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Conservation concern for Europe's hedgehog species (Erinaceidae): Current statuses, issues and needs

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ABSTRACT

Recent regional updates to the IUCN Red List reveal a discouraging tendency: the hedgehog species of Europe are either declining and/or neglected by research and monitoring programmes to such a degree that evaluation of their conservation status remains challenging. Hedgehogs are charismatic nature ambassadors, and they are appreciated widely by the public with numerous individuals and organisations willing to contribute to their conservation, yet there exists a disconnect between general interest in hedgehogs and broad-scale monitoring efforts. Here, we clarify the current conservation statuses of the five species of hedgehogs in Europe, knowledge of threats, what is being done to mitigate declines, and where the conservation and research gaps lie. There are several common risks posed to hedgehog species in Europe including roads, and habitat loss and degradation. For some species, regional-scale action is urgently needed to prevent populations from shrinking any further. For all, there remains a comprehensive lack of knowledge of populations, ecology and threats.

1. Introduction

Ancestors of hedgehogs (Erinaceidae) have been present in Europe since at least the Paleogene (Eberle et al., 2014) and today, these small, ground-dwelling mammals are popular and recognisable emblems of native rural and urban wildlife (Morris, 2018). However, despite their generalist behaviour and historic persistence, regional-level conservation assessments recently published on the IUCN (International Union for Conservation of Nature) Red List (hereafter, Red List) have highlighted a worrying downward trend for several species of hedgehog within Europe.

Nineteen species of spiny hedgehog (subfamily Erinaceinae) are currently recognised, with native distributions in regions of Africa, Europe and Asia, and classified across five genera: *Atelerix* (4 species), *Erinaceus* (4 species), *Hemiechinus* (2 species), *Mesechinus* (5 species) and *Paraechinus* (4 species) (Mammal Diversity Database, 2024). In Europe, five species of hedgehogs occur, encompassing three genera: the Western European Hedgehog (*Erinaceus europaeus,* <1.5 kg), Northern White-breasted Hedgehog (*Erinaceus roumanicus*, <1.2 kg), Southern White-breasted Hedgehog (*Erinaceus concolor*, <1.5 kg), Long-eared Hedgehog (*Hemiechinus auritus,* <1.1 kg) and North African Hedgehog (*Atelirix algirus*, <0.9 kg) (Best, 2018; Hutterer, 2005) (See Fig. 1). Of these, the Western European Hedgehog is endemic to the European region, with the remaining species having wider global ranges beyond the continent. Nonetheless, even for these non-endemic species, it is prudent to consider conservation statuses and issues on regional – e.g., European – levels, as these are the scales at which conservation policies are often implemented. For many taxa, the threats and trends outlined in regional Red List assessments also reflect the global situation (e.g., Brito et al. (2010)), thus complementing, or even informing, updates to global-level assessments.

The hedgehog species of Europe share a number of morphological and ecological traits: they are all nocturnal, solitary, spiny Erinaceids with diets that comprise primarily invertebrate prey though may also

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include other items such as vertebrates and birds' eggs (Best, 2018; Mikov, 2020; Morris, 2018; Zidane et al., 2024). The species belonging to *Erinaceus* are generally considered to have broad habitat requirements, occurring in both rural (including woodland and agriculture) and urban areas (Best, 2018; Mikov, 2020; Morris, 2018). Conversely, the Long-eared Hedgehog is known more from open spaces such as dry steppes, semi-deserts and deserts, and the North African Hedgehog from semi-desert, dry Mediterranean scrub, grasslands and cultivated areas, though, in some places, both are reported from areas of human habitation (Boye, 1991; Zidane et al., 2024). It is perhaps this overlap with residential settings and thus opportunity for human-wildlife interaction, as well as their non-aggressive nature and deep-rooted significance within media and folklore (Hamilton, 2022; Hedgehog Street, 2018; Razauskas and Civjan, 2004), that has led to hedgehogs becoming such widely appreciated components of wildlife today.

Hedgehogs are considered the UK's favourite mammal (Royal Society of Biology, 2016) and a national emblem of nature (Barkham, 2013). Organisations like Zoogdiervereniging in The Netherlands and Deutsche Wildtier Stiftung in Germany have named hedgehogs the "animal of the year" (in 2020 and 2024, respectively). They are consistently highly favoured in studies of wildlife perception (Baker and Harris, 2007; Bjerke and Østdahl, 2004; Bjerke et al., 2003; Borgi and Cirulli, 2015; Morris, 1987) and there is a significant level of interest in their preservation and welfare, as exhibited by the numerous community groups and wildlife rescues that have been set up for hedgehogs across Europe (e.g., Garces et al. (2020); Hedgehog Friendly Campus (2024); Jersey Hedgehog Preservation Group (2024); Lukešová et al. (2021)). Despite this high level of public attention and awareness for hedgehogs, conservation concern is growing. What's more, current studies, conservation projects and rescue efforts are almost entirely directed towards the Western European Hedgehog, and we have comparatively little grasp on the situation for any other Erinaceid species.

In this article, we present the first review of the conservation statuses of the five Erinaceidae species within Europe. We highlight existing conservation and research focuses and draw attention to key gaps for hedgehog taxa. We also attempt to consider threats, conservation successes and shortfalls, and suggest focuses for future conservation and research initiatives directed towards these important species.

