Stacks

What is the future for The *Martes* Complex (*Guloninae*) in the face of climate change and ecological breakdown?

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Accepted by 2 of 2 reviewers

Funding Information
No funding was received for this study.

Conflicts of Interest
The authors declare no conflict of interest.

Publishing History
Submitted 12 April 2024
Accepted 17 April 2025
Published 13 June 2025

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Guloninae | Conservation Biology | Conservation Planning | Wildlife Policy | Climate Change

Abstract

The climate and ecological emergency (CEE) is impacting the natural world with increasing severity, with likely serious consequences for the *Martes* Complex (Guloninae) including range contraction and fragmentation, ecosystem collapse and disrupted inter-species relationships. We assessed the relative vulnerability of each species of Guloninae to the CEE based on IUCN listings, threats to preferred habitat, habitat specificity, global range size, and the nature and number of Köppen-Geiger climate zones occupied. This assessment indicated that ten of the eleven Guloninae are moderately or highly vulnerable to the impacts of the CEE, and only the stone marten *Martes foina* is of relatively low vulnerability.

Abstract photo. *European pine marten. Photo credit David Baird.*

We explored biotic and abiotic factors to identify the range of known and likely impacts upon Guloninae, with deforestation and wildfires as recurring themes. Mitigation for Guloninae should focus on landscape-scale efforts to expand and connect suitable forested habitat, ideally on a north-south axis so as to facilitate predicted range shifts. In anticipation of reduced funding for wildlife research and conservation in an increasingly unstable geopolitical context, the best opportunities for mitigation will likely depend upon influencing the forestry industry and national carbon capture reforestation policies.

Keywords: biodiversity loss, climate change, global heating, *Guloninae, Martes,* mitigation, reforestation

Introduction

The Earth's life-support systems are breaking down in response to global-scale processes driven by human activity. Referred to as the Climate and Ecological Emergency (CEE) (Gardner et al., 2021) because of the prominent influence of anthropogenic global heating and biodiversity loss, its impacts are increasingly harming humanity and the natural world (Fletcher et al., 2024). Notably, as a consequence of rising emissions of greenhouse gasses such as carbon dioxide, nitrous oxide and methane, the climatic stability that characterized much of the Holocene has been replaced by increasing global temperatures, rising sea levels, unpredictable seasons and a growing frequency and intensity of extreme weather events such as heatwaves, droughts, wildfires, high-energy storms, torrential rain and severe flooding (IPCC, 2023). Some scientists argue that we have left the Holocene and entered the Anthropocene, a new geological epoch characterized by the scale and severity of planetary processes driven by human activity (Zalasiewicz et al., 2010). Increasingly scientists view climate breakdown and biodiversity loss as symptoms of ecological overshoot driven by a crisis of unsustainable human behavior (Merz et al., 2023; Fletcher et al., 2024).

Since 1970 global populations of vertebrate wildlife have fallen on average by more than two-thirds (Almond et al., 2020). With an estimated one million species at risk of extinction, the five key drivers of biodiversity loss identified by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019) are: changes in land and sea use; direct exploitation of natural resources; climate change; pollution; and invasion of alien species. Ceballos and Ehrlich (2023) warn that we are in a human-driven sixth mass extinction event that is more severe than previously assessed and rapidly accelerating; predicted extinction rates for mammals are especially high at 511 times above background rates.

One of many consequences of the CEE is that ecosystems around the globe are being impacted by unprecedented environmental conditions that now compromise their capacity to support endemic species. The high probability of ever more catastrophic ecosystem impacts requires biologists to focus on identifying and mitigating impacts and helping natural systems to adapt to change as far and as fast as this is possible (Lawler et al., 2024). Whilst the CEE is a consequence of several anthropogenic drivers (IPBES, 2019), current societal concern and associated research effort relates primarily to the impacts of global heating and climate change. This is reflected in the focus of this paper.

In their review of efforts to assess species' vulnerability to climate change, Pacifici et al. (2015) defined vulnerability as 'the predisposition to be adversely affected', with both intrinsic and extrinsic factors contributing. Assessing the vulnerability of species to climate change typically involves an evaluation of exposure (the type and magnitude of climatic changes that the species has experienced or is projected to experience), sensitivity (how much it is affected by or susceptible to a climate-related change) and adaptive capacity (the species' ability to cope with, adjust to and persist under current and future climate change) (Thurman et al., 2020). Attempts at predicting the likely effects of climate change on species have used a range of different measures to assess their vulnerability, but very few (c. 4%) of the published studies reviewed by Pacifici et al. (2015) assessed species' vulnerability globally. An important role for conservation biologists is to identify those species that are most vulnerable to environmental changes of this magnitude in order to minimize global biodiversity loss (Pacifici et al., 2015).

