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Perspective

Rat Eradication from Mediterranean Islands Using Brodifacoum: A Critical Assessment of Biodiversity Conservation and Environmental Impacts

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Abstract

The Island of Montecristo, part of the Tuscan Archipelago, was subjected to an "invasive species" eradication effort co-financed by the European Union under the Life+ "Montecristo 2010" project in 2012. Biocidal agents were utilized in abundance, with the objective of targeting select species of flora and fauna. This included the aerial broadcast of pellets containing brodifacoum to attempt to eradicate the rat population. Brodifacoum's environmental persistence has led to concerns regarding its potential for secondary, tertiary, and subsequent poisoning of numerous species. This article presents an analysis of probabilistic body mechanics simulations indicating that 4.12 tons of pellets containing brodifacoum would have likely reached the sea following the aerial distribution on Montecristo; a comprehensive literature review of the adverse effects and environmental persistence of second-generation anticoagulant rodenticides (SGARS); as well as a theoretical application of the European Industrial Accident Scale (EIAS) to assess environmental contamination. The question of whether the practice of distributing substantial amounts of pesticides to eradicate a selected species constitutes a conservation initiative or could lead to environmental damage is a salient one, and this article aims to provide a multidisciplinary approach to address this question.

Keywords: brodifacoum; SGARs; rat eradication; Montecristo; *Puffinus yelkouan*; bioaccumulation; rodenticides; biocides; invasive alien species

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1. Introduction

This study was developed according to the proceedings of the 23 May 2023 conference in Rome entitled "The Management of Italy's Natural Heritage," which was promoted by the National Federation of Biologists (FNOB) [1].

Conservation actions involving the use of pesticides have generated significant contradictions, raising ethical questioning about the foundational principles of such actions [2–5]. The use of pesticides is commonly recognized as a major cause of biodiversity loss (e.g., [6,7]) in terms of non-target organisms [8], soil microbiota [9], entomofauna (e.g., [10]), aquatic communities [11–13], and wildlife (e.g., [14–17]), along with the destruction of habitats implemented by humans through deforestation, management of forests, intensive agriculture, industrialization, and urbanization. Pesticides have been demonstrated to exert toxic effects on organisms that have been exposed to them, whether directly or indirectly. These effects may be immediate or protracted, manifesting over extended periods through alterations in ecological niches and subsequent ramifications along the food chain. The utilization of pesticides has been shown to compromise the quality of water, soil, and air, leading to environmental degradation and, by extension, the endangerment of human health and well-being.

These observations prompt further inquiry into the extent to which efforts to eradicate or regulate "alien" (anthropogenically introduced) species should be pursued. However, it is important to determine the extent to which the consequences of the presence of an "alien" species surpass those of our own actions against them. A critical question that arises in this context is the ability to delineate the threshold between a successful eradication effort and environmental contamination.

Information concerning the outcomes of this type of project is frequently restricted to reports or publications produced by authors involved in the actions or by other individuals who have promoted the project. Consequently, this introduces potential biases in the interpretation of the reported data.

Although projects of this kind continue to be carried out on numerous islands and on the mainland, few of these initiatives have been evaluated in terms of their overall effectiveness [18]. Although several studies document a recovery of seabird populations following the eradication of rats [18–20], these projects are often carried out without adequate preliminary studies or scientific evidence and without taking the precautionary principle into account (e.g., [5,21,22]). In this case study, for example, no sediment or soil analyses were conducted to quantify the environmental contamination caused by the spread of poisoned baits [23], and although the project's beneficiaries themselves—while underestimating it—had anticipated the risk to numerous non-target species, no analyses were conducted to detect brodifacoum residues on the carcasses of the hundreds of dead animals that were actively or occasionally collected [24].

The present study endeavors to provide a different perspective following the precautionary principle, with an analysis of available data in ascertaining the possible environmental contamination that occurred following the dispersion of biocides in a protected area. This innovative multidisciplinary approach was performed through the use of probabilistic engineering analysis of body mechanics simulations; literature reviews regarding the adverse effects of biocides used on a wide range of species, as well as their persistence in the ecosystem; and the theoretical application of the European Industrial Accident Scale (EIAS) to assess the magnitude of environmental contamination.

2. The Isola di Montecristo

The Isola di (Island of) Montecristo (42°20′00″ N, 10°19′00″ E) is of significant importance within the "Isole dell'Arcipelago Toscano" islands and the Tyrrhenian Sea (see Figure 1). It is included in the "Parco Nazionale dell'Arcipelago Toscano" National Park, a Biosphere Reserve within the "Islands of Tuscany" under the UNESCO MAB Program, and is located within an environmentally fragile Pelagos Sanctuary for Mediterranean Marine Mammals, a State Nature Reserve established by the Ministerial Decree of 4 March 1971, and a biogenetic nature reserve designated by the Council of Europe in 1988 [25].

The island is a granitic cone (see Figure 2) whose apex reaches 645 m above sea level, with a surface area (considering the projection of the island's above-water portion on a horizontal plane) of approximately 10.39 km^2 [26–29]. It is characterized by numerous perennial freshwater springs and a typical Mediterranean phytocoenosis [27].

Figure 1. (**A**) Geographic location of the Island of Montecristo. (**B**) View of the southeastern coastline of Montecristo, 2013. Photograph from the photo archive of Cesare Scarfo.

Figure 2. Aerial photograph of the northern coastline of the Island of Montecristo, 2013. Photograph from the photo archive of Cesare Scarfo.

Prior to the implementation of the rat eradication project, the island's fauna was composed of the Montecristo goat (*Capra aegagrus* Erxleben, 1777 [26–28,30]), a few species of Passeriformes (*Passer italiae* Vieillot, 1817; *P. hispanioliensis* Temminck, 1820; *Serinus serinus* Linnaeus, 1766; *Carduelis chloris* Linnaeus, 1758), a small population of chukar partridge (*Alectoris chukar* Gray, 1830), numerous pairs of yellow-legged gulls (*Larus michahellis* Naumann, 1840), the common raven (*Corvus corax* Linnaeus, 1758), barn owls (*Tyto alba* Scopoli, 1769), diurnal and nocturnal birds of prey present on the island mainly during migration (*Falco tinnunculus* Linnaeus, 1758 and *Falco peregrinus* Tunstall, 1771), and a large population of yelkouan shearwaters (*Puffinus yelkouan* Acerbi, 1827), whose numbers were estimated in 2009 at 400–750 pairs [29].

The fauna of the region also includes various reptiles and amphibians, such as the green whip snake (*Hierophis viridiflavus* Lacépède, 1789), viper (*Vipera aspis hugyi* Schinz, 1833), and Tyrrhenian painted frog (*Discoglossus sardus* Tschudi, 1837). Additionally, numerous species of invertebrates inhabit the area [27,29]. In particular, the Montecristo goat (*C. aegagrus* Erxleben, 1777, or *C. aegagrus pictus* Erhard, 1858), regardless of taxonomic position, is a species of great naturalistic interest whose population is found only on the Island of Montecristo (hence the name) and included in Group A of the IUCN Caprine Specialist Group classification of wild goats. The presence of this taxon resulted in the recognition of the "European Diploma for Protected Areas at Montecristo Island" [28]. The Montecristo goat population is significant for reasons related to conservation as well as to historical and cultural heritage. It represents an early stage of domestication of the Aegagrus (*Capra aegagrus* Erxleben, 1777, or *C. aegagrus pictus* Erhard, 1858) and its subsequent dispersal across the Mediterranean basin by humans [26,31].

Additionally, two animal species were regarded as "alien" on the island: the black rat (*Rattus rattus* Linnaeus, 1758) and the wild rabbit (*Oryctolagus cuniculus huxley* Linnaeus, 1758), including crosses of the latter with domestic phenotypes. Human presence was limited to two guardians of the island, who resided there until 2018, with a hiatus between 2012 and 2014 [32]. With regard to the flora of Montecristo Island, the most recent inventory counts 582 taxa, of which 515 are spontaneous and 67 cultivated [33].

The main geographical distribution elements are Euro-Siberian-Mediterranean and Mediterranean species, while the predominant life form is the therophyte, with the presence of endemic and subendemic taxa characteristic of the island [34,35]. The vegetation cover of Montecristo is extremely fragmented [36,37] and appears to consist mainly of low scrub. The island is covered by about 49.1% low scrub [37], approximately 15% high scrub, 1.6% *Pteridium aquilinum* L., which occurs near springs and wet valley bottoms, and 0.1% *Quercus ilex* L. Approximately 31.1% of the territory is characterized by outcropping rock, with mosses and lichens on these surfaces [38]. Other tree species cover around 3.1% of the island [39].

3. The Project LIFE+ "Montecristo 2010"

The LIFE08 NAT/IT/000353 project, known as "Montecristo 2010" [40], with a total eligible budget of € 1,584,856 and an EU contribution of € 792,428, began on 1 January 2010 and ended on 30 June 2014. The project aimed to eradicate the flora-faunal components considered "alien" and "invasive" from the Montecristo and Pianosa islands.

The implementation of interventions using broad-spectrum biocides can cause significant, often irreversible, environmental damage, even in the long term, without being truly effective in eradicating the target species and ultimately leading to a significant increase in anthropogenic pressure and environmental pollution. In-depth studies and investigations are needed to better understand how these compounds could synergistically affect flora and fauna, both terrestrial, aquatic, and marine, within this island ecosystem over time.

The primary objective of the "Montecristo 2010" project was the eradication effort aimed at eliminating the black rat (*Rattus rattus*, Linnaeus, 1758), believed to be the main reproductive threat to the yelkouan shearwater (*Puffinus yelkouan* Acerbi, 1827). The eradication consisted of the aerial dispersal of pellets containing brodifacoum or the placement of bait stations on the ground in a small portion of the island. Brodifacoum is one of the most potent second-generation anticoagulant toxins, known to be highly persistent in the environment (e.g., [41–44]).

In January and February 2012, three launching sessions of pellets containing brodifacoum were carried out by helicopter: the first on 11 January (5600 kg), the second on 12 January (8000 kg), and the third on 28 February (500 kg) [45]. With the three launches, the entire area of Montecristo (actual treated area of approximately 1300 ha) was covered with the dispersal of about 14,100 kg of brodifacoum-containing pellets (average 10.8 kg/ha), with the exception of an enclosure (25 ha) that housed some goats, the area inhabited by the guardians and surrounding areas, and the area including the island's main freshwater stream [29] for a total of 33 ha out of 1039 ha (2.4 percent of the island's area). Brodifacoum bait stations were used in areas where aerial dispersal of pellets was not carried out [45].

The pellets utilized in the project were 2 g, paraffin-coated pellets containing 0.1 mg of pure brodifacoum [46]. A total of 705 g of brodifacoum was dispersed via helicopter. While our case study primarily focuses on the effects of brodifacoum within the context of an uninhabited island, it must be taken into consideration that an exposure pathway for humans exists through consuming contaminated fish. During a similar rat eradication effort on Wake Atoll in the Tropical Pacific, where brodifacoum contaminated an ocean ecosystem in 2012, a fishing ban was established for a 942-day period to reduce the exposure risk to humans [47]. No such ban was put in place for Montecristo Island following the release of brodifacoum into the environment.

One of the potential risks identified by the project was the possibility that the aerial distribution of brodifacoum could also result in the poisoning of non-target species, including the Montecristo goat population [29]. The high palatability of the pellets to goats was documented during the rat eradication project subsequently conducted on the island of Tavolara, where "results indicated excellent durability of the pellets and a modest rate of disappearance, with the exception of one site constantly frequented by goats, where only one pellet out of thirty was still present after the second night." [48]. Consequently, in order to ensure the survival of a limited number of specimens, around 45–50 goats were confined to an enclosure of approximately 25 hectares [29] in close proximity to the sole human settlement on the island. These goats were not selected with attention to the ancient Montecristo goat phenotype [28]. An additional group of five goats was removed from the island and relocated to the Bioparco in Rome, where they constituted a nucleus for ex situ conservation [49]. The goats within the enclosure predominantly demonstrated markings consistent with the agrimi phenotype rather than the Montecristo goat phenotype [28]. The goats selected for ex situ conservation, therefore, were also not representative of the ancient original Montecristo goat phenotype but rather of a more "modern" domestic breed [28].

The goats contained within the fence on the island during the rat eradication project were not released until pellets were no longer visually apparent outside the enclosure. It was not until 3 and 4 December 2012 [45], eleven months after the first application of brodifacoum pellets, that all goats in the pen were released, subject to ear tagging, both for their remote monitoring and to check for any residual mortality [31]. The release of goats occurred in December because numerous pellets were still present until July, 5 months after distribution, and were still largely intact due to lack of rainfall [45]. Thus, brodifacoum-containing baits remained available within the habitat for several months after distribution.

The LIFE+ "Montecristo 2010" project anticipated that animals belonging to non-target species would die either from primary poisoning (ingestion of the pellets containing brodifacoum) or from secondary poisoning, i.e., ingestion of remains of dead animals or species insensitive to the toxicant (e.g., invertebrates) but contaminated [29]. A representative illustration of potential primary and secondary poisoning as brodifacoum enters the food chain can be seen in the following diagram (see Figure 3).

In particular, according to Sposimo et al. [29], non-target mortalities were predicted to occur in the following populations:

- Chukar partridge (*Alectoris chukar* Gray, 1830)
- Passerines (*Passeriformes* Linnaeus, 1758)
- Yellow-legged gull (*Larus michahellis* Naumann, 1840)
- Common raven (*Corvus corax* Linnaeus, 1758)
- Barn owl (*Tyto alba* Scopoli, 1769)
- Diurnal (*Accipitriformes* and *Falconiformes*) and nocturnal (*Strigiformes*) raptors present on the island mainly during migration and occasionally in winter
- Goat of Montecristo (*C. aegagrus* Erxleben, 1777)
- Wild rabbit or crosses of it with the domestic rabbit (*Oryctolagus cuniculus huxley* Linnaeus, 1758)

It should be noted that most of these species were and are also protected under national legislation [50]. Risks to the marine ecosystem were also postulated in the project plan, as the Island of Montecristo has high, steep faces, making it impossible to avoid spilling unspecified amounts of brodifacoum-containing pellets into the sea [29].

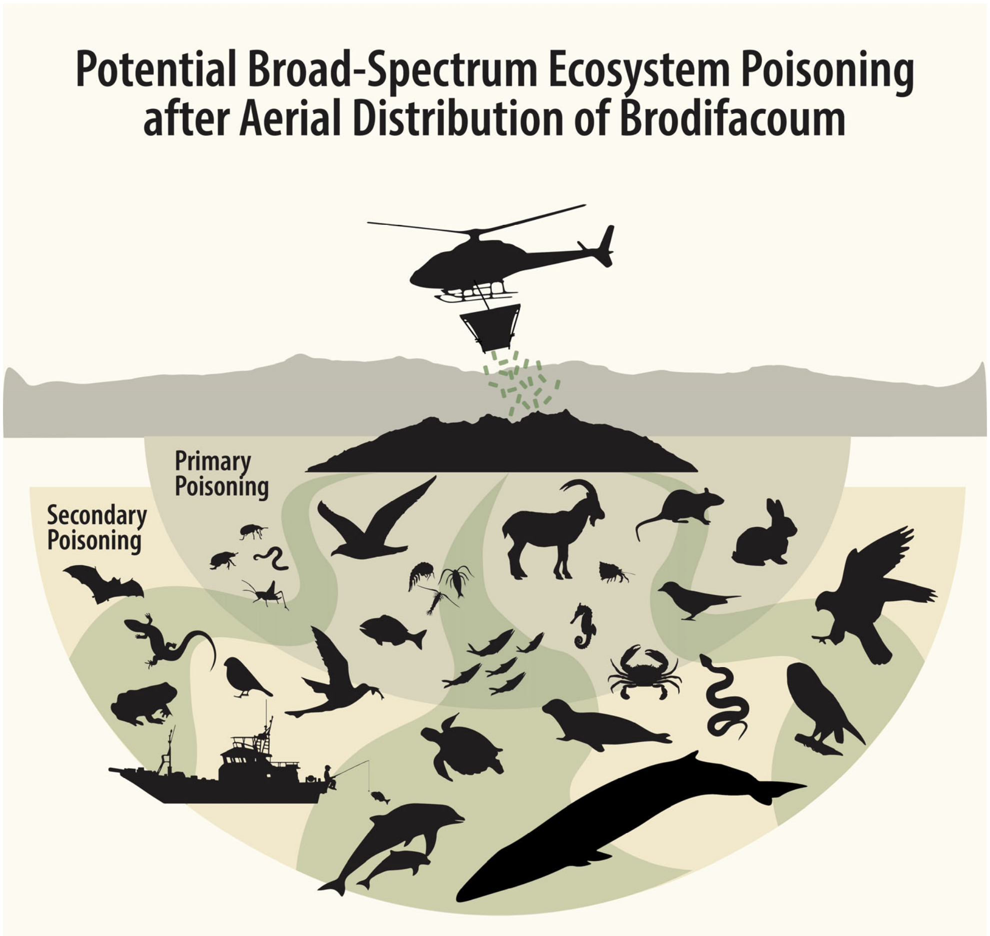

Figure 3. Visual summary of the potential broad-spectrum ecosystem poisoning after aerial distribution of pellets containing brodifacoum.

In drafting the plan for the eradication of the black rat on the Island of Montecristo, the authors of the project stated that they deliberately disregarded the possible legislative constraints related to the aerial distribution of anticoagulants, an action not allowed by existing laws in Italy; the category of anticoagulants that could be used (low environmental persistence allowed, high environmental persistence not allowed); and possible opposition from animal welfare, environmental associations, or citizens concerned about the impact of the poisoned pellets on the island's ecosystem [29].

During the period of the project's implementation, the 2010 Ministerial Ordinance on "Regulations on the Prohibition of the Use and Possession of Poisoned Bait or Poisoned Pellets" (G.U. General Series no. 33, 10 February 2010) issued by the Ministry of Health (O.M. 14 January 2010, G.U. General Series no. 33, 10 February 2010 [51]) Article 6 prescribed:

[. . .] "In protected areas, for reasons of safeguarding wild species subject to protection measures of an international nature, where they are particularly threatened by rats, it is possible to carry out, after notifying the Ministry of Health, rat eradication operations using rodenticides without the use of the appropriate bait containers provided that:

a. the active ingredient used as rodenticide is of low environmental persistence in order to avoid contamination of the food chain and the environment;
b. the maximum duration of persistence of the baits in the environment is established in relation to the objectives to be achieved, based on the most up-to-date scientific literature;
c. at the end of the operation, the unused baits are removed from the environment and an appropriate report is drawn up by the person in charge of the operation, in which the number of baits placed in the environment, the area affected by the operation and the number of baits, unused and removed at the end of the operation, are indicated. The aforementioned report, a copy of which is sent to the Ministry of Health, is available to the competent authorities for possible review" [. . .].

The Italian Ministry of Health's ban on the use of rodenticides with high environmental persistence was predicated on the understanding that the use of such substances would inevitably result in the comprehensive contamination of the ecosystem with unpredictable, harmful long-term consequences.

The news of the aerial dispersal of pellets on the Island of Montecristo, theoretically aimed at biodiversity protection purposes, sparked numerous protests from animal welfare associations and private individuals concerned about the environmental toxicity of brodifacoum, which resulted in reports to the judiciary and even parliamentary interrogations [52], including recent ones to the Senato della Repubblica [53] and the Consiglio Regionale della Toscana [54].

As a result, in February 2012, the Italian Ministry of Health requested a scientific expert opinion on the environmental persistence of brodifacoum from the Centro di Referenza Nazionale per la Medicina Forense Veterinaria of the Istituto Zooprofilattico Sperimentale del Lazio e della Toscana, a highly specialized facility for countering malicious poisonings of animals. The Centro di Referenza Nazionale corroborated the hypothesis that brodifacoum exhibits persistent environmental toxicity. In light of the violation of Article 6 of the current M.O., the Ministry of Health petitioned the judiciary for sanctions [55].

4. The Use of Brodifacoum to Eradicate the Black Rat (*Rattus rattus*, Linnaeus, 1758)

4.1. Brodifacoum

Brodifacoum (3-[3-[4-(4-bromophenyl)phenyl]-1,2,3,4-tetrahydronaphthalen-1-yl]-4-hydroxychromen-2-one [56]) is a second-generation anticoagulant rodenticide (SGAR) belonging to Group 3, Type 14, and is classified as a persistent, bioaccumulative, and toxic substance [57,58].

Its toxic action blocks the synthesis of a group of K vitamins that are essential for the synthesis of prothrombin and other blood clotting factors in vertebrates. The lethal outcome of poisoning by this substance (including death in humans [59]) occurs from hemorrhagic shock due to internal bleeding. Once ingested, brodifacoum can remain within the body for an extended period of time at a sublethal level. Consequently, symptoms of poisoning may manifest even several weeks after ingestion. It is important to note that the compound remains intact, particularly within the liver of the affected subjects, regardless of whether the affected subjects are deceased or alive. This phenomenon precipitates the initiation of a bioaccumulation mechanism [60].

In birds and mammals, brodifacoum causes damage to the myocardium, liver, and skeletal system [61]. Due to its high environmental persistence, it is possible for an animal to be re-exposed to the compound several times, which results in a gradual increase in its toxic action with lethal effects that can manifest long after its first ingestion [60].

The persistence of brodifacoum in the ecosystem is attributed to its ability to bind to numerous organic substrates, thereby contaminating them through mechanisms that remain poorly understood [62].

Several research studies have demonstrated the persistence and accumulation of this substance in both terrestrial and aquatic environments, where it persists and disperses throughout the food chains (e.g., [63–65]), from microorganisms in the soil and plankton [66] in aquatic environments to the top (e.g., mountain lions [67], bobcats [68–70], wolves [71], foxes [72], raptors [73–75], cormorants [76], humans [77], etc.). Consequently, the aerial dispersal of pellets containing brodifacoum poses a substantial risk of primary and secondary poisoning of non-target species such as mammals, birds, invertebrates, and reptiles (e.g., [78,79]).