2. Methods

Red List assessments include information regarding population, distribution, threats and more, drawn from published and unpublished sources, as well as incorporating expert opinion, to categorise the risk of extinction faced by a species. Possible categories include Least Concern,

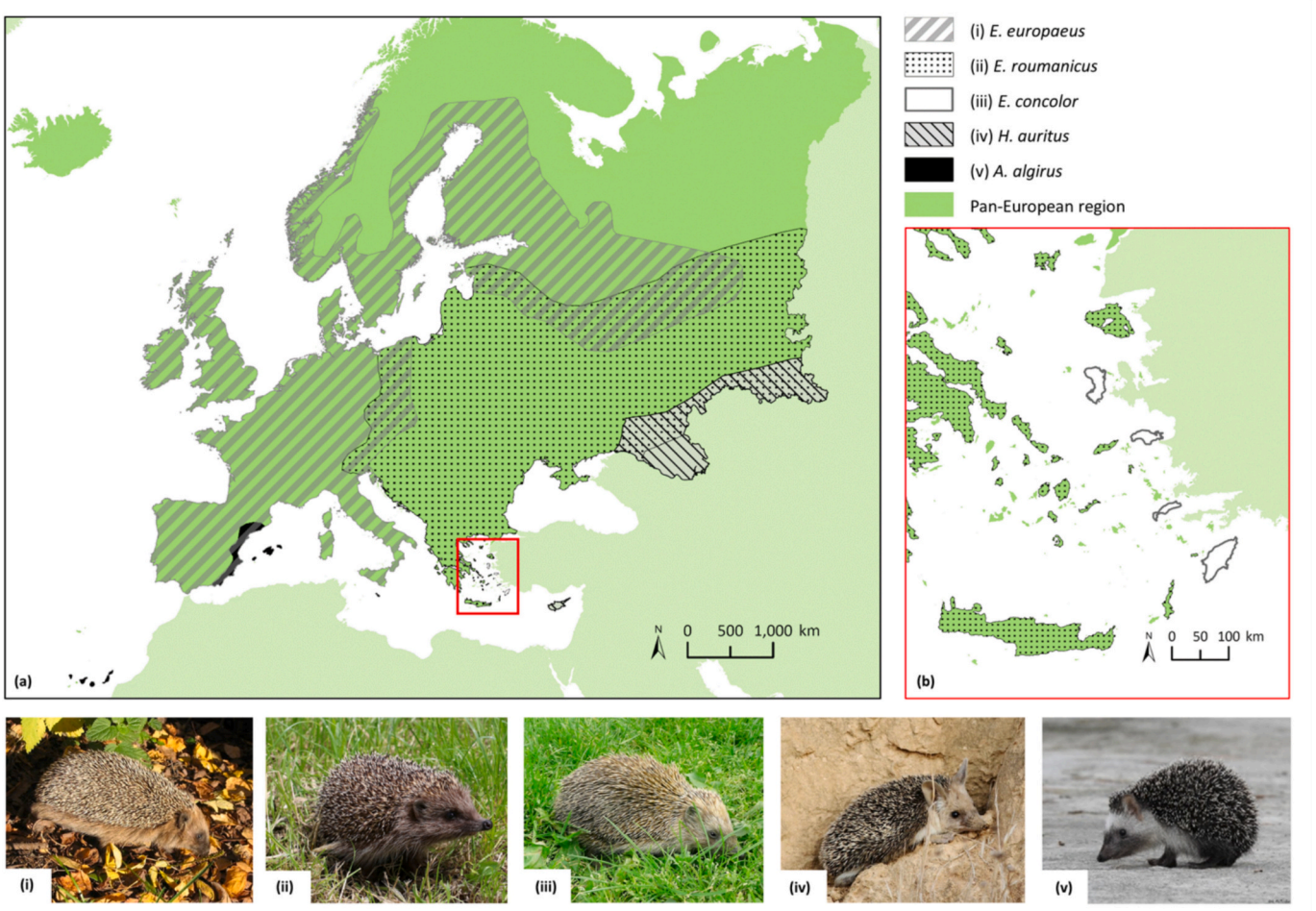

Fig. 1. (a) The distribution of five hedgehog species (Erinaceidae) within Europe, as per regional assessment boundaries used in recent IUCN Red List assessments, and (b) a focused view of *E. roumanicus*' and *E. concolor*'s island distribution. NB. The Azores, within which *E. europaeus* occurs as a non-native species, are not shown here. Corresponding species photographs are also provided (i-v). Data were adapted from: Gazzard and García (2024); Gazzard and Georgiev (2024); Gazzard and Rasmussen (2024); Gazzard and Zagorodniuk (2024); and Mitsainas (2023). Photo credits: (i) Estormiz and (ii) George Chernilevsky (public domain); (iii) Nevit Dilmen (CC BY-SA 3.0, Wikimedia); (iv) © George Konstantinou; (v) © Mirella Zeeders. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Near Threatened, Threatened (Vulnerable, Endangered or Critically Endangered), Extinct (also including categories for regionally extinct and extinct in the wild), and Data Deficient. Categories are assigned based on five quantitative criteria that consider indicators of threat of extinction, e.g., declining population size (IUCN Standards and Petitions Committee, 2024), with appropriate adjustments made for regional-level evaluations (IUCN, 2012).

For this review of conservation statuses of hedgehogs in Europe, we used the data available from recently published European-level Red List assessments of the Western European Hedgehog (Gazzard and Rasmussen, 2024), Northern White-breasted Hedgehog (Gazzard and Georgiev, 2024), Long-eared Hedgehog (Gazzard and Zagorodniuk, 2024) and North African Hedgehog (Gazzard and García, 2024). The fifth European hedgehog species – the Southern White-breasted Hedgehog – was also recently assessed as part of the Greek National Red List (Mitsainas, 2023). Since Greece is the only area within Europe where this species occurs, for the purpose of this article, we refer to its Greek assessment as a European-level assessment. All five species were last assessed regionally between 2006 and 2008 as Least Concern (Amori, 2007; Amori et al., 2010; Amori et al., 2008; Kryštufek, 2007; Zagorodniuk, 2007).

First, we summarise the updated statuses of hedgehogs in Europe, including an overview of the supporting evidence. Second, we pool knowledge of the threats posed to these taxa to determine any primary and also common concerns. Last, we identify any national-scale conservation initiatives that are in place for hedgehogs in Europe, as well as ongoing research projects, to highlight where schemes are succeeding but also where more effort is needed, taxonomically and regionally. Information regarding wide-scale conservation schemes was gathered from the authors, who are members of the European Hedgehog Research Group, but also supplemented with an online search.

3. Conservation statuses

Table 1 provides an overview of the regional Red List categories and conservation statuses of the five hedgehog species found in Europe. The assessments, all published between 2023 and 2024, show final categorisations ranging from Least Concern, to Near Threatened and Vulnerable. The Western European and Long-eared Hedgehogs have both worsened in status since their previous regional-level assessments of Least Concern (Amori et al., 2008; Zagorodniuk, 2007).

