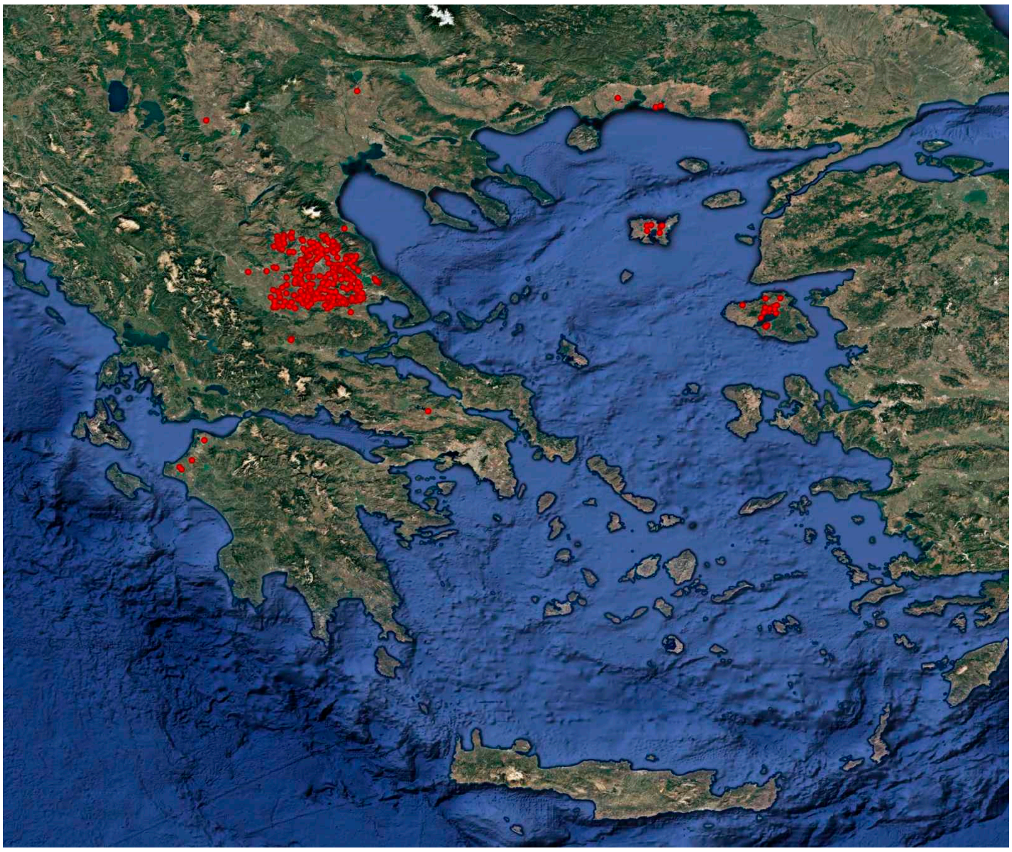

Figure 5. Map of discrete geographical regions in Greece where the Barn Owl nest boxes are installed. The main volume of 300 nest boxes is located in the agroecosystems of central Greece, Thessaly. Pilot projects with a smaller number of boxes appear in western Peloponnese, Thiva in central Greece, Florina and Thrace in northern Greece, and the islands of Lemnos and Lesvos in eastern Aegean. Each nest box is indicated with a red dot.

During the 4 years of monitoring the 102 Barn Owl nest boxes in Thessaly plains (2019–2023—the current year 2024 has not been analyzed yet), an average of 60% of the nest boxes were used from Barn Owls (roosting, staying, shelter, feeding), whereas in an average of 30% were successful broods each year. More than 700 owlets have been bred to the installed nest boxes in Thessaly plains (Figure 5).

In addition, during the last couple of years, 2023 and 2024, with funding from AG Leventis Foundation, TYTO also installed 15 Barn Owl nest boxes in the island of Lesvos and a small number (6) of nest boxes in the island of Lemnos. In Lesvos, the grant was directed to TYTO, which realized the project, and in Lemnos AG Leventis Foundation supported the CSO MedINA while TYTO cooperated and realized the Barn Owl box installment (Figure 5). These two small projects have also brought the philosophy of Barn Owl natural rodent control into the insular ecosystems of Greece.

2.5. The Barn Owl Project in Morocco

In Morocco, the Barn Owl project was recently initiated in 2023 with funding from the AG Leventis Foundation in cooperation with Mohammed V University in Rabat. Up to date, a total of 43 nest boxes have been installed in five different geographical regions of Morocco: Larache (20 nest boxes), Side Boughaba (5 nest boxes), Taza (8 nest boxes), Meknes (5 nest boxes), and Ben Slimane (4 nest boxes) (Figure 6). The target is to install 100 nest boxes in total. It was noted after a first monitoring round of the 43 installed nest boxes that 17 had been destroyed, indicating the increased need to first create awareness-raising and informative meetings before proceeding to nest box installment.

Figure 6. Map of discrete geographical regions in Morocco where the Barn Owl nest boxes are installed. Larache, Sidi Boughaba, Taza, Meknes, Ben Slimane.

The project in Morocco has been implemented by the Sciences and Development Association since June of 2023 and the University of Mohamed V.

2.6. The Barn Owl Project in Spain

In Spain, a similar Barn Owl project was initiated in 2009 and 2010 with the provision of 300 nest boxes in three discrete areas (Valladolid, Palencia, Zamora) under the coordination of GREFA (Group for the Rehabilitation of Indigenous Fauna), the Ministry for Ecological

Transition and Demographic Challenge, and the Technological Agricultural Institute of Castilla y León [53–55]. The nest boxes were placed both for Barn Owls and Kestrels. Although the project in Spain is built upon natural pest-rodent control with the management of raptors, it included both Barn Owls and Kestrels as biological organisms for which the nest boxes were built. The nest boxes were installed with a rate of one nest box for each 20 ha (0.2 sq.km), indicating a total number of five nest boxes per square km of agricultural surface. From 2009 to 2011, a total of 179 Kestrel breeding attempts were recorded and 24 Barn Owl attempts. Although Barn Owl attempts were lower, the studies published in Spain showed clearly that nest box provisioning in Spanish cropland areas clearly increased local Barn owl and common kestrel breeding population densities.

In an analytical monitoring that took place in the small mammal communities, both with live trapping sessions and by measuring line transects of vole burrow entrances (Indirect Abundance Index—IAI), it was estimated that vole density (IAI) was significantly lower near nest boxes (experimental plots) than in control plots away from nest boxes [54,55]. It is suggested that avian predators could be at least partially limiting vole populations, keeping them at an intermediate fluctuating density in the study area and limiting vole density during the increase phase of the vole cycles. Overall, after 3 years of nest box provisioning, it was estimated that within experimental plots with occupied nest boxes, vole abundance had practically disappeared, whereas in control areas in a distance of more than 5 km from nest boxes, vole abundances increased 3-fold times [53–55].

2.7. The Barn Owl Project in California, USA

The use of Barn Owl nest boxes as a natural pest management strategy in California began in earnest in the mid-1990s, and it is spearheaded by the Humboldt State University, with the additional help from local groups such as Napa Green. This initiative has continued to the present day, reflecting a long-term commitment among farmers, particularly in vineyard landscapes [56]. The integration of Barn Owls into Integrated Pest Management (IPM) programs has been supported by the installation of "hundreds, if not thousands" of nest boxes across the state. Studies and monitoring efforts have spanned several years, with specific data and observations noted in papers from as recent as 2016 and 2018. This ongoing project exemplifies widespread adoption of environmentally friendly practices aimed at leveraging natural predators to control pest populations, thereby reducing reliance on chemical treatments [56,57].

Various monitoring studies have been implemented through the years in California; 297 Barn Owl nest boxes were monitored during the 2015 breeding season, and a subsample of 150 nest boxes was monitored during the 2016 breeding season. In 2020, a total of 29 nest boxes were video-monitored to collect data on prey deliveries and rodent removal, and in 2022, a study monitored 13 operational nest boxes at the Soscol Vineyard. The results indicate that the deployment of Barn Owl nest boxes has led to substantial reductions in local rodent populations, with vineyard-based studies indicating that occupied boxes can lead to the removal of over 69,000 rodents annually from a single vineyard [56–58]. Notably, about 43% of all rodents removed by Barn Owls are captured directly from the vineyard habitat, underscoring the owls' effectiveness in targeting pests within the crop areas. Barn Owls significantly contribute to rodent control in California's agricultural settings, primarily through their predation in vineyards where nest boxes are installed. In one study from Napa Valley, a family of Barn Owls was estimated to remove between 1821 and 7563 rodents annually, with an average of 3466 rodents per year. This range is influenced by variations in prey size and type within the owls' diet, notably when they consume smaller preys such as mice and juvenile rodents, which increases the count of rodents removed. It was noted in California that Barn Owls could significantly reduce the local rodent populations, specifically in directly adjacent crop areas, denoting that Barn Owls prefer habitats that coincide with high rodent populations, thus optimizing their impact on pest control within agricultural plots [56–58]. However, while Barn Owls can significantly reduce rodent numbers, especially in high-density nesting scenarios, their impact does not always suffice to control rapidly reproducing species (like pocket gophers at peak density).

2.8. The Barn Owl Project in Malaysia

The use of Barn Owls for biological pest control in Malaysia began in 1969, with a focus on managing rodent populations in oil palm plantations [59]. The project aimed to control pests naturally by introducing Barn Owls as predators rather than relying on chemical rodenticides. Over the years, the project has expanded to various landscapes, including semi-urban areas and islands, to enhance the effectiveness of rodent control across different environments [59–62].

In Malaysia, the use of Barn Owl nest boxes varies across various agricultural and urban settings. In oil palm plantations, the density of nest boxes ranges from 1 per 5 hectares to 1 per 25 hectares (4 to 20 nest boxes per 1 sq.km) depending on the specific study or management practice. In certain areas, 16 nest boxes were provided per 25 hectares (64 nest boxes per sq.km). In rice fields, nest boxes are installed at a density of 1 box per 40 hectares to 1 box per 45 hectares (2.1 to 2.5 nest boxes per sq.km). In more densely managed areas, even 5 nest boxes per 5, 10, and 20 hectares are installed [59–62]. Finally, in urban gardens and other landscapes, nest boxes are provisioned at a density of 1 box per 15 hectares (6.5 nest boxes per sq.km). In environments like cocoa-coconut farmlands, the placement strategies differ, such as positioning the boxes within two rows of old coconut fields. Quantitative evidence proves the reduction in rat populations associated with areas where Barn Owls are active and occupy nest boxes. In palm plantations that were specifically monitored, the rodenticide use decreased in areas where Barn Owls breed successfully in nest boxes, from 45% up to 80% during the years 2017 to 2020.