Although most brodifacoum residues are known to accumulate in the liver, trace quantities may be present throughout the body. These quantities may be present even when the dosage is not immediately lethal. These residues enter the food chain of a broad array of animal species in the ecosystem when scavenging invertebrates ingest the contaminated remains [80].

This mode of secondary poisoning has been described in insectivorous birds (*Charadrius obscurus* Gmelin, 1789) from New Zealand [81], where, after aerial dispersal of brodifacoum-containing pellets, 50 percent of the population of these birds disappeared. In this case, secondary mortality of these insectivorous birds by brodifacoum is believed to have been caused by the ingestion of arthropods of the genus *Talorchestia* spp., a common component of their diet, which in turn had ingested residues of brodifacoum-containing pellets [81].

In contrast, the effects on invertebrate survival of long-term exposure to lower concentrations of the toxicant, such as those of approximately 1 ppm, which are typically found in soil following brodifacoum dispersal, remain unknown. Additionally, the duration of brodifacoum's presence at a sub-lethal level in the bodies of invertebrates that have ingested it is yet to be determined [82].

A recent study [71] reports the presence of second-generation anticoagulant rodenticides (SGARs), including brodifacoum, in 115 wolves (*Canis lupus* Linnaeus, 1758) out of 186 specimens found dead from a variety of causes in some areas of North-Central Italy.

Of these, only 19 specimens (16.5 percent) displayed an anatomopathological profile consistent with anticoagulant exposure. This apparent positive outcome, however, belies the fact that all the remaining wolves, which died from disparate causes, endured the sub-lethal effects of the toxicant. Furthermore, the authors emphasize the concerning pervasiveness of second-generation anticoagulants across the entirety of Europe's terrestrial food chains. In light of this, they propose an approach to rodent control that primarily relies on trapping techniques and the use of chemical compounds with low persistence and toxicity for non-target species, in accordance with the Ministry of Health Ordinance. The toxicity and environmental persistence of brodifacoum have been documented for over two decades through a substantial body of scientific literature (e.g., [41–43,83]). For further details, please see the following references: Howald et al. [84,85], Hoare et al. [86], Fisher et al. [80–82,87], Harper et al. [88], and Nakayama et al. [89].

4.1.1. Is "Degradation" of the Pellet Synonymous with "Degradation" of the Toxic Compound?

It is frequently asserted that the disintegration of the brodifacoum-containing pellet resulting from weathering is tantamount to the degradation of the toxicant compound (e.g., [90,91]). However, this is incorrect. The disintegration of the pellet does not result in the inactivation of the compound; rather, it results in its increased diffusion. This is due to the pellet dispersing in the form of microparticles, which are more mobile than the original, larger, and heavier pellet. These minute particles are only occasionally discernible to the unaided eye, due to their association with a dye that renders them conspicuous. This process of particle dispersal has been observed in non-target species situated up to 8 km from the point of pellet dispersion [42].

Consequently, the use of the term "degradation" of the pellet with the meaning of "inactivation" of the brodifacoum compound is incorrect and misleading.

The sole parameter that can be utilized to ascertain the duration of a compound's continued activity within the environment is the so-called half-life (DT_{50}), which is the time it takes for a chemical to be reduced by 50 percent from its initial amount.

In December 2007, the Joint Nature Conservation Committee published a study [92] in which it was asserted that brodifacoum may have a considerable impact on biodiversity due to its exceptionally high environmental persistence. The authors provide a comprehensive overview of the existing knowledge regarding the persistence of brodifacoum at the time of publication.

In soil, the half-life (DT_{50}) of brodifacoum is between 77 and 1332 days depending on the nature of the substrate [92].

In the organs of animals that have died from the action of the toxicant, particularly in the liver, it can persist for months. In the opossum (*Trichosurus vulpecula* Kerr, 1792), after an initial half-life (DT_{50}) of 14 days, brodifacoum is detectable in the liver of the dead animal more than 9 months (270 days) after the animal ingested the toxin [93,94]. In the liver of deceased rats, the DT_{50} was estimated to be 130 days, or more than 4 months after ingestion [43].

Sheep given brodifacoum in a sublethal dose (0.2 to 2.0 mg/kg), then subsequently euthanized after 128 days, still had residues of the toxicant in the liver [93].

In sandy soils and soils rich in clay, brodifacoum has been observed to have a half-life of 156.8 days [82]. For instance, one-third of soil samples (33%) collected at a depth of 5 cm from the surface exhibited evidence of pellet breakdown [95]. On Anacapa Island, the toxicant was detected in 20% of randomly selected invertebrate samples six months (180 days) after its dispersal by aerial means [95].

4.1.2. Is Brodifacoum Toxic to Fish or Other Marine Life? What About Cetaceans?

In relation to the presence of pellets in the marine environment, it is often asserted that these pellets experience rapid dissolution within 15 to 30 min of being deposited in coastal areas [96]. The assertion further contends that the concentration of rodenticide in seawater would be undetectable, thereby posing minimal to no risk to fish. However, these considerations appear to be rather superficial, given the substantial quantities of pellets that typically enter the sea in island areas, both during the distribution of bait by helicopter and following the initial heavy rainfall and given that extensively used second-generation anticoagulant rodenticides, such as brodifacoum, are highly persistent and bioaccumulative. Furthermore, although the pellets can disintegrate in a matter of minutes [97], once reduced to minute particles, they exhibit increased mobility and dispersal within the marine environment, becoming available to a wide variety of life forms, including zooplankton, crustaceans, and mollusks, as well as predators and scavengers. In addition to the risks associated with primary and secondary poisoning, exposure through water contamination must also be considered. For instance, as part of the project to eradicate two species of rats (*Rattus norvegicus* Berkenhout, 1769 and *R. exulans* Peale, 1848) implemented in 1996 on Kapiti Island, New Zealand, with the helicopter release of pellets containing brodifacoum at 20 ppm, observations were carried out on various species of fish in aquariums in order to assess their behavior and record mortality. In the course of the investigation, it was determined that in addition to the fish that had ingested the pellets, a significant number of fish that had not ingested any bait had also perished. The authors of the study posited a hypothesis that the active ingredient may have been absorbed through the skin or scales [97]. Consequently, even in the context of pellet dispersal in the sea, their disintegration does not entail a loss of effectiveness; rather, it results in an increase in their mobility and availability.

The toxicity of brodifacoum to fish has been demonstrated to be contingent upon the concentration of the substance in the water and the duration of the fish's exposure to it. The toxicity of the compound is experimentally expressed by the LC50, or the lethal concentration in water of the compound capable of killing 50% of fish being studied [98]. For example, the LC50 for rainbow trout [*Oncorhynchus mykiss* (Walbaum, 1792)] is 0.04 mg/L/96 h [46].

Schmieg et al. recently published a study [99] which, for the first time, reports the results of exposing rainbow trout to brodifacoum at concentrations previously detected in another study by Regnery et al. [76] conducted on wild freshwater fish. Trout sampling was conducted every 15 days over a period of 60 days, allowing for monitoring of brodifacoum concentrations in serum, liver, and muscle tissue, as well as the effects on fish health. The minimum hepatic concentration of brodifacoum associated with deleterious effects in rainbow trout was on average 122.6 ng/g wet liver weight, which is within the range of residues previously detected in wild fish [76]. This first study conducted on fish (rainbow trout) clearly reveals that the exposure of fish to lethal or sub-lethal levels of brodifacoum is far from negligible and that, until now, the implications of this have been largely underestimated. The release of bait containing SGARs on islands is associated with the dispersion of these toxins into the marine environment, and these first scientifically conducted studies show that such interventions should not be allowed because, given the persistence, toxicity, and bioaccumulation characteristics of second-generation rodenticides such as brodifacoum in the environment, the effects are much more significant than previously thought. In another study conducted following the aerial distribution of baits containing brodifacoum during rat eradication operations on an island, brodifacoum residues in the whole bodies of wild fish found dead—indicative of lethal poisoning—ranged from 58 to 1160 ng/g of wet weight, while other fish captured alive a few days after the bait was deployed had brodifacoum residues in their whole bodies of up to 315 ng/g wet weight [97,99]. Apart from this single study conducted by Schmieg et al. [99], we are not aware of any experimental data that would allow for the interpretation of the effects of SGAR residues in wild fish in the context of environmentally relevant concentrations and routes of exposure.

Brodifacoum is also toxic to corals, affecting their reproductive success rates [100]. It also affects plankton [66,101], which underlies the food chain of many marine life forms (e.g., [102]) as well as algae [103]. Pellets containing brodifacoum are found to be extremely attractive to crabs, shrimp, and hermit crabs [104–106], which form the basis of the diet of many marine and terrestrial mammals. Regnery [107,108] recently produced a comprehensive review on the risks to the aquatic environment resulting from the land-based release of anticoagulants, especially second-generation anticoagulants such as brodifacoum. Due to their low solubility in water, these toxic compounds persist and accumulate in aquatic ecosystems, where they are adsorbed to suspended particulate matter and sediment (rich in organics) and contaminate the biological tissues of aquatic organisms. Immediate adsorption to sediment was observed for brodifacoum, followed by a slow transformation with low levels of degradation products, representing less than 10 percent of the initial active substance. Although anticoagulants have been in use for decades, relatively little is known about their pharmacokinetics and toxicokinetics in aquatic organisms and the effects of chronic exposure to multiple active ingredients [109]. In some studies, residual concentrations of brodifacoum have been detected in coastal marine species such as sedentary mollusks following rodent eradication efforts from islands [110,111] or accidental discharges [112]. Although it is evident that anticoagulant rodenticides can enter the food chains of aquatic ecosystems, the behavior and fate of these toxicants have received insufficient attention from environmental research groups to date [113,114].

The processes of bioaccumulation can differ significantly among aquatic species due to the complex interactions among various pathways of uptake, including direct absorption of chemicals carried by water, dietary uptake through ingestion of food or contaminated particles, excretion, passive release, and metabolization [115]. It is therefore essential to have an understanding of the biological parameters of the species in question, including its trophic level, age, and lipid content, in order to identify the exposure of aquatic organisms to anticoagulant rodenticides and to link residues of these compounds with the identified sources of release. The ability to detect brodifacoum residues in fish from the coastal strip of an island following the aerial dispersal of this toxicant is significantly influenced by several factors, including the sample size analyzed, the feeding ecology of the selected fish species, and the analytical methods employed [109,113]. For instance, an investigation into the presence of brodifacoum and its potential consequences was conducted on a total of fifteen fish specimens belonging to eight distinct species (sampling range 1 to 4 specimens/species) from the coastal zone of Tavolara Island. This was carried out ten days after the complete dispersion of approximately 18,000 kg of bait containing brodifacoum at a concentration of 50 ppm. The results of this investigation were negative. However, the negative results obtained are likely due to the limited sample size and the species of fish examined, as the authors have acknowledged. These findings cannot be considered indicative of the actual impact of brodifacoum on the marine ecosystem, as they do not account for potential exposure to this anticoagulant. The data obtained do not preclude the possibility that fish and other organisms, such as crustaceans and mollusks, which were not examined in the study, may not have traces of consumed pellets or accumulated brodifacoum residues [116].

Two studies of coastal marine fauna in parts of New Zealand [97] and one case of accidental spillage of brodifacoum-treated grains into the sea [110,112] demonstrated persistent positive test results of the chemical compound in fish and shellfish under experimental conditions. In the case of the accidental spillage of brodifacoum into the water, following the overturning of a truck due to a traffic accident, the toxicological surveillance plan, which was immediately put in place on fish and shellfish subject to human food consumption, lasted for 2 years and 7 months. In fact, in five specimens of shellfish belonging to various edible species, the mean concentration of brodifacoum in the whole organism exceeded the detection threshold of the analytical method employed (high-performance liquid chromatography, HPLC) for a period of 353 days following the spill. Furthermore, the mean concentration remained above the maximum permissible threshold for human consumption, which in New Zealand is 0.001 ppm. The presence of brodifacoum in mollusk tissues fell below the detectable level only after 31 months (930 days), which is to say, two years and seven months. This very high persistence was attributed to two factors: the prolonged half-life of the compound in these invertebrates and the bioaccumulation caused by their repeated re-exposure to brodifacoum in the intertidal environment of the spill area [110].

No systematic studies have been conducted to determine the LD50, or lethal dose responsible for killing 50% of animals being studied [98], relating to the ingestion of brodifacoum-containing bait by fish or other organisms in the marine environment. In fact, the risk associated with the dispersion of rodenticide-containing bait in the marine environment is greatly underestimated by both academia and the authorities that manage protected areas.

The only study that has documented the mortality of fish and crustaceans following direct or indirect ingestion of pellets containing brodifacoum was conducted in 2011 on Palmyra Atoll and published by Pitt et al. in 2015 [44]. From 1 to 30 June 2011, a total of 38.561 tons of pellets containing brodifacoum at 25 ppm were dispersed from helicopters with the objective of eradicating rats (*Rattus rattus*) from Palmyra Atoll, which encompasses approximately 232 hectares of emerged land [117]. A preliminary effort to eradicate the rat using the same method in 2001–2002 [117] was unsuccessful due to the substantial consumption of pellets by crabs and hermit crabs inhabiting the island. According to the findings of Pitt [44], approximately 14–19% of the pellets were released into the sea during the distribution process, occurring at a distance of 7 m from the coastline. Subsequent to the launch of brodifacoum-containing pellets, a total of 84 animal carcasses, encompassing 15 different species of birds, fish, reptiles, and invertebrates, were collected opportunistically. Additionally, live fish, reptiles, and invertebrates were captured for residue analysis. The analyses were executed with an MLOD (defined as the lowest amount of analyte in a sample that can be detected but not necessarily quantified as an exact value) that varied depending on the samples analyzed and the various species (Annex A in [44]). Traces of brodifacoum were detected in freshwater samples (MLOD = 0.009 ng/mL), seawater samples (MLOD = 0.011 ng/mL), and soil samples (MLOD = 0.003 μg/g) (Appendix B in [44]). Brodifacoum residues were detected in 84.3% of the animal samples that were analyzed, thereby demonstrating the biocide's capacity to enter the terrestrial and marine food chain. With regard to samples taken from specimens collected opportunistically between the first and twenty-fifth day after the first launch, brodifacoum residues were detected in 100% of the 25 dead fish specimens collected (MLOD = 0.013 μg/g); in 93.5% of the 77 hermit crabs collected, both dead and alive (MLOD = 0.018 μg/g); in 73.4% of the 15 dead *Cardisoma* spp. crabs collected (MLOD = 0.018 μg/g); in 87.5% of the 14 samples of cockroaches collected (MLOD = 0.020 μg/g); in 100% of the 15 samples of ants collected (MLOD = 0.012 μg/g); in 46.7% of the 75 geckos collected (MLOD = 0.011 μg/g); in 90% of the 30 black-spot sergeant fish caught still alive (MLOD = 0.013 μg/g).

This important and isolated study, in which the carcasses of animals that had died from poisoning were collected opportunistically rather than through active purposeful searching, shows that the fall or washout of baits containing brodifacoum (the same would apply to other biocides used) in the marine environment is associated with the contamination of the entire food chain and the death of a significant, but still undetermined, percentage of individuals belonging to various species. The authors of the study point out that the number of animal carcasses found was not negligible, considering that, although it was estimated that approximately 20,000 rats were killed by poisoning during the eradication [118], only a few dozen carcasses of rats killed by poisoning were found during the project.

During the planning phase of the "Montecristo 2010" project, the potential for pellets to enter the sea was considered, and a test was conducted to ascertain the risk of brodifacoum being ingested by fish [29]. The results demonstrated that 9 out of 28 fish species observed exhibited attraction to, tasted, or ingested the bait, including *Oblada melanura* Linnaeus, 1758; *Diplodus vulgaris* Geoffroy Saint-Hilaire, 1817; *Salpa salpa* Linnaeus, 1758; *Coris julis* Linnaeus, 1758; *Symphodus roissali* Pallas, 1814; *Symphodus tinca* Linnaeus, 1758; *Thalassoma pavo* Linnaeus, 1758; *Serranus scriba* Linnaeus, 1758b; and *Serranus cabrilla* Linnaeus, 1758 [29].

As evidenced in the study by Pitt et al. [44], the widespread contamination of the food chain with brodifacoum within an island ecosystem can extend beyond terrestrial habitat into the marine environment. It has also been documented that various species of fish [29] and crustaceans [104–106] readily consume cereal-based pellets containing various biocides, including brodifacoum, and that small fragments of the pellets and brodifacoum can easily be carried by currents via particulate matter dispersal [119] and plankton [66].

The impact of aerial dispersal of second-generation anticoagulant rodenticides on islands and the contamination of terrestrial and marine ecosystems is a subject that requires increased attention [120]. With emerging evidence from similar case studies, a closer examination should be made of the detrimental effects on marine ecosystems, including the occurrence of unexpected and concentrated cetacean mortality episodes, which have been designated as Uncommon Stranding Events (USE).

During the initial three months of 2013 [121], there was an Uncommon Stranding Event (USE) of 122 cetaceans on the Italian coast. A USE of this magnitude did not occur in subsequent years (see Figures 4 and 5) [122]. A study published by Casalone et al. regarding the 2013 USE suggests that no definitive conclusions could be drawn based on post-mortem analyses [121]. According to the study, dolphin morbillivirus was considered the most likely cause, although other infectious diseases or environmental factors may have contributed to the mortality event. The results of histopathological examination of cetaceans involved in this USE indicated evidence of chronic inflammation affecting multiple organs and a compromised immune system, accompanied by a high parasite load. Additionally, septic shock, characterized by an unusually high prevalence of pathogenic organisms, was diagnosed. The authors attributed the impairment of the cetaceans' immune system to the presence of morbillivirus and organochlorine pesticide residues in the carcasses [121]. However, although no tests for brodifacoum have been carried out on the tissues of stranded cetaceans, it cannot be ruled out, hypothetically, that the impairment of their immune system might be due to the ingestion of sublethal levels of this toxin via the food chain (see Section 4.1.3).

A plausible criticism of the hypothesis that the cetaceans were contaminated by brodifacoum is that their stranding occurred some 11 months after the pellets were dispersed on the Island of Montecristo and never again in the years that followed, but this possibility cannot be entirely ruled out.

This is a highly topical issue, and other human-made chemical compounds that have contaminated marine ecosystems are also proving to be lethal for marine mammals [120].

These environmental factors may act synergistically, contribute to stress, or weaken the immune response, thereby constituting a factor contributing to mortality from secondary infections. We therefore believe that this issue warrants further in-depth investigation in the future.

This underscores the necessity of improving the criteria and standards for research on such toxic substances, whether in water, soil, living organisms, or the analysis of the carcasses of deceased animals. Based on the information presented, SGARs should be included in the toxicological screening protocol for future cetacean stranding investigations. This improvement is fundamental to facilitating a more comprehensive understanding and monitoring of the effects of toxic chemical compounds released into the environment and those that have entered trophic networks.

A concern identified in other case studies pertains to the limited sensitivity of available testing methods. This limitation results in the potential for a toxin to be present in an organism but to be undetectable at low concentrations using these methods [109]. Boesch [109] draws attention to the stranding of multiple cetaceans between 2015 and 2021, which occurred concurrently with the aerial dispersal of high-persistence rodenticides utilized in rodent control operations on select Pacific Ocean islands. It is also relevant to note that the author identifies the challenge of detecting secondary poisoning episodes in non-target species when adequate amplitude sampling and standardized analytical methods with high sensitivity are not employed.

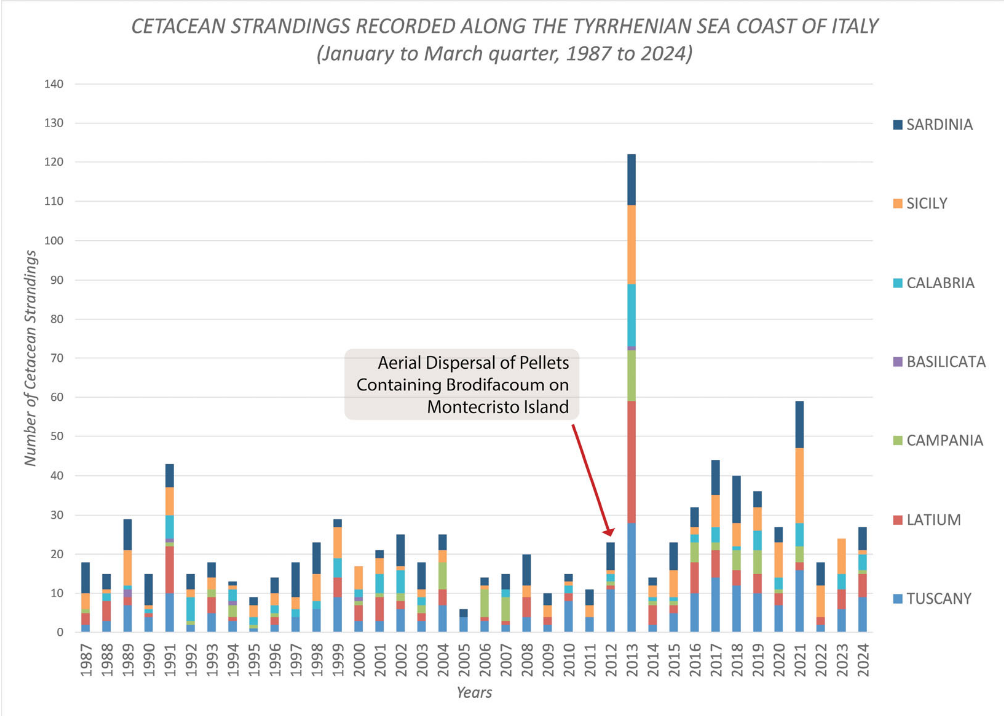

Figure 4. Cetacean strandings recorded along the Tyrrhenian Sea coast of Italy (January to March quarter, 1987 to 2024 [122]).