Despite having a large geographical range spanning from the British Isles through much of continental Europe, the Western European Hedgehog has undergone a population decline that has likely approached 30 % across extensive parts of its range, leading to its current listing as Near Threatened. This concern has already been recognised in several national-level assessments where it is categorised as Vulnerable (Great Britain: Mathews and Harrower, 2020) or Near Threatened (Switzerland: Capt, 2022; Sweden: Eide (editor), 2020; Norway: Eldegard et al., 2021; Germany: Meinig et al., 2020; Austria: Spitzenberger, 2005).

The Long-eared Hedgehog has moved to a further heightened threat status, now listed as Vulnerable in Europe, having reached a suspected >30 % decline in population. In this region, this hedgehog is found in small areas of the south of European Russia (Zalikhanov, 2018) as well as Cyprus (Boye, 1991), where its origin is uncertain. The species was also previously known from southeast Ukraine, but it is now likely to have become extinct there (Burgin et al., 2020; Corbet, 1988; Tembotova and Kononenko, 2017; Zagorodniuk, 2017) with the most recent unequivocal records dating to the 1990s. In European Russia, the Long-eared Hedgehog is uncommon and declining (Minoranskiy et al., 2021; Tembotova and Kononenko, 2017) and its numbers are now likely to be extremely low (i.e., less than thousands) (Gazzard and Zagorodniuk, 2024). Although it has a wider range outside of Europe (northeast Africa, the Middle East and Central Asia), these areas are considered to be largely disconnected from the European extent of its distribution and any rescue effect is unlikely (Gazzard and Zagorodniuk, 2024).

Fortunately, the outlook for the Northern White-breasted, Southern White-breasted, and North African Hedgehogs is comparatively positive, and these species are assessed as Least Concern, though some localised declines are suspected for, e.g., the North African Hedgehog in Spain (Burgin et al., 2020; García and Puig, 2014). Nonetheless, for all three of these species, populations remain largely unmonitored.

4. Threats

For three of the five species, habitat change is considered a major threat (Table 1), associated with urbanisation, agriculture and the changing management of such land. Across Europe, more than three-quarters of habitats are considered to be in poor or bad conservation status, with large areas of land converted – and often impoverished by – forestry, infrastructure, urbanisation and intensive agriculture (European Environment Agency, 2020). Agriculture covers 38 % of the total land area of the EU (Eurostat, 2023) and farming pressures continue to intensify, with food demands projected to increase substantially by 2050 (Tilman et al., 2011) – under these circumstances, the pressures for hedgehogs in rural environments will only worsen. Reductions in invertebrate abundance and diversity in cropland (Hof and Bright, 2010; Mancini et al., 2023), as well as loss of suitable nesting habitats, present significant challenges in particular. For the Long-eared Hedgehog, similar loss and degradation of rural landscapes has resulted from substantial over-grazing and ploughing of steppes (Parnikoza, 2011), large-scale conversion to cropland (Schierhorn et al., 2013), replacement with pine monocultures (Akimov, 2009), and abandonment of managed land (Kawada and Nakamura, 2011).

Climate-induced weather changes might also lead to habitat alterations such as a shift in vegetation zones, turnover in species composition, and/or reduced growth (Wesche et al., 2016), though the potential impacts of this upon hedgehog taxa are unquantified. It is likely, however, that changes to seasonal weather and temperatures might directly impact the hibernation or aestivation behaviours of hedgehogs (e.g. Rasmussen et al. (2019a)). Prolonged periods of dormancy are normal for hedgehogs in many, though not all, regions, presumably in response to a reduction in food availability, although changing temperatures are also thought to trigger the onset of and emergence from hibernation and aestivation (Rutovskaya et al., 2019; Santana et al., 2010; Schoenfeld and Yom-Tov, 1985). Climate-induced changes to patterns of dormancy (such as delays in entering into dormancy, or premature emergences) could ultimately impact survival and longevity (Gazzard and Baker, 2020), but the implications of this on both individual- and population-levels remain unknown.

Some species of hedgehog appear to be fairly adaptable. For example, the Northern White-breasted and Southern White-breasted Hedgehogs are occasionally referred to as “common” in urban or suburban environments (Girisgin et al., 2015; Mihály et al., 2019), though populations remain generally unsurveyed. More extensive data are available on the Western European Hedgehog, with studies indicating that this species might actively favour (Doncaster et al., 2001; Pettett et al., 2017) and be more more abundant in urban habitats than in rural landscapes (Hubert et al., 2011; Schaus et al., 2020; van de Poel et al., 2015). In the UK, long-term monitoring results suggest that urban populations, despite a past decline, may now be stabilising (Wembridge et al., 2022). On the other hand, localised declines are still being documented in some urban areas of mainland Europe, such as Zurich, Switzerland (Taucher et al., 2020). Within these urban landscapes, hedgehogs might be accessing sites lacking in natural predators and/or areas with abundant food resources, including artificial food sources (Hubert et al., 2011). However, urban hedgehogs will still likely encounter risks of limited natural prey availability (Szabó et al., 2023), poisoning and accumulation of pesticides and other chemicals (Brakes and Smith, 2005; Dowding et al., 2010b; Rasmussen et al., 2024a; Rasmussen et al., 2024b; Rasmussen et al., 2024e), general human disturbance (Dowding et al., 2010a; Rasmussen et al., 2019a) and

Table 1
Summary of regional (i.e., European) Red List categories, distributions, key threats and supporting evidence for said categories of the five hedgehog species (Erinaceidae) occurring in Europe, based on Red List assessments published between 2023 and 2024 (Gazzard and García, 2024; Gazzard and Georgiev, 2024; Gazzard and Rasmussen, 2024; Gazzard and Zagorodniuk, 2024; Mitsainas, 2023). Assessments followed regional Red List guidelines (IUCN, 2012), and threats quoted are adapted from the IUCN Threats Classification Scheme (Version 3.3).