3. Lessons Learned and Experience Gained: How to Establish a Barn Owl Project for Natural Pest-Rodent Control in Agricultural Ecosystems

3.1. Biological and Ecological Traits That Set Barn Owls as an Effective Pest-Rodent Natural Control

3.1.1. Diet and Rodent Predation

Barn Owls primarily feed on small mammals, which make up 90–95% of their prey intake, with rodents reaching from 50–60% up to 90% of consumed prey [63–65]. This strong dietary preference for rodents makes them highly effective in controlling pest populations naturally. Studies have shown that a single Barn Owl family can consume thousands of rodents annually (2000 to 4000 prey items), creating a significant potential in reducing crop damage and rodent infestations [50,51,59]. Barn Owls possess exceptional nocturnal vision and acute hearing, enabling them to hunt effectively at night when rodent activity is highest [66]. Their silent flight and predatory skills allow them to locate and capture rodents with high efficiency, making them formidable natural pest controllers [67,68]. In years with high rodent abundances, Barn Owls are able to reproduce multiple broods. Each brood typically consists of 5–6 chicks but can sometimes reach up to 9–10 chicks [69]. This high reproductive rate ensures rapid population growth, which can be further supported through the provision of nest box schemes, and the fast population growth ensures that owls can “track” the rodents’ population and increase the consumption rate. Furthermore, younglings stay for a total of three months in the nest with their parents, which is a key aspect since the adults remove high numbers of rodents to feed the large Barn Owl families. As such, Barn Owls give broods to many chicks, they are sedentary species and not migratory throughout their whole global distribution range, and they consequently form a fruitful “investment” for farmers.

3.1.2. Habitat and Nesting

Barn Owls live in close proximity to human activities [47]. They readily use man-made structures such as barns, silos, warehouses, and old, abandoned places [47]. However, Barn Owls are often limited by the availability of natural nesting sites, making them highly susceptible to human presence and interventions. Since Barn Owls are cavity-nesting birds, the lack of potential nesting sites in open agricultural fields explains why the deployment of nest boxes promotes breeding in these areas. This dependency makes them very susceptible to human presence as well as to nest box deployment, which allows us to increase their populations in areas of interest [65,70–72]. By deploying nest boxes and spatially positioning them, we can significantly increase Barn Owl populations in areas of interest, ensuring continuous and effective rodent control through stable predator populations, given that the Barn Owl exploits agricultural fields as indicated by radio-tracking studies, even exploiting habitats in transboundary frontiers [73–76]. The transboundary exploitation of habitats between frontiers is also presented in the current paper.

3.2. Constructing and Installing Barn Owl Nest Boxes: Mechanisms and Parameters

Constructing the Adequate Barn Owl Nest Box

Constructing an adequate Barn Owl nest box is the first step, and it is essential for maximizing Barn Owl effectiveness as natural pest controllers. The design of the nest box should take into account the specific biological and ecological needs of Barn Owls as well as the local climate, an appropriate nest box size that can accommodate Barn Owls and typical broods of 4–6 eggs [71], a construction that will prevent the risk of owlets falling out prematurely [77,78], and a correct orientation that can aid in temperature regulation by not leaving the nest box exposed to drying noon and afternoon hours. In Supplementary Material S1, concrete details pinpoint the exact steps for correctly constructing a Barn Owl nest box and for mounting it in buildings and trees, with photos and designs from various countries that deploy Barn Owl projects (Cyprus, Israel, Greece, Switzerland).

3.3. Scientific Research: Implementing Scientific Protocols A Priori and Posteriori to the Installment of a Barn Owl Nest Box Scheme

3.3.1. Geographical and Spatial Aspects

Before initiating a new Barn Owl nest box project aimed for pest-rodent control, it is crucial to have a comprehensive understanding of the local Barn Owl populations and their natural breeding sites. The presence of natural Barn Owl populations can significantly influence the success of the project, since a faster and robust occupation of nest boxes will lead to higher predation rates of pest rodents. Identifying whether there are existing wild Barn Owls breeding in the region helps in understanding the potential for natural rodent control and guides the placement of artificial nest boxes to supplement natural sites. Natural breeding sites, such as old barns, silos, and tree cavities, should be mapped and monitored to determine the density and health of the existing owl population [79]. These data are essential for enhancing natural breeding through the strategic placement of nest boxes, especially in areas lacking adequate natural nesting opportunities on the one hand, but also near to existing breeding sites in order to boost the quick and gradual adoption of artificial nest boxes. In this context, understanding the distribution range of Barn Owls in the area is utterly important.

In addition, it is beneficial to conduct preliminary pest surveys to pinpoint areas experiencing significant rodent problems. These hotspots are typically found in regions with extensive agricultural activities, where rodents can cause substantial damage to crops (e.g., cereals, alfa alfa, orchards, fruit tree cultivations, grazing lands). By integrating geographical and spatial data on Barn Owl populations and rodent outbreak areas, a targeted strategy can be developed for nest box placement. This ensures that the Barn Owl population is supported and expanded in regions where they can provide the most benefit for natural pest control.

The total extension of the agricultural area where a nest box scheme can be applied and the total land it can cover, along with the number of nest boxes installed per surface unit, depend on five factors:

(i) The total agricultural area recorded to suffer from rodent outbreaks. The land can be mapped through remote sensing and satellite photo interpretation or through

UAV ultra-high-resolution images of specific locations and interpretations [80–83]. Alternatively, given the lack of this technical approach, estimations combining in-situ recordings (on-site measurements and an assessment of habitat, landscape, land uses in vertical and horizontal contexts) and information from municipalities and regional government authorities can function as a data source [84].

(ii) An overlap of that agricultural area suffering from rodent outbreaks with Barn Owl natural breeding sites and foraging areas is important to take place. The overlap is necessary to support the gradual adoption and occupation of the installed nest boxes from the existing natural Barn Owl population pool [85]. In cases where the Barn Owl is totally absent and no overlap occurs, and the nearest natural Barn Owl breeding sites are further than 10 km away, two solutions are suggested. Firstly, the natural colonization of the installed nest boxes could be delayed without any easy estimation of time delay. Secondly, the "soft-release" method of Barn Owl owlets can be applied by transferring and placing young individuals in the nest boxes, using a concrete soft-release protocol for raptors to adopt the nest boxes [86,87].

(iii) The total budget available to be invested in the Barn Owl scheme is also a limiting factor. Funds availability may limit the number of nest boxes that can be constructed and applied in the field. Funds will define the total number of nest boxes constructed, and then an adequate area extension defined at points i and ii will be spatially selected, ensuring it can support the number of constructed boxes. Typically, the area with the largest rodent problem should form part of this pilot area. There is always the option to construct nest boxes with old wood and not marine plywood. Nest boxes will work equally well, but may have a smaller circle of life.

(iv) Number of Barn Owl nest boxes installed per surface unit. There are various suggestions for and approaches to determining the number of Barn Owl nest boxes that should be installed per surface unit. The recommended approach is to install at least two nest boxes as a minimum for every square kilometer of agricultural land. That number can reach up to 6, 8, 10, and even 20 nest boxes per square kilometer.

(v) Finally, even if in an area there are fewer problems with rodents, it is a good strategy to install nest boxes because Barn Owl population requires immigrants to maintain healthy gene flow and promote genetic diversity, which is essential for long-term evolutionary potential. As such, attracting immigrant Barn Owls into new areas creates more robust Barn Owl populations.

3.3.2. Barn Owl Monitoring Program: Nest Boxes Occupation and Breeding Parameters

Monitoring Barn Owl nest boxes is crucial for understanding their occupation rates, their breeding success, and the overall effectiveness of these boxes in pest control schemes. By keeping detailed records of nest box occupancy (ideally box-specific data), including dates of egg laying and brood size at hatching and at fledging, researchers can gain insights into the reproductive success of Barn Owls in different environments, and what placements and design work best locally [50,51,69,70,72,88]. Such data help in assessing the health of owl populations and their potential as natural pest controllers. Regular monitoring with at least four visits per year allows for the creation of maps showing occupied nest boxes, which can be used to identify trends and patterns in owl breeding behavior across various regions.

Interannual and intra-annual comparisons of breeding data are essential for evaluating the long-term stability of Barn Owl populations. By comparing results from different years, researchers can determine how variables such as weather conditions, prey availability, and habitat changes affect breeding success [89–91]. These comparisons can also highlight the impact of different agricultural practices on owl populations. For instance, areas with intensive agriculture and high rodenticide use might show lower occupancy rates and breeding success compared to regions employing more sustainable practices.

Geographical comparisons provide valuable information on how Barn Owl breeding varies across different landscapes and climates. Monitoring programs should consider diverse habitats, including arable lands, pastoral fields, and natural grasslands, to understand how these environments influence nesting success [92–94]. Different land uses and agricultural challenges, such as frequent rodent outbreaks, can affect owl populations differently. By comparing breeding parameters in these varied settings, researchers can tailor nest box placement and management strategies to optimize rodent control efforts in specific regions.

To ensure comprehensive data collection, it is recommended to conduct multiple site visits, at least four, during the breeding season and complete concrete protocols for building a robust long-term database. This helps in accurately recording the number of eggs, hatching success, and fledgling rates. Additionally, integrating remote sensing and GIS technology can enhance the monitoring process by providing spatial analysis of nest box distribution and occupancy [91]. This combination of ground-based monitoring and advanced technological tools allows for a more precise and holistic understanding of Barn Owl breeding dynamics and their role in agricultural pest management. It is important to monitor Barn Owls in nest boxes without interrupting basic biological procedures (copulation, egg laying, hatching, delivering food to the young). Banding and capturing/handling adults should be avoided during the incubation period until after chicks have hatched. A strict protocol would have night visits to the nest boxes during the first nesting stage (eggs) and day visits after eggs hatch. Whenever visits take place in the nest boxes, it is important to block the entrance before inspecting the box through the inspection door in order to avoid birds abandoning the nest (for details see, Supplementary Material S1).

If biometric measurements and bird handling take place (weighting, measurements, banding), when the Barn Owls are placed back in the box, an average of 10 min should pass before unblocking the entrance, so that the birds can relax and not leave the nest box. In order to avoid Barn Owls that leave the nest, the interior separation part that leaves a darker chamber not in immediate contact with the entrance is strongly advised.

3.3.3. Barn Owl Monitoring Program: Feeding Ecology and Diet

Monitoring the feeding ecology and diet of Barn Owls is essential for understanding their role in controlling pest rodent populations since they also feed on non-pest rodents and other small mammals. Detailed diet studies involve analyzing the composition of prey consumed by Barn Owls, typically conducted through pellet analysis. Owls regurgitate pellets containing undigested parts of their prey, which can be examined to identify the consumed small mammal species.

Pellet analysis allows researchers to track changes in the diet of Barn Owls across different seasons and years, revealing how prey availability and owl feeding habits fluctuate. For example, in periods of prey scarcity, Barn Owls may shift their diet to include a broader range of small mammal species [47,48,63–65]. Conversely, during times of prey abundance, they might specialize more narrowly on one or two small mammal species. This dynamic can indicate broader ecological changes and help in understanding the impact of environmental factors on small mammal populations [48,65,95]. Additionally, diet studies can be enhanced by using camera traps to monitor feeding behavior directly at nest sites, providing real-time data on prey delivery rates and types [96,97].

To comprehensively understand Barn Owl feeding ecology, it is crucial to combine diet analysis with field studies of small mammal populations. Methods such as live trapping and counting small mammal burrow entrances can provide direct and indirect estimates of prey abundance and distribution [98,99]. These data can then be correlated with pellet analysis results to assess the accuracy of pellets as indicators of prey availability. This combined approach helps in validating the use of Barn Owl diet studies for monitoring small mammal communities and assessing the effectiveness of Barn Owls in controlling pest species.