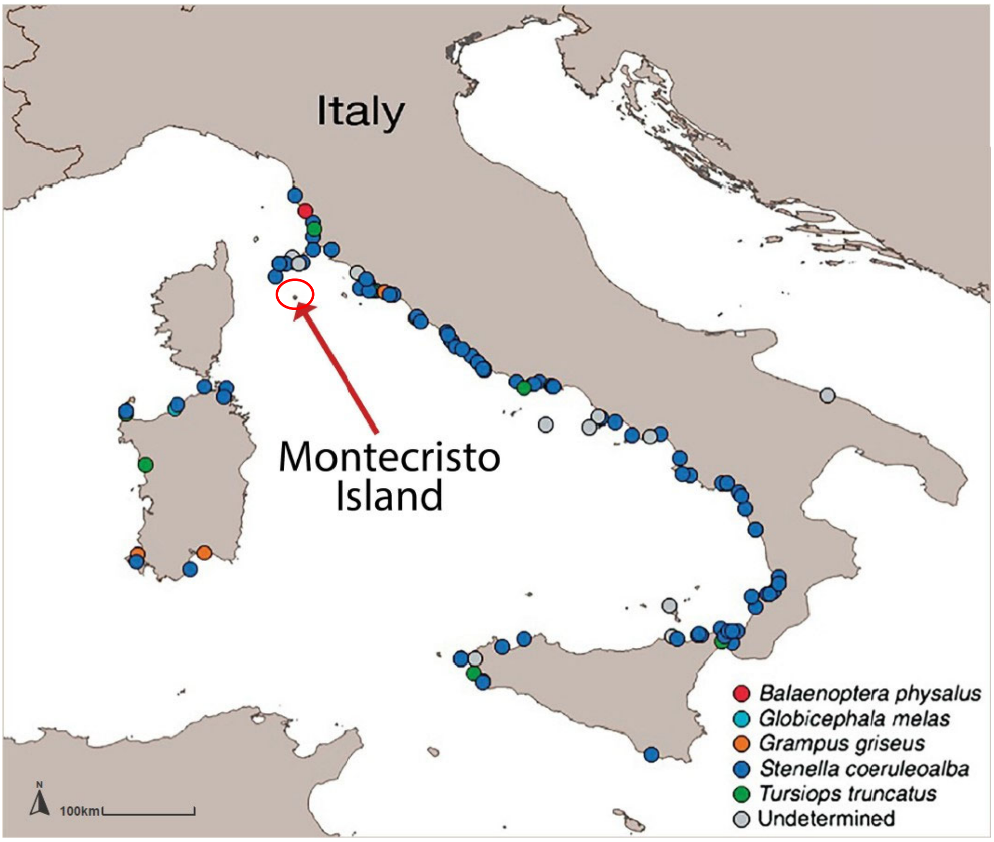

Figure 5. Geographical distribution of cetacean strandings along the Italian coastline (1 January to 30 March 2013) [121] (modified image).

4.1.3. Sub-Lethal Chronic Toxicity of Brodifacoum and Its Effects on the Immune System of Mammals

From an ecological standpoint, the sub-lethal chronic toxicity of brodifacoum—that is, toxicity that does not result in acute mortality of animals—is of particular significance. This is because [123]:

- Chronic exposure to contaminants is a more frequent condition in natural environments than acute exposure.
- Moderately contaminated environments are more common than highly contaminated environments.
- The effects of sub-lethal doses may have greater ecological relevance than lethal doses in highlighting possible alterations in organisms subjected to prolonged exposure to contaminants.

The long-term environmental persistence of brodifacoum has prompted concern regarding its potential for adverse effects on animal populations exposed to sublethal doses of the chemical compound. The reproductive effects of exposure to anticoagulants at sub-lethal doses have already been demonstrated in humans, dogs, and sheep. These effects include spontaneous abortions, fetal toxicity, and hypospermia [68]. Brodifacoum poisoning has been documented in newborn puppies from female dogs that had been exposed to the compound four weeks prior to parturition [124]. Additionally, 50% of ewes that had ingested the toxicant at a sub-lethal level miscarried or gave birth to stillborn lambs [68].

Further research has highlighted the extreme danger of exposure to sub-lethal levels of brodifacoum in impairing the efficiency of the immune system in mammals. In southern California, from 2002 to 2005, an outbreak of notohedral mange associated with other ectoparasitoses was the leading cause of mortality in bobcats (*Lynx rufus*). The uniqueness of the case is due to the fact that all bobcats tested positive for the presence of low-concentration anticoagulants, including brodifacoum, and exposure to the toxicants was demonstrated as early as the fetal period [68–70]. In mammals, a fatal infection with notohedral mange and other parasitosis is frequently accompanied by significant impairment of the immune system. Given that all the tested bobcats were positive for residual anticoagulants, including brodifacoum, some researchers have postulated a potential link between the immune deficiency and chronic exposure to anticoagulants, as proposed by Riley et al. [125] and Irokawa-Otani [68]. This hypothesis was confirmed in 2017 by a molecular genetic study conducted on 52 bobcats captured near Los Angeles, California, of which 26 were positive for the presence of anticoagulants and 26 were negative [126]. The study confirmed that sub-lethal levels of anticoagulants in the blood, including brodifacoum, had dramatic consequences in the expression of some regulatory genes of the circulating white blood cell population that are known to be involved in immune system activity. The authors emphasize the importance of the findings, especially with regard to the fact that the effect of anticoagulants can severely affect the survival of a mammalian population without the symptoms of acute poisoning (e.g., hemorrhage from blood hypocoagulability), simply by making the immune system less effective against pathogens or parasites.

4.2. Is It Possible to Estimate the Distribution of Pellets Immediately After They Are Dropped from the Helicopter?

4.2.1. Calculation Method for Determining the Percentage of Pellets Reached the Sea as a Result of Aerial Distribution (Probabilistic Method "Montecristo Case Study Simulation")

The probabilistic calculation of the number of pellets that would reach the sea during distribution from a helicopter was performed using the program AZTEC ROCK Fall of Masses [127]. This software is dedicated to the analysis of the most frequent problems addressed by Rock Mechanics and its applications in engineering, geological, and environmental fields. The software was utilized for the analysis of falling pellets in the three-dimensional field. In the three-dimensional model, input was incorporated through both graphical means (orography derived from polyline contour files in DXF format) and numerical methods (implementation of the pellets at the fall position). The input procedure entails an initial step of defining the extent of the slope to be analyzed, characterizing the soil, and entering the free-fall masses under study. Slope geometry and land cover characterization were generated based on data available on the Regione Toscana portal [128].

The program utilizes automatic triangulation (Delaunay Triangulation, see [129,130]) for its analysis. The topographic profile is comprised of materials contained in an archive, and the physical-mechanical characteristics, to be provided for each of the defined materials, are the normal and tangential restitution coefficient and the friction angle. These parameters, necessary for the calculation of the mass-versant interaction, represent, respectively, the ratio between the velocity before and after the impact of the mass with the ground (in-flight motion) and the dissipation of kinetic energy (rotational and translational motion). The analysis is conducted under the assumption of mass as a material point (considering the motion of its barycenter) moving along a plane or spatial trajectory from a zone (detachment zone). The island was subdivided into a grid with a 100 m $\times$ 100 m pitch, that is, into pixels of one hectare each. The quantity of pellets discharged in each pixel was determined by extrapolating data from the image depicting the distribution of pellets on the island [31,45]. Based on the information gathered through interviews with Heliwest s.r.l., the company responsible for the pellet distribution, it was determined that the flight height ranged from approximately 20 to 200 m above ground level, with an average hopper height above the ground of about 60 m (ex verbis, testimony collected by Scarfo', 2024). This variability was attributed to the presence of precipitous slopes and abrupt changes in elevation, characteristics of the island's topography.

The probabilistic approach was employed for modeling, a necessity arising from the uncertainty inherent in the choice of quantities to be introduced into the model simulation, such as the coefficient of restitution, the pellet-versus-pellet friction angle, and the shape of the pellets. The probabilistic Monte Carlo method [131–134], which is based on random number generation, was applied to allow for the entry of a range of values for the initial position and velocity of the mass, the coefficients of restitution, and the angle of friction for the constituent materials of the slope. Upon completion of the analysis, the program renders both summary and detailed numerical results, as well as graphical results. The summary results indicate the number of trajectories analyzed, the minimum and maximum distance traveled by the masses, the maximum speed reached, and the maximum height on the slope. The detailed results display the outcomes concerning each analyzed trajectory, including travel time, distance traveled, coordinates of the rebound points, impact, and rebound velocity. The graphical representations offer a visual depiction of the analyzed trajectories, velocity plots, kinetic energy, total energy, stopping points, and maximum height of the mass during its descent down the slope. To construct the map of the distribution of pellets—qualitatively described as the "visual distribution"—the modeling was executed by reducing the number of masses to the square root of 10 in the x and y directions (i.e., a total reduction of masses to one-tenth), while maintaining the height constant. To calculate the amount of pellets that likely reached the sea and various altitudes immediately after launch, calculations were made by implementing the actual number of pellets for each individual pixel. The quantities were calculated using a special program function that allows for automatic calculation of masses whose final position, following launch, is less than a given altitude. The use of the deflector on the hopper distributing the pellets does not result in a reduction in the number of pellets that ultimately reach the sea for an island characterized by steeply sloping coastlines, analogous to an inclined plane.

4.2.2. Calculation of the Percentage of Pellets That Reached the Sea Shortly After Distribution by Helicopter: "Montecristo Case Study Simulation"

The percentage of pellets that consequently reached the sea after distribution by helicopter was theoretically calculated using the AZTEC ROCK Fall of Masses program [127], as previously described. The probability of significant pellet deposition was determined by analyzing repeated helicopter passes along the coast and the precipitous rock face slopes (illustrated in Figure 6), particularly those oriented towards the east.

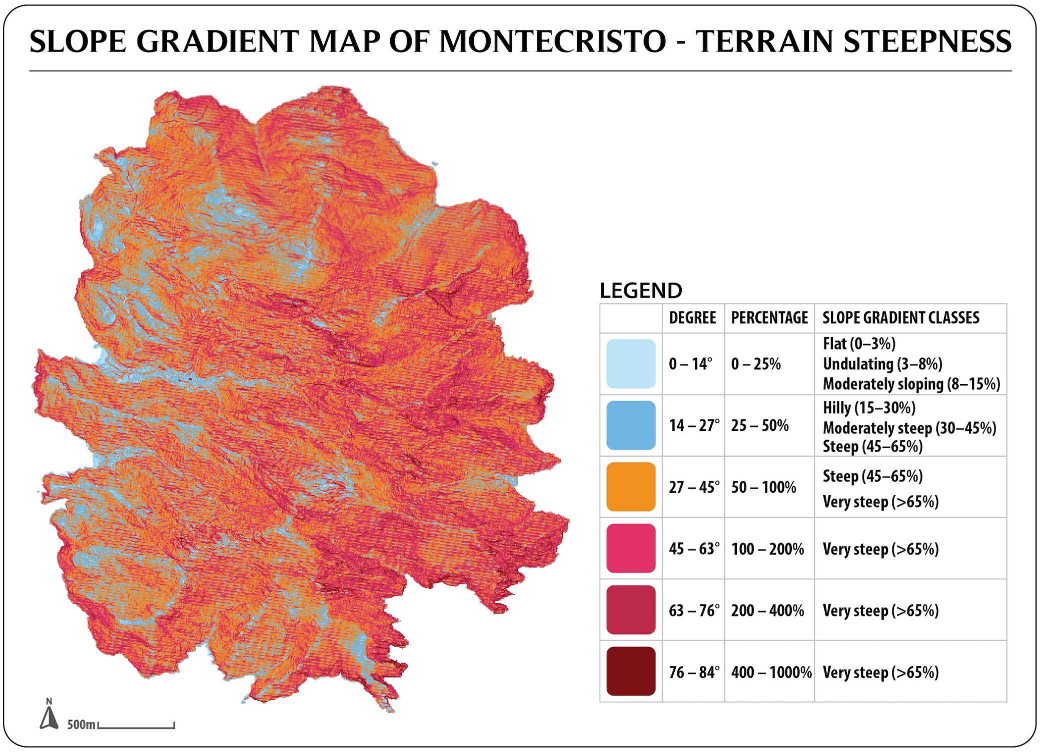

Figure 6. Slope gradient map of Montecristo Island with description of slope gradient classes as they relate to percent gradation.

In order to model the free-fall of pellets, the projection of the island on the horizontal plane was placed in a grid of squares of area equal to one hectare (i.e., with sides in the orthogonal x and y directions equal to 100 m) (see Figure 7). The quantity of pellets launched was then implemented by processing the available data [31,45], resulting in a grid for which the coordinates in the horizontal plane (x and y) were known. As the height above the ground was entered, the height of the highest point on the ground within the one-hectare reference square, 60 m, was added, which can be considered the average height of the hopper above the ground during flight. The horizontal component of the falling velocity was disregarded because the distribution bands were traversed in alternating opposite directions. The component of horizontal velocity imparted to the individual pellets by the rotation of the spinner (the rotating component inside the bucket) was also not taken into account, since the pellets are ejected radially with velocities of similar modulus and in diametrically opposite senses, in a 360-degree fan pattern, producing a nearly uniform distribution on the ground, as if the pellets had been launched, over a given time interval, uniformly along a line as wide as the distribution band (approximately 90 m [45]) rather than from a single point (the spinner's axis).

The terrain classification (see Figure 8), similarly to the slope geometry, was derived from data accessible on the Regione Toscana portal [128].

As stated on the Regione Toscana website [135], each designated zone was characterized by the requisite parameters for model construction (see Table 1).

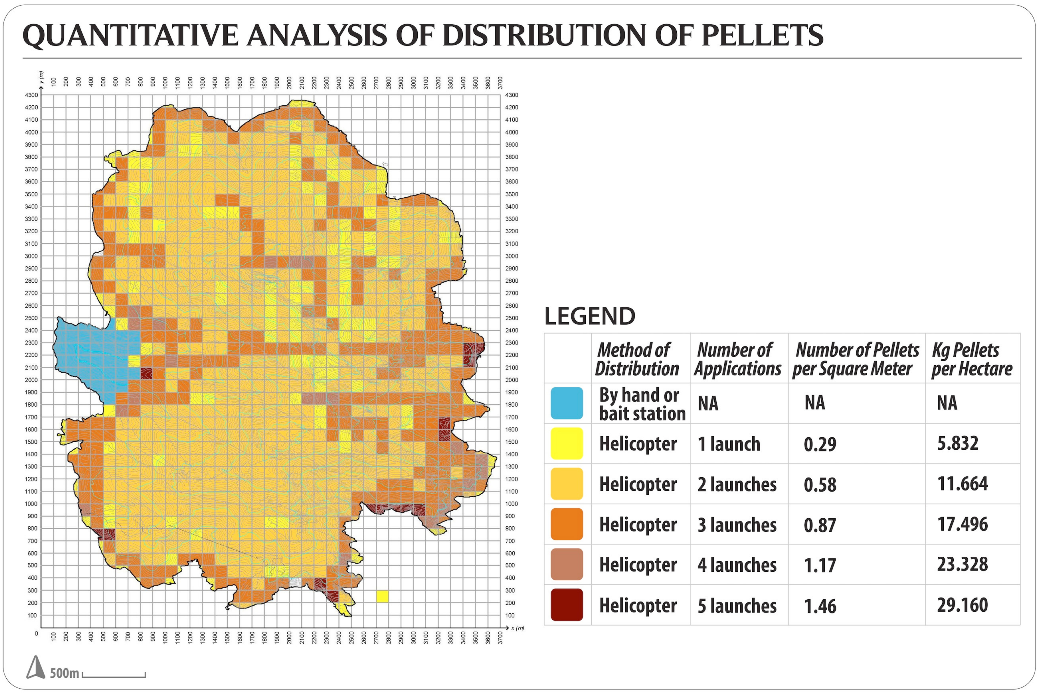

Figure 7. Quantitative analysis of distribution of pellets indicating the number of pellets per square meter and kilograms of pellets per hectare in relation to the number of helicopter launches. Note that along the coastline—since it was anticipated and observed that the pellets easily ended up in the sea—three to five consecutive distributions of pellets were carried out, rather than one or two distributions as in the inland areas. This procedure contributed to the high percentage of pellets that reached the sea following the release.

Since it was not possible to conduct a field experiment to determine the Kn, Kt, and Phi parameters related to the impact interaction between the cereal pellets used and the different terrain types, the following considerations were formulated for their evaluation. The 2 g paraffin-coated pellets used for the launch consist primarily of compressed and extruded grains. The density of the pellets is approximately 1308 kg/m^3 [46]. Although no studies pertaining to the above parameters are available on pellets containing brodifacoum, some research has determined the coefficients of restitution and the angle of friction for wood pellets launched against a wall [136], which have very similar characteristics in terms of the raw material from which they are made and their density, which is approximately 1247 kg/m^3 [136]—slightly lower than the density of the pellets launched on the Island of Montecristo [46]. To obtain results that would underestimate the number of pellets that fell into the sea after being launched, it was assumed that the coefficient of restitution normal to the ground was lower (ranging from 47 to 71% of the coefficients determined for wood pellets, depending on the terrain type) and therefore corresponded to a smaller bounce compared to the values determined for wood pellets, while the pellet-terrain friction angle was assumed to be higher (equal to approximately 161–188% of the values determined for wood pellets-wall) and consequently corresponding to a shorter rolling distance than that determined for wood pellets.

The modeling results were analyzed both qualitatively and quantitatively. Qualitatively, the trajectories and stopping points of the simulation performed with the implementation of about 705,000 free-falling masses (one-tenth of the pellets actually launched) were visualized. Visual assessments corroborated the anticipated outcomes, namely that the pellets remained at the point of impact within the vegetated regions of the island, while in the barren rock areas, the pellets traversed greater distances, undergoing bounces and rolls downhill, resulting in an accumulation of pellets in the gullies.

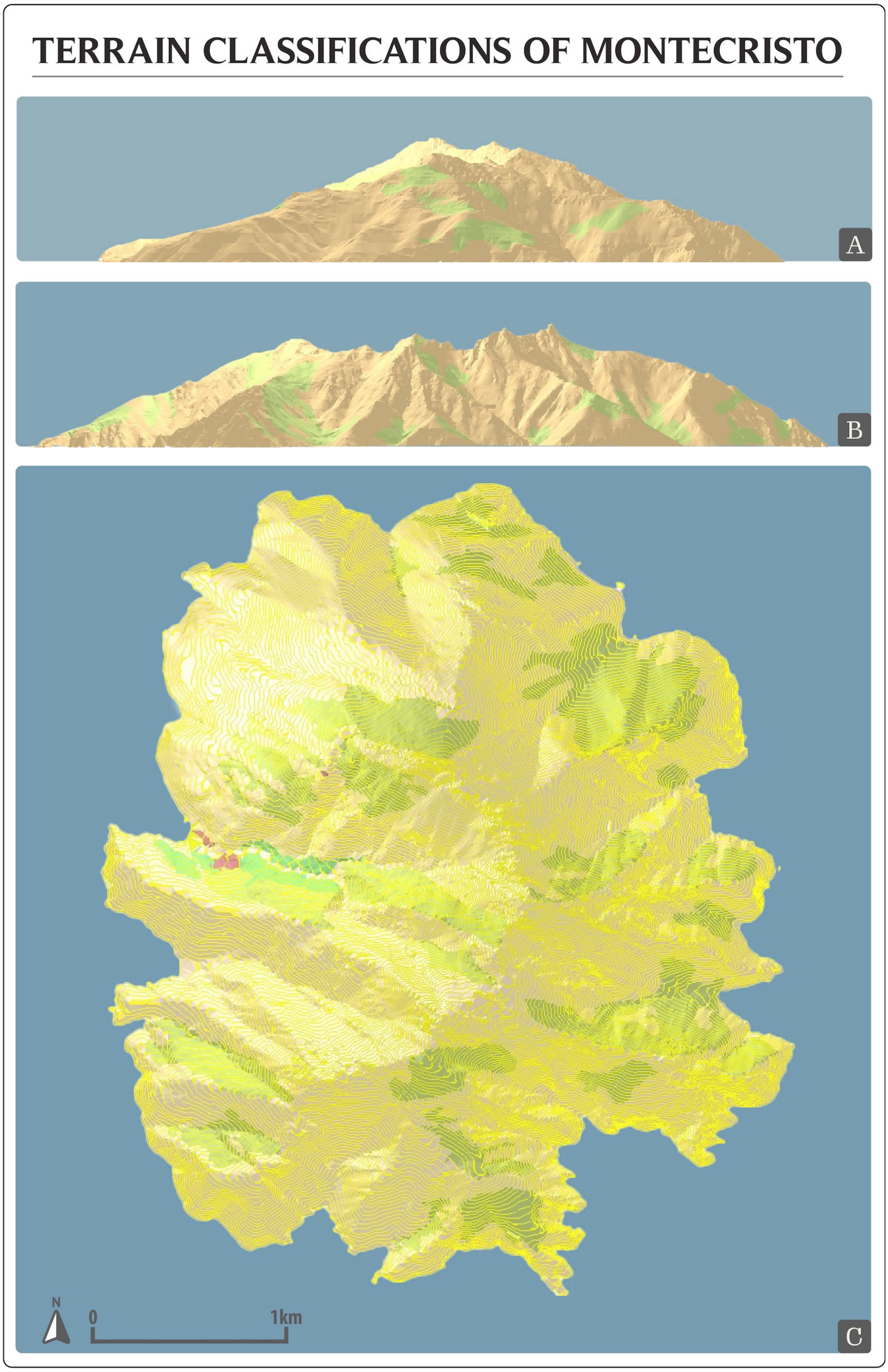

Figure 8. (**A**) View of Montecristo from the south; (**B**) view of Montecristo from the east; (**C**) map indicating terrain classifications of Montecristo. Images generated using "AZTEC ROCK—Caduta Massi" software version 18.02 H [127]. See Table 1 for legend with classifications of the terrain.

Table 1. Soil classification and characterization for implementing the following data [127]: Kn min, minimum restitution coefficient normal to the plane; Kn max, maximum restitution coefficient normal to the plane; Kt min, minimum restitution coefficient tangent to the plane; Kt max, maximum coefficient of restitution tangent to the plane; Phi min, minimum material friction angle; Phi max, maximum friction angle of the material.