The purpose of this paper is to assess the relative vulnerability of Guloninae to the CEE across their global distribution and to identify the range of known and likely impacts. The Guloninae comprises the eleven species within the genera *Martes*, *Pekania*, *Gulo* and *Eira*. These species share many life history traits, habitat associations and conservation challenges as detailed by Proulx & Aubry (2017).

The Guloninae's responses to CEE impacts are likely to vary between species according to their vulnerability and resilience, and some responses will be more predictable than others. Species' responses may affect many aspects of their biology including population density, demography and interspecific relations (Wereszczuk, 2023). Separate from climate change impacts, a related consideration is the vulnerability of each species to the existing direct and indirect impacts of human activity upon biodiversity, such as resource use and pollution. Species that are already declining due to non-climate change-related pressures are likely to be more sensitive to climate change. For example, Pearson et al. (2014) found that decreasing population size and/or occupied area, as well as increasing range fragmentation, were associated with higher extinction risk under climate change. Degradation and loss of habitat have already been identified as major threats to many Guloninae (Proulx et al., 2004), and Carroll (2007) identifies that this threat is exacerbated by the interacting effect of climate change leading to range fragmentation.

Most Guloninae have a strong affinity for or dependence upon forested habitats (Proulx & Aubry, 2017; Wright et al., 2022). From 2001 to 2023, there was a total of 488 Mha of tree cover loss globally, equivalent to a 12% decrease in tree cover since 2000 (Global Forest Review, 2024a) and forests are under accelerating multiple pressures, including increasing resource use, wildfires, shifting agriculture, and emerging diseases (Global Forest Review, 2024a; Tew et al., 2023). The geography and chronology of forest loss vary across the globe, with many countries in the global north having undergone major deforestation some centuries ago. Rates of tree cover loss have been rising since the year 2000, and there have been consistent differences in the extent of tree cover loss across the world's ecozones, with tropical and subtropical forests suffering greater losses than boreal and temperate forests (Global Forest Review, 2024a).

Direct anthropogenic deforestation to create space for agriculture and other land uses in boreal and temperate forests has now been superseded by increasing losses of tree cover to severe fires and insect pests, both fueled by global heating and drought related to the CEE, in addition to timber harvesting (Jolly et al., 2015; Pureswaran et al., 2018). Analyses by Global Forest Watch distinguish between these temporary impacts (identified as tree cover loss) that now account for 99% of losses in boreal and temperate forests, and permanent forest clearance for agriculture and urbanization (identified as deforestation) that dominates losses in the tropics (Global Forest Review, 2024a). Currently >96% of global deforestation (as opposed to tree cover loss) occurs in the tropics (Global Forest Review, 2024a). 32 million hectares of primary or recovering forest were lost in the highly biodiverse tropics between 2010 and 2015 (IBPES, 2019). Global Forest Watch reports that tropical primary forest loss remains on an increasing trend, with 3.7 million hectares destroyed in

2023 (Global Forest Review, 2024b) and this loss must be viewed as a significant driver of harm to the tropical Guloninae.

Rising global temperatures are predicted to be one of the greatest drivers of faunal change this century (Lawler et al., 2009). A review by Pigot et al. (2023) of geographical data for approximately 36,000 wild animal species, including >5,000 mammals, indicates that global heating is already driving widespread population change and geographical range contractions. Projections to the year 2100 under different heating scenarios show that species will suffer abrupt increases in the area of their geographical ranges where they will be at risk of thermal exposure. Some Guloninae are cold-adapted, so are likely to be adversely affected by global processes driving rising temperatures and associated reductions in snow cover. For example, for cold-adapted Guloninae it is of concern that the Paris Accord's 'safe guardrail' heating limit of 1.5oC (Schleussner et al., 2022) was breached in 2024 (Copernicus Climate Change Service, 2025) and large parts of the northern hemisphere were more than 1.5 degrees warmer than the 1991-2020 average (Figure 1; Copernicus Climate Change Service, 2025); and the Arctic region has been warming nearly four times faster than the global average since 1979 (Rantanen et al., 2022). Current policies intended to curb global emissions of greenhouse gases are inadequate and average temperatures are projected to increase to 2.7oC above pre-industrial levels by 2100 (Climate Action Tracker, 2023).