Furthermore, monitoring the diet of Barn Owls across different geographical regions and land uses can provide insights into how agricultural practices influence small mammal populations and owl feeding habits [95]. By comparing diet composition and feeding success in varied habitats, researchers can better understand the ecological interactions between Barn Owls and their prey, leading to more informed conservation and pest management strategies.

3.3.4. Barn Owl Monitoring Program: Barn Owl Spatial Use, Foraging, Exploitation of the Agricultural Habitat, and the Prospects of Movement Ecology

Monitoring the spatial use and foraging behavior of Barn Owls is vital for understanding how these predators exploit agricultural landscapes and contribute to pest control. Barn Owls predominantly forage in open habitats such as fields and grasslands, which are common in agricultural regions [47,95]. These areas provide ample prey, mainly small mammals, making them ideal hunting grounds for the owls. By studying the spatial use patterns, researchers can identify critical foraging areas and understand how landscape elements like crop type, field boundaries, and habitat diversity influence owl hunting efficiency [75]. For instance, preference for hunting from perches can presumably allow us to enhance predation pressure in particular sites of interest.

The use of radio telemetry, GPS, and other modern and advanced tracking technologies has revolutionized the study of Barn Owl movement ecology. GPS tags provide high-resolution data on owl movements, revealing detailed patterns of nightly foraging trips, home range sizes, and habitat preferences [76]. For example, GPS data can show how far owls travel from their nests to hunt, which areas they frequent, how their movement patterns change throughout the breeding season, and other aspects of their space use and interaction with prey [100]. Such data are invaluable for optimizing the placement of nest boxes to support effective rodent control.

One of the main limitations of GPS tags for this nocturnal species (preventing solar changing as performed elsewhere) is their limited lifetime, typically allowing for only a few days to weeks of medium- to high-resolution tracking. The ATLAS system, on the other hand, used extensively in Israel, offers an alternative approach to GPS tagging, which overcomes this limitation by having a much higher energetic efficiency, facilitating tracking for many months at very high resolutions (e.g., a fix every 4–8 s) [101]. ATLAS systems use a network of ground-based stations to track the movements of tagged individuals continuously, providing real-time data without the need for heavy on-board batteries or a recollection of the GPS unit to download the data. Accordingly, this system allows for the collection of extensive datasets on owl movements, facilitating studies on their spatial behavior over longer periods and larger areas and across substantially larger sample sizes. An ATLAS system is limited to a specific region (e.g., an area of ~300 km^2) and requires the deployment and maintenance of receiver towers infrastructure, limiting its applicability to sites where such a system is established or to a well-funded project that can support the erection of a designated system. A few ATLAS systems were established in Israel and have been demonstrated how to effectively track local owl populations (and other species). Additional ATLAS systems established elsewhere (e.g., the Netherlands, Germany), as well as the ability to erect systems in areas of interest, highlight the potential of this alternative tracking method for barn owl tracking. Insights gained from these studies can help in understanding how different agricultural practices and land uses impact owl foraging behavior and effectiveness in pest control [73], as well as how age group, sexes, and even individuals differ in their behavior [75].

Monitoring Barn Owl movement and foraging also has significant implications for conservation and agricultural management. By mapping the areas most frequently used by owls, conservationists can identify key habitats that need protection or enhancement. Additionally, understanding movement patterns can help in mitigating risks such as road collisions and exposure to pesticides [102,103]. Integrating movement ecology data with other ecological studies, such as diet analysis and breeding success, provides a comprehensive picture of Barn Owl ecology, aiding in the development of more effective conservation strategies and sustainable agricultural practices. In the current paper, we demonstrate the value of such tracking by investigating the border-crossing behavior of owls between Israel and Jordan, pinpointing the inherent connectivity of these two adjacent countries and the importance of international collaboration for ensuring effective project management.

3.3.5. Barn Owl Monitoring Program: Combinatory Research Including Biotic and Abiotic Environmental Parameters

Integrating biotic and abiotic environmental parameters into the monitoring program of Barn Owls is essential for a comprehensive understanding of their ecology and effectiveness in pest control. Biotic factors include the availability and distribution of prey species, predator presence, and the health of the owl populations themselves, which exhibit a strong genetic flow and an absence of pathogens that could, otherwise, lead to genetic drift, inbreeding, or disease-related declines. Abiotic factors encompass climatic variables, habitat characteristics, land use practices, and agricultural activities. By combining these data with information on diet, breeding success, and movement patterns, researchers can develop a holistic view of how environmental conditions affect Barn Owl populations and their role in controlling rodent pests [104–107].

3.3.6. Barn Owl Monitoring Program: Side Effects and Disadvantages

By placing nest boxes near these rodent-outbreak hotspots, the project can leverage the Barn Owls' natural predatory behavior to control rodent populations more effectively and minimize the maladaptive service of predation upon non-target species, often local endangered rodents. On the contrary, there is a possibility of side effects from Barn Owl predation upon protected small mammal species with threatened/vulnerable populations [108]. Although the side effects may be detrimental, nest box placement, if possible, should be at a distance of more than 5 km from areas with threatened/vulnerable small mammal species, although if a rodent is rare, it will not be killed in numbers by Barn Owls. In respect to insular ecosystems, despite problems with rodents on islands, it might not be a good idea to favor Barn Owls if they prey upon rare species (birds, mammals). Thus, on islands with endemic species that may be potential prey, special caution should be taken. On the other hand, there are occasions where natural Barn Owl breeding sites pre-exist within protected areas (e.g., Thessaly, Greece), which are designated for avian species, not small mammals. The factor to consider is, consequently, the prior knowledge of existing threatened/vulnerable populations of small mammals within a candidate area for a nest box grid. An additional factor that should be taken into account is the total niche of nocturnal raptors in an area where a new Barn Owl nest box grid is to be installed. Competition must not outrun and create pressure on other sympatric species.

3.4. Societal Engagement

For a Barn Owl nest box scheme to succeed in a new region, it is essential to engage a wide range of stakeholders, including local municipalities, regional governments, central authorities, farmers, and agricultural associations [109,110]. Local authorities have a direct influence on land use policies and agricultural management practices within their jurisdictions. They can provide valuable resources and logistical support, helping to identify optimal locations for nest boxes based on local knowledge of rodent outbreaks and Barn Owl populations, and establish a long-term cooperative context. Informing and involving them can facilitate a smoother implementation of the nest box scheme and ensure alignment with regional agricultural policies.

In broader geographical Barn Owl projects, the involvement of central government authorities may also become necessary. Central governments can provide a higher level of coordination and policy support, ensuring that the project aligns with national biodiversity and pest management strategies. Engaging the central authorities can also help in securing funding and regulatory approvals, which are essential for the long-term sustainability of the project. Additionally, the central government involvement can promote the replication of successful regional projects on a national scale, amplifying the benefits of Barn Owl-based pest control.

The active participation of farmers and livestock breeders is also highly critical, as they are the primary beneficiaries of the pest control services provided by Barn Owls [51]. Engaging farmers ensures that they support and actively participate in the project, for instance, by maintaining and monitoring the nest boxes. Agricultural associations can play a pivotal role in mobilizing farmers and providing a platform for disseminating information and best practices.

Moreover, societal engagement fosters transparency and builds trust among stakeholders [111]. When communities are involved in the decision-making process, they are more likely to support the project and contribute to its success [112]. By promoting a sense of ownership and community involvement, the project can achieve greater acceptance and resilience against potential challenges, ensuring that it meets the ecological and economic needs of the region.

3.5. Educative and Awareness Campaigns

Creating a series of educational and awareness campaigns is fundamental to the success of a Barn Owl nest box scheme, as it ensures that all relevant stakeholders are informed, engaged, and supportive of the initiative. These campaigns should target a wide range of audiences, including children, students, rural citizens, farmers, livestock breeders, and public servants at various levels of central, decentralized, and regional governments.

For children and students, environmental education can be integrated into school curriculums through interactive lessons, field trips, and hands-on activities such as building nest boxes and participating in habitat restoration projects and pellet analysis workshops.

For rural citizens, farmers, and livestock breeders, workshops and seminars can include demonstrations on how to build and install nest boxes, as well as discussions on how reducing rodenticide use can lead to healthier ecosystems and improved agricultural yields. Field visits to successful Barn Owl nest box sites can offer practical insights and inspire farmers to adopt similar practices.

Public servants and administrative officers at the municipal and regional levels also play a critical role in the implementation and sustainability of the Barn Owl projects. Training sessions and informational meetings can help these officials understand the environmental and economic benefits of the scheme.

The use of various educational tools such as videos, online tutorials, and interactive games can enhance the reach and effectiveness of these campaigns. For instance, video documentaries on the life cycle of Barn Owls and their role in pest control can be shared on social media platforms to reach a broader audience. Additionally, educational games and apps can be developed to teach children and adults alike about the importance of biodiversity and sustainable agricultural practices.

4. Discussion

4.1. The Recurring Rodent Problem in Agriculture: The Need for Creating a Different Integrative Model in Pest Management

The persistent problem of rodent infestations in agriculture is a multifaceted issue that stems from the ecological, biological, and reproductive characteristics of rodents, coupled with the economic and management challenges faced by farmers globally [1,3]. Rodents, due to their vast diversity and adaptability, pose significant threats to agricultural production, as they are capable of thriving in a wide range of environments and are often the main culprits behind substantial crop losses [4–6].

One of the core reasons for the recurring nature of rodent problems in agriculture is their remarkable reproductive capacity, which allows them to quickly repopulate an area even after control measures have been applied [10]. This rapid population rebound is facilitated by rodents' short gestation periods and the ability to produce multiple litters annually, each containing a high number of offspring. This biological edge makes sustained management efforts particularly challenging and often requires continuous and intensive control strategies to keep their numbers in check.

Economically, the impact of rodents on agriculture is profound [10,11]. They not only consume a significant portion of crops in the field but also damage stored products, which further exacerbates food loss. This not only leads to direct economic losses in terms of reduced crop yields but also increases the costs associated with pest management and the repair of structural damage caused by rodents [6]. The economic burden is especially heavy in regions where agriculture forms a substantial part of the local economy and food security, like most regions of the Mediterranean.

Management strategies often fail to achieve long-term success due to several factors, including the inadequacy of conventional control methods, such as trapping and the use of rodenticides, which rodents can sometimes develop resistance to [113,114]. In addition, in the EU, most rodenticides have been banned from application on open fields and are allowed only in closed safe spaces. Additionally, the spatial and temporal heterogeneity of rodent populations necessitate localized management approaches that are often difficult to implement effectively on a large scale. These challenges are compounded by the need for coordination among multiple landowners and the variability in the acceptance and implementation of different control methods due to cultural, legal, and environmental concerns.

The integration of ecological and economic considerations into rodent management strategies is critical. A deeper understanding of rodent ecology and behavior, combined with cost-effective and ecologically sustainable management practices, could enhance the effectiveness of control measures. This includes the development of integrated pest management (IPM) strategies that utilize a combination of biological, mechanical, and chemical control methods tailored to specific agricultural settings [115]. In this context, Barn Owl, as a natural control agent to control pest rodents in agriculture, surfaces in various parts of the globe as the most adequate NbS solution, which is what we demonstrate in this review paper as well.