Classification of the Terrain (Regione Toscana Portal [135])	"Montecristo Simulation" Implementation	Kn Min	Kn Max	Kt Min	Kt Max	Phi Min [°]	Phi Max [°]	Color
Bare rocks, cliffs, crags, and outcrops	Rock in place	0.300	0.400	0.700	0.870	30.00	35.00	
Areas with sclerophyllous vegetation	Vegetated shrub detritus	0.200	0.300	0.500	0.700	30.00	35.00	
Areas with sparse vegetation	Vegetated shrub detritus	0.200	0.300	0.500	0.700	30.00	35.00	
Mixed coniferous and deciduous forests	Vegetated woodland detritus	0.180	0.280	0.400	0.600	30.00	35.00	
Coniferous forests	Vegetated woodland detritus	0.180	0.280	0.400	0.600	30.00	35.00	
Housing structures, scattered buildings	Paved surfaces	0.300	0.400	0.800	0.900	30.00	35.00	
Beaches, dunes, and sand	Medium fine non-vegetated detritus	0.200	0.310	0.700	0.830	30.00	35.00	

The terrain classification was derived from the official maps of the Regione Toscana portal [135]. The values assigned to Kn, Kt, and Phi are those that the "AZTEC ROCK—Caduta Massi" software version 18.02 H [127] associates with the various soil types, as previously determined.

To simulate the launch of pellets and to study their individual trajectories, as well as to determine the probabilistic points reached by each individual mass subsequent to launch, 7,051,045 masses distributed over the island were analyzed according to the mapping of the final report [45]. The analysis yielded the following results: 2,059,846 ± 47,170 pellets (representing 29.21% ± 2.29% of the total pellets) were consequently deposited in the sea, corresponding to a mass of 4119.7 ± 94.3 kg of pellets (see Table 2 and Figure 9).

Table 2. The distribution has been segmented into elevation (z) bands, a result of the probabilistic study of the individual trajectories of each pellet after the helicopter launch; approximately 4.12 tons of pellets would reach the sea following the launch on the island.

Pellets Distribution	N Pellets	Uncertainty (N. Pellets)	% Pellets	Uncertainty [%]	Tons	Uncertainty [Tons]
$0 < z < 5$ m	2,059,846	±47,170	29.21%	±2.29%	4.12	$\pm 9.43 \times 10^{-2}$
5 m < z < 100 m	1,715,897	±39,294	24.34%	±2.29%	3.43	$\pm 7.86 \times 10^{-2}$
100 m < z < 200 m	1,496,932	±34,280	21.23%	±2.29%	2.99	$\pm 6.85 \times 10^{-2}$
200 m < z < 300 m	910,204	±20,844	12.91%	±2.29%	1.82	$\pm 4.17 \times 10^{-2}$

Table 2. *Cont.*

Pellets Distribution	N Pellets	Uncertainty (N. Pellets)	% Pellets	Uncertainty [%]	Tons	Uncertainty [Tons]
300 m < z < 400 m	535,143	±12,255	7.59%	±2.29%	1.07	$\pm 2.45 \times 10^{-2}$
400 m < z < 500 m	275,740	±6314	3.91%	±2.29%	0.55	$\pm 1.26 \times 10^{-2}$
500 m < z < 600 m	56,000	±1282	0.79%	±2.29%	0.11	$\pm 2.56 \times 10^{-3}$
600 m < z < 645 m	1283	±29	0.02%	±2.29%	0.00	$\pm 5.87 \times 10^{-5}$

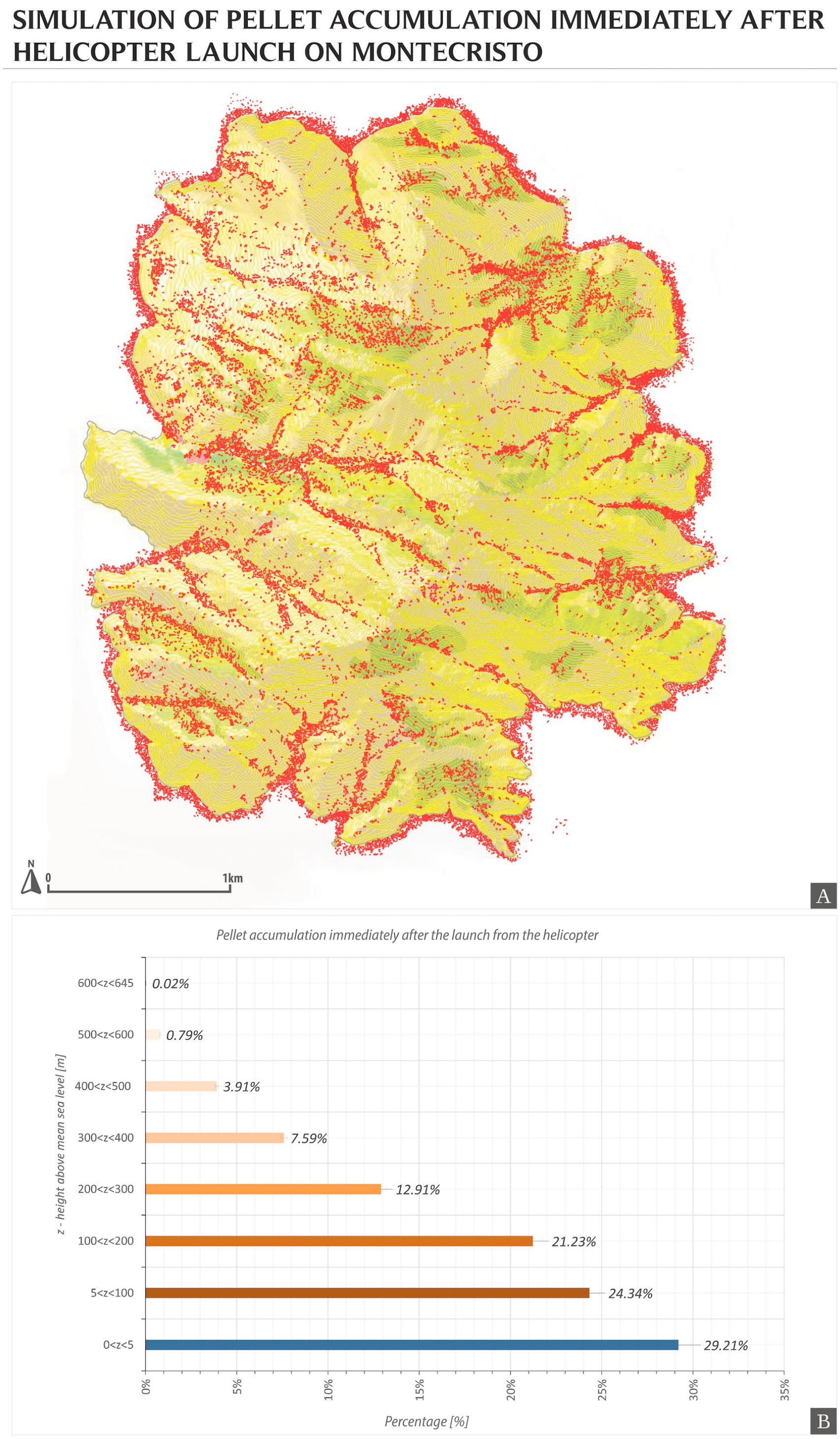

Figure 9. (**A**) Simulation of the pellet accumulation (pellets indicated in red) immediately after launch. (**B**) Histogram of the pellet percentages for each altitude range (see Table 2).

Independently of this study, it should be noted that, as Regnery's studies [107,108] have shown, much of the active ingredient contained in rodenticide baits tends to disperse and reach waterways and the sea after rainfall. Consequently, even on islands with minimal inclines, a substantial proportion of the active ingredient contained in baits launched or distributed will reach the sea, the timing of which will depend on rainfall, tide, and climatic conditions.

4.3. Contamination of Protected Marine Waters Through Aerial Dispersion of Pellets Containing Brodifacoum

The probabilistic calculation of the number of pellets that would reach the sea during distribution from a helicopter (see Section 4.2.2) indicates that a substantial proportion of pellets—approximately 4.12 tons, equivalent to 29.21% of the total quantity—reached the sea following their aerial distribution. This phenomenon can be attributed to the topography of the island and the tendency of the cylindrical pellets to cascade down steep surfaces into the water below. This result was also achieved because, along the coast—since it had been anticipated and observed that the pellets easily reached the sea—three to five consecutive dispersions of pellets were carried out, rather than one or two as in inland areas (see Figure 7). It is also important to acknowledge the role of wind when pellets are released during aerial dispersion, as it functions as an additional force that displaces pellets remaining in proximity to the coastline, thereby causing them to move toward or into the sea. Part of the pellets are fragmented or reduced to dust during transport or launch, becoming even more mobile depending on the wind [5]. Furthermore, the heavy rains that fell in November 2012 on Montecristo Island (weather station interrupted data report: temperatures, humidity, winds, and rainfall for the year 2012, LAMMA weather data [137]) may have triggered sudden and vigorous erosive processes, resulting in the displacement of remaining pellets, residues, and carcasses containing the toxic substance from the surfaces of the island into the sea below, resulting in a further abundance of brodifacoum within the marine ecosystem. To date, no monitoring efforts have been undertaken to detect brodifacoum in marine sediments [23,24].

4.4. The Impact of Brodifacoum on Non-Target Species Following Aerial Dispersal of Pellets on the Island of Montecristo

The following table (Table 3) presents a summary of the mortality of non-target species, including some of special conservation interest, recorded following the aerial dispersal of pellets containing brodifacoum on the Island of Montecristo [24,29,31,138,139].

Photographic evidence collected in the months following the aerial dispersion of pellets containing brodifacoum demonstrates the appearance of the characteristic blue-green dye used in the pellets present in bird droppings as well as the carcasses of various bird species (see Figures 10–12).

The histogram (Figure 12) illustrates the annual number of dead birds found. Although it is not known whether the intensity of monitoring in the years following 2012 was comparatively similar, these data allow for the calculation of peak mortality, as demonstrated in Figure 12. While an active search for carcasses was conducted for the seagulls, only occasional discoveries were made for the other bird species [24]. In 2012, following the distribution of the pellets, as many as 891 dead gulls were found. The carcasses of 35 dead goats were actively recovered in 2012 following the release of the pellets; the postmortem examination was limited to a macroscopic assessment of anatomopathological lesions. Although no post-mortem examinations or laboratory toxicological analyses were carried out on the remains of the animals found dead, creating a gap from a scientific and documentary standpoint, it is reasonable to assume, in accordance with the authors, that the post-intervention deaths observed are due to secondary poisoning by brodifacoum [24].

Table 3. Documented mortality of non-target species on the Island of Montecristo.

Species	Estimated Pre-Intervention Population	Expected Mortality	Estimated Post-Intervention Population	Estimated Actual Mortality
Yellow-legged gull (*Larus michaellis* Naumann, 1840)	800–1800 couples [29]	25–50 couples [29]	300 couples [31]	500–1500 Couples (62.5–83.3%) [24,31]
Goat of Montecristo (*C. aegagrus* Erxleben, 1777)	184–218 individuals [31]	Probable	107 individuals [31]	77–111 individuals (35.3–60.3%) [31]
Common raven (*Corvus corax* Linnaeus 1758)	1–2 couples [31,138,139]	Probable	0 couples [31,138,139]	100% [31,138,139]
Wild rabbit and crossbreeds (*Oryctolagus cuniculus huxley* Linnaeus 1758)	Present, but not surveyed [29]	Probable	0 individuals [138,139]	100% [138,139]

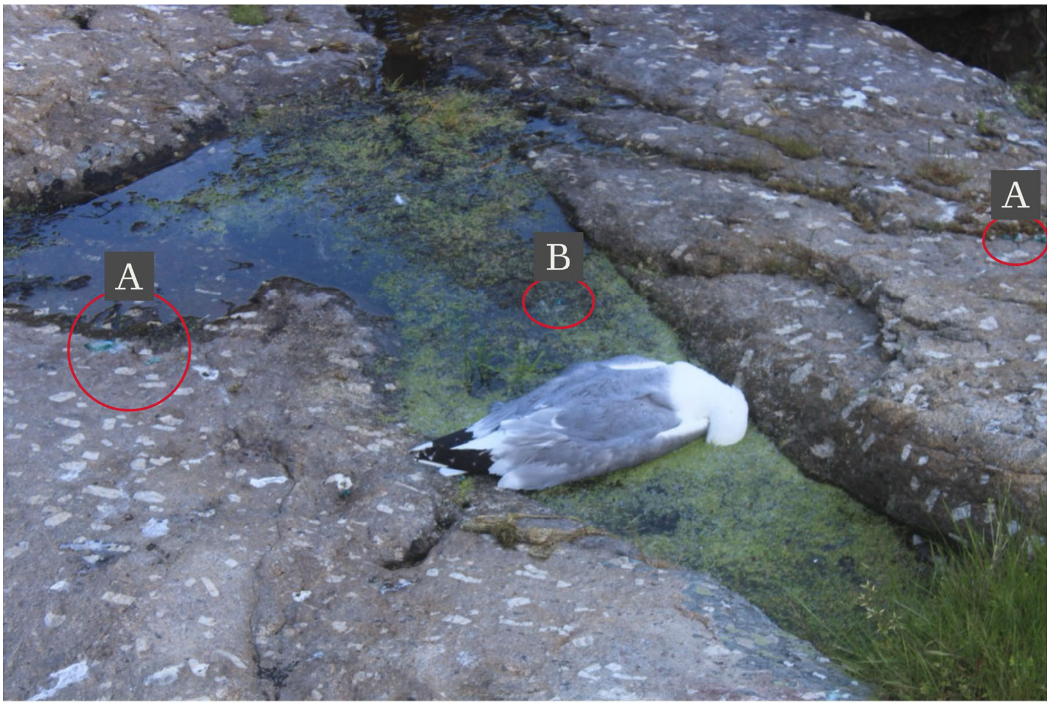

Figure 10. Carcass of a yellow-legged gull (*Larus michahellis* Naumann, 1840) photographed on Montecristo between 25 April and 28 April 2012, Località Fosso della Valle dei Lecci. (**A**) The blue-green dye present in the pellets can be seen in the bird droppings on the rock. (**B**) A blue-green pellet can also be observed in the water near the bird cadaver. The pellets were launched on 11 and 12 January and 28 February 2012. Photo courtesy of Umberto Segnini.

It is relevant to consider that pellets remained available during the migration period and that birds could die from primary and secondary poisoning [81], given that the pellets were grain-based. Studies have recently been published showing that even birds that feed mainly on fish and crustaceans can ingest SGARs through secondary poisoning by preying on fish, mollusks, and crustaceans that have consumed the bait [96]. By July of 2012, well-preserved pellets were still identifiable, even five months after their dispersal [45].

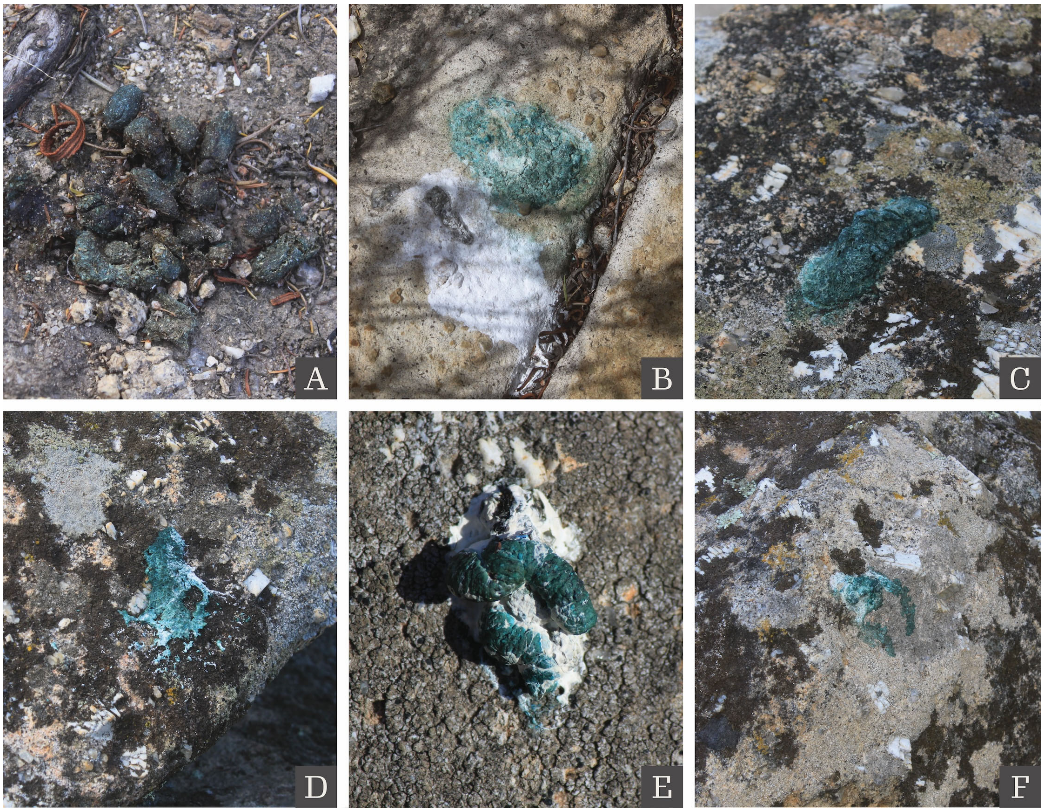

Figure 11. Photographic documentation of fecal matter from various species collected between 25 April and 28 April 2012 on Montecristo. The droppings exhibit the characteristic blue-green dye present in the pellets. (**A**) Goat droppings. (**B**–**F**) Droppings from various bird species. Photo courtesy of Umberto Segnini.

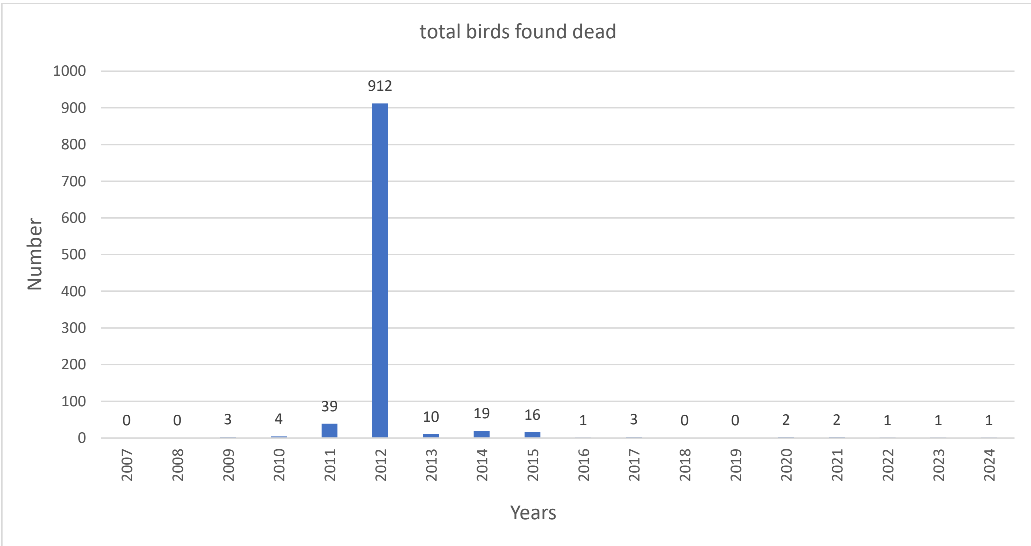

Figure 12. Annual number of birds found dead on the Island of Montecristo [24].

4.5. Calculation of Environmental Disaster Magnitude Using the European Industrial Accident Scale (EIAS): The "Montecristo Case Study Simulation"

The theoretical rationale for the use of the European Industrial Accident Scale (EIAS) can be explained through the lack of similar assessment tools available specifically for the evaluation of actions undertaken within the conservation sector. The absence of a method for the effective analysis and quantification of conservation actions that produce potential detrimental effects within a given habitat or ecosystem reveals a significant gap in accountability. The EIAS is generally employed for the purpose of industrial assessment. In this particular study, the scale has been utilized in the context of a planned conservation action, thereby constituting a simulation exercise rather than a formal regulatory classification.

An environmental disaster [140] is defined as an event caused by human activity that has a widespread impact on the environment and the health of the organisms that inhabit it. The magnitude of an ecological crisis is determined by the number of living organisms affected, the severity of the impacts on those organisms, and the extent of the affected territory. Throughout history, a multitude of anthropogenic environmental disasters have been documented, with their causative agents including, but not limited to, industrial activities [141], intensive agricultural practices [142], deforestation [143], mining [144], and oil extraction [145], as well as military actions [146]. In Italy, a notable example is the environmental disaster that occurred in Seveso on 10 July 1976, following an industrial accident [147,148] that had serious repercussions on public health and the environment. In the aftermath of the incident, the European Community undertook the drafting of the so-called “Seveso II Directive” (Directive 96/82/EC [149–152]), a regulatory measure aimed at the prevention and control of the risks associated with major industrial accidents. The Committee of the Competent Authorities of the European Union Member States formally established the “European Industrial Accident Scale (EIAS)” to serve as a metric for evaluating the magnitude of industrial accidents and comparing their environmental impact with that of the environmental disaster that historically occurred in Seveso.

In this study, an innovative investigation was conducted, using this scale to assess the extent of an environmental disaster resulting from an industrial chemical incident applied to the deliberate dispersal of chemical biocides for conservation projects. In this regard, the test was carried out by applying the “European Industrial Accident Scale (EIAS)” to assess the environmental disaster scale ranking [153] applied in the context of the “Life Montecristo 2010” project. This assessment was used to determine the consequences of the chemical biocides used. To date, the environmental impact of eradications carried out through the extensive use of biocides has never been quantified using these methodologies. The scale is based on 18 technical, measurable parameters that are used to objectively characterize the effects and consequences of industrial accidents or similar events involving dangerous substances, with magnitudes ranging from 0 to 6. The 18 parameters are divided into 4 groups:

(1) Dangerous materials released (2 parameters);
(2) Human and social consequences (7 parameters);
(3) Environmental consequences (5 parameters);
(4) Economic consequences (4 parameters).