Species	Distribution notes	Regional Red List category and criteria	Population trend	Key threats	Supporting evidence for regional status
Western European Hedgehog (*Erinaceus europaeus*)	British Isles through much of continental Europe towards central areas, and north into northern Russia. Endemic to European region.	Near Threatened[1] (approaching A2ac, i.e., past population reduction of nearly 30 %, estimated based on survey data and decline in habitat quality)	Declining	• Agro-industry farming (crops) • Agro-industry grazing, ranching or farming (livestock) • Herbicides and pesticides • Roads & railroads • Human intrusions & disturbance • Problematic native species/ diseases (*Meles meles*) • Pollution, garbage & waste • Climate change	The decline is evidenced across different scales and localities, reflecting inconsistencies in monitoring and research efforts across the region. In Sweden, hedgehog monitoring as part of the Swedish Breeding Bird Assessment suggests a rate of decline of 40 % over the previous 12 years (Eide (editor), 2020; Krange, 2015). In Norway, there has been relative drop of 35 % in the observations registered nationally between 2011 and 2021 (Eldegard et al., 2021), and in the Netherlands, data from the national DagActieve Zoogdieren project suggests a reduction between 25 and 50 % across 1994–2018 (Dijkstra, 2019; van Norren et al., 2020). In Great Britain, data from a range of studies has been used to infer a 39 % decline over ~13 years (Mathews and Harrower, 2020). In other countries, there have been no large-scale monitoring or recording efforts, and population data are either limited to local-level studies, or non-existent. Nonetheless, the data available from local-level studies across both rural and urban habitats paint a similar picture. For example, changes in roadkill data – which have been proven to be generally reliable indicators of abundance (Baker et al., 2004) including that of the Western European Hedgehog (Bright et al., 2014; Roos et al., 2012) – consistently show downward trends in observations. Roadkill reductions have been reported from the Po-Venetian plain in Italy (Canova and Balestrieri (2019)), the Fulda-Rhön Mountains (Müller (2018)) and Bavaria (Meinig et al. (2020)); Reichholf (2015)) in Germany, from Great Britain (Wembridge et al. (2022)), Armada in Portugal (Bom (2020)) and Flanders in Belgium (Swinnen et al. (2022); Vercayie (2019)). It is likely that declines are occurring in any area where this species is under pressure from habitat change, intensive agricultural practices and other ongoing threats. Overall, the reduction is thought to have approached, and in some areas exceeded the thresholds for the population decline criterion of the Red List (i.e. >30 % in 10 years) across extensive parts of its distribution.

(*continued on next page*)

Table 1 (*continued*)

Species	Distribution notes	Regional Red List category and criteria	Population trend	Key threats	Supporting evidence for regional status
Northern White-breasted Hedgehog (*Erinaceus roumanicus*)	Central and eastern Europe to European Türkiye and the Mediterranean region. Outside of Europe, its range extends to Georgia, Azerbaijan and Kazakhstan, and as far as western Siberia.	Least Concern[1]	Stable	• Roads & railroads • Hunting for meat and perceived medicinal value	Data are lacking, but there is no anecdotal evidence or otherwise to suggest any significant decline in numbers. In fact, the Northern White-breasted Hedgehog is considered common in a number of countries such as Greece, Hungary and Bulgaria (Berndt et al., 2019; Kontsiotis et al., 2023). In some local-level studies, increases in abundance have been reported (Lipkovich and Kovaleva, 2020; Minoranskiy et al., 2021).
Southern White-breasted Hedgehog (*Erinaceus concolor*)	Occurs on some Greek islands (Chios, Samos, Kos and Rhodes) though, outside of Europe, has a much larger global range across the Middle East and into the Caucasus.	Least Concern[2]	Unknown	• Roads & railroads	This species appears to be common, with no notable threats, other than roads and road traffic. As such, there is no urgent conservation concern for this species within Europe. However, to reliably inform future assessments, there is a need for genetic studies to determine the extent of its presence in Greece, and/or the presence of the Northern White-breasted Hedgehog, which is nearly morphologically indistinguishable from the former and may co-occur with this species on some Greek islands.
Long-eared Hedgehog (*Hemiechinus auritus*)	Small areas of the south of European Russia as well as Cyprus, where its origin is uncertain. It is possibly also present in a small, isolated region of Tatarstan, Russia (unmapped), though its origin and status there are unknown. The species was also previously known from southeast Ukraine. Outside of Europe, its global range extends across northeast Africa, the Middle East and Central Asia, to the North Caucasus region.	Vulnerable[1] (A2c, i.e., past population reduction that has reached 30 %, suspected due to a a decline in area of occupancy, extent of occurrence and quality of habitat)	Declining	• Urbanisation • Small-holder and agro-industry grazing, ranching or farming • Roads & railroads • Persecution/control • Invasive non-native/alien species/diseases (*Canis familiaris* and *Nyctereutes procyonoides*) • Problematic native species/diseases (*Erinaceus roumanicus*)	In Ukraine, the Long-eared Hedgehog was, in 2009, considered threatened in the national Red Data Book (Akimov, 2009). However, the most recent unequivocal records of this species in Ukraine date to the 1990s; two amateur observations from 2003 (Dhoz, 2015) and 2004 (Timoshenkov, 2006) remain unverified and possibly false. Thus, the species may have disappeared from Ukraine entirely. Its population in Europe is now thought to be restricted to Cyprus and European Russia. There are no population estimates available from Cyprus, but it is believed to occur across the island. In European Russia, the Long-eared Hedgehog is uncommon and significantly declining (Minoranskiy et al., 2021; Tembotova and Kononenko, 2017). It is listed within multiple regional Red Books (e.g. Aminovich (2016); Zalikhanov (2018)) which, in Russia, only include those species that are considered already rare (Popov et al., 2017). Its numbers in Europe are now likely to be extremely low (i.e., less than thousands) and experts suspect that at least a 30 % decline has occurred over the previous decade, triggering the status of Vulnerable.
North African Hedgehog (*Atelerix algirus*)	A relatively small and fragmented range in mainland Spain and on a number of islands including the Canary Islands, Balearic Islands and Malta. Outside of Europe, its range stretches across North Africa.	Least Concern[1]	Unknown	• Urbanisation • Roads & railroads • Hunting for meat and perceived medicinal value (potentially no longer occurs), as well as taken from the wild to be kept as pets	Population data are unavailable, but on the Canary Islands, the North African Hedgehog has, in the past, been reported to be common (Lapini, 1999; Palomo et al., 2007). Conversely, decline is suspected in some European areas (Burgin et al., 2020; García and Puig, 2014), and in mainland Spain it has disappeared from a number of localities. Overall, however, since populations remain largely unmonitored and there is no evidence to suggest that this species has reached any of the Red List thresholds for threatened status, the species has been assessed as Least Concern.