Furthermore, in the context of escalating climate change, revising agricultural management models becomes imperative to addressing the intertwined challenges of environmental shifts, persistent rodent problems, and their compounded impact on agriculture. Climate change is predicted to exacerbate rodent infestations in agricultural settings due to shifts in habitat and weather patterns that may favor rodent breeding and survival rates [116], and may also have negative impacts on their predators [117]. For instance, warmer winters and extended growing seasons can lead to increased rodent activity and expanded geographic ranges. Additionally, extreme weather events like floods and droughts can disrupt traditional agricultural practices and create conditions conducive to rodent proliferation by altering their habitats and available food sources.

This necessitates a transformation in agricultural management to incorporate more resilient practices that can withstand the unpredictability of climate change while curbing the burgeoning rodent populations. Leveraging biological control methods and enhancing natural predatory cycles could also play crucial roles in managing rodent populations effectively under changing climatic conditions.

4.2. National Barn Owl Projects: Different Velocities, Different Needs, Different Goals

Malaysia was the first country that started the implementation of the Barn Owl project in the 1970s [59–62]. Nonetheless, it was Israel's Barn Owl Project and its evolution that established it as the pioneering Barn Owl project in the world. It was initiated in the 1980s and is one of the most established and successful implementations globally [50,51]. The project has expanded significantly, with about 5000 nest boxes installed across the nation's agricultural territories as of 2024, leading to a notable reduction in the use of rodenticides by 45% according to the Ministry of Agriculture (Figure 2). In terms of research, various researchers and academics have assisted during these years in deepening research questions for the Barn Owl project in Israel [50,51,71,73,75,76,118,119]. During these almost 4 decades of continuous evolution, Israel has successfully combined research, academic institutes, agricultural stakeholders, and administrative local and regional authorities in order to calibrate a thorough and successful national project.

California's integration of Barn Owl nest boxes into its agricultural pest management practices as well, particularly in vineyards, has shown satisfactory results for pest-rodent control. The project began in the mid-1990s and is still ongoing, and it is supported by numerous studies confirming the significant decrease in local rodent populations due to Barn Owl predation [56–58]. This demonstrates the project's sustainability and effectiveness in a major agricultural state. Thousands of Barn Owl nest boxes are raised in Californian vineyards. Extensive research in the USA (California Barn Owl project) from the research group of Humbold State University has shed light on the success of the project, and various factors that must be additionally taken under consideration, during research [70,98]. Similarly, important results for the success of another Mediterranean Barn Owl project come from three pilot areas in Spain: Valladolid, Palencia, and Zamora [53–55]. In Spain, highly successful results were produced in adjacent areas to the occupied nest boxes. It was also deduced that habitat plays a crucial role for Barn Owl nest box occupation, whereas it is suggested that hacking and Barn Owl population restocking may be a necessary mechanism in vast agricultural ecosystems with low Barn Owl populations.

In Cyprus, the project started in 1995 with a few boxes and has grown to exceed 1300 nest boxes in recent years. This effort was extended across all districts and involved various governmental departments, highlighting a nationwide commitment to integrating Barn Owls into pest management strategies. Although rodenticide numbers have decreased in Cyprus during the last 3 years of the project (after 2020), it cannot be deduced that this is a cause-effect result due to increased Barn Owl nest boxes and occupation, since many factors can contribute to it. In Greece as well, The Greek Barn Owl Project began in 2019 in Thessaly, driven by a local conservation group "TYTO" and supported by agricultural organizations. The initial deployment of 100 nest boxes had grown to 290 by 2023, with the Region of Thessaly signing a four-year contract to continue and expand the project. This indicates a strong institutional backing and a positive reception to natural pest control methods. With a total of 900 sq.km of agricultural area with annual pest-rodent problems, a minimum of 1800 nest boxes should be installed (minimum of 2 boxes per sq.km). On the other hand, in order to gradually evolve all necessary axes of the project (awareness actions, field nest box implementation, social and administrative engagement, education, research), it was considered more crucial to begin with a small number of boxes in each one of the nine collaborating municipalities and gradually evolve all axes of the project in Greece. Similarly, Jordan has increased their boxes up to 250 and gradually included more farmers and engaged them in awareness and implementation actions.

It must be noted that the Barn Owl is also considered a "bad omen" in Arab and African cultures and large parts of the Palearctic, where there was a broad perception that the species should be eliminated from rural areas [120]. Years of fruitful efforts and awareness seminars are invested in order to shift this attitude and recognize the beneficial ecosystem service of the Barn Owl. These joint activities not only foster environmental cooperation (e.g., between Jordan and Israel) but also significantly improve relationships between countries (Israeli and Jordanian farmers on both sides of the river).

This fact pinpoints that different speeds and axes are necessary for different national Barn Owls projects, with a diverse focus needed to be placed on societal engagement, research, implementation practices, and field deployment, depending on local culture, environmental conditions, and ecological factors and constraints in each national Barn Owl project.

4.3. Barn Owl as the Adequate NbS for Pest Rodent Control in Agriculture: Potential and Limitations

Barn Owls, as a Nature-Based Solution (NbS), offer significant benefits for controlling pest rodents in agricultural settings as effective predators of rodent species that cause substantial damage to crops worldwide, preying exclusively on small mammals and mainly on those that are more abundant [48,49,63,64]. As a natural process, it may take time, depending on local environmental, climatic, and habitat factors and nest boxes density, but, eventually, it will lead to a successful implementation.

Barn Owls are considered an optimal NbS for controlling pest rodents in agriculture due to their inherent biological and ecological traits. Their diet primarily consists of rodents, which aligns perfectly with the needs of agricultural pest management [96,108]. By consuming thousands of rodents annually, Barn Owls, which are sedentary and, hence, can act as a biological pest control agent all year long, significantly reduce the crop damage and economic losses associated with rodent infestations. Furthermore, their ability to thrive in diverse regions globally, specifically agricultural settings, allows them to be effective control agents across various geographic locations [47]. Moreover, the deployment of nest boxes enhances Barn Owl populations in targeted areas, directly contributing to increased pest control. This method of pest management not only reduces the reliance on harmful chemical rodenticides, which pose significant ecological and health risks, but also supports biodiversity. Barn Owls serve as a key species in maintaining the ecological balance, helping control not only rodent populations but also potentially other pest species indirectly through their presence in the ecosystem. In terms of Barn Owl species in the areas of study, the species *Tyto alba* is encountered in the Mediterranean region in Israel, Jordan, Cyprus, Morocco, and Greece, whereas in Malaysia *Tyto javanica* is present while *Tyto furcata* is present in the USA [121].

From an ecological perspective, the management of Barn Owls also needs to take into account intrusive species and possible food resources competition with other predators in the area. Intrusive species may claim Barn Owl nest boxes (e.g., *Corvus monedula*, *Columba livia*) [122]; thus, it would be wise for future constructions of nest boxes to include mechanisms that could possibly drive away intruders. In respect to other native predator species and food resource competition between Barn Owls and other predators, it must be highlighted that open agroecosystems, where Barn Owls reside and breed, are vast ecosystems with possibility to host high numbers of raptors due to high numbers of rodents as well. Nonetheless, due to the low availability of nesting sites, there is a low species richness in the predator-niche agricultural ecosystems [123,124]. As such, and in combination with the extremely high numbers of rodents in agro-ecosystems, along with the adaptation of Barn Owls to rodent cycles, competition for food resources may rarely be a possible case.

It is highly important, though, to cautiously explore any initiative for a Barn Owl nest box project in regions where Barn Owls are not native [125]. Barn Owl introduction could lead to unforeseen ecological impacts, so introduction schemes must be very carefully designed. Therefore, while Barn Owls are a valuable tool for natural pest control, their use must be part of an integrated pest management (IPM) strategy that considers ecological balance and sustainability. In addition, in regions where Barn Owls are native but have low numbers and low nest box occupancy, it is suggested by some researchers to restock their population through Barn Owl hacking processes [55].

Management of Barn Owls population as a pest management strategy comes with certain limitations. One major limitation is the dependency on suitable nesting sites, which can restrict their population growth and distribution. As such, artificial nest boxes are highly suggested as the main "tool" to support their numbers. Consequently, in Barn Owl nest box schemes, we can have precise control over where Barn Owls should and could breed. In the case of open agricultural ecosystems with low height vegetation (no tree plantations), it is imprescindible to spatially position Barn Owl nest boxes upon poles. The presence of Barn Owls might not sufficiently control rodent populations if the environmental conditions favor high reproductive rates of rodents or if the area is too large for the number of owls present [56,57]. On this occasion, practice as in Israel and Malaysia has shown that a higher density of nest boxes per land unit must be applied. This, in fact, is another advantage of the Barn Owl; in years when there are many rodents, the Barn Owls are not territorial, and pairs can breed very close to each other.

4.4. Research and Practical Implementation: A Two-Speed Vehicle That Drives Successful Barn Owl Pest-Rodent Control in Different Agroecosystems of the World

Globally, the implementation of Barn Owl-based pest control programs has seen varying degrees of adoption, influenced by the following: (i) local agricultural practices, (ii) local environmental factors, (iii) the economic costs of setting up and maintaining nest boxes, (iv) the personnel and material investment for constant farmer education on the benefits of using natural predators over chemical methods, (v) the extension of agricultural areas in need of integrated pest management strategies, and (vi) the budget ceilings in each country and region.

In all cases, though, in order to lead a successful Barn Owl project, it is necessary to invest equally in (i) research, (ii) practical field implementation, (iii) stakeholder engagement, and (iv) awareness reachouts. These form the cornerstone of the strategic deployment of Barn Owl projects worldwide. Research not only elucidates the ecological dynamics of Barn Owls—such as their diet preferences, reproductive behavior, habitat needs, and foraging patterns—but also provides essential data for fine-tuning practical applications. For instance, studies across various regions have detailed the diet of Barn Owls, focusing heavily on their consumption of pest rodents, thus reinforcing their role in maintaining agricultural health by naturally controlling these populations. A key factor for the success of a Barn Owl project also lies in the presence of motivated ornithologists in a region to start supporting the project, but since ornithology is very popular, there are always ornithologist representatives to actively support the initiation of a project.

However, the application of this research in practical settings, such as the design and placement of nest boxes, encounters varied speeds of adoption and effectiveness. The integration of scientific findings into practical implementations like nest box programs has proven successful in regions like Israel, where extensive monitoring and adaptive management practices based on ongoing research have led to notable decreases in rodent populations and reduced reliance on rodenticides. Yet, in other regions, the practical application lags due to different ecological conditions, lack of local research, or varying degrees of stakeholder engagement and available budget. This disparity underscores the need for localized research efforts that can inform tailored implementation strategies that align with specific agroecosystem characteristics and challenges.

The case studies from around the world suggest a compelling need for a symbiotic relationship between research and practical application. Implementing scientifically informed strategies ensures that Barn Owl populations are effectively managed and utilized for pest control, contributing to sustainable agricultural practices and biodiversity conservation.