The level corresponding to the highest magnitude (1 to 6) of the 4 groups (18 parameters) determines the severity of the environmental disaster. To perform this measurement, it is sufficient to have data available to calculate at least one parameter. The maximum value of the calculated parameters determines the magnitude of the event. For the purposes of this case study, the focus was on two of the five parameters in the third group, which were then studied and calculated (see Table 4).

In consideration of the environmental disaster, as measured by the SEVESO European Industrial Accident Scale previously delineated, the calculation of parameters Env11 and Env13 was feasible, given the partial availability of data [24,29,31,138,139].

Env11 is defined as the proportion P of rare or protected animals or vegetal species destroyed (or eliminated by biotope damage) in the zone of the accident. The calculation of this parameter is based on four species (*Larus michaellis* Naumann, 1840; *C. aegagrus* Erxleben, 1777; *Corvus corax* Linnaeus, 1758; and *Oryctolagus cuniculus huxley* Linnaeus, 1758, see Table 3). As outlined in Table 5 and shown in Figure 13, the magnitude to be attributed to this parameter is maximum, i.e., 6, given the mortality rate exceeding 50% associated with protected species [50].

Table 4. Categories of the European Industrial Accident Scale (EIAS/ARIA) relating to environmental consequences and relative parameters for ascertaining environmental disaster magnitude [153].

Environmental Consequences	Magnitude 1	Magnitude 2	Magnitude 3	Magnitude 4	Magnitude 5	Magnitude 6
Env10 * Q [t]	$Q < 0.1$	$0.1 \leq Q < 1$	$1 \leq Q < 10$	$10 \leq Q < 50$	$50 \leq Q < 200$	$Q \geq 200$
Env11 ** P [%]	$P < 0.1\%$	$0.1\% \leq P < 0.5\%$	$0.5\% \leq P < 2\%$	$2\% \leq P < 10\%$	$10\% \leq P < 50\%$	$P \geq 50\%$
Env12 *** V [m^3]	$V < 10^3$	$10^3 \leq V < 10^4$	$10^4 \leq V < 10^5$	$10^5 \leq V < 10^6$	$10^6 \leq V < 10^7$	$V \geq 10$ millions
Env13 **** S [ha]	$0.1 \leq S < 0.5$	$0.5 \leq S < 2$	$2 \leq S < 10$	$10 \leq S < 50$	$50 \leq S < 200$	$S \geq 200$
Env14 ***** L [km]	$0.1 \leq L < 0.5$	$0.5 \leq L < 2$	$2 \leq L < 10$	$10 \leq L < 50$	$50 \leq L < 200$	$L \geq 200$

* Env10: Quantity Q of wild animals killed, injured, or rendered unfit for human consumption (t); ** Env11: Proportion P of rare or protected animal or vegetal species destroyed (or eliminated by biotope damage) in the zone of the accident; *** Env12: Volume V of water polluted (in m^3). The volume is determined with the expression Q/Clim, where Q is the quantity of substance released and Clim is the maximal admissible concentration in the milieu concerned established by the European directives in effect; **** Env13: Surface area S of soil or underground water surface requiring cleaning or specific decontamination (in ha); ***** Env14: Length L of water channel requiring cleaning or specific decontamination (in km).

Table 5. Environmental consequences with magnitudes associated with the event as an environmental disaster [149,153].

Environmental Consequences		
Technical Parameters	**Parameter Quantification**	**Magnitude**
Env10 * Q [t]	N/A	N/A
Env11 ** P [%]	$P \geq 50\%$	6
Env12 *** V [m^3]	N/A	N/A
Env13 **** S [ha]	$S \geq 200$	6
Env14 ***** L [km]	N/A	N/A
Magnitude associated with the event as an environmental disaster		**6**

* Env10: Quantity Q of wild animals killed, injured, or rendered unfit for human consumption (t); ** Env11: Proportion P of rare or protected animal or vegetal species destroyed (or eliminated by biotope damage) in the zone of the accident; *** Env12: Volume V of water polluted (in m^3). The volume is determined with the expression Q/Clim, where Q is the quantity of substance released and Clim is the maximal admissible concentration in the milieu concerned established by the European directives in effect; **** Env13: Surface area S of soil or underground water surface requiring cleaning or specific decontamination (in ha); ***** Env14: Length L of water channel requiring cleaning or specific decontamination (in km). N/A: Not Available.

The parameter Env13 concerns the surface area S of soil or underground water surface requiring cleaning or specific decontamination, measured in hectares (ha). In the present case, the poisoned pellets were distributed over approximately 1300 hectares, resulting in the maximum magnitude of 6.

The Env13 parameter refers to the area S of soil or underground water requiring cleaning or specific decontamination (in ha). In this case, the area to be cleaned up coincides with the area over which the poisoned pellets were distributed, namely approximately 1300 hectares [45], since no systematic remediation of the island has been carried out. Env13 corresponds to a maximum magnitude for an area to be cleaned up that is greater than or equal to 200 hectares. Therefore, the parameter Env13 also has a maximum magnitude, namely 6.

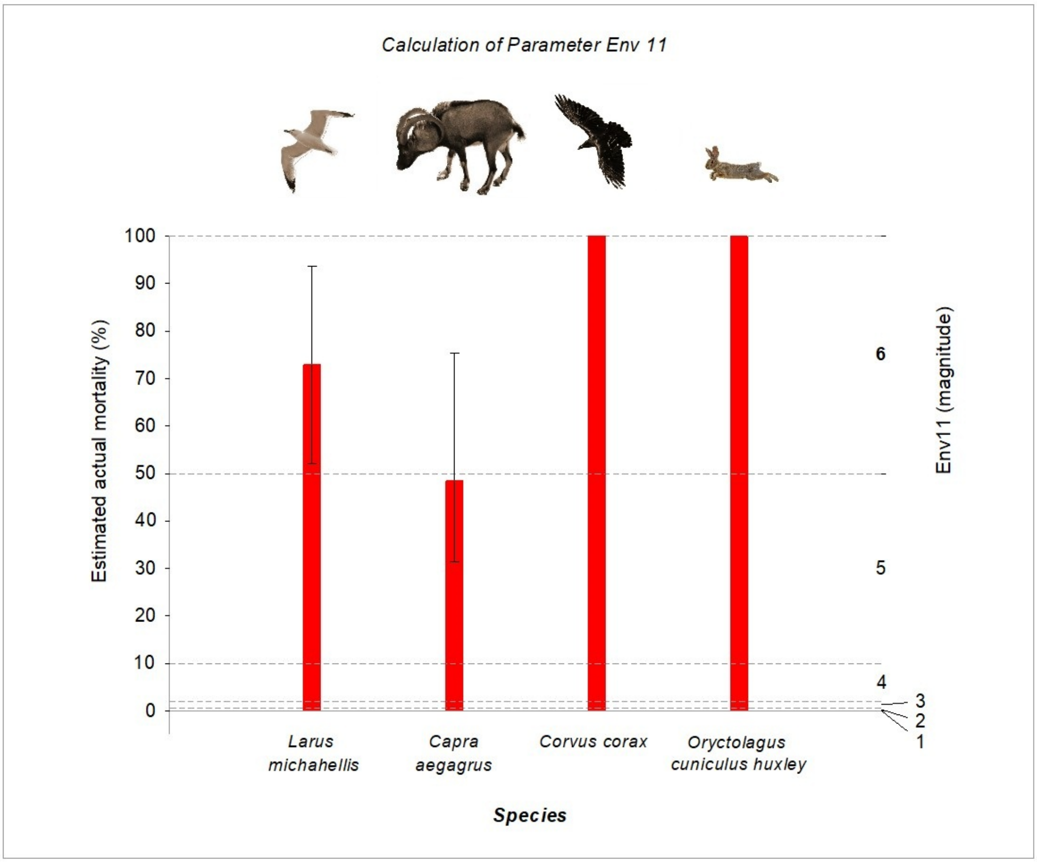

Figure 13. Determination of the Env11 parameter magnitude.

Consequently, by measuring the effects caused by eradication measures carried out by the introduction of large quantities of brodifacoum into the environment, using an objective scale based on factual data rather than subjective deductions and assumptions, it can be asserted that the LIFE Montecristo 2010 project is comparable to an environmental disaster of magnitude 6, the maximum magnitude according to the SEVESO European Industrial Accident Scale [153].

4.6. Discussion

4.6.1. Rats in the Mediterranean Islands and Seabirds: The Biological Paradox

Although several studies document a recovery of seabird populations following the eradication of rats on international islands [18–20], the Mediterranean islands constitute a unique ecosystem that differs from that of other islands around the world. It has been theorized by some scientists that one of the most significant threats to the survival of seabird populations and island biota worldwide is the presence of the black rat (*Rattus rattus* Linnaeus, 1758), which was introduced by humans to 80 percent of the islands. However, the coexistence of rats with stable seabird populations on Mediterranean islands has been observed [154,155]. In the Mediterranean basin, despite the presence and spread of rats, there is no evidence that seabird populations have become extinct due to their impact [156]. Some authors posit that this unexpected result in the Mediterranean can be attributed to the fact that over thousands of years of coexistence between different species of seabirds and rats, a balance has been achieved in the various island ecosystems, allowing for their populations to coexist without significant negative interference [139,156,157]. For example, in a somewhat paradoxical situation, the yelkouan shearwater (*Puffinus yelkouan* Acerbi, 1827), a species that is the subject of the Life + Montecristo 2010 project, does not occur on islands where there are no rats [155]. The oldest evidence for the presence of rats in the Western Mediterranean islands dates back to Roman times (e.g., Corsica 393-151 B.C. [158]). However, it is probable that their presence can also be placed in earlier historical periods [156]. In Sardegna and the Isola di Palmaria islands, archeological evidence from the Neolithic period (10,000–2200 BC) indicates the presence of rats [158]. In the Mediterranean, among the various species of Procellariiformes, the only species whose abundance seems to be conditioned by the presence of rats is the small storm petrel (*Hydrobates pelagicus*, Linnaeus, 1758). All other species appear to be influenced more by the ecological characteristics (size, orography, vegetation cover, etc.) of individual islands [156]. In a study conducted in 2008 on 292 Mediterranean islands, an analysis of available data on the presence and abundance of seabird colonies, rats, and other constituents of island ecosystems, including orographic and environmental features, revealed that rats were present in 68.8 percent of cases (n = 201). However, in no instance did their presence appear to influence the size of yelkouan shearwater populations. This result was not anticipated by the researchers, but there may be an explanation, particularly in regard to *Puffinus yelkouan* Acerbi 1827, which prefers deep, winding nesting sites on near-vertical cliffs that are inaccessible to rats [156]. With regard to the Island of Montecristo, a similar hypothesis has been proposed, namely, that the yelkouan shearwater population is stably present on the island despite the presence of rats. This is thought to be due to either the location of a substantial number of nests in sites inaccessible to rats or to periodic fluctuations in the rodent population, which allow the chicks to hatch [31]. These considerations give rise to concerns regarding the necessity of eradicating the rat from the Island of Montecristo through the aerial dispersal of pellets containing a toxicant with high environmental persistence, as this operation has the potential to produce a substantial detrimental impact on the ecosystem and may result in significant lethal consequences for non-target animal species.

4.6.2. The Predatory Impact of Rats on Yelkouan Shearwater Nests in Mediterranean Islands

A study was conducted in the Parc National des îles de Port-Cros et Porquerolles [154] to ascertain the potential for rats to interfere with the reproductive success of yelkouan shearwaters. The study involved monitoring 60 cavities for a period of one year, which were deemed suitable for use as nesting sites by the birds but also accessible to rats. This resulted in a total of 1440 observations being made. The findings were unexpectedly different from what had been anticipated. The prolonged monitoring of nesting sites revealed that the interference of rats with the reproductive success of the yelkouan shearwater is, in fact, minimal. The study revealed the following findings:

- The yelkouan shearwater utilized only 42% (n = 25) of the identified cavities as nesting sites.
- In the majority of cases (92%), the cavities utilized by the shearwaters were only visited by the rats after the birds had vacated the nests at the conclusion of the breeding season, and consequently, these visits had no impact on the birds' reproductive success.
- A single visit by rats was recorded during the period when the cavities housed eggs or nestlings vulnerable to predation. However, no predation occurred.
- In 76% of cases (n = 19), reproduction was successful, with the chick successfully flying away from the nest. In the cases where reproduction was unsuccessful, there was never evidence of rat visitation within the cavity. Therefore, it can be concluded that the failure to reproduce was not due to rat predation. It can be stated with certainty

that there is no evidence to suggest that rats played a part in the failure of reproduction among yelkouan shearwaters.

This study illustrates that a rat population can coexist with established seabird colonies in the same habitat without significantly impacting their population dynamics, contrary to the prevailing belief.

It seems reasonable to posit that the lengthy period of coexistence, spanning thousands of years, has led to the formation of intricate ecological balances on Mediterranean islands. These balances, undoubtedly distinct from one island to another, facilitate the coexistence of rat and procellariiformes bird populations without significant concerns regarding survival [154,157]. The study of island ecosystems is hindered by a lack of research, which may be attributed to their inherent complexity. However, the dearth of knowledge regarding the ecology of the black rat in Mediterranean island ecosystems [139] represents a particularly glaring gap in the scientific landscape. This deficiency precludes an accurate evaluation of the efficacy of eradication or reduction strategies targeting black rat populations, which aim to promote the abundance of seabird populations. The population dynamics of procellariiformes appear to be minimally influenced by the reproductive success of individual years, whereas environmental factors that determine the survival of individuals to sexual maturity exert a considerably greater influence. This would appear to be the underlying reason why populations of seabirds have remained viable for thousands of years, competing with the rat on Mediterranean islands [154]. A similar situation was observed on the Island of Montecristo, where, despite the presence of rats, the number of breeding pairs of yelkouan shearwaters (*Puffinus yelkouan* Acerbi 1827) had been estimated at 400–750 pairs prior to the dispersal operation of pellets containing brodifacoum. This accounted for 3–10% of the global population of this species [29,31].

One potential limitation in assessing the efficacy of rat eradication efforts on islands is the tendency to define success based on increased reproductive success in a subset of nests over a limited time frame. This approach may not align with the established bibliographic precedent, as evidenced by studies such as Towns [159], which emphasize monitoring the overall bird population size over an extended period before and after the eradication operation. To illustrate, in the case of the LIFE + "Montecristo 2010" project, the reproductive success of the species was assessed before and after the operation. The sample consisted of 15 yelkouan shearwater nests in 2009 (representing 2.0% to 3.75% of the estimated total number of breeding pairs) and 40 in 2010 (representing 5.3% to 10.0% of the estimated total number of breeding pairs). At the end of the project, surveys were carried out in June, before the juveniles flew from the nests, on 19 nests in 2012 (2.5% to 4.75% of the estimated total number of breeding pairs), 28 nests in 2013 (3.7% to 7% of the estimated total number of breeding pairs), 27 in 2014 (3.6% to 6.7%), 26 in 2015 (3.6% to 6.7%), and 35 nests in 2016 (4.6% to 8.7%) [138].

The methodology employed in this study presents two critical issues that may compromise the reliability of the data as a demonstration of the success of the project. Firstly, the sample size of nests examined is relatively small in comparison to the total estimated breeding pairs, raising concerns about the representativeness of the data. Secondly, the nests examined are those accessible to researchers, limiting the generalizability of the findings to the entire population of yelkouan shearwater nests on the island. Additionally, it is important to note that the majority of nests are located in areas with limited accessibility, both for humans and rats, which further complicates the monitoring process [31]. The lack of reproductive success in some nests of yelkouan shearwaters on the Island of Montecristo has been attributed to rats; however, this conclusion is contingent upon the use of a methodology that can unequivocally attribute the loss of eggs or pullus to rat-mediated predation. The discovery of abandoned or broken eggs or the remains of dead nestlings may be attributed to other factors [154] that have not been investigated. A method that could be considered certain would have been the one used in the Parc National des îles de Port-Cros et Porquerolles study, namely the scattering of fine sand at the entrance of nests to detect rat footprints during the period of egg or nestling presence. This would have enabled the unequivocal establishment that the egg and nestling were preyed upon and did not die due to other causes [154].

The absence of a detailed account of the methodology employed to ascertain with certainty the role of predation in the observed egg or pullus loss prevents the attribution of the reduced reproductive success of the yelkouan shearwater on the Island of Montecristo to rats with the same degree of confidence. It can be reasonably assumed that the population of yelkouan shearwaters on the Island of Montecristo was already of considerable size prior to the commencement of the aforementioned operation. This is likely due to the fact that the majority of nests are situated in inaccessible locations [31].

It is worth noting that island seabird populations experience significant annual fluctuations, which can be attributed to a multitude of climatic, ecological, or other factors that are not always fully understood. The complex and intricate interactions among these factors often make them challenging to investigate. It is, therefore, important to exercise caution when attributing the decline of seabird populations to rats alone, given that other factors can also precipitate significant fluctuations in their numbers from year to year (e.g., [154,159]). In fact, although rat eradication operations have now been conducted on nearly 900 islands worldwide [18,160], there are few studies that have provided sufficient evidence that it was the eradication of rats or other predator species that was the sole factor that led to a significant increase in seabird populations. These studies are characterized by multi-year monitoring of the populations of the birds under protection before and after the eradication operation, carried out through the use of standardized transects encompassing the various environmental types in the study area [160]. To illustrate this critical issue, one might consider the analysis of data on the population size of the yellow-legged gull (*Larus michahellis* Naumann, 1840) on the Island of Montecristo [31]. Indeed, before anthropogenic operations were conducted to control the population, the number of breeding pairs ranged from 800 to 1800 [29], while following the aerial dispersal of pellets containing brodifacoum, the number of breeding pairs dropped to 300 [31]. Therefore, the yellow-legged gull population on the Island of Montecristo has experienced a notable decline in its size over time, the underlying causes of which remain uncertain and appear to be unrelated to human activity, with the exception of the aerial dispersal of brodifacoum on the island in 2012, which contributed significantly to the further decline of the population. In contrast, no specific population estimates of yelkouan shearwaters are available for the years following the intervention on the Island of Montecristo. This lack of data makes it challenging to ascertain whether the project was truly successful or not. In the sole available table [91] in which the data pertaining to estimated pairs of yelkouan shearwaters on the islands of Molara and Montecristo are aggregated, the total estimated population of this species is found to be in the range of 500 to 600 pairs. However, prior to the intervention, on the Island of Montecristo alone, an estimated 400–750 pairs were identified [29,31]. It would appear that the project did not result in a notable increase in the population of yelkouan shearwaters on the island.

4.6.3. Eradication of Rats on Mediterranean Islands Through Aerial Dispersion of Second-Generation Anticoagulants: Nature Conservation or Ecological Contamination?

Within the Mediterranean region, a total of 66 rodent eradications were carried out using toxic substances, yielding a reported temporary success rate of 53.03% (35 out of 66 eradications) and a failure rate of 46.97% [161]. Given the inherent uncertainty in the data, the potential for rodent recolonization of the islands, and the rodents' resistance to rodenticides [162], these data suggest a probability of success and failure, short-term, of approximately 50% each. In the long term, the islands are most likely to be repopulated by the eradicated biological elements, drastically reducing this already low percentage.

The issues related to the dispersal of brodifacoum in the environment, especially in protected areas, with the theoretical aim of protecting biodiversity by favoring one species to the detriment of others, are numerous and complex (e.g., [5,44,109]). The results of these studies are often conflicting:

(1) The scientific literature indicates that the poisoning of non-target wildlife species by brodifacoum is a common occurrence. This phenomenon is caused by the long-lasting persistence of the compound in the environment, which results in contamination of food chains through mechanisms that are not fully understood. The contamination of the environment by this compound is further evidenced by the presence of residues of unused pellets, feces of animals that have ingested brodifacoum, even at sublethal dosages, and remnants of organs of animals that have died from poisoning (e.g., [44,139]). Despite evidence dating back to the 1990s (e.g., [163]) indicating that the persistence of brodifacoum in the environment results in secondary mortality among a range of non-target animal species, even long after its initial dispersal, long-term monitoring programs designed to assess the broader ecosystem-level impacts of this compound have rarely been implemented.

(2) The reappearance of rats on islands that have undergone an eradication operation resulting in significant mortalities in non-target species and contamination of the ecosystem with highly persistent toxic substances represents a disastrous eventuality that completely undermines the economic, personnel, and time effort associated with the eradication project [164]. This eventuality, which only becomes apparent years after eradication operations, is typically attributed to either the ability of rats to swim from nearby islands where they are still present or the fact that they can be carried by watercraft or voluntarily reintroduced with the intention of "sabotaging" the operation [164]. However, another reason, perhaps the most logical one, is overlooked. This is that not all rats on the "rat-eradicated" island were reached by the toxic baits. Therefore, the surviving specimens gradually reconstitute a population as large as it was before the intervention based on the "carrying capacity" of the territory. To ascertain whether or not the rat eradication has been effective, it is essential to conduct periodic and consecutive monitoring over several years after the intervention. This should employ methods that allow the results to be compared with those obtained in years preceding the intervention [160].

(3) It is challenging to demonstrate the actual long-term benefit of rat eradication operations in favor of species that may be affected in their survival by these rodents. This is due to the fact that the impact of rats can vary greatly by area, season, and year [159]. The evidence presented thus far, in the form of one or two surveys on the increased reproductive success of a small percentage of nests, is insufficient to establish the success of the operation, given the substantial and persistent contamination of the island ecosystem and the lack of identification of the full effects of such contamination. Islands characterized by steep cliffs, crags, and sparse vegetation provide seabirds with vast nesting areas that are poorly accessible to rats, thereby limiting the impact of these rodents on the total reproductive capacity of these birds. A study of 26 islands that had previously undergone eradication operations, which involved the use of both bait stations and aerial dispersion of pellets containing brodifacoum, found that 8 of these islands (31%) experienced a subsequent reinvasion by rats, despite the initial success of the attempted eradication efforts [139]. In at least one instance, deliberate reintroduction was suspected. On 12 islands (46%), the eradication was deemed to

have been entirely successful. On one island (3.8%), the eradication of the rats was unsuccessful. For the remaining five islands (26%), the results are still inconclusive. Moreover, only 20 of the 26 islands have published data [139], while the results for the remaining six islands are only available in verbal reports. In light of the available data (n = 20), it can be concluded that the operation was deemed successful in only 50% (n = 10) of the cases. In 45% of the cases (n = 9), the eradication was unsuccessful, either due to failure or initial success followed by reinvasion by rats. The outcome for one island (Ventotene, LT) remains undetermined.