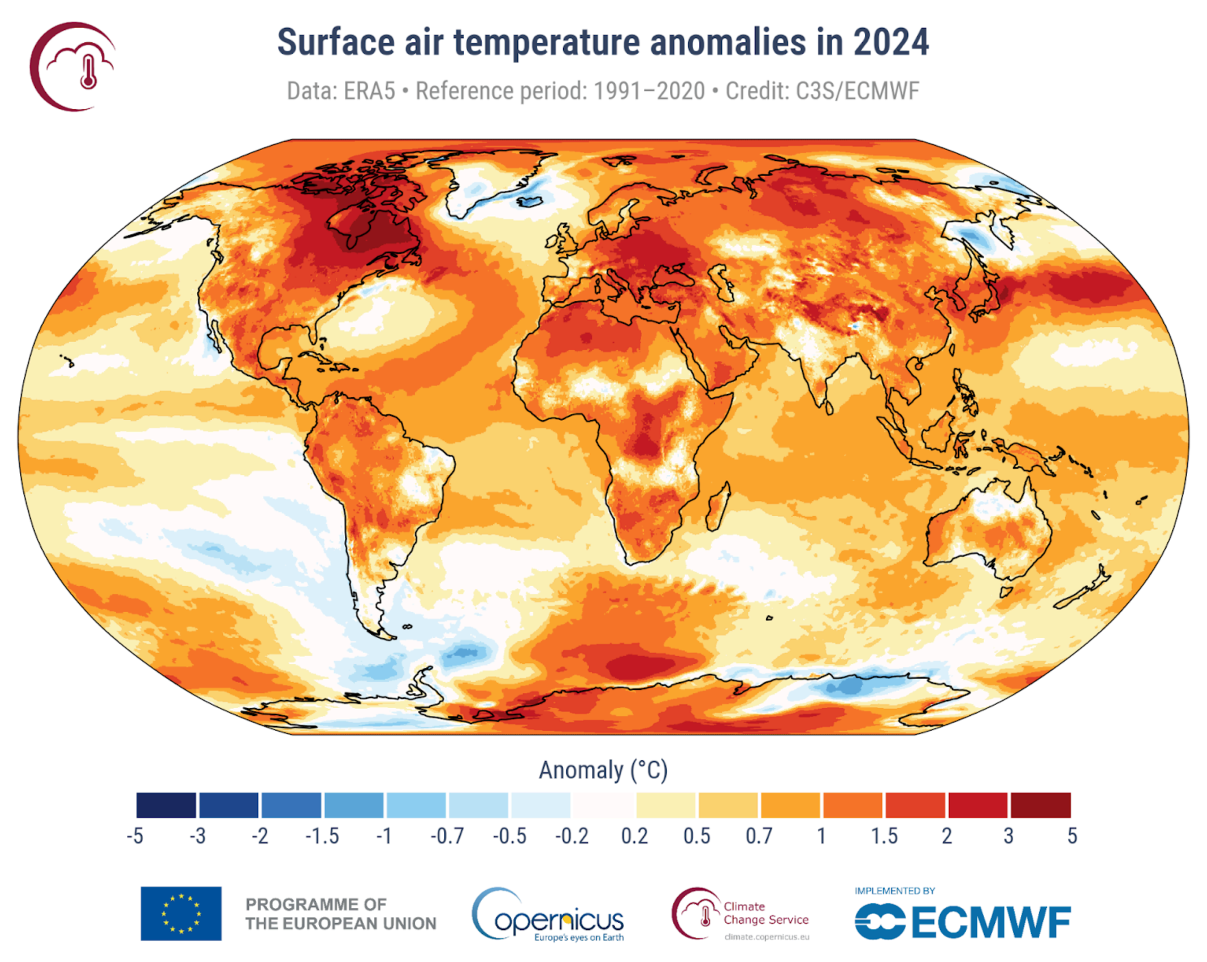

Figure 1. *Average surface air temperature anomaly in 2024 compared with the 1991-2020 average, showing that most of the world was hotter than normal in the record-breaking year of 2024. Notably, in 2024 parts of North America and Eurasia occupied by cold-adapted members of the Guloninae were >1.5oC warmer than the 1991-2020 average (Copernicus Climate Change Service, 2025).*

Methods and Materials

To assess the relative vulnerability of Guloninae species to the CEE we used a trait-based vulnerability assessment (TVA) framework. This framework uses the three dimensions of climate change vulnerability, namely sensitivity, exposure and adaptive capacity, to assign species to vulnerability classes (Foden et al., 2013). Although TVAs such as ours that are based on expert opinion and interpretation of the published literature can be somewhat subjective, the method nevertheless allows for a relatively rapid assessment of multiple species, which is useful for prioritizing and implementing conservation measures and is accessible to practitioners who may not have extensive knowledge of modeling techniques.

Each of the eleven Guloninae species (see Figure 2) was assigned - via the process outlined below - to a high, medium or low overall relative vulnerability class based on their combination of sensitivity, exposure and adaptive capacity. Species identified as having high vulnerability to the CEE are of greatest concern and are the highest priority for monitoring responses to climate change and likely the most at risk of serious harm in the absence of effective conservation action. Species identified as having medium vulnerability to the CEE have the potential to adapt but warrant close monitoring. Species identified as having low vulnerability to the CEE are those most likely to withstand harmful impacts but monitoring is needed to ensure that this assessment of vulnerability is realized.

We assessed seven factors to demonstrate sensitivity, exposure and adaptive capacity and used these to assign each species to a class of relative vulnerability to the CEE:

- Global range size
- Number of Köppen-Geiger climate zones (Peel et