4.5. The International Barn Owl Network and Initiative: Current Status and Future Plans

The Barn Owl project in Israel has evolved into a model of international collaboration, involving multiple countries and diverse stakeholders. This initiative underscores a unique model of cooperation involving countries, farmers, academics, conservationists, and governmental and public organizations, bridging cultural and national divides. Significant contributions from the University of Lausanne in Switzerland and Tel Aviv University have been crucial in establishing and expanding these international collaborations. A working group was also initiated in the International Ornithologists' Union (IOU) called Birds for Peace, emphasizing the project's mission to bridge cultural and national divides [126]. Their efforts have fostered scientific cooperation, promoted sustainable agricultural practices, and demonstrated how ecological innovations can transcend political boundaries, facilitating global ecological and agricultural advancements [126]. Recently, there has been great interest from Ukraine, Italy, Germany, and several African countries interested in joining the project. The international contact via science was also a very powerful platform in the evolution of the international Barn Owl network, since science proved very powerful in making contact and then motivating researchers around the globe to enlarge their vision towards environmentally friendly agriculture.

4.6. No Frontiers for the Peace Ambassadors: Barn Owls as an Ecological Platform for Peace Negotiations

Barn Owls, renowned for their role in natural pest control, are also gaining recognition as unlikely ambassadors for peace in conflict-ridden regions. This idea has been particularly highlighted through collaborative environmental projects in the Middle East, where the Barn Owl's presence transcends borders and fosters dialogue among nations often divided by political tensions [126]. The project, which began by addressing the mutual agricultural pest issues faced by farmers in Israel, Jordan, and the Palestinian territories, utilizes Barn Owls to control rodent populations, a natural alternative to harmful pesticides. The introduction of nesting boxes has encouraged the proliferation of these owls across farms in the adjacent countries, and as this initiative has expanded, it has shown promising signs of fostering cooperation among nations. Researchers and conservationists have documented instances where these owls traveled between Israel and Jordanian and Palestinian areas, symbolizing a natural connection between the communities despite political boundaries (Figure 7).

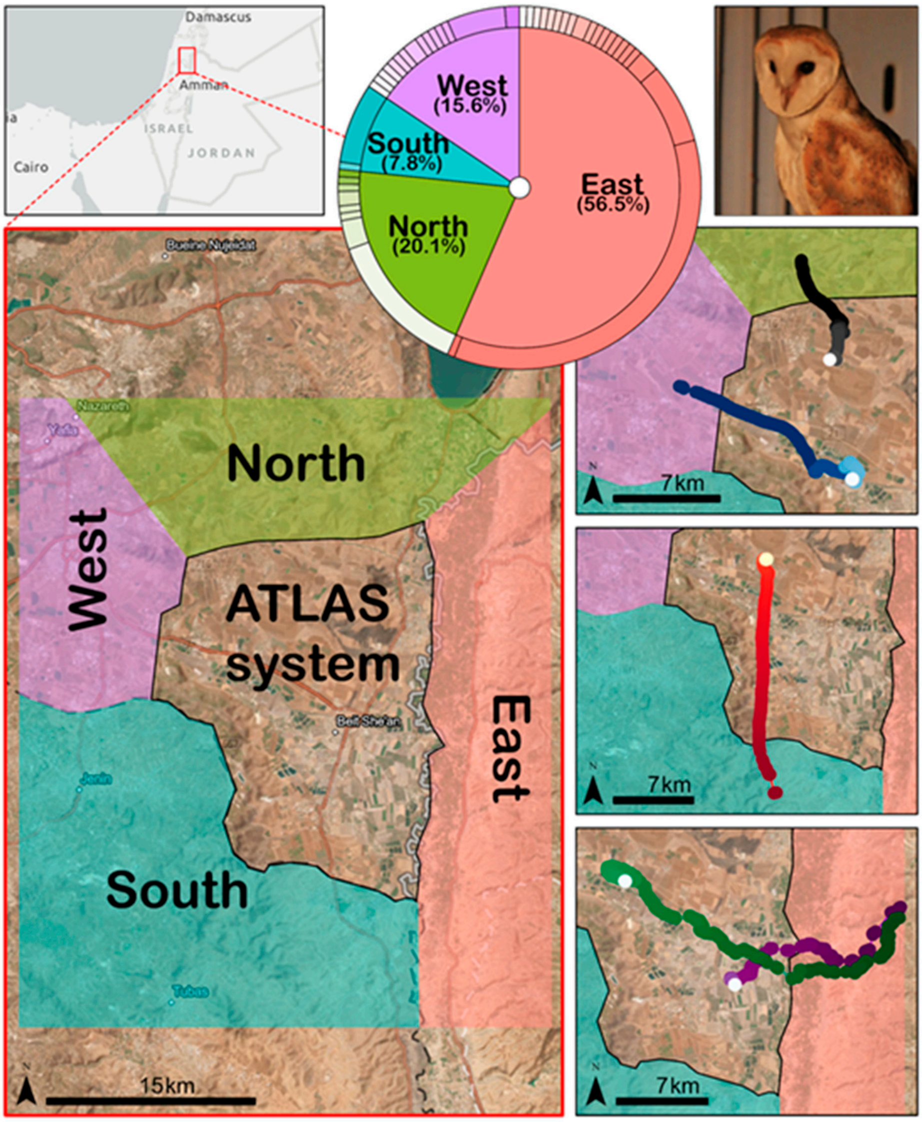

Figure 7. Distribution of Barn Owl flights exiting the boundaries of the Harod ATLAS system (center top) and the contribution of different individuals to this distribution (outer ring). On the left: the ATLAS system boundaries and the division of the surrounding area into 4 polygons—**East**:the Israel–Jordan border; **South**: Israel–Palestinian Authority border; **North**: the reception boundary of

the system towards the north, the Lower Galilee; **West**: the reception boundary of the system towards the Jezreel Valley. On the right, three maps show the flight paths of different individuals exiting the system (different color lines indicate flight paths of different Barn owl individuals), with the top map showing flights towards the north and west; the middle map showing flights towards the south; and the bottom map showing flights towards the east.

Furthermore, the initiative has been instrumental in engaging various community segments, including children and local farmers, in environmental education and conservation efforts. Schools and community groups from different backgrounds come together, learning about sustainable farming practices and the ecological benefits of Barn Owls. These interactions have helped break down stereotypes and build trust among communities, using the Barn Owl as a symbol of mutual interest and respect.

This unique blend of environmental science and peacebuilding suggests that nature conservation projects like these can serve as a neutral platform for dialog and cooperation, even in regions marred by long-standing conflicts. The success of the Barn Owl conservation projects has even sparked interest in applying similar models to other geopolitical conflicts around the world, suggesting a broader potential impact beyond the initial regions. Such endeavors underscore the powerful role that environmental stewardship can play in diplomatic relations and community building.

5. Conclusions

Our paper on managing Barn Owls as a Nature-Based Solution (NbS) to control pest rodents in agricultural ecosystems presents a comprehensive approach to integrating Barn Owls into pest management strategies across various regions. The study underscores the severe economic and environmental challenges posed by rodent infestations in agriculture, noting that traditional chemical control methods, while effective in the short term, have significant negative impacts on non-target species and overall ecosystem health without creating a permanent long-term control solution. In response, the paper advocates the use of Barn Owls as a sustainable alternative, leveraging their natural predation on rodents to mitigate crop damage and reduce the reliance on chemical rodenticides.

We present the roadmap of Barn Owl-based pest control programs, particularly through the strategic deployment of nest boxes in agricultural areas. The success of these programs is evident in several case studies from Israel, Spain, and USA, and is being implemented in a large scale in Cyprus, Jordan, Greece, and Morocco. Substantial reductions in rodenticide use and improved crop protection have been recorded in Israel, Spain, California, and Cyprus. The paper emphasizes that the success of such initiatives depends on a multifaceted approach, integrating scientific research, societal engagement, supportive policy frameworks, and education. By involving local communities, farmers, and policymakers, these projects not only address pest control but also contribute to broader biodiversity conservation efforts and sustainable agricultural practices.

However, we also acknowledge the challenges associated with implementing Barn Owl programs, such as habitat suitability, potential conflicts with other wildlife, and the need for continuous monitoring and research. The variability in the success of these programs across different regions underscores the importance of tailoring strategies to local environmental conditions and socio-cultural contexts. For instance, the introduction of Barn Owls in new areas must consider potential negative impacts on local endangered species and the need for public awareness campaigns to overcome cultural perceptions of Barn Owls, which still have a negative aspect.

Our paper advocates the broader adoption of Barn Owl-based pest management as a viable and sustainable solution for agricultural ecosystems. It calls for ongoing international collaboration, sharing best practices, and continuous research to optimize the effectiveness of these programs. By doing so, Barn Owls can serve as a critical component of integrated pest management strategies, promoting ecological balance and reducing the environmental footprint of agriculture.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/conservation4040039/s1, Supplementary Material S1: Constructing the adequate Barn owl nest box.

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References

1. Aulicky, R. Rodents in Crop Production Agricultural Systems—Special Issue. *Agronomy* **2022**, *12*, 2813. [CrossRef]
2. Singleton, G.R.; Belmain, S.R.; Brown, P.R.; Hardy, B. (Eds.) *Rodent Outbreaks: Ecology and Impacts*; International Rice Research Institute: Los Baños, Philippines, 2010; p. 289.
3. Savary, S.; Ficke, A.; Aubertot, J.-N.; Hollier, C. Crop losses due to diseases and their implications for global food production losses and food security. *Food Secur.* **2012**, *4*, 519–537. [CrossRef]
4. Oerke, E.C.; Dehne, H.W.; Schönbeck, F.; Weber, A. *Crop Production and Crop Protection: Estimated Losses in Major Food and Cash Crops*; Elsevier: Amsterdam, The Netherlands, 1994; p. 808.
5. Oerke, E.C. Crop Losses to Pests. *J. Agric. Sci.* **2006**, *144*, 31–43. [CrossRef]
6. Witmer, G. Rodents in Agriculture: A Broad Perspective. *Agronomy* **2022**, *12*, 1458. [CrossRef]
7. Govinda, R.G. Rodents. In *Pests and Their Management*, 1st ed.; Omkar, Ed.; Springer Nature Singapore Pte Ltd.: Singapore, 2018; pp. 973–1014.
8. Wood, B.J.; Singleton, G.R. Rodents in agriculture and forestry. In *Rodent Pests and Their Control*, 2nd ed.; Buckle, A.P., Smith, R.H., Eds.; CABI: Wallingford, UK, 2015; p. 432.
9. FAO. *FAO′s Plant Production and Protection Division*; FAO: Rome, Italy, 2022; p. 32. [CrossRef]
10. Stenseth, N.C.; Leirs, H.; Skonhoft, A.; Davis, S.A.; Pech, R.P.; Andreassen, H.P.; Singleton, G.R.; Lima, M.; Machang'u, R.S.; Makundi, R.H.; et al. Mice, Rats, and People: The Bio-Economics of Agricultural Rodent Pests. *Front. Ecol. Environ.* **2003**, *1*, 367–375. [CrossRef]
11. Singleton, G.R. *Impacts of Rodents on Rice Production in Asia*; IRRI Discussion Paper Series No. 45; International Rice Research Institute: Los Baños, Philippines, 2003; pp. 1–30.
12. Morand, S.; Jittapalapong, S.; Kosoy, M. Rodents as Hosts of Infectious Diseases: Biological and Ecological Characteristics. *Vector-Borne Zoonotic Dis.* **2015**, *15*, 1–2. [CrossRef]
13. Meerburg, B.G.; Singleton, G.R.; Kijlstra, A. Rodent-borne diseases and their risks for public health. *Crit. Rev. Microbiol.* **2009**, *35*, 221–270. [CrossRef]
14. Haouas, D.; Hufnagel, L. (Eds.) *Pests Control and Acarology*; IntechOpen: London, UK, 2020; pp. 1–176.
15. Smith, R.H.; Shore, R.F. Environmental Impacts of Rodenticides. In *Rodent Pests and Their Control*, 2nd ed.; Buckle, A., Smith, R., Eds.; CABI: Wallingford, UK, 2015; pp. 330–380.
16. Regnery, J.; Friesen, A.; Geduhn, A.; Göckener, B.; Kotthoff, M.; Parrhysius, P.; Brinke, M. Rating the risks of anticoagulant rodenticides in the aquatic environment: A review. *Environ. Chem. Lett.* **2019**, *17*, 215–240. [CrossRef]