(4) The video documentary directed by Wischnewski, M. [165] provides a valuable opportunity to consider the pressing need for effective rat population management strategies. Wischnewski's discussion underscores the necessity to adopt a different perspective on rats, their presence, and their management. It has been demonstrated that the systematic use of rodenticides results in the accumulation of toxic substances in the environment, leading to the contamination of other organisms, including fish. This phenomenon is frequently accompanied by considerable financial expenditures that ultimately fail to achieve the desired outcome and instead result in additional complications. It is also important to note that rats develop strong resistance to chemical substances (e.g., [166–169]), which renders even the most recent biocides increasingly ineffective. This, in turn, causes harm to other living beings, including humans, as well as environmental degradation. If this is true for urban environments, equal attention should be given to other contexts, including natural environments, agricultural land, and protected areas [170].

(5) The eradication methods involving the use of copious amounts of environmentally persistent, toxic substances have been documented to cause damage within the ecosystem that has not yet been fully quantified in terms of environmental pollution and mortality of non-target species. By transitioning from a deductive to an inductive approach to analysis, it becomes possible to quantify the magnitude of the damage caused by the use of biocides on the islands, which can be classified as an environmental disaster through use of a specific range of measurable parameters such as those used by the European Industrial Accident Scale, a severity scale developed by EU member states in order to adhere to the EU "SEVESO" Directive [153].

It is thus important to implement meticulous and sustained monitoring of the animal populations present in areas designated for the execution of an extremely invasive intervention, such as the aerial dispersal of toxic baits containing a highly environmentally persistent substance, which will inevitably result in the contamination of the entire ecosystem for years to come. This monitoring is necessary to ascertain whether the intervention was truly justified and whether it yielded minimal benefits at the expense of significant biological damage to the island ecosystem, particularly if data relating to the ecosystem prior to the introduction of the rats are lacking. Indeed, the success of a rat eradication project on an island for the purpose of fostering the reproductive success of seabird species believed to be threatened by the presence of the rodent should be measured at least a decade after the operation. This allows for the verification of whether the positive trend results from population fluctuations due to natural factors, such as annual climate variability and recruitment by immigration from other populations. Some authors (e.g., [160]) argue that medium- to long-term pre- and post-eradication monitoring is necessary to ascertain whether the eventual positive response of the seabird population is sustained enough to confirm the benefits of rat eradication for conservation purposes.

The rationale for restoring the ecosystems of the islands, including those in the Mediterranean, to their original, pre-rat introduction state is also somewhat tenuous and does not justify the use of such toxic, persistent, and bioaccumulative substances for environments whose integrity and preservation were paradoxically to be safeguarded. This is because there is no consensus on what the original, pre-rat introduction state was, rendering the rationale for the use of these substances somewhat questionable. It would be of interest to ascertain how many islands were home to populations of procellariiformes in the absence of rats and, similarly, how many seabird populations have declined or disappeared with the arrival of rats [139,155]. It can be stated with certainty that over the course of thousands of years, rats and procellariiformes have coexisted in the Mediterranean region on a number of different islands. This coexistence has been made possible by a number of factors, including density-dependent dynamics, which have been little studied [139]. For these reasons, although the use of brodifacoum via aerial dispersal for rat eradication on islands remains prevalent, numerous interest groups have, over the past decade, begun to regard this approach as ethically untenable, largely due to the mortality of non-target species and the difficulty of accurately gauging the true efficacy of the intervention (e.g., [95,159]).

Furthermore, the full extent of the consequences of anticoagulant exposure in long-term non-target wild populations remains largely unknown (e.g., [67]). The ethical implications of this approach, particularly the necessity of causing the death of several hundred animals belonging to non-target species as a collateral effect of the rat eradication operation, remain a subject of debate. The effectiveness of this operation in terms of a stable increase in the yelkouan shearwater population is also not yet fully understood. Indeed, in the case of the Island of Montecristo, the population of yelkouan shearwaters appeared to coexist peacefully with rats due to the ecological balance achieved over time. This resulted in the shearwaters accounting for as much as 3–10% of the overall population of this species, with a size of 400–750 pairs [29]. Following the rat eradication intervention, there is no published data indicating a significant increase in the shearwater population. It is desirable that studies be conducted on the impact of brodifacoum dispersion on other islands impacted by similar interventions in order to determine the actual ecological consequences.

Re-naturalization, conservation, and environmental restoration should not be considered exclusively as the cancellation of every type of trace left by man, including the presence of taxa that arrived with him, but instead as a much more complex process [171,172]. It is absolutely essential that a balanced and holistic approach to the conservation of species biodiversity be prioritized, with due consideration of ethical practices, human cultural heritage values, and the well-being and dignity of living organisms. Moreover, extreme solutions and radical concepts should be avoided in conservation initiatives, and instead, a focus on balanced and pragmatic approaches should be emphasized. It is crucial to give precedence to the expansion of environmental awareness and education while simultaneously challenging the legitimacy of existing policies and practices that may not align with the principles of sustainability and ethical conduct [5,109,172,173]. In order to achieve successful outcomes in nature conservation, it is essential to demonstrate a profound dedication to scientific integrity, a comprehensive approach to environmental conservation, and an unwavering respect for the natural world [174].

5. Conclusions

It is important to acknowledge the significant disparity between the "damage" that a species could potentially inflict upon its environment and the damage caused by humans through the release of substances and agents that have an immediate and often irreversible impact on the entire ecosystem.

A new paradox has emerged: chemical substances that are ultimately slated for reduced use, or even prohibition, in agricultural, urban, and industrial contexts (e.g., [175–178]) are, in certain instances, being proposed with increasing intensity in natural areas with a substantial increase in the financial resources allocated to "nature conservation programs" aimed at the eradication of animal or plant species (e.g., [179–182]). This trend requires further review and scrutiny by the international scientific community and regulatory authorities. These observations prompt further inquiry into the extent to which efforts to eradicate or regulate "alien" (anthropogenically introduced) species should be pursued. The question of whether humans should decide which species are "worthy" of existence and which should be destroyed, effectively replacing nature, has been raised (e.g., [174,183,184]). This position is arguably equivalent to a willful ignorance of the importance of evolutionary processes, one of whose prerequisites is the mobility of species (e.g., [185–187]).

In the case we studied, the aerial dispersal of baits containing brodifacoum for the eradication of rats probably caused widespread environmental contamination and considerable mortality among non-target species, including protected species, as predicted by the project's authors. Furthermore, contrary to what one might reasonably expect, no post-mortem examinations were carried out on the animals found dead following the operation, nor were any toxicological analyses conducted on the various components of the ecosystem to determine the extent to which the toxic substance had spread and contaminated the environment and for how long.

As highlighted in our study, a substantial amount of scientific research has been published in recent decades, providing indisputable and persuasive evidence of the risks to public health and the environment associated with the introduction of toxic chemicals such as brodifacoum into ecosystems.

In recent years, several studies have also been published documenting how pesticides released into the environment can quickly reach waterways and the sea through runoff, contaminating not only the soil and food webs but also groundwater, surface water, and the marine environment.

To quantitatively assess the environmental impact of the actions involving the use of biocidal chemical compounds within the Life "Montecristo 2010" project, a scale for evaluating industrial chemical accidents was theoretically implemented for the first time within this context. The assessment was conducted by utilizing the published data available on mortality and the extent of the contaminated territory in the "European Industrial Accident Scale (EIAS)". In this simulation exercise, the application of this scale identifies the event in question as an industrial accident of maximum magnitude six (6).

Implementing solutions grounded in common sense, characterized by sustainability and a reduced impact on the habitat, would be a more ethical and scientifically sound approach than pursuing eradication of select species at any cost. This reasoning restricts possibilities in a binary framework, thereby establishing a false dichotomy. As such, the act of framing an issue as a simplistic good versus bad, native versus alien, or a species to be protected versus a species to be eradicated constitutes a fallacy.

Conservation strategies should take into account the intricate ecological balances and long-term impacts of "nature conservation strategies" on the entire ecosystem. This approach is in contrast to extreme measures, which have been shown to have significant risks and detrimental effects on the environment and biocoenosis. The conservation of species should be significantly enhanced by the preservation of habitats, thereby ensuring the viability of ecosystems without the need for drastic and questionable interventions. Nature and protected areas must be safeguarded from the use of pesticides and the extensive removal of plant or animal species. The strategic acquisition of additional land is essential for the expansion of existing protected areas and the establishment of new ones, such as national parks.

A comprehensive reassessment of the use and availability of brodifacoum and other such biocidal agents is strongly advised. Furthermore, the novel use of probabilistic simulations and the theoretical application of the European Industrial Accident Scale provide valuable tools to quantify the risk of environmental contamination prior to the implementation of an intervention or to determine the degree of contamination in the aftermath. The integration of these assessment tools could yield substantial benefits for the field of nature conservation, as it would be instrumental in preventing damage to delicate ecosystems.

The medical field is guided by the fundamental principle of "primum, non nocere", a philosophy attributed to the ancient Greek physician Hippocrates. This principle of "first, do no harm" underscores the necessity of exercising caution and minimizing unnecessary interventions. All individuals and entities that are engaged in endeavors aimed at ensuring human health and well-being, preserving biodiversity, and protecting the environment through conservation efforts should take this principle into greater consideration.

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References

1. Atti Della Conferenza "La Gestione Del Patrimonio Naturalistico Italiano Degli Ultimi Decenni". Available online: https://www.fnob.it/2023/11/01/atti-della-conferenza-la-gestione-del-patrimonio-naturalistico-italiano-degli-ultimi-decenni/ (accessed on 5 November 2025).

2. Khan, B.A.; Nadeem, M.A.; Nawaz, H.; Amin, M.M.; Abbasi, G.H.; Nadeem, M.; Ali, M.; Ameen, M.; Javaid, M.M.; Maqbool, R.; et al. Pesticides: Impacts on Agriculture Productivity, Environment, and Management Strategies. In *Emerging Contaminants and Plants*; Emerging Contaminants and Associated Treatment Technologies; Springer: Cham, Switzerland, 2023; pp. 109–134. [CrossRef]
3. Citizen, T.E. Ethical Responsibilities in Invasion Biology. Available online: https://ecologicalcitizen.net/article.php?t=ethical-responsibilities-invasion-biology (accessed on 7 May 2026).
4. Haubrock, P.J.; Parker, B.; Błońska, D.; Briski, E.; Everts, T.; Fernandez, R.D.; Kouba, A.; Kourantidou, M.; Kurtul, I.; Mammola, S.; et al. Conceptual and Ethical Considerations in Invasion Science. *BioScience* **2025**, *75*, 317–330. [CrossRef]
5. Pollard, J.C. Towards Ethical and Effective Conservation of New Zealand's Natural Heritage. *Conservation* **2025**, *5*, 47. [CrossRef]
6. Brühl, C.A.; Zaller, J.G. Biodiversity Decline as a Consequence of an Inappropriate Environmental Risk Assessment of Pesticides. *Front. Environ. Sci.* **2019**, *7*, 464007. [CrossRef]
7. Albaseer, S.S.; Jaspers, V.L.B.; Orsini, L.; Vlahos, P.; Al-Hazmi, H.E.; Hollert, H. Beyond the Field: How Pesticide Drift Endangers Biodiversity. *Environ. Pollut.* **2025**, *366*, 125526. [CrossRef]
8. Wan, N.-F.; Fu, L.; Dainese, M.; Kiær, L.P.; Hu, Y.-Q.; Xin, F.; Goulson, D.; Woodcock, B.A.; Vanbergen, A.J.; Spurgeon, D.J.; et al. Pesticides Have Negative Effects on Non-Target Organisms. *Nat. Commun.* **2025**, *16*, 1360. [CrossRef]
9. Kremer, R.J. Disruption of the Soil Microbiota by Agricultural Pesticides. In *Synthetic Pesticide Use in Africa*; CRC Press: Boca Raton, FL, USA, 2021; pp. 147–164. [CrossRef]
10. Sánchez-Bayo, F.; Wyckhuys, K.A.G. Worldwide Decline of the Entomofauna: A Review of Its Drivers. *Biol. Conserv.* **2019**, *232*, 8–27. [CrossRef]
11. Relyea, R.A. The Impact of Insecticides and Herbicides on the Biodiversity and Productivity of Aquatic Communities. *Ecol. Appl.* **2005**, *15*, 618–627. [CrossRef]
12. Beketov, M.A.; Kefford, B.J.; Schäfer, R.B.; Liess, M. Pesticides Reduce Regional Biodiversity of Stream Invertebrates. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 11039–11043. [CrossRef]
13. Ito, H.C.; Shiraishi, H.; Nakagawa, M.; Takamura, N. Combined Impact of Pesticides and Other Environmental Stressors on Animal Diversity in Irrigation Ponds. *PLoS ONE* **2020**, *15*, e0229052. [CrossRef]
14. Isenring, R. *Pesticides and the Loss of Biodiversity—How Intensive Pesticide Use Affects Wildlife Populations and Species Diversity*; Pesticide Action Network Europe: Brussels, Belgium, 2010; pp. 1–28.
15. Geiger, F.; Bengtsson, J.; Berendse, F.; Weisser, W.W.; Emmerson, M.; Morales, M.B.; Ceryngier, P.; Liira, J.; Tscharntke, T.; Winqvist, C.; et al. Persistent Negative Effects of Pesticides on Biodiversity and Biological Control Potential on European Farmland. *Basic Appl. Ecol.* **2010**, *11*, 97–105. [CrossRef]
16. Dudley, N.; Attwood, S.J.; Goulson, D.; Jarvis, D.; Bharucha, Z.P.; Pretty, J. How Should Conservationists Respond to Pesticides as a Driver of Biodiversity Loss in Agroecosystems? *Biol. Conserv.* **2017**, *209*, 449–453. [CrossRef]
17. Delibes-Mateos, M.; Smith, A.T.; Slobodchikoff, C.N.; Swenson, J.E. The Paradox of Keystone Species Persecuted as Pests: A Call for the Conservation of Abundant Small Mammals in Their Native Range. *Biol. Conserv.* **2011**, *144*, 1335–1346. [CrossRef]
18. Jones, H.P.; Holmes, N.D.; Butchart, S.H.; Tershy, B.R.; Kappes, P.J.; Corkery, I.; Aguirre-Muñoz, A.; Armstrong, D.P.; Bonnaud, E.; Burbidge, A.A.; et al. Invasive Mammal Eradication on Islands Results in Substantial Conservation Gains. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 4033–4038. [CrossRef]
19. Duron, Q.; Shiels, A.B.; Vidal, E. Control of Invasive Rats on Islands and Priorities for Future Action. *Conserv. Biol.* **2017**, *31*, 761–771. [CrossRef]
20. Holmes, N.D.; Spatz, D.R.; Oppel, S.; Tershy, B.; Croll, D.A.; Keitt, B.; Genovesi, P.; Burfield, I.J.; Will, D.J.; Bond, A.L.; et al. Globally Important Islands Where Eradicating Invasive Mammals Will Benefit Highly Threatened Vertebrates. *PLoS ONE* **2019**, *14*, e0212128. [CrossRef]
21. Olea, P.P.; Sánchez-Barbudo, I.S.; Viñuela, J.; Barja, I.; Mateo-Tomás, P.; Piñeiro, A.; Mateo, R.; Purroy, F.J. Lack of Scientific Evidence and Precautionary Principle in Massive Release of Rodenticides Threatens Biodiversity: Old Lessons Need New Reflections. *Environ. Conserv.* **2009**, *36*, 1–4. [CrossRef]
22. Whiting-O'Keefe, Q.; Whiting-O'Keefe, P. Aerial Monofluoroacetate in New Zealand's Forests. Available online: https://1080science.co.nz/aerial-monofluoroacetate-in-new-zealands-forests/ (accessed on 8 March 2026).
23. Burlando, M. *Richiesta Di Accesso Agli Atti Ai Sensi e per Gli Effetti Dell'art. 5, c. 2, D. Lgs. n. 33/2013, Disciplinante Il Diritto Di Accesso Generalizzato Ai Dati e Documenti Detenuti Dall'Ente Inerente al Progetto LIFE Montecristo 2010 (LIFE08 NAT/IT/000353)—Nota Del 01.10.2024 Prot. n. 7337*; Parco Nazionale Arcipelago Toscano: Portoferraio, Italy, 2024.
24. Genovesi, P.; Baccetti, N. *Oggetto: Istanza Accesso Civico Generalizzato Ai Sensi Degli Artt. 5 e Seguenti Del Decreto Legislativo 14 Marzo 2013 N° 33 Così Come Modificato Dal Decreto Legislativo 25 Maggio 2016 N° 97, in Relazione a: 'Svolgimento Del Progetto Life Montecristo 2010'*; ISPRA: Rome, Italy, 2024.
25. Montecristo. Available online: https://www.parcoarcipelago.info/montecristo/ (accessed on 13 December 2025).

26. Masseti, M. The Wild Goats *Capra Aegagrus* Erxleben, 1777 of the Mediterranean Sea and the Eastern Atlantic Ocean Islands. *Mammal Rev.* **2009**, *39*, 141–157. [CrossRef]
27. Masseti, M. The Wild Goat, *Capra aegagrus* Erxleben, 1777, of the Island of Montecristo (Northern Tyrrhenian Sea, Italy): Does It Still Exist? *Mammalia* **2016**, *80*, 125–141. [CrossRef]
28. Masseti, M. On the Elusive Origin of the Wild Goat, *Capra aegagrus* Erxleben, 1777, on the Island of Montecristo (Italy). *Biodivers. J.* **2022**, *13*, 651–662. [CrossRef]
29. Sposimo, P.; Baccetti, N.; Raganella Pelliccioni, E.; Guberti, V.; Giannini, F.; Capizzi, D. *Piano per L′eradicazione del ratto nero Rattus rattus Nell′lsola di Montecristo (Arcipelago Toscano)*; Progetto LIFE NAT/IT/000353—Montecristo 2010: Eradicazione di componenti floro-faunistiche aliene invasive e tutela di specie e habitat nell'Arcipelago Toscano; Parco Nazionale Arcipelago Toscano: Portoferraio, Italy, 2011.
30. Bar-Gal, G.K.; Smith, P.; Tchernov, E.; Greenblatt, C.; Ducos, P.; Gardeisen, A.; Horwitz, L.K. Genetic Evidence for the Origin of the Agrimi Goat (*Capra aegagrus cretica*). *J. Zool.* **2002**, *256*, 369–377. [CrossRef]
31. Gotti, C.; Cozzo, M.; De Faveri, A.; Zenatello, M.; Baccetti, N.; Lazzaro, L.; Ferretti, G.; Foggi, B. Il monitoraggio della fauna e della flora a Montecristo. In *Quaderni del Parco, Documenti Tecnici 2, Progetto Life + Montecristo 2010, Eradicazione di Componenti Floro Faunistiche Aliene Invasive e Tutela di Specie e Habitat nell'Arcipelago Toscano*; Parco Nazionale Arcipelago Toscano: Portoferraio, Italy, 2014; pp. 54–69. Available online: https://www.mase.gov.it/portale/documents/d/guest/life_pubblicazione_montecristo2010-pdf (accessed on 10 May 2026).
32. Zarrilli, L.V. Montecristo, Tornano I Guardiani e Si Scopre Com'era L'isola Nell'ottocento. Available online: https://corrierefiorentino.corriere.it/firenze/notizie/cronaca/2014/9-giugno-2014/montecristo-tornano-guardiani-si-scopre-com-era-l-isola-nell-ottocento-223362455302.shtml (accessed on 27 November 2025).
33. Siccardi, E.; Ferretti, G.; Foggi, B.; Mugnai, M.; Bardaro, M.R.; Landi, M.; Quilghini, G.; Zoccola, A.; Lazzaro, L. An updated inventory of the vascular flora of the island of Montecristo (Tuscan Archipelago, Italy). *Ital. Bot.* **2025**, *19*, 87–106. [CrossRef]
34. Paoli, P. Aspetti Fitogeografici Dell'isola Di Montecristo. *Biogeogr. J. Integr. Biogeogr.* **1976**, *5*, 27–54. [CrossRef]
35. Paoli, P.; Romagnoli, G. La Flora Vascolare Dell'isola Di Montecristo (Arcipelago Toscano). *Webbia* **1976**, *30*, 303–456. [CrossRef]
36. Filipello, S.; Sartori, F. La vegetazione dell'Isola di Montecristo (Arcipelago Toscano). *J. Plant Taxon. Geogr.* **1980**, *6*, 113–202.
37. Filipello, S.; Sartori, F.; Tomaselli, R. *Carta Fisionomico-Strutturale Della Vegetazione Dell'Isola di Montecristo*; Istituto di Botanica: Pavia, Italy, 1977.
38. Raganella Pelliccioni, E.; Lazzaro, L.; Gotti, C.; Baccetti, N. Piano Di Gestione E Conservazione Della Capra Di Montecristo: Sintesi Del Contesto E Azioni. Available online: https://www.restoconlife.eu/wp-content/uploads/2015/06/Piano-di-gestione-della-capra-di-Montecristo.pdf (accessed on 27 November 2025).
39. Bruno, S.; Sauli, G. Montescristo. *Nat. Mont.* **1976**, *1*, 7–27.
40. Montecristo 2010: Eradication of Invasive Plant and Animal Aliens and Conservation of Species/Habitats in the Tuscan Archipelago, Italy. Available online: https://webgate.ec.europa.eu/life/publicWebsite/project/LIFE08-NAT-IT-000353/montecristo-2010-eradication-of-invasive-plant-and-animal-aliens-and-conservation-of-species-habitats-in-the-tuscan-archipelagoitaly (accessed on 25 November 2025).
41. Dowding, J.E.; Murphy, E.C.; Veitch, C.R. Brodifacoum residues in target and non-target species following an aerial poisoning operation on Motuihe Island, Hauraki Gulf, New Zealand. *N. Z. J. Ecol.* **1999**, *23*, 207–214. Available online: https://newzealandecology.org/nzje/2076 (accessed on 8 May 2026).
42. Booth, L.H.; Eason, C.T.; Spurr, E.B. Literature review of the acute toxicity and persistence of brodifacoum to invertebrates. *Sci. Conserv.* **2001**, *177*, 1–9. Available online: https://www.doc.govt.nz/documents/science-and-technical/Sfc177.pdf (accessed on 8 May 2026).
43. Eason, C.T.; Murphy, E.C.; Wright, G.R.G.; Spurr, E.B. Assessment of risks of Brodifacoum to Non-target birds and Mammals in New Zealand. *Ecotoxicology* **2002**, *11*, 35–48. [CrossRef]
44. Pitt, W.C.; Berentsen, A.R.; Shiels, A.B.; Volker, S.F.; Eisemann, J.D.; Wegmann, A.S.; Howald, G.R. Non-Target Species Mortality and the Measurement of Brodifacoum Rodenticide Residues after a Rat (*Rattus Rattus*) Eradication on Palmyra Atoll, Tropical Pacific. *Biol. Conserv.* **2015**, *185*, 36–46. [CrossRef]
45. Vagniluca, S.; Quilghini, G.; Giannini, F.; Puppo, F.; Baccetti, N.; Gotti, C.; Raganella Pelliccioni, E. *Montecristo 2010: Eradicazione di Componenti Floro-Faunistiche Aliene Invasive e Tutela di Specie e Habitat Nell'arcipelago Toscano*; LIFE08 NAT/IT/000353, Final Report; Parco Nazionale Arcipelago Toscano: Portoferraio, Italy, 2014; Available online: https://www.lifegoproforgp.eu:9003/goproforlife/best-practice/30/LIFE08_NAT_IT_000353_FTR_IT.pdf (accessed on 10 May 2026).
46. COLKIM S.r.L. Scheda Dati di Sicurezza Brocum Pellet. Revisione n.8. 2018. Available online: https://web.archive.org/web/20240510123559/https://www.colkim.it/site/wp-content/uploads/2018/02/SDS-BROCUM-PELLET.pdf (accessed on 21 July 2023).
47. State of California—Natural Resources Agency. CD-0006-21 (USFWS) Th11b. San Francisco, CA. Available online: https://documents.coastal.ca.gov/reports/2021/12/Th11b/Th11b-12-2021-appendices.pdf (accessed on 7 May 2026).