[1] Species assessed on pan-European level.
[2] Species assessed on country-level (Greece), its only country of occurrence within Europe.

Table 2
Summary of the primary gaps that exist in conservation and research for the five hedgehog species occurring in Europe. N/A indicates that no urgent conservation action is currently needed.

Species and regional Red List category	Conservation needs	Research gaps
Western European Hedgehog (*Erinaceus europaeus*); Near Threatened	• National/regional campaigns encouraging householder-level conservation • Habitat (and prey availability) improvements in especially rural settings • Mitigation strategies for roads and road traffic	• Population estimates and trends in countries currently lacking such data • Threat impacts: population-level impacts of competition, predation, urban-associated hazards, habitat change, climate change and roads, as well as impacts on survival, fitness, breeding success • Effectiveness of existing conservation tools such as supplementary feeding, nest boxes, urban hazard mitigation, and habitat management • Scale and impacts of rehabilitation • Genetic confirmation of limits of distribution, as well as investigation of fitness impacts of hybridisation with *E. roumanicus*
Northern White-breasted Hedgehog (*Erinaceus roumanicus*); Least Concern	N/A	• Population estimates and trends (lower priority as population currently presumed very large and stable, possibly expanding)
Southern White-breasted Hedgehog (*Erinaceus concolor*); Least Concern	N/A	• Population estimates and trends • Basic ecology: habitat requirements, disturbance tolerance, movement behaviour, life history • Genetic confirmation of range in Europe/areas of overlap with *E. roumanicus*
North African Hedgehog (*Atelerix algirus*); Least Concern	• Habitat management (dependent on research of habitat requirements) • Mitigation strategies for roads and road traffic	• Population estimates and trends • Basic ecology: habitat requirements, disturbance tolerance, movement behaviour, life history • Threat impacts: in the first instance, identification of key threats driving localised declines • Scale of harvest from the wild, in Europe and beyond • Potential conservation tools and their effectiveness
Long-eared Hedgehog (*Hemiechinus auritus*); Vulnerable	• Ex-situ programmes to ultimately reintroduce individuals/populations in suitable areas • Habitat improvements in rural settings • Invasive species control • Mitigation strategies for roads and road traffic	• Population estimates and trends • Basic ecology: habitat requirements, disturbance tolerance, movement behaviour, life history • Threat impacts: population-level impacts of competition, predation, habitat change, climate change and roads, as well as impacts on survival, fitness, breeding success • Potential conservation tools and their effectiveness

attacks and predation by dogs (*Canis lupus familiaris*). Additionally, there may be risks associated with the consumption of artificial foods, such as pathogen transmission, increased stress and malnutrition (Murray et al., 2016). Living within urban areas is clearly not without its challenges, but the direct impacts of these challenges on a population-scale are unknown. Further, we currently have a very poor understanding of the ecology of North African and Long-eared Hedgehogs in urban habitats, nor whether these species utilise urban areas to the extent that they could potentially serve as habitat strongholds.

Besides dogs in urban areas, several other species have been cited as potentially problematic for hedgehogs. For the Western European Hedgehog, researchers have expressed concern about the possible impacts of competition with, and/or predation by, foxes (*Vulpes vulpes*) (Rasmussen et al., 2019a) and badgers (*Meles meles*) (Hof et al., 2019; Hubert, 2011; Pettett et al., 2017; Young et al., 2006) across both rural and urban landscapes, yet the mechanisms of these relationships are poorly understood and predation rates are unquantified. Hedgehogs appear to exhibit avoidance behaviours in spaces used by badgers (Young et al., 2006) but such spatial avoidance, as well as the likelihood of predation, might also be tied to food availability, refuges and habitat connectivity, rather than simply badger occupancy (Ward et al., 1997; Yarnell and Pettett, 2020). Regardless, in the UK, this negative relationship has been demonstrated on a national scale: the likelihood of hedgehog presence across the country is significantly related to badger presence (Hof et al., 2019), with the same negative link observed for abundance (Pettett et al., 2017).

For the Long-eared Hedgehog, as well as foxes and dogs (Akimov, 2009), jackals (*Canis aureus*) (Lipkovich and Kovaleva, 2020) and the introduced Raccoon Dog (*Nyctereutes procyonoides*) are considered to pose notable threat. The species disappeared from Meotida Regional Landscape Park in Ukraine following high levels of predation by the latter (Shevchenko, 2008). However, no research into the rate or long-term impacts of predation has been conducted. Additionally, this species may be affected by competition with its cousin species, the Northern White-breasted Hedgehog. In Rostov Nature Reserve of southern Russia, as steppe habitat has become less arid over time, the ratio of Northern White-breasted Hedgehogs to Long-eared Hedgehogs has shifted from 5:1 in the 1990s to 10:1 in 2020 (Minoranskiy et al., 2021). The Long-eared Hedgehog potentially has a narrower dietary niche (Schoenfeld and Yom-Tov, 1985) and lower tolerance of habitat change than its congener, which may be considered more of a generalist. Thus, in a changing landscape and at the limits of both species' distributions, replacement by competitors may be relatively rapid.