17. van den Brink, N.W.; Elliott, J.E.; Shore, R.F.; Rattner, B.A. (Eds.) *Anticoagulant Rodenticides and Wildlife*; Springer: Cham, Switzerland, 2018; p. 398. [CrossRef]
18. Matthews, G.A. *Pesticides: Health, Safety and the Environment*, 2nd ed.; Wiley: Chichester, UK, 2016; p. 248.
19. Nakayama, S.M.M.; Ikenaka, Y.; Morita, A.; Mizukawa, H.; Ishizuka, M. A review: Poisoning by anticoagulant rodenticides in non-target animals globally. *J. Vet. Med. Sci.* **2019**, *81*, 298–313. [CrossRef]
20. Erofeeva, E.V.; Surkova, J.E.; Shubkina, A.V. Rodenticides and Wildlife Extermination. *Biol. Bull. Rev.* **2022**, *12*, 178–188. [CrossRef]
21. Treu, G.; Slobodnik, J.; Alygizakis, N.; Badry, A.; Bunke, D.; Cincinelli, A.; Claßen, D.; Dekker, R.W.R.J.; Göckener, B.; Gkotsis, G.; et al. Using environmental monitoring data from apex predators for chemicals management: Towards better use of monitoring data from apex predators in support of prioritisation and risk assessment of chemicals in Europe. *Environ. Sci. Eur.* **2022**, *34*, 82. [CrossRef]
22. Seddon, N.; Chausson, A.; Berry, P.; Girardin, C.A.J.; Smith, A.; Turner, B. Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philos. Trans. R. Soc. B Biol. Sci.* **2020**, *375*, 20190120. [CrossRef] [PubMed]
23. Seddon, N.; Daniels, E.; Davis, R.; Chausson, A.; Harris, R.; Hou-Jones, X.; Huq, S.; Kapos, V.; Mace, G.M.; Rizvi, A.R.; et al. Global recognition of the importance of nature-based solutions to the impacts of climate change. *Glob. Sustain.* **2020**, *3*, e8. [CrossRef]
24. Xie, L.; Bulkeley, H.; Tozer, L. Mainstreaming sustainable innovation: Unlocking the potential of nature-based solutions for climate change and biodiversity. *Environ. Sci. Policy* **2022**, *132*, 119–130. [CrossRef]
25. Fischer, J.; Riechers, M.; Loos, J.; Martin-Lopez, B.; Temperton, V.M. Making the UN Decade on Ecosystem Restoration a Social-Ecological Endeavour. *Trends Ecol. Evol.* **2021**, *36*, 20–28. [CrossRef]
26. Aronson, J.; Goodwin, N.; Orlando, L.; Eisenberg, C.; Cross, A.T. A World of Possibilities: Six Restoration Strategies to Support the United Nation's Decade on Ecosystem Restoration. *Restor. Ecol.* **2020**, *28*, 730–736. [CrossRef]
27. Abhilash, P.C. Restoring the Unrestored: Strategies for Restoring Global Land during the UN Decade on Ecosystem Restoration (UN-DER). *Land* **2021**, *10*, 201. [CrossRef]
28. Simelton, E.; Carew-Reid, J.; Coulier, M.; Damen, B.; Howell, J.; Pottinger-Glass, C.; Tran, H.V.; Van Der Meiren, M. NBS Framework for Agricultural Landscapes. *Front. Environ. Sci.* **2021**, *9*, 678367. [CrossRef]
29. Iseman, T.; Miralles-Wilhelm, F. Nature-Based Solutions in Agriculture: The Case and Pathway for Adoption. In *Food and Agriculture Organization of the United Nations*; The Nature Conservancy: Arlington County, VA, USA, 2021; pp. 1–32. [CrossRef]
30. Pultrone, G. Through and beyond the Poli(s)crisis: Guiding the Eco-Social Transition in UE. *UPLanD-J. Urban Plan. Landsc. Environ. Des.* **2020**, *5*, 61–76.
31. de Luca, C.; Naumann, S.; Davis, M.; Tondelli, S. Nature-Based Solutions and Sustainable Urban Planning in the European Environmental Policy Framework: Analysis of the State of the Art and Recommendations for Future Development. *Sustainability* **2021**, *13*, 5021. [CrossRef]
32. Maes, J.; Jacobs, S. Nature-Based Solutions for Europe's Sustainable Development. *Conserv. Lett.* **2017**, *10*, 121–124. [CrossRef]
33. Nwaogu, C.; Cherubin, M.R. Integrated Agricultural Systems: The 21st Century Nature-Based Solution for Resolving the Global FEEES Challenges. *Adv. Agron.* **2024**, *185*, 1–73. [CrossRef]
34. Miralles-Wilhelm, F.; Iseman, T. *Nature-Based Solutions in Agriculture: Sustainable Management and Conservation of Land, Water, and Biodiversity*; FAO: Rome, Italy; The Nature Conservancy: Arlington County, VA, USA, 2021. [CrossRef]
35. Mrunalini, K.; Behera, B.; Jayaraman, S.; Abhilash, P.C.; Dubey, P.K.; Swamy, G.N.; Prasad, J.V.N.S.; Rao, K.V.; Krishnan, P.; Pratibha, G.; et al. Nature-Based Solutions in Soil Restoration for Improving Agricultural Productivity. *Land Degrad. Dev.* **2022**, *33*, 1269–1289. [CrossRef]
36. Keesstra, S.; Nunes, J.P.; Novara, A.; Finger, D.; Avelar, D.; Kalantari, Z.; Cerdà, A. The Superior Effect of Nature-Based Solutions in Land Management for Enhancing Ecosystem Services. *Sci. Total Environ.* **2018**, *610–611*, 997–1009. [CrossRef]
37. Lal, R. Nature-Based Solutions of Soil Management and Agriculture. *J. Soil Water Conserv.* **2022**, *77*, 23A–29A. [CrossRef]
38. Ferreira, C.S.S.; Kašanin-Grubin, M.; Solomun, M.K.; Sushkova, S.; Minkina, T.; Zhao, W.; Kalantari, Z. Wetlands as Nature-Based Solutions for Water Management in Different Environments. *Curr. Opin. Environ. Sci. Health* **2023**, *33*, 100476. [CrossRef]
39. Barriuso, F.; Urbano, B. Green Roofs and Walls Design Intended to Mitigate Climate Change in Urban Areas across All Continents. *Sustainability* **2021**, *13*, 2245. [CrossRef]
40. van Hespen, R.; Hu, Z.; Borsje, B.; De Dominicis, M.; Friess, D.A.; Jevrejeva, S.; Kleinhans, M.G.; Maza, M.; van Bijsterveldt, C.E.J.; Van der Stocken, T.; et al. Mangrove Forests as a Nature-Based Solution for Coastal Flood Protection: Biophysical and Ecological Considerations. *Water Sci. Eng.* **2023**, *16*, 1–13. [CrossRef]
41. Keesstra, S.; Veraart, J.; Verhagen, J.; Visser, S.; Kragt, M.; Linderhof, V.; Appelman, W.; van den Berg, J.; Deolu-Ajayi, A.; Groot, A. Nature-Based Solutions as Building Blocks for the Transition towards Sustainable Climate-Resilient Food Systems. *Sustainability* **2023**, *15*, 4475. [CrossRef]
42. Faivre, N.; Fritz, M.; Freitas, T.; de Boissezon, B.; Vandewoestijne, S. Nature-Based Solutions in the EU: Innovating with Nature to Address Social, Economic and Environmental Challenges. *Environ. Res.* **2017**, *159*, 509–518. [CrossRef]
43. Stefanakis, A.I.; Calheiros, C.S.C.; Nikolaou, I. Nature-Based Solutions as a Tool in the New Circular Economic Model for Climate Change Adaptation. *Circ. Econ. Sustain.* **2021**, *1*, 303–318. [CrossRef]
44. Kooijman, E.D.; McQuaid, S.; Rhodes, M.-L.; Collier, M.J.; Pilla, F. Innovating with Nature: From Nature-Based Solutions to Nature-Based Enterprises. *Sustainability* **2021**, *13*, 1263. [CrossRef]