48. Life 3.0—Life Project Public Page. Available online: https://webgate.ec.europa.eu/life/publicWebsite/project/LIFE12-NAT-IT-000416/protection-of-the-largest-population-of-puffinus-yelkouan-on-earth-and-containment-and-eradication-of-invasive-alien-species (accessed on 7 May 2026).
49. Giannini, F.; Sposimo, P.; Baccetti, N.; Vagniluca, S.; Quilghini, S.; Gotti, C.; Zanichelli, F.; Puppo, F. *'Montecristo 2010'—After Life Conservation Plan*; LIFE08 NAT/IT/000353; Parco Nazionale Arcipelago Toscano: Portoferraio, Italy, 2014; Available online: https://webgate.ec.europa.eu/life/publicWebsite/project/LIFE08-NAT-IT-000353/montecristo-2010-eradication-of-invasive-plant-and-animal-aliens-and-conservation-of-species-habitats-in-the-tuscan-archipelagoitaly# (accessed on 20 November 2025).
50. Repertorio Della Fauna Italiana Protetta. Available online: https://www.mase.gov.it/portale/repertorio-della-fauna-italiana-protetta (accessed on 1 December 2025).
51. Ministero Della Salute. Ordinanza 14 Gennaio 2010, Proroga e Modifica Dell'ordinanza 18 Dicembre 2008, Come Modificata Dall'ordinanza 19 Marzo 2009, Recante: «Norme sul Divieto di Utilizzo e di Detenzione di Esche o di Bocconi Avvelenati». (10A01779) (GU Serie Generale n.33 del 10 February 2010). Available online: https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2010-02-10&atto.codiceRedazionale=10A01779&elenco30giorni=false (accessed on 20 November 2025).
52. Atto Camera, Interrogazione a Risposta Scritta n. 4/14926 Presentata da Barani Lucio in data 15 Febbraio 2012, 16th Legislature. Available online: http://dati.camera.it/ocd/aic.rdf/aic4_14926_16 (accessed on 20 November 2025).
53. Senato della Repubblica, Legislatura 18 Atto di Sindacato Ispettivo n° 3-03062 (in Commissione), Pubblicato l'8 Febbraio 2022, Nella Seduta n. 400. Available online: https://www.senato.it/printable/route/sen_showdoc.show_doc_controller_structure?tipodoc=Sindisp&leg=18&id=1331963&printable_format=print&legislature=19 (accessed on 29 November 2025).
54. Regione Toscana, Interrogazione con Richiesta di Risposta Scritta Consiglio Regionale Della Toscana, Protocollo n. 0000773 del 23 January 2024, Fascicolo: LEX11_IS_1460. Available online: https://iterlegis.consiglio.regione.toscana.it/#/atto/65afd49ad56f2677d6bec0e9/ (accessed on 29 November 2025).
55. Fico, R. *Verifica Corretta Applicazione dell'Ordinanza Ministeriale del 18 Dicembre 2008 e Ssmm in Relazione al Progetto Life + "Montecristo 2010"*; Rif. Vs. Nota del 2 February 2012 prot. n. 0001985-P-02/02/2012; Centro di Referenza Nazionale per la Medicina Forense Veterinaria: Grosseto, Italy, 2012.
56. National Center for Biotechnology Information. PubChem Compound Summary for CID 54680676, Brodifacoum. Available online: https://pubchem.ncbi.nlm.nih.gov/compound/Brodifacoum (accessed on 15 November 2025).
57. Ipcs International Programme On Chemical Safety, Brodifacoum (HSG 93, 1995). Available online: https://www.inchem.org/documents/hsg/hsg/hsg093.htm (accessed on 7 November 2025).
58. European Union. Document 32011R0253, Commission Regulation (EU) No 253/2011 of 15 March 2011 Amending Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) as Regards Annex XIII Text with EEA Relevance. Available online: https://eur-lex.europa.eu/eli/reg/2011/253/oj/eng (accessed on 29 November 2025).
59. Feinstein, D.L.; Brodsky, S.; Weinberg, G.; van Breeman, R.; Rubinstein, I. Brodifacoum Poisoning: A Clear and Present Danger to Public Health in the USA. *Toxicol. Lett.* **2017**, *268*, 71–72. [CrossRef]
60. Gutierrez, I.; Loarie, G.C. Proposed Regulations Designating Brodifacoum, Bromadiolone, Difenacoum, and Difethialone as Restricted Materials—DPR Regulation No. 13-0002. 2013. Available online: https://abcbirds.org/wp-content/uploads/2015/05/Rodenticides_CA_Technical_Comments_on_Proposed_Restricted_Use_Regs_4_Oct_20131.pdf (accessed on 28 January 2026).
61. Rahmy, T.R. Myocardial alterations in animal intoxicated with anticoagulant rodenticide. *J. Egypt. Ger. Soc. Zool.* **1993**, *12*, 87–98.
62. Elliott, J.E.; Hindmarch, S.; Albert, C.A.; Emery, J.; Mineau, P.; Maisonneuve, F. Exposure pathways of anticoagulant rodenticides to Nontarget Wildlife. *Environ. Monit. Assess.* **2013**, *186*, 895–906. [CrossRef]
63. Cooke, R.; Whiteley, P.; Death, C.; Weston, M.A.; Carter, N.; Scammell, K.; Yokochi, K.; Nguyen, H.; White, J.G. Silent Killers? The Widespread Exposure of Predatory Nocturnal Birds to Anticoagulant Rodenticides. *Sci. Total Environ.* **2023**, *904*, 166293. [CrossRef]
64. Maron, D.F. Rat Poison's Long Reach. *Science* **2024**, *385*, 134–137. [CrossRef]
65. Martín Cruz, B.; Acosta Dacal, A.; Macías-Montes, A.; Rial-Berriel, C.; Zumbado, M.; Henríquez-Hernández, L.A.; Gallo-Barneto, R.; Cabrera-Pérez, M.Á.; Luzardo, O.P. Widespread Contamination by Anticoagulant Rodenticides in Insectivorous Wildlife from the Canary Islands: Exploring Alternative Routes of Exposure. *Toxics* **2025**, *13*, 505. [CrossRef]
66. Spiller, H.A. Brodifacoum. In *Encyclopedia of Toxicology*, 3rd ed.; Elsevier: Amsterdam, The Netherlands, 2014; pp. 543–545. [CrossRef]
67. Kopanke, J.H.; Horak, K.E.; Musselman, E.; Miller, C.A.; Bennett, K.; Olver, C.S.; Volker, S.F.; VandeWoude, S.; Bevins, S.N. Effects of Low-Level Brodifacoum Exposure on the Feline Immune Response. *Sci. Rep.* **2018**, *8*, 8168. [CrossRef]

68. Irokawa Otani, L. Proposed Regulation Designating Brodifacoum, Bromadiolone, Difenacoum and Difethialone as restricted materials-DPR Regulation No 13-0002. 2013. Available online: http://saferodentcontrol.org/site/wp-content/uploads/2013/11/LaurelSerieys_UCLA_PublicCommentLetter.pdf (accessed on 4 August 2023).
69. Serieys, L.E.; Foley, J.; Owens, S.; Woods, L.; Boydston, E.E.; Lyren, L.M.; Poppenga, R.H.; Clifford, D.L.; Stephenson, N.; Rudd, J.; et al. Serum Chemistry, Hematologic, and Post-Mortem Findings in Free-Ranging Bobcats (*Lynx rufus*) with Notoedric Mange. *J. Parasitol.* **2013**,
mboxemph99, 989–996. [CrossRef]
70. Serieys, L.E.; Armenta, T.C.; Moriarty, J.G.; Boydston, E.E.; Lyren, L.M.; Poppenga, R.H.; Crooks, K.R.; Wayne, R.K.; Riley, S.P. Anticoagulant Rodenticides in Urban Bobcats: Exposure, Risk Factors and Potential Effects Based on a 16-Year Study. *Ecotoxicology* **2015**, *24*, 844–862. [CrossRef]
71. Musto, C.; Cerri, J.; Capizzi, D.; Fontana, M.C.; Rubini, S.; Merialdi, G.; Berzi, D.; Ciuti, F.; Santi, A.; Rossi, A.; et al. First Evidence of Widespread Positivity to Anticoagulant Rodenticides in Grey Wolves (*Canis Lupus*). *Sci. Total Environ.* **2024**, *915*, 169990. [CrossRef]
72. Rocchi, R.; Castellani, F.; Salini, R.; Salucci, S.; Tieri, E.E.; Scortichini, G.; Tora, S.; Coccaro, A.; Cocco, A.; Colombo, M.; et al. One Health Approach and Tiered Strategy to Assess Anticoagulant Rodenticides Exposure in Red Foxes (*Vulpes vulpes*) from Central Italy. *Environ. Pollut.* **2025**, *376*, 126403. [CrossRef]
73. Carromeu-Santos, A.; Martín-Cruz, B.; Neves, T.; Acosta-Dacal, A.; Macías-Montes, A.; Casero, M.; da Mathias, M.; Luzardo, O.P.; Gabriel, S.I. Toxic Legacy: The Hidden Impact of Anticoagulant Rodenticides on Portuguese Raptors. *Sci. Total Environ.* **2025**, *1002*, 180547. [CrossRef]
74. Hernández, M.; Margalida, A. Poison-Related Mortality Effects in the Endangered Egyptian Vulture (Neophron Percnopterus) Population in Spain. *Eur. J. Wildl. Res.* **2009**, *55*, 415–423. [CrossRef]
75. Oliva-Vidal, P.; Martínez, J.M.; Sánchez-Barbudo, I.S.; Camarero, P.R.; Colomer, M.À.; Margalida, A.; Mateo, R. Second-Generation Anticoagulant Rodenticides in the Blood of Obligate and Facultative European Avian Scavengers. *Environ. Pollut.* **2022**, *315*, 120385. [CrossRef]
76. Regnery, J.; Schmieg, H.; Schrader, H.; Zinke, O.; Gethöffer, F.; Dahl, S.-A.; Schaffer, M.; Bachtin, J.; Möhlenkamp, C.; Friesen, A. Rodenticide Contamination of Cormorants and Mergansers Feeding on Wild Fish. *Environ. Chem. Lett.* **2024**, *22*, 2611–2617. [CrossRef]
77. Mercer, M.A.; Davis, J.L.; Riviere, J.E.; Baynes, R.E.; Tell, L.A.; Jaberi-Douraki, M.; Maunsell, F.P.; Lin, Z. Mechanisms of Toxicity and Residue Considerations of Rodenticide Exposure in Food Animals—A Farad Perspective. *J. Am. Vet. Med. Assoc.* **2022**, *260*, 514–523. [CrossRef]
78. Donlan, C.J.; Howald, G.R.; Tershy, B.R.; Croll, D.A. Evaluating Alternative Rodenticides for Island Conservation: Roof Rat Eradication from the San Jorge Islands, Mexico. *Biol. Conserv.* **2003**, *114*, 29–34. [CrossRef]
79. Pascotto, E.; Maset, M.; Tome, P. Aspetti tossicologici ed epidemiologici dell'avvelenamento da rodenticidi negli strigiformi e possibili risvolti gestionali. In *Proceedings of the 6th Venetian Faunists Conference*; Bon, M., Mezzavilla, F., Scarton, F., Eds.; Museo di Storia Naturale di Venezia: Venice, Italy, 2011; Volum 61, pp. 214–225.
80. Fisher, P.M. Residual Concentrations and Persistence of the Anticoagulant Rodenticides Brodifacoum and Diphacinone in Fauna. Ph.D. Thesis, Lincoln University, Philadelphia, PA, USA, 2009. Available online: https://researcharchive.lincoln.ac.nz/server/api/core/bitstreams/54b5d911-84c8-4ba7-a6df-c037a39a63b6/content (accessed on 28 January 2026).
81. Dowding, J.E.; Lovegrove, T.G.; Ritchie, J.; Kast, S.N.; Puckett, M. Mortality of northern New Zealand dotterels (*Charadrius obscurus aquilonius*) following an aerial poisoning operation. *Notornis* **2006**, *53*, 235–239. Available online: https://www.birdsnz.org.nz/wp-content/uploads/2021/12/Notornis_53_2_235.pdf (accessed on 9 May 2026). [CrossRef]
82. Fisher, P.M. Environmental monitoring for Brodifacoum residues after aerial application of baits for rodents' eradication. In *Islands Invasives: Eradication and Management*; Veitch, C.R., Clout, M.N., Towns, D.R., Eds.; IUCN: Gland, Switzerland, 2011; pp. 300–304.
83. Stone, W.B.; Okoniewski, J.C.; Stedelin, J.R. Poisoning of Wildlife with Anticoagulant Rodenticides in New York. *J. Wildl. Dis.* **1999**, *35*, 187–193. [CrossRef]
84. Howald, G.; Donlan, C.J.; Faulkner, K.R.; Ortega, S.; Gellerman, H.; Croll, D.A.; Tershy, B.R. Eradication of Black Rats *Rattus Rattus* from Anacapa Island. *Oryx* **2009**, *44*, 30–40. [CrossRef]
85. Howald, G.; Donlan, C.J.; Galván, J.P.; Russell, J.C.; Parkes, J.; Samaniego, A.; Wang, Y.; Veitch, D.; Genovesi, P.; Pascal, M.; et al. Invasive Rodent Eradication on Islands. *Conserv. Biol.* **2007**, *21*, 1258–1268. [CrossRef]
86. Hoare, J.M.; Hare, K.M. The impact of brodifacoum on non-target wildlife: Gaps in knowledge. *N. Z. J. Ecol.* **2006**, *30*, 157–167. Available online: https://newzealandecology.org/nzje/2312 (accessed on 9 May 2026).
87. Fisher, P.M. *Environmental Fate and Residual Persistence of Brodifacoum in Wildlife*; Envirolink 884-HBRC131; Landcare Research: Auckland, New Zealand, 2010. Available online: http://envirolink.govt.nz/assets/Envirolink/884-HBRC131-Environmental-fate-of-brodifacoum-in-wildlife.pdf (accessed on 28 January 2026).

88. Harper, G.A.; Zabala-Albizua, J.; Carrion, V. Monitoring of population of Galàpagos land iguanas (*Conolophus subcristatus*) during rat eradication using Brodifacoum. In *Islands Invasives: Eradication and Management*; Veitch, C.R., Clout, M.N., Towns, D.R., Eds.; IUCN: Gland, Switzerland, 2011; pp. 309–312. Available online: http://library.iucn-isg.org/documents/2011/Harper_2011.pdf (accessed on 9 May 2026).
89. Nakayama, S.M.M.; Morita, A.; Ikenaka, Y.; Mizukawa, H.; Ishizuka, M. A Review: Poisoning by Anticoagulant Rodenticides in Non-Target Animals Globally. *J. Vet. Med. Sci.* **2019**, *81*, 298–313. [CrossRef]
90. Progetto LIFE + Montecristo 2010. Available online: https://www.youtube.com/watch?v=ARi74dJCbh8 (accessed on 8 December 2025).
91. Capizzi, D.; Baccetti, N.; Sposimo, P. Fifteen Years of Rat Eradication on Italian Islands. In *Problematic Wildlife*; Springer: Berlin/Heidelberg, Germany, 2016; pp. 205–227. [CrossRef]
92. Way, L.; Baker, H.; Best, J. *Determining Which Chemicals May Have Significant Impacts on Biodiversity*; Joint Nature Conservation Committee: Peterborough, UK, 2007; Volume 7, pp. 2–6. Available online: https://web.archive.org/web/20101013201830/http://www.jncc.gov.uk/pdf/COMM_07N08.pdf (accessed on 28 January 2026).
93. Eason, C.T.; Wright, G.R.; Batcheler, D. Anticoagulant effects and the persistence of Brodifacoum in possums (Trichosurus vulpecula). *N. Z. J. Agric. Res.* **1996**, *39*, 397–400. [CrossRef]
94. Crowell, M.D.; Broome, K.G.; Eason, C.T.; Fairweather, A.A.C.; Ogilvie, S.; Murphy, E.C. *How Long Do Vertebrate Pesticides Persist in Living Mammals? Priorities for Research*; DOC Research and Development Series 337; Department of Conservation: Wellington, New Zealand, 2013; 18p. Available online: https://www.doc.govt.nz/globalassets/documents/science-and-technical/drds337entire.pdf (accessed on 28 January 2026).
95. Howald, G.R.; Faulkner, K.R.; Tershy, B.; Keit, B.; Gellerman, H.; Creel, E.M.; Grinnell, M.; Ortega, S.T.; Croll, D.A. Eradication of black rat from Anacapa Island: Biological and social considerations. *Oryx* **2005**, *44*, 30–40. Available online: https://www.californiaislands.org/s/howald_etal_2009.pdf (accessed on 9 May 2026).
96. U.S. Fish & Wildlife Service. Midway Seabird Protection Project, Draft Environmental Assessment, Sand Island, Midway Atoll, Papahanaumokuakea Marine National Monument, issued March 2018. Available online: https://www.govinfo.gov/content/pkg/GOVPUB-I49-PURL-gpo92843/pdf/GOVPUB-I49-PURL-gpo92843.pdf (accessed on 7 May 2026).
97. Empson, R.A.; Miskelly, C.M. The risks, costs and benefits of using brodifacoum to eradicate rats from Kapiti Island, New Zealand. *N. Z. J. Ecol.* **1999**, *23*, 241–254.
98. Government of Canada, C.C. for O. H. and S. What Is a LD_{50} and LC_{50}? Available online: https://www.ccohs.ca/oshanswers/chemicals/ld50.html (accessed on 26 April 2026).
99. Schmieg, H.; Ferling, H.; Bucher, K.A.; Jacob, S.; Regnery, J.; Schrader, H.; Schwaiger, J.; Friesen, A. Brodifacoum Causes Coagulopathy, Hemorrhages, and Mortality in Rainbow Trout (*Oncorhynchus mykiss*) at Environmentally Relevant Hepatic Residue Concentrations. *Ecotoxicol. Environ. Saf.* **2025**, *289*, 117629. [CrossRef]
100. Barkman, A.L.; Richmond, R.H. The Effects of Brodifacoum Cereal Bait Pellets on Early Life Stages of the Rice Coral *Montipora Capitata*. *PeerJ* **2022**, *10*, e13877. [CrossRef]
101. Sánchez-Bayo, F. Comparative Acute Toxicity of Organic Pollutants and Reference Values for Crustaceans. I. Branchiopoda, Copepoda and Ostracoda. *Environ. Pollut.* **2006**, *139*, 385–420. [CrossRef]
102. Levinton, J.S. Plankton. In *Marine Biology*; Oxford University: New York, NY, USA, 2021. [CrossRef]
103. Human Health and Ecological Risk Assessment for the Use of Wildlife Damage Management Methods by APHIS-Wildlife Services. 2025. Available online: https://www.aphis.usda.gov/sites/default/files/28-nonchemical-deterrent.pdf (accessed on 28 January 2026).
104. Griffiths, R.; Miller, A.; Climo, G. Addressing the Impact of Land Crabs on Rodent Eradications on Islands. *Pac. Conserv. Biol.* **2011**, *17*, 347–353. [CrossRef]
105. Samaniego-Herrera, A.; Boudjelas, S.; Harper, G.A.; Russell, J.C. Assessing the Critical Role That Land Crabs Play in Tropical Island Rodent Eradications and Ecological Restoration. In *Island Invasives: Scaling Up to Meet the Challenge*; Veitch, C.R., Clout, M.N., Martin, A.R., Russell, J.C., West, C.J., Eds.; Occasional Paper SSC no. 62; IUCN: Gland, Switzerland, 2019; pp. 209–222. Available online: https://portals.iucn.org/library/sites/library/files/documents/SSC-OP-062-En.pdf (accessed on 8 May 2026).
106. Samaniego, A.; Kappes, P.; Broome, K.; Cranwell, S.; Griffiths, R.; Harper, G.; McClelland, P.; Palmer, R.; Rocamora, G.; Springer, K.; et al. Factors Leading to Successful Island Rodent Eradications Following Initial Failure. *Conserv. Sci. Pract.* **2021**, *3*, e404. [CrossRef]
107. Regnery, J.; Friesen, A.; Geduhn, A.; Göckener, B.; Kotthoff, M.; Parrhysius, P.; Petersohn, E.; Reifferscheid, G.; Schmolz, E.; Schulz, R.S.; et al. Rating the Risks of Anticoagulant Rodenticides in the Aquatic Environment: A Review. *Environ. Chem. Lett.* **2018**, *17*, 215–240. [CrossRef]