In Iberia, Western Europe, the North African Hedgehog overlaps with areas inhabited by the Western European Hedgehog. However, the former is more typically associated with maquis, scrubland, cultivated areas and the outskirts of urban areas (El-Farhati et al., 2021; Sayah et al., 2009), whilst the larger Western European Hedgehog is better-able to exploit urbanised landscapes and is even drawn to them (Doncaster et al., 2001; Pettett et al., 2017). Thus, on a fine-scale, habitat competition may not be a risk between these species. Conversely, within-genus, the Western European Hedgehog could be experiencing some pressures exerted by the Northern White-breasted Hedgehog. Where their distributions overlap in Central and Eastern Europe, hybridisation has been reported; one study reported up to 20 % of individuals possessing mixed genotypes in a contact zone (Zolotareva et al., 2021). Again, the impacts of this upon fitness, survival and populations are unknown. It has been theorised that in these contact zones, despite hybridisation, the pressures of competing for the same food sources and spaces are not strong enough to result in divergence, but rather, convergent selection and the development of more similar morphology (Černá Bolfíková et al., 2020). Lastly, in Greece, there might exist a contact zone between the Northern White-breasted and Southern White-breasted species (similarly both of the *Erinaceus* genus), but studies of hybridisation have not taken place. In fact, given their similar morphology, exact occupancy across the Greek islands is unclear,

with the species possibly co-occurring in some areas (Mitsainas, 2023). Further research is needed to identify the implications of these zones of overlap for hedgehogs, particularly where species are declining at the edges of their distributions.

Hedgehogs are occasionally targeted by humans; in Cyprus, the Long-eared Hedgehog was previously reported to be controlled by farmers in effort to prevent crop damage (Boye, 1991), though up-to-date data on this are lacking. Also in Europe, there are reports of Western European, Northern White-breasted and North African Hedgehogs being taken from the wild for meat, perceived medicinal value and/or to be kept as pets (Ninov et al., 2002), though such information is entirely qualitative and its limited nature might indicate that this is not a common practice regionally. In some areas further afield, the North African hedgehog is at heightened risk of hunting and trade, with one study recording >100 hedgehog items for sale in 25 shops in Morrocco (Nijman and Bergin, 2015), and it is reportedly one of the top ten most commonly observed species sold in Moroccan markets (Bergin, 2019). The threat of use and trade of hedgehogs is therefore an area that might warrant further research attention across global-level distributions rather than within Europe alone.

Another way through which humans are directly affecting hedgehogs is via wildlife rescue and rehabilitation. With the exception of the Southern White-breasted Hedgehog, of which records in Europe are already limited, each hedgehog species in Europe has been documented within rescue centres in varying regions of the continent (e.g., Cyprus Wildlife Research Institute, 2022; Molina-Lopez et al., 2024; Sós and Sós-Koroknai, 2023). For the Western European Hedgehog, rehabilitation is likely having population-level impacts: in the UK, it has been estimated that 31,000 wild hedgehogs are admitted to veterinary practices per annum (Barnes and Farnworth, 2016). Further research suggests that >40,000 hedgehogs were admitted to wildlife rehabilitation establishments in a single year (2016) and approximately 20,000 then released, potentially representing 10 % of the pre-breeding urban population (Bearman-Brown and Baker, 2022). Whilst the motivation may often be more welfare- than preservation-related, these rates of rescue could have notable conservation impacts for the species, possibly combating some level of decline (Bearman-Brown and Baker, 2022). However, generally, the conservation impacts of these efforts are unmonitored and there may be some negative factors to consider. Concern has been raised regarding the genetic consequences of uncontrolled translocations, including outbreeding depression, hybridisation and introgression (Ploi et al., 2020), risk of disease transmission to the recipient population (Rasmussen et al., 2021a; Rasmussen et al., 2019b), as well as the population-level effects of unregulated capture of wild hedgehogs, their euthanasia and retaining individuals in captivity (Taylor and Copsey, 2023). Further investigations are needed to establish the extent to which hedgehog taxa are taken from the wild (and released), and the broad-scale consequences of this.

In all environments and to all hedgehog species, roads present a prominent threat (Table 1). As barriers to movement (Huijser, 2000; Huijser and Bergers, 2000; Moore et al., 2020), some studies have implicated roads as drivers of genetic clustering in local populations of the Western European Hedgehog (Braaker et al., 2017). It is estimated that traffic casualties could remove 9–25 % of the total population in the Netherlands (Huijser, 2000) and 10–30 % in the UK annually (Wembridge et al., 2016). Whilst these fragmentation and mortality effects have not been measured in other hedgehog species, it is nonetheless known that roads are likely to be a significant issue; the Northern White-breasted Hedgehog is often reported as at risk of road traffic accidents (Mikov, 2020; Mikov, 2018) and considered a highly common road-traffic casualty (Berndt et al., 2019; Bituší k et al., 2017). Similarly, in studies of wildlife-vehicle collisions, counts of the Southern White-breasted Hedgehog (Özcan and Özkazanç, 2017), North African Hedgehog (Sacramento et al., 2022) and Long-eared Hedgehog (Rayimov et al., 2022) tend to constitute the most highly-recorded mammalian mortalities. As highlighted by Moore et al. (2020), however, understanding the impacts of roads and road traffic on these species is greatly hindered by a lack of fundamental biological, ecological and population knowledge.

Overall, the threats posed to hedgehogs in Europe are complex, little-quantified and likely varied across taxa. Whilst some species appear to be adaptable to urban environments, others – i.e., the North African and Long-eared Hedgehogs – are less associated with highly urbanised areas and thus may be more sensitive to the loss or degradation of rural habitats. Competition and predation might present key challenges when conditions are already poor, e.g., where habitat is declining or food availability is low. Under all scenarios, however, it is clear that roads are likely to be a major concern.