45. Kan, I.; Motro, Y.; Horvitz, N.; Kimhi, A.; Leshem, Y.; Yom-Tov, Y.; Nathan, R. Agricultural Rodent Control Using Barn Owls: Is It Profitable? *Conservation* **2024**, *12*, 345–362. [CrossRef]
46. Gómez Martín, E.; Giordano, R.; Pagano, A.; van der Keur, P.; Máñez Costa, M. Using a System Thinking Approach to Assess the Contribution of Nature Based Solutions to Sustainable Development Goals. *Sci. Total Environ.* **2020**, *738*, 139693. [CrossRef]
47. Roulin, A. *Barn Owls: Evolution and Ecology*; Cambridge University Press: Cambridge, UK, 2020; pp. 1–352.
48. Janžekovič, F.; Klenovšek, T. The Biogeography of Diet Diversity of Barn Owls on Mediterranean Islands. *J. Biogeogr.* **2020**, *47*, 2353–2361. [CrossRef]
49. Riegert, J.; Šindelář, J.; Zárybnická, M.; Horáček, I. Large-Scale Spatial Patterns of Small-Mammal Communities in the Mediterranean Region Revealed by Barn Owl Diet. *Sci. Rep.* **2021**, *11*, 5975. [CrossRef]
50. Meyrom, K.; Motro, Y.; Leshem, Y.; Aviel, S.; Izhaki, I.; Argyle, F.; Charter, M. Nest-Box Use by the Barn Owl *Tyto alba* in a Biological Pest Control Program in the Beit She'an Valley, Israel. *Ardea* **2009**, *97*, 463–467. [CrossRef]
51. Peleg, O.; Nir, S.; Leshem, Y.; Meyrom, K.; Aviel, S.; Charter, M.; Roulin, A.; Izhak, I. Three Decades of Satisfied Israeli Farmers: Barn Owls (*Tyto alba*) as Biological Pest Control of Rodents. In Proceedings of the Vertebrate Pest Conference, Rohnert Park, CA, USA, 26 February–1 March 2018; Volume 28, pp. 208–217. [CrossRef]
52. Meyrom, K.; Leshem, Y.; Charter, M. Barn Owl *Tyto alba* Breeding Success in Man-Made Structures in the Jordan Rift Valley, Israel. *Sandgrouse* **2008**, *30*, 134–137.
53. Paz, A.; Jareño, D.; Arroyo, L.; Viñuela, J.; Mougeot, F.; Luque-Larena, J.J.; Fargallo, J.A. Avian Predators as a Biological Control System of Common Vole (*Microtus arvalis*) Populations in North-Western Spain: Experimental Set-Up and Preliminary Results. *Pest Manag. Sci.* **2013**, *69*, 444–450. [CrossRef]
54. Paz Luna, A.; Bintanel, H.; Viñuela, J.; Villanúa, D. Nest-Boxes for Raptors as a Biological Control System of Vole Pests: High Local Success with Moderate Negative Consequences for Non-Target Species. *Biol. Control* **2020**, *146*, 104267. [CrossRef]
55. Jareño, D.; Paz Luna, A.; Viñuela, J. Local Effects of Nest-Boxes for Avian Predators over Common Vole Abundance during a Mid-Density Outbreak. *Life* **2023**, *13*, 1963. [CrossRef] [PubMed]
56. Kross, S.M.; Baldwin, R.A. Gopherbusters? A Review of the Candidacy of Barn Owls as the Ultimate Natural Pest Control Option. In Proceedings of the Vertebrate Pest Conference, Newport Beach, CA, USA, 7–10 March 2016; Volume 27, pp. 345–352. [CrossRef]
57. Johnson, M.D.; Wendt, C.; St. George, D.; Huysman, A.E.; Estes, B.R.; Castañeda, X.A. Can Barn Owls Help Control Rodents in Winegrape Vineyard Landscapes? A Review of Key Questions and Suggested Next Steps. In Proceedings of the Vertebrate Pest Conference, Rohnert Park, CA, USA, 26 February–1 March 2018; Volume 28, pp. 207–214. [CrossRef]
58. Hansen, A.; Johnson, M. Evaluating the Use of Barn Owl Nest Boxes for Rodent Pest Control in Winegrape Vineyards in Napa Valley. In Proceedings of the Vertebrate Pest Conference, Reno, NV, USA, 7–10 March 2022; Volume 30, pp. 1–8.
59. Bessou, C.; Verwilghen, A.; Beaudoin-Ollivier, L.; Marichal, R.; Ollivier, J.; Baron, V.; Bonneau, X.; Carron, M.-P.; Snoeck, D.; Naim, M.; et al. Agroecological Practices in Oil Palm Plantations: Examples from the Field. *OCL* **2017**, *24*, D305. [CrossRef]
60. Murgianto, F.; Edyson; Putra, S.K.; Ardiyanto, A. Role of The Barn Owl *Tyto alba javanica* as a Biological Agent for Rat Pest Control in The Oil Palm Plantation of Bumitama Agri Ltd. In Proceedings of the IOP Conference Series: Earth and Environmental Science, Depok, Indonesia, 27–28 August 2022; Volume 985, p. 012048. [CrossRef]
61. Zainal Abidin, C.M.R.; Noor, H.M.; Hamid, N.H.; Ravindran, S.; Puan, C.L.; Kasim, A.; Salim, H. Breeding Parameters of an Introduced Barn Owl (*Tyto alba javanica*) Population in an Agricultural Area. *J. Raptor Res.* **2022**, *56*, 455–465. [CrossRef]
62. Mah, A.N.M.M.A.; Puan, C.L.; Zakaria, M. The Use of Nest Boxes in Malaysia: Design and the Potential for Research and In-situ Conservation of Birds. *Pertanika J. Trop. Agric. Sci.* **2023**, *46*, 951–969. [CrossRef]
63. Milana, G.; Luiselli, L.; Amori, G. Forty Years of Dietary Studies on Barn Owl (*Tyto alba*) Reveal Long Term Trends in Diversity Metrics of Small Mammal Prey. *Anim. Biol.* **2018**, *68*, 129–146. [CrossRef]
64. Love, R.A.; Webbon, C.; Glue, D.E.; Harris, S. Changes in the Food of British Barn Owls (*Tyto alba*) between 1974 and 1997. *Mammal Rev.* **2000**, *30*, 107–129. [CrossRef]
65. Romano, A.; Séchaud, R.; Roulin, A. Global Biogeographical Patterns in the Diet of a Cosmopolitan Avian Predator. *J. Biogeogr.* **2020**, *47*, 1467–1481. [CrossRef]
66. Konishi, M. How the Owl Tracks Its Prey: Experiments with Trained Barn Owls Reveal How Their Acute Sense of Hearing Enables Them to Catch Prey in the Dark. *Am. Sci.* **2012**, *100*, 494–501. [CrossRef]
67. Bachmann, T.; Blazek, S.; Erlinghagen, T.; Baumgartner, W.; Wagner, H. Barn Owl Flight. In *Nature-Inspired Fluid Mechanics, Notes on Numerical Fluid Mechanics and Multidisciplinary Design*; Tropea, C., Bleckmann, H., Eds.; Springer: Berlin/Heidelberg, Germany, 2012; Volume 119, pp. 101–116. [CrossRef]
68. Boonman, A.; Zadicario, P.; Mazon, Y.; Rabi, C.; Eilam, D. The Sounds of Silence: Barn Owl Noise in Landing and Taking Off. *Behav. Process.* **2018**, *157*, 484–488. [CrossRef]
69. Frey, C.; Sonnay, C.; Dreiss, A.; Roulin, A. Habitat, Breeding Performance, Diet and Individual Age in Swiss Barn Owls (*Tyto alba*). *J. Ornithol.* **2011**, *152*, 279–290. [CrossRef]
70. Wendt, C.A.; Johnson, M.D. Multi-Scale Analysis of Barn Owl Nest Box Selection on Napa Valley Vineyards. *Agric. Ecosyst. Environ.* **2017**, *247*, 75–83. [CrossRef]
71. Charter, M.; Rozman, G. The Importance of Nest Box Placement for Barn Owls (*Tyto alba*). *Animals* **2022**, *12*, 2815. [CrossRef] [PubMed]

72. Bank, L.; Haraszthy, L.; Horváth, A.; Horváth, G.F. Nesting Success and Productivity of the Common Barn-Owl *Tyto alba*: Results from a Nest Box Installation and Long-Term Breeding Monitoring Program in Southern Hungary. *Ornis Hung.* **2019**, *27*, 1–31. [CrossRef]
73. Vissat, L.L.; Cain, S.; Toledo, S.; Spiegel, O.; Getz, W.M. Categorizing the Geometry of Animal Diel Movement Patterns with Examples from High-Resolution Barn Owl Tracking. *Mov. Ecol.* **2023**, *11*, 15. [CrossRef]
74. Séchaud, R.; Schalcher, K.; Machado, A.P.; Roulin, A. Behaviour-Specific Habitat Selection Patterns of Breeding Barn Owls. *Mov. Ecol.* **2021**, *9*, 18. [CrossRef]
75. Cain, S.; Solomon, T.; Leshem, Y.; Toledo, S.; Arnon, E.; Roulin, A.; Spiegel, O. Movement Predictability of Individual Barn Owls Facilitates Estimation of Home Range Size and Survival. *Mov. Ecol.* **2023**, *11*, 10. [CrossRef]
76. Rozman, G.; Izhaki, I.; Roulin, A.; Charter, M.; Leshem, Y.; Alshamlih, M.; Bahaa, N.; Hatzofe, O.; Peleg, O.; Shenbrot, G. Movement Ecology, Breeding, Diet, and Roosting Behavior of Barn Owls (*Tyto alba*) in a Transboundary Conflict Region. *Reg. Environ. Change* **2021**, *21*, 26. [CrossRef]
77. Available online: https://www.barnowltrust.org.uk/barn-owl-nestbox/barn-owl-nestboxes/ (accessed on 23 July 2024).
78. Available online: https://www.barnowlbox.com/ht-faq/new-faq-question-46/ (accessed on 23 July 2024).
79. Leech, D.I.; Shawyer, C.R.; Barimore, C.J.; Crick, H.Q.P. The Barn Owl Monitoring Programme: Establishing a Protocol to Assess Temporal and Spatial Variation in Productivity at a National Scale. *Ardea* **2009**, *97*, 421–428. [CrossRef]
80. Keshet, D.; Brook, A.; Malkinson, D.; Izhaki, I.; Charter, M. The Use of Drones to Determine Rodent Location and Damage in Agricultural Crops. *Drones* **2022**, *6*, 396. [CrossRef]
81. Regev, T.; Kogel, I.; Segev, D.; Benzion, B.; Muller, Y.; Motro, Y. Precise Control of Rodents in Alfalfa Fields Using Drones. In Proceedings of the 49th California Alfalfa & Grain Symposium, Reno, NV, USA, 19–21 November 2019.
82. Shi, H.; Pan, Q.; Luo, G.; Hellwich, O.; Chen, C.; Voorde, T.V.d.; Kurban, A.; De Maeyer, P.; Wu, S. Analysis of the Impacts of Environmental Factors on Rat Hole Density in the Northern Slope of the Tienshan Mountains with Satellite Remote Sensing Data. *Remote Sens.* **2021**, *13*, 4709. [CrossRef]
83. Gao, X.; Bi, Y.; Du, J. Identification of Ratholes in Desert Steppe Based on UAV Hyperspectral Remote Sensing. *Appl. Sci.* **2023**, *13*, 7057. [CrossRef]
84. Jurišić, A.; Ćupina, A.I.; Kavran, M.; Potkonjak, A.; Ivanović, I.; Bjelić-Čabrilo, O.; Meseldžija, M.; Dudić, M.; Poljaković-Pajnik, L.; Vasić, V. Surveillance Strategies of Rodents in Agroecosystems, Forestry and Urban Environments. *Sustainability* **2022**, *14*, 9233. [CrossRef]
85. Radley, P.M.; Bednarz, J.C. Artificial Nest Structure Use and Reproductive Success of Barn Owls in Northeastern Arkansas. *J. Raptor Res.* **2005**, *39*, 164–170.
86. Fajardo, I.; Babiloni, G.; Miranda, Y. Rehabilitated and wild Barn Owls (*Tyto alba*): Dispersal, life expectancy and mortality in Spain. *Biol. Conserv.* **2000**, *94*, 287–295. [CrossRef]
87. Saufi, S.; Ravindran, S.; Hamid, N.H.; Abidin, C.M.R.Z.; Ahmad, H.; Ahmad, A.H.; Salim, H. Establishment of Barn Owls (*Tyto alba* javanica) in an Urban Area on Penang Island, Malaysia. *J. Raptor Res.* **2020**, *54*, 265–272. [CrossRef]
88. Huysman, A.E.; Johnson, M.D. Multi-year nest box occupancy and short-term resilience to wildfire disturbance by barn owls in a vineyard agroecosystem. *Ecosphere* **2021**, *12*, e03438. [CrossRef]
89. Toms, M.P.; Crick, H.Q.P.; Shawyer, C.R. The Status of Breeding Barn Owls *Tyto alba* in the United Kingdom 1995–97. *Bird Study* **2001**, *48*, 23–37. [CrossRef]
90. Martínez, J.A.; López, G. Breeding Ecology of the Barn Owl (*Tyto alba*) in Valencia (SE Spain). *J. Ornithol.* **1999**, *140*, 93–99. [CrossRef]
91. Milliet, E.; Schalcher, K.; Grangier-Bijou, A.; Almasi, B.; Butera, F.; Roulin, A. The Effects of Land Use Changes on Site Occupancy and Breeding Success of the Barn Owl (*Tyto alba*) from 1993 to 2020. *Glob. Ecol. Conserv.* **2024**, *52*, e02988. [CrossRef]
92. Séchaud, R.; Schalcher, K.; Almasi, B.; Roulin, A. Home Range Size and Habitat Quality Affect Breeding Success but Not Parental Investment in Barn Owl Males. *Sci. Rep.* **2022**, *12*, 6516. [CrossRef]
93. Castañeda, X.A.; Huysman, A.E.; Johnson, M.D. Barn Owls Select Uncultivated Habitats for Hunting in a Winegrape Growing Region of California. *Ornithol. Appl.* **2021**, *123*, 1–11. [CrossRef]
94. Latorre, D.; Merino-Aguirre, R.; Fletcher, D.H.; Cruz, A.; Almeida, D. Effects of Habitat Structure and Feeding Habits on Productivity and Nestling Quality of Barn Owl *Tyto alba* (Scopoli, 1769) (Strigiformes: Tytonidae) in the Iberian Peninsula. *Acta Zool. Bulg.* **2022**, *74*, 203–214.
95. Bontzorlos, V. Shrew Communities in Mediterranean Agro-Ecosystems of Central Greece: Associations with Crop Types, Land Uses, and Soil Parameters. *Life* **2023**, *13*, 2248. [CrossRef]
96. St. George, D.A.; Johnson, M.D. Effects of Habitat on Prey Delivery Rate and Prey Species Composition of Breeding Barn Owls in Winegrape Vineyards. *Agric. Ecosyst. Environ.* **2021**, *312*, 107322. [CrossRef]
97. Glåmseter, A.T. The Effects of Precipitation on Parental Food Provisioning in the Barn Owls (*Tyto alba*) Breeding in Norfolk, UK. Master's Thesis, Norwegian University of Life Sciences, Ås, Norway, 2021. Available online: https://hdl.handle.net/11250/2829112 (accessed on 15 October 2024).
98. Stuhler, J.D.; Portillo-Quintero, C.; Goetze, J.R.; Stevens, R.D. Efficacy of Remote Sensing Technologies for Burrow Count Estimates of a Rare Kangaroo Rat. *Wildl. Soc. Bull.* **2024**, *48*, e1510. [CrossRef]