108. Regnery, J.; Schulz, R.S.; Parrhysius, P.; Bachtin, J.; Brinke, M.; Schäfer, S.; Reifferscheid, G.; Friesen, A. Heavy Rainfall Provokes Anticoagulant Rodenticides' Release from Baited Sewer Systems and Outdoor Surfaces into Receiving Streams. *Sci. Total Environ.* **2020**, *740*, 139905. [CrossRef]
109. Boesch, R. Challenges and Perspectives in Proving Harm of Anticoagulants to Marine Predators and Scavengers. *Conservation* **2024**, *4*, 762–777. [CrossRef]
110. Siers, S.; Shiels, A.; Goldade, D.; Volker, S.; Mcauliffe, T.; Coad, H.; Pitt, W. *Wake Atoll Fish Tissue Sampling and Analysis Three Years After an Island Wide Rodenticide Application*; Report QA 2241, USDA, APHIS, WS; National Wildlife Research Center: Hilo, HI, USA, 2016.
111. Siers, S.; Shiels, A.; Volker, S.; Rex, K. Brodifacoum Residues in Fish Three Years after an Island-Wide Rat Eradication Attempt in the Tropical Pacific. *Manag. Biol. Invasions* **2020**, *11*, 105–121. [CrossRef]
112. Primus, T.; Wright, G.; Fisher, P. Accidental Discharge of Brodifacoum Baits in a Tidal Marine Environment: A Case Study. *Bull. Environ. Contam. Toxicol.* **2005**, *74*, 913–919. [CrossRef]
113. Regnery, J.; Parrhysius, P.; Schulz, R.S.; Möhlenkamp, C.; Buchmeier, G.; Reifferscheid, G.; Brinke, M. Wastewater-Borne Exposure of Limnic Fish to Anticoagulant Rodenticides. *Water Res.* **2019**, *167*, 115090. [CrossRef]
114. Regnery, J.; Snelinski, B.; Bachtin, J.; Möhlenkamp, C.; Schmolz, E.; Friesen, A. Indirect Contamination of Cockroaches by Anticoagulant Rodenticides. *Environ. Chem. Lett.* **2025**, *23*, 759–764. [CrossRef]
115. Streit, B. Bioaccumulation of Contaminants in Fish. In *Fish Ecotoxicology*; Birkhäuser: Basel, Switzerland, 1998; pp. 353–387. [CrossRef]
116. Caliani, I.; Di Noi, A.; Amico, C.; Berni, R.; Romi, M.; Cai, G.; Guarnieri, M.; Navone, A.; Spano, G.; Howald, G.R.; et al. Brodifacoum levels and biomarkers in coastal fish species following a rodent eradication in an Italian marine protected area: Preliminary results. *Life* **2023**, *13*, 415. [CrossRef]
117. Wegmann, A.; Flint, E.; White, S.; Fox, M.; Howald, G.; McClelland, P.; Alifano, A.; Griffiths, R. Pushing the Envelope in Paradise: A Novel Approach to Rat Eradication at Palmyra Atoll. In *Proceedings of the Vertebrate Pest Conference*; University of California: Oakland, CA, USA, 2012; Volume 25. [CrossRef]
118. USFWS. *Palmyra Atoll National Wildlife Refuge Rat Eradication Project Final Environmental Impact Statement*; The U.S. Fish and Wildlife Service: Portland, OR, USA, 2011; 210p. Available online: https://www.fws.gov/sites/default/files/documents/FINAL%20-PalmyraRatEradicationFEIS-complete.pdf (accessed on 10 May 2026).
119. Kotthoff, M.; Rüdel, H.; Jürling, H.; Severin, K.; Hennecke, S.; Friesen, A.; Koschorreck, J. First Evidence of Anticoagulant Rodenticides in Fish and Suspended Particulate Matter: Spatial and Temporal Distribution in German Freshwater Aquatic Systems. *Environ. Sci. Pollut. Res.* **2018**, *26*, 7315–7325. [CrossRef]
120. Navas, I.; Felipo-Benavent, M.; Crespo-Picazo, J.L.; García-Párraga, D.; Martínez-Romero, A.; García-García, F.; O'Connor, J.-E.; Rubio-Guerri, C.; García-Fernández, A.J. Exposure to Pharmaceutical Contaminants in Stranded Wild Dolphins of the Western Mediterranean. *Sci. Total Environ.* **2026**, *1048*, 182064. [CrossRef]
121. Casalone, C.; Mazzariol, S.; Pautasso, A.; Di Guardo, G.; Di Nocera, F.; Lucifora, G.; Ligios, C.; Franco, A.; Fichi, G.; Cocumelli, C.; et al. Cetacean Strandings in Italy: An Unusual Mortality Event along the Tyrrhenian Sea Coast in 2013. *Dis. Aquat. Org.* **2014**, *109*, 81–86. [CrossRef]
122. Database of Monitoring of Cetacean Strandings of Italian Coast. Available online: http://mammiferimarini.unipv.it/ (accessed on 23 December 2024).
123. Renzi, M. (BIO/07) Ecotossicologia. Available online: https://moodle2.units.it/pluginfile.php/366793/modresource/content/0/4_Saggimonospecifici35slcompressed.pdf (accessed on 3 August 2023).
124. Munday, J.S.; Thompson, L.J. Brodifacoum Toxicosis in Two Neonatal Puppies. *Vet. Pathol.* **2003**, *40*, 216–219. [CrossRef]
125. Riley, S.P.; Bromley, C.; Poppenga, R.H.; Uzal, F.A.; Whited, L.; Sauvajot, R.M. Anticoagulant Exposure and Notoedric Mange in Bobcats and Mountain Lions in Urban Southern California. *J. Wildl. Manag.* **2007**, *71*, 1874–1884. [CrossRef]
126. Fraser, D.; Mouton, A.; Serieys, L.E.; Cole, S.; Carver, S.; Vandewoude, S.; Lappin, M.; Riley, S.P.D.; Wayne, R. Genome-wide Expression Reveals Multiple Systemic Effects Associated with Detection of Anticoagulant Poisons in Bobcats (*Lynx rufus*). *Mol. Ecol.* **2018**, *27*, 1170–1187. [CrossRef]
127. Aztec Rock—Caduta Massi. Available online: https://www.aztec.it/aztec-rock-caduta-massi/ (accessed on 30 November 2025).
128. Available online: https://www502.regione.toscana.it/geoscopio/cartoteca.html (accessed on 7 November 2025).
129. Shekhar, S.; Xiong, H.; Zhou, X. (Eds.) Delaunay Triangulation. In *Encyclopedia of GIS*; Springer: Cham, Switzerland, 2017; p. 469. [CrossRef]
130. Available online: https://helios2.mi.parisdescartes.fr/ lomn/Cours/CV/BME/3D/Articles/Engineering/Delaunay.pdf (accessed on 30 November 2025).
131. Rubinstein, R.Y. *Simulation and the Monte Carlo Method*; Wiley Series in Probability and Statistics; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 1981. [CrossRef]
132. Shreider, Y.A. *Method of Statistical Testing: Monte Carlo Method*; Elsevier: Amsterdam, The Netherlands, 1964.

133. James, F. Monte Carlo Theory and Practice. *Rep. Prog. Phys.* **1980**, *43*, 9. [CrossRef]
134. Lyons, L. *Statistics for Nuclear and Particle Physicists Louis Lyons*; Cambridge University Press: Cambridge, UK, 2010.
135. Available online: https://www502.regione.toscana.it/geoscopio/download/tematici/ucs_rt/index.html?catIdx=0/6&layIdx=0&tolobbox=602342.47741063:611528.54859895:4684988.4791636:4690532.5332698&tolosrid=EPSG:25832&tolozoom=32236.712885463454&tololayerserver=https://www502.regione.toscana.it:443/wmsraster/com.rt.wms.RTmap/wms?map=wmssfondo&version=1.1.1&map_mnt=cartoteca&tololayername=a (accessed on 1 December 2025).
136. Gallego, E.; Fuentes, J.M.; Ruiz, Á.; Hernández-Rodrigo, G.; Aguado, P.; Ayuga, F. Determination of Mechanical Properties for Wood Pellets Used in Dem Simulations. *Int. Agrophysics* **2020**, *34*, 485–494. [CrossRef]
137. Il Meteo in Toscana: Consorzio Lamma. Available online: https://www.lamma.toscana.it/ (accessed on 1 December 2025).
138. Sposimo, P.; Capizzi, D.; Cencetti, T.; De Pietro, F.; Giannini, F.; Gotti, C.; Puppo, F.; Quilghini, G.; Raganella Pelliccioni, E.; Sammuri, G.; et al. Rat and lagomorph eradication on two large islands of central Mediterranean: Differences in island morphology and consequences on methods, problems and targets. In *Island Invasives: Scaling up to Meet the Challenge*; Veitch, C.R., Clout, M.N., Martin, A.R., Russell, J.C., West, C.J., Eds.; Occasional Paper SSC no. 62; IUCN: Gland, Switzerland, 2019; pp. 231–235. Available online: https://portals.iucn.org/library/sites/library/files/documents/SSC-OP-062-En.pdf (accessed on 8 May 2026).
139. Gotti, C.; Capizzi, D.; Petrassi, F.; Sposimo, P.; dell'Agnello, F.; Baccetti, N.; Raganella Pelliccioni, E. L' eradicazione del Ratto nero (*Rattus rattus*) dalle isole del Mediterraneo: Linee guida, buone pratiche, casi di studio. Ispra, Manuali e Linee Guida n. 199/2022. 2022. Available online: https://www.isprambiente.gov.it/it/pubblicazioni/manuali-e-linee-guida/l-eradicazione-del-ratto-nero-rattus-rattus-dalle-isole-del-mediterraneo-linee-guida-buone-pratiche-casi-di-studio (accessed on 28 January 2026).
140. Disastro Ambientale: Definizione E Situazione in Italia. Available online: https://mesotelioma-pleurico.it/disastro-ambientale/ (accessed on 22 February 2026).
141. Meharg, A.A. Ecological Impact of Major Industrial Chemical Accidents. In *Reviews of Environmental Contamination and Toxicology*; Springer: New York, NY, USA, 1994; pp. 21–48. [CrossRef]
142. Cianfaglione, K.; Bănăduc, D.; Bottacci, A.; Rîșnoveanu, G. *Natural and Anthropogenic Stressors in Aquatic Ecosystems*; Reference Module in Earth Systems and Environmental Sciences; Elsevier: Amsterdam, The Netherlands, 2025. [CrossRef]
143. Carpio-Domínguez, J.L. The Harms and Crimes of Logging and Deforestation. In *Oxford Research Encyclopedia of Criminology and Criminal Justice*; Oxford Academic: New York, NY, USA, 2024. [CrossRef]
144. Samosir, A.G.; Sutisna, S.; Prakoso, L.Y. Literature Study: Review of the Negative Impacts of Mining Activities in Various Countries on the Environment, Society, and Local Economies, and Mitigation Strategies. *Gold. Ratio Data Summ.* **2025**, *5*, 87–101. [CrossRef]
145. Omokaro, G.O. Oil Extraction and the Environment in Nigeria's Niger Delta: A Political-Industrial Ecology (PIE) Perspective. *Asian J. Adv. Res. Rep.* **2024**, *18*, 161–169. [CrossRef]
146. Kotsis, K.T. The Impact of War on the Environment. *Eur. J. Ecol. Biol. Agric.* **2024**, *1*, 89–100. [CrossRef]
147. Seveso: La Storia. Available online: https://www.arpa.piemonte.it/scheda-informativa/seveso-storia (accessed on 22 February 2026).
148. Seveso. *Lancet* **1976**, *308*, 297. [CrossRef]
149. Available online: https://minerva.jrc.ec.europa.eu/EN/content/minerva/4c84b75d-5479-4444-b025-e9b21b7341d9/seveso_ii_general_presentation_and_explanation_of_requirements (accessed on 1 December 2025).
150. Hakkinen, P.J. Seveso Disaster, and the Seveso and Seveso II Directives. In *Encyclopedia of Toxicology*; Elsevier: Amsterdam, The Netherlands, 2005; pp. 1–4. [CrossRef]
151. Nerin, C.; Seco, B.; Tena, A.; Calvo, M. The Seveso Disaster and the European Seveso Directives. In *Encyclopedia of Toxicology*; Elsevier: Amsterdam, The Netherlands, 2024; pp. 477–481. [CrossRef]
152. Available online: https://eur-lex.europa.eu/legal-content/IT/TXT/?uri=celex%3A31996L0082 (accessed on 22 February 2026).
153. European Scale of Industrial Accidents. Available online: https://www.aria.developpement-durable.gouv.fr/in-case-of-accident/european-scale-of-industrial-accidents/?lang=en (accessed on 7 November 2025).
154. Ruffino, L.; Bourgeois, K.; Vidal, E.; Icard, J.; Torre, F.; Legrand, J. Introduced Predators and Cavity-Nesting Seabirds: Unexpected Low Level of Interaction at Breeding Sites. *Can. J. Zool.* **2008**, *86*, 1068–1073. [CrossRef]
155. Baccetti, N.; Capizzi, D.; Corbi, F.; Massa, B.; Nissardi, S.; Spano, G.; Sposimo, P. Breeding shearwaters on italian islands: Population size, island selection and co-existence with their main alien predator, the black rat. *Riv. Ital. Ornitol.* **2009**, *78*, 83–100.
156. Ruffino, L.; Bourgeois, K.; Vidal, E.; Duhem, C.; Paracuellos, M.; Escribano, F.; Sposimo, P.; Baccetti, N.; Pascal, M.; Oro, D. Invasive Rats and Seabirds after 2,000 Years of an Unwanted Coexistence on Mediterranean Islands. *Biol. Invasions* **2009**, *11*, 1631–1651. [CrossRef]
157. Martin, J.; Thibault, J.; Bretagnolle, V. Black Rats, Island Characteristics, and Colonial Nesting Birds in the Mediterranean: Consequences of an Ancient Introduction. *Conserv. Biol.* **2000**, *14*, 1452–1466. [CrossRef]

158. Masseti, M. Current knowledge on the early occurrence of the black rat, *Rattus rattus* L., 1758 (Muridae, Rodentia), on the Italian mainland and islands. In: Atti del I Convegno Nazionale di Archeozoologia. *Quad. Padusa* **1995**, *1*, 348–358. Available online: https://www.aiaz.it/wp-content/uploads/2023/12/1_Convegno_Nazionale_di_Archeozoologia_R.pdf (accessed on 28 January 2026).
159. Towns, D.R.; Atkinson, I.A.; Daugherty, C.H. Have the Harmful Effects of Introduced Rats on Islands Been Exaggerated? *Biol. Invasions* **2006**, *8*, 863–891. [CrossRef]
160. Philippe-Lesaffre, M.; Thibault, M.; Caut, S.; Bourgeois, K.; Berr, T.; Ravache, A.; Vidal, E.; Courchamp, F.; Bonnaud, E. Recovery of Insular Seabird Populations Years after Rodent Eradication. *Conserv. Biol.* **2023**, *37*, e14042. [CrossRef]
161. DIISE. The Database of Island Invasive Species Eradications, Developed by Island Conservation, Coastal Conservation Action Laboratory UCSC, IUCN SSC Invasive Species Specialist Group, University of Auckland and Landcare Research New Zealand. 2019. Available online: http://diise.islandconservation.org (accessed on 6 November 2024).
162. Gallozzi, F.; Attili, L.; Colangelo, P.; Giuliani, D.; Capizzi, D.; Sposimo, P.; Dell'Agnello, F.; Lorenzini, R.; Solano, E.; Castiglia, R. A Survey of VKORC1 Missense Mutations in Eleven Italian Islands Reveals Widespread Rodenticide Resistance in House Mice. *Sci. Total Environ.* **2024**, *953*, 176090. [CrossRef]
163. Eason, C.T.; Spurr, E.B. *The Toxicity and Sub-Lethal Effects of Brodifacoum in Birds and Bats: A Literature Review*; Department of Conservation: Wellington, New Zealand, 1995.
164. Capizzi, D.; Sposimo, P.; Sozio, G.; Petrassi, F.; Gotti, C.; Raganella Pelliccioni, E.; Baccetti, N. Black rat eradication on Italian islands: Planning forward by looking backward. In *Island Invasives: Scaling up to Meet the Challenge*; Veitch, C.R., Clout, M.N., Martin, A.R., Russell, J.C., West, C.J., Eds.; Occasional Paper SSC no. 62; IUCN: Gland, Switzerland, 2019; pp. 15–20. Available online: https://portals.iucn.org/library/sites/library/files/documents/SSC-OP-062-En.pdf (accessed on 8 May 2026).
165. Wischnewski, M. (Director) Les Rats Des Villes: Tout un Monde! [Video Documentary]. Available online: https://zoopolis.fr/decouvrir/les-pratiques/les-rats-des-villes-lecons-dun-documentaire-incontournable/ (accessed on 18 August 2026).
166. Brooks, J.E.; Bowerman, A.M. Anticoagulant Resistance in Wild Norway Rats in New York. *J. Hyg.* **1973**, *71*, 217–222. [CrossRef]
167. Pelz, H.-J. Spread of Resistance to Anticoagulant Rodenticides in Germany. *Int. J. Pest Manag.* **2007**, *53*, 299–302. [CrossRef]
168. Berny, P.; Esther, A.; Jacob, J.; Prescott, C. Development of Resistance to Anticoagulant Rodenticides in Rodents. In *Emerging Topics in Ecotoxicology*; Springer: Cham, Switzerland, 2017; pp. 259–286. [CrossRef]
169. Buckle, A.; Cawthraw, S.; Neumann, J.; Prescott, C. *Confidential Report Series: Anticoagulant Resistance in Rats and Mice in the UK—Summary Report with New Data for 2021 and 2022*; Campaign for Responsible Rodenticide Use UK: Ossett, UK, 2022. [CrossRef]
170. Available online: https://www.lemonde.fr/sciences/article/2026/03/04/l-usage-de-pesticides-bouleverserait-en-profondeur-la-biodiversite-microbienne-des-sols_6669455_1650684.html (accessed on 14 March 2026).
171. Biasetti, P.; De Mori, B. Le matrici etiche nella conservazione della Biodiversità. *Etica Politica/Ethics Politics* **2019**, *1*, 233–254. Available online: https://sites.units.it/etica/2019_1/BIASETTI_De%20MORI.pdf (accessed on 28 January 2026).
172. Cianfaglione, K. An Editorial to Introduce the New Journal Wild: Issues, Approaches, Ideas and Proposals. *Wild* **2024**, *1*, 30–38. [CrossRef]
173. Cianfaglione, K. Editorial from the New Editor in Chief, Open Questions and Outlooks for the Future. *J. Zool. Bot. Gard.* **2022**, *3*, 714–724. [CrossRef]
174. Conservation Editorial Office. A Retrospective and Interview with Dr. Kevin Cianfaglione—Editorial Board Member of Conservation. *Conservation* **2023**, *3*, 319–333. [CrossRef]
175. Sharma, A.; Kumar, V.; Shahzad, B.; Tanveer, M.; Sidhu, G.P.; Handa, N.; Kohli, S.K.; Yadav, P.; Bali, A.S.; Parihar, R.D.; et al. Worldwide Pesticide Usage and Its Impacts on Ecosystem. *SN Appl. Sci.* **2019**, *1*, 1466. [CrossRef]
176. Mokaya, P. Impact of Synthetic Pesticides on the Health of the African People, Animals and Environment. In *Synthetic Pesticide Use in Africa*; CRC Press: Boca Raton, FL, USA, 2021; pp. 1–5. [CrossRef]
177. Rodríguez, A.; Castrejón-Godínez, M.L.; Monterrosas-Brisson, N. Pesticides: Environmental Stressors Implicated in the Development of Central Nervous System Disorders and Neurodegeneration. *Stresses* **2025**, *5*, 31. [CrossRef]
178. Zhou, W.; Li, M.; Achal, V. A Comprehensive Review on Environmental and Human Health Impacts of Chemical Pesticide Usage. *Emerg. Contam.* **2025**, *11*, 100410. [CrossRef]
179. Predator Free 2050. Available online: https://www.doc.govt.nz/nature/pests-and-threats/predator-free-2050/ (accessed on 8 December 2025).
180. Battler Resource Base: Battler Resource Base. Available online: https://brb.sprep.org/ (accessed on 8 December 2025).
181. Platform Meeting on Invasive Alien Species (IAS). Available online: https://naturachevale.it/en/platform-meeting-on-invasive-alien-species-ias/ (accessed on 11 January 2026).
182. Funding Rapid Action to Combat Invasive Alien Species in Europe. Available online: https://iucnsos.org/funding-rapid-action-to-combat-invasive-alien-species-in-europe/ (accessed on 11 January 2026).

183. Theodoropoulos, D.I. *Invasion Biology: Critique of a Pseudoscience*; Avvar Books: Blythe, CA, USA, 2003.
184. Génot, J.-C.; Terrasson, M.-C. *La Nature Malade de La Gestion*; Éditions Hesse: Saint-Claude-de-Diray, France, 2020.
185. Cox, G.W. *Alien Species and Evolution: The Evolutionary Ecology of Exotic Plants, Animals, Microbes, and Interacting Native Species*; Recording for the Blind & Dyslexic; Island Press: Washington, DC, USA, 2005.
186. Davis, M.A. *Invasion Biology*; Oxford University Press: Oxford, UK, 2023.
187. Vermeij, G.J. When Biotas Meet: Understanding Biotic Interchange. *Science* **1991**, *253*, 1099–1104. [CrossRef]