5. Hedgehog research and conservation in Europe

5.1. Existing initiatives

In many countries, NGOs and other groups have noticed and begun to tackle the decline of the Western European Hedgehog. Even where data are lacking, the downward trend has been widely recognised – the disappearance of hedgehogs from local areas from one generation to the next is often reported anecdotally by members of the public, for example Warwick (2013). In the UK, downward trends in roadkill were noticed as long ago as the 1950s and 1960s (Morris, 2018). A multitude of UK surveys has since complemented anecdotal evidence over the previous several decades (Roos et al., 2012; Wembridge et al., 2022). There, arguably the longest-running formal conservation efforts for this species can be seen: the British Hedgehog Preservation Society (BHPS) was set up in 1982 to advocate for hedgehog welfare and protect the future of this species in Britain. In 2011, BHPS and People's Trust for Endangered Species (PTES) launched "Hedgehog Street" as an initiative to promote conservation action and engage with citizen scientist "champions" around the country. The campaign has now recruited >130,000 hedgehog champions, encouraging them to map and log hedgehog observations in the UK, as well as make hedgehog-friendly improvements to gardens by, for example, creating access points for hedgehogs, resource provisioning and leaving areas to grow "wild". Similar garden-based approaches are promoted by a range of wildlife organisations across the country, such as the Wildlife Trusts (The Wildlife Trusts, 2024), Royal Society for the Prevention of Cruelty to Animals (RSPCA, 2024) and The Conservation Volunteers (The Conservation Volunteers, 2024). It is these sorts of householder-focused efforts – as well as the generally high levels of interest in hedgehog conservation in the UK – that may have led to a potential improvement in annual trends in gardens (Wembridge et al., 2022).

However, surveys continue to show a loss of hedgehogs in British rural areas and, acknowledging this, the National Hedgehog Conservation Strategy was launched by PTES and BHPS in October 2024 (BHPS and PTES, 2024). The Strategy – developed by a collaboration of NGOs, academics, rehabilitators and stakeholders from within the transport and farming sectors – highlights key threats, what is needed to monitor them, and how to potentially overcome them. The Strategy identifies the following causes: a decrease in availability and distribution of natural food and associated habitat; increased vehicle collisions; unintentional mortality and stress due to human intervention; accidental death and misadventure; toxin accumulation, and genetic isolation. The intention is for the Strategy to evolve as new research findings become available, whilst using it as a framework and reference point for all actions relating to hedgehogs in Britain. Lastly, it complements the National Hedgehog Monitoring Programme (National Hedgehog Monitoring Programme, 2024), launched earlier in 2024 also by BHPS and PTES, which will provide important data on population changes at local and national levels.

Compared to other small mammal taxa, conservation and monitoring efforts for the Western European Hedgehog in the UK have been immense. Yet, the UK comprises only a fraction of this species' global

range. Indeed, campaigns in several other European countries have commenced, such as "Deutschland sucht Igel & Maulwurf" (Deutschen Wildtier Stiftung et al. established in, 2023) in Germany, and "Danmarks Pindsvin" (Rasmussen and Denmark established in, 2023) in Denmark. The "Danmarks Pindsvin" campaign hosts annual, national hedgehog counts and seasonal citizen science research projects, and communicates methods on how to provide hedgehog-friendly gardens. Inspired by the Danish campaign, WWF Sweden also recently launched a hedgehog conservation initiative in collaboration with Nordens Ark called "Vi Räkner Sveriges Igelkottar" (WWF Sweden and Nordens Ark established in, 2024). Our search did not yield any further examples of campaigns from other areas of the Western European Hedgehog's range, including countries from which (i) decline has been quantified on some level and/or (ii) hedgehogs are already listed as Near Threatened on a national Red List. This leaves the species potentially at heightened risk in such regions, where urgent conservation intervention may be needed to prevent it from deteriorating further in status.

When it comes to other hedgehog species, there has been a distinct lack of conservation interest. This is perhaps unsurprising because, until recently, there has been no significant cause for concern for other Erinaceids within Europe. However, we know now that the Long-eared Hedgehog should be a regional priority as it is at the greatest risk of extinction of all hedgehog species in Europe, having already reached Vulnerable status. It is not known to be the focus of any in-situ conservation work neither within Europe nor globally. Its decline may have reached similar levels within its distribution outside of Europe (northeast Africa, the Middle East and Central Asia) though no data are publicly available and global trends remain unknown (Stubbe et al., 2021). In the first instance, this species would therefore benefit from a review of its global-level Red List status to ascertain whether populations are declining more widely than currently recognised. On a regional level, action should be taken to protect this species and its habitats, with reintroduction programmes also being a potential option (Akimov, 2009; Lipkovich and Kovaleva, 2020). Lipkovich and Kovaleva (2020) recommended the establishment of a specialised breeding centre, though it is not known whether any progress has been made towards this. The control of non-native species such as the Raccoon Dog may also be vital in areas with surviving populations. A regional action plan, similar to that recently adopted for hedgehogs in the UK, would be valuable in bringing together these conservation ideas for the Long-eared Hedgehog.

The suspected decline of the North African Hedgehog in some regions is also of concern and warrants further investigation into the rate and spread of reduction. Again, however, we know of no current conservation projects focused on this species. The remaining two species – the Southern White-breasted and Northern White-breasted Hedgehogs – are not known to be undergoing any significant population reduction and arguably do not represent conservation priorities at present. In fact, the Northern White-breasted Hedgehog is considered so successful that it may be outcompeting the Vulnerable Long-eared species in areas of overlap, and/or better able to exploit disturbed habitats. Despite the favourable status of the Northern White-breasted Hedgehog, researchers have demonstrated that members of the public would be willing to contribute considerably towards its conservation, by up to 21.9 million euros annually in Greece alone (Kontsiotis et al., 2023). Considering this, it is possible that new conservation initiatives aimed at other hedgehog taxa could garner sufficient support from members of the public for, e.g., implementing actions within individually-owned properties (e.g., "Hedgehog Street"), but also potentially supporting projects financially. That being said, the rates people may be willing to pay may vary widely across demographics, geographies and cultures, and this remains unstudied.

5.2. Research directions

For the Western European Hedgehog, research attention continues to grow and several innovative conservation studies have begun. For instance, researchers are investigating the effects of robotic lawn mowers on hedgehogs (Rasmussen et al., 2021b; Rasmussen et al., 2024c) and have launched collaborations within the industry to create hedgehog-friendly robotic lawn mowers, alongside standardised safety tests (Rasmussen et al., 2024d). The hearing of Western European Hedgehog has very recently been quantified for the first time (in prep. pers. comm. Sophie Lund Rasmussen) to explore the possibility of creating sound repellents for hazards such as lawn mowers and, perhaps even more importantly, cars. Scientists have also investigated the potential value of conservation tools such as road tunnels (People's Trust for Endangered Species PTES, 2024), nest boxes (Gazzard and Baker, 2022), habitat connectivity (App et al., 2022; Turner et al., 2022) and supplemental food sources (Hogs On Film, 2024).