99. Torre, I.; Freixas, L.; Arrizabalaga, A.; Díaz, M. The Efficiency of Two Widely Used Commercial Live-Traps to Develop Monitoring Protocols for Small Mammal Biodiversity. *Ecol. Indic.* **2016**, *66*, 481–487. [CrossRef]
100. San-Jose, L.M.; Séchaud, R.; Schalcher, K.; Judes, C.; Questiaux, A.; Oliveira-Xavier, A.; Roulin, A. Differential Fitness Effects of Moonlight on Plumage Colour Morphs in Barn Owls. *Nat. Ecol. Evol.* **2019**, *3*, 1331–1340. [CrossRef]
101. Toledo, S.; Shohami, D.; Schiffner, I.; Lourie, E.; Orchan, Y.; Bartan, Y.; Nathan, R. Cognitive Map-Based Navigation in Wild Bats Revealed by a New High-Throughput Tracking System. *Science* **2020**, *369*, 188–193. [CrossRef]
102. Arnold, E.M.; Hanser, S.E.; Regan, T.; Thompson, J.; Lowe, M.; Kociolek, A.; Belthoff, J.R. Spatial, Road Geometric, and Biotic Factors Associated with Barn Owl Mortality Along an Interstate Highway. *Ibis* **2019**, *161*, 36–47. [CrossRef]
103. Hindmarch, S.; Elliott, J.E.; McCann, S.; Levesque, P. Habitat Use by Barn Owls Across a Rural to Urban Gradient and an Assessment of Stressors Including Habitat Loss, Rodenticide Exposure and Road Mortality. *Landsc. Urban Plan.* **2017**, *164*, 132–143. [CrossRef]
104. Chausson, A.; Henry, I.; Almasi, B.; Roulin, A. Barn Owl (*Tyto alba*) Breeding Biology in Relation to Breeding Season Climate. *J. Ornithol.* **2014**, *155*, 273–281. [CrossRef]
105. Charter, M.; Izhaki, I.; Meyrom, K.; Aviel, S.; Leshem, Y.; Roulin, A. The Relationship Between Weather and Reproduction of the Barn Owl *Tyto alba* in a Semi-Arid Agricultural Landscape in Israel. *Avian Biol. Res.* **2017**, *10*, 242–250. [CrossRef]
106. Altwegg, R.; Roulin, A.; Kestenholz, M.; Jenni, L. Demographic Effects of Extreme Winter Weather in the Barn Owl. *Oecologia* **2006**, *149*, 44–51. [CrossRef]
107. Bontzorlos, V.; Vlachopoulos, K.; Xenos, A. Distribution of Four Vole Species through the Barn Owl *Tyto alba* Diet Spectrum: Pattern Responses to Environmental Gradients in Intensive Agroecosystems of Central Greece. *Life* **2023**, *13*, 105. [CrossRef]
108. Zaitzove-Raz, M.; Comay, O.; Motro, Y.; Dayan, T. Barn Owls as Biological Control Agents: Potential Risks to Non-Target Rare and Endangered Species. *Anim. Conserv.* **2020**, *23*, 646–659. [CrossRef]
109. Glikman, J.A.; Frank, B.; Bogardus, M.; Meysohn, S.; Sandström, C.; Zimmermann, A.; Madden, F. Evolving Our Understanding and Practice in Addressing Social Conflict and Stakeholder Engagement Around Conservation Translocations. *Front. Conserv. Sci.* **2022**, *3*, 783709. [CrossRef]
110. Hart, P.S.; Nisbet, E.C.; Shanahan, J.E. Environmental Values and the Social Amplification of Risk: An Examination of How Environmental Values and Media Use Influence Predispositions for Public Engagement in Wildlife Management Decision Making. *Soc. Nat. Resour.* **2011**, *24*, 276–291. [CrossRef]
111. Maak, T. Responsible Leadership, Stakeholder Engagement, and the Emergence of Social Capital. *J. Bus. Ethics* **2007**, *74*, 329–343. [CrossRef]
112. Milliet, E.; Plancherel, C.; Roulin, A.; Butera, F. The effect of collaboration on farmers' pro-environmental behaviors—A systematic review. *J. Environ. Psychol.* **2024**, *93*, 102223. [CrossRef]
113. Frankova, M.; Stejskal, V.; Aulicky, R. Efficacy of Rodenticide Baits with Decreased Concentrations of Brodifacoum: Validation of the Impact of the New EU Anticoagulant Regulation. *Sci. Rep.* **2019**, *9*, 16779. [CrossRef]
114. Blažić, T.; Stojnić, B.; Milanović, S.; Jokić, G. A Strategy to Improve Rodent Control While Reducing Rodenticide Release into the Environment. *Heliyon* **2024**, *10*, e29471. [CrossRef]
115. Witmer, G.W. *Perspectives on Existing and Potential New Alternatives to Anticoagulant Rodenticides and the Implications for Integrated Pest Management*; USDA National Wildlife Research Center—Staff Publications: Fort Collins, CO, USA, 2018; Volume 2095. Available online: https://digitalcommons.unl.edu/icwdm_usdanwrc/2095 (accessed on 15 October 2024).
116. Gubler, D.J.; Reiter, P.; Ebi, K.L.; Yap, W.; Nasci, R.; Patz, J.A. Climate Variability and Change in the United States: Potential Impacts on Vector- and Rodent-Borne Diseases. *Environ. Health Perspect.* **2001**, *109* (Suppl. 2), 223–233. [CrossRef]
117. Martínez-Ruiz, M.; Dykstra, C.R.; Booms, T.L.; Henderson, M.T. Conservation Letter: Effects of Global Climate Change on Raptors. *J. Raptor Res.* **2023**, *57*, 92–105. [CrossRef]
118. Sethi, V.; Spiegel, O.; Salter, R.; Cain, S.; Toledo, S.; Getz, W.M. An Information Theory Framework for Movement Path Segmentation and Analysis. *bioRxiv* **2024**, *4*, 1–13. [CrossRef]
119. Arnon, E.; Cain, S.; Uzan, A.; Nathan, R.; Spiegel, O.; Toledo, S. Robust Time-of-Arrival Location Estimation Algorithms for Wildlife Tracking. *Sensors* **2023**, *23*, 9460. [CrossRef]
120. Bontzorlos, V.A.; Johnson, D.H.; Poirazidis, K.; Roulin, A. Owl Symbolism in Greek Civilization Over the Last 5000 Years: Social Perceptions and Implications for Conservation. *Eur. Zool. J.* **2023**, *90*, 691–707. [CrossRef]
121. Uva, V.; Päckert, M.; Cibois, A.; Fumagalli, L.; Roulin, A. Comprehensive molecular phylogeny of barn owls and relatives (Family: Tytonidae), and their six major Pleistocene radiations. *Mol. Phylogenetics Evol.* **2018**, *125*, 127–137. [CrossRef]
122. Meek, W.R.; Burman, P.J.; Nowakowski, M.; Sparks, T.H.; Burman, N.J. Barn Owl Release in Lowland Southern England—A Twenty-One Year Study. *Biol. Conserv.* **2003**, *109*, 271–282. [CrossRef]
123. Grande, J.M.; Orozco-Valor, P.M.; Liébana, M.S.; Sarasola, J.H. Birds of Prey in Agricultural Landscapes: The Role of Agriculture Expansion and Intensification. In *Birds of Prey*; Sarasola, J.H., Grande, J.M., Negro, J.J., Eds.; Springer: Cham, Switzerland, 2018; pp. 289–310. [CrossRef]
124. Assandri, G.; Bazzi, G.; Siddi, L.; Nardelli, R.; Cecere, J.G.; Rubolini, D.; Morganti, M. The Occurrence of a Flagship Raptor Species in Intensive Agroecosystems Is Associated with More Diverse Farmland Bird Communities: Opportunities for Market-Based Conservation. *Agric. Ecosyst. Environ.* **2023**, *349*, 108441. [CrossRef]

125. Raine, A.F.; Holmes, N.D.; Travers, M.; Cooper, B.A.; Day, R.H. The Impact of an Introduced Avian Predator, the Barn Owl (*Tyto alba*), on Hawaiian Seabirds. *Mar. Ornithol.* **2019**, *47*, 33–38. Available online: http://www.marineornithology.org/PDF/47_1/47_1_33-38.pdf (accessed on 15 October 2024).
126. Roulin, A.; Abu Rashid, M.; Spiegel, B.; Charter, M.; Dreiss, A.N.; Leshem, Y. Nature Knows No Boundaries: The Role of Nature Conservation in Peacebuilding. *Trends Ecol. Evol.* **2017**, *32*, 305–310. [CrossRef] [PubMed]

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