Moreover, projects are being planned to improve survey methods. For example, researchers have considered the use of artificial intelligence (AI) to enable inexpensive, commercially-available GPS tags that can store positional data in accessible servers (pers. comm. Rasmussen). This would permit the generation of much larger movement datasets. Additionally, the authors suggest that AI techniques could be used to pinpoint hedgehogs in recordings taken by drones mounted with thermal imaging cameras, to allow for counting and mapping of local populations. AI could also be used to automate the process of identifying hedgehogs on camera trap footage (National Hedgehog Monitoring Programme, 2024) and even potentially recordings from nest boxes and robotic lawn mowers equipped with built-in cameras (pers. comm. Rasmussen). Such processes could contribute vast amounts of incidental data that inform studies of habitat use, behaviours in gardens, and local population trends. The automated collection of observational data from householder-purchased items, such as robotic lawn mowers, comes with the advantage of requiring little to no external funding, administration or engagement effort from conservation or research organisations. Going one step further, by training algorithms through AI to better recognise hedgehogs, robotic lawn mowers could more efficiently detect and avoid hedgehogs (Rasmussen et al., 2024d).

Many of these research and conservation techniques may be of relevance to other understudied Erinaceid taxa, for which the main research themes have thus far centred on genetics (e.g., Bogdanov et al. (2009); El-Farhati et al. (2021); Velo-Antón et al. (2019); Özmen et al. (2024)) and parasitology (e.g., Baz-González et al. (2023); Dziemian et al. (2015); Moshaverinia et al. (2016)). Compared to the Western European Hedgehog, the other hedgehog species of Europe have been almost entirely neglected by research and there are few data on, e.g., general ecology, life histories, spatial behaviour, species interactions and patterns of torpor. Further, we are unaware of any projects measuring the population demographics and trends, distribution, or threats to these species. Understandably, already-limited funding should prioritise the species at greatest risk. However, by the point at which we reach such levels of heightened risk – such as with the Long-eared Hedgehog – it would be advantageous to have developed a sufficient baseline understanding of species' ecology. This lack of fundamental knowledge and attention is not unusual when it comes to small mammal taxa (Bertolino et al., 2015; Fisher, 2011) and, in fact, it seems that the Western European Hedgehog is "the exception to the rule".

In any case, the major priorities should include increased and widespread population monitoring of all European hedgehog species, as well as quantification of threat impacts on population- and individual-scales in terms of, e.g., breeding success, fitness and survival. Studies of conservation tools will also be beneficial; whilst it has been suggested that householder-based actions have been key in preserving urban populations of the West European Hedgehog, we know little about how similar methods could be implemented in rural environments, or for other taxa. Above all, efforts for the lesser-studied hedgehogs should be increased, so that fundamental knowledge of their ecology (e.g., habitat requirements) as well as population trends is included in future conservation assessments and planning. Table 2 summarises these priorities

and denotes where research is needed to fill important data gaps.

6. Concluding remarks

In Europe, the Southern White-breasted, Northern White-breasted and North African Hedgehogs are currently of lesser conservation concern, whereas, worryingly, the Long-Eared Hedgehog has reached Vulnerable status, regionally, and the Western European Hedgehog is now considered Near Threatened, globally. All species appear to be at some level of risk from road traffic accidents, with many also threatened by habitat loss, anthropogenic disturbance, and invasive species. The declines of such culturally-valued and emblematic species are alarming, particularly given the impressive scale of attention that hedgehogs receive from the public worldwide. It is this widespread interest in hedgehogs that has boosted engagement in conservation schemes for the Western European Hedgehog, though many existing approaches, such as the improvement of garden habitat, remain untested. Nonetheless, conservationists are hopeful that householder-based action is helping to sustain the higher hedgehog densities observed in some urban settings. We now need to see such initiatives replicated across their range. For the Long-eared Hedgehog, known more typically from steppe habitat, efforts should focus on habitat recovery and protection, challenges with non-native species, and potentially also ex-situ methods, though in the first instance, increased conservation and research interest will be vital.

Public engagement in hedgehog conservation could be a driving force for such schemes, be it through wildlife improvements to privately-owned land, crowdfunding, observation reporting, or even applying a pressure to the scientific community. However, the benefits go beyond this, and public involvement in conservation projects is likely to promote positive outcomes for other wildlife as well as humans. For example, spending time in urban green spaces has been linked to pro-environmental attitudes and behaviours (Alcock et al., 2020; Whitburn et al., 2019), and biodiversity-related experiences like these could be considered a type of ecosystem service, providing cultural, recreational, and spiritual benefits (Hausmann et al., 2016). The use of hedgehogs as flagship fauna, therefore, could create overarching benefits for their habitats but also bolster individual and community well-being (Allgood et al., 2023).

Not only are hedgehogs nature ambassadors, but they may be considered indicators of broader ecosystem health whilst playing key roles in their respective habitats. They have important trophic functions as predators, prey and, for some, burrowers, actively modifying their environments. Hedgehogs can be used as model organisms in urban adaptation studies (Gazzard, 2022) and in other areas of science focusing on e.g., zoonotic disease transfer, antibiotic resistance, exposure to, and accumulation of, xenobiotics (e.g., Larsen et al. (2022); Rasmussen et al., 2024a; Rasmussen et al., 2024b). Despite this, many Erinaceid species receive relatively little research attention and populations remain poorly monitored. Research to describe their ecology and statuses will be vital if we wish to optimise conservation efforts and strategies for these taxa. Therefore, with the recent Red List status changes in mind, we encourage increased research and conservation efforts for documenting and preventing further decline of these important and charismatic species.

CRediT authorship contribution statement

Abigail Gazzard: Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation, Conceptualization. **David W. Macdonald:** Writing – review & editing, Supervision. **Sophie Lund Rasmussen:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Abigail Gazzard reports a relationship with IUCN that includes employment with the IUCN SSC Small Mammal Specialist Group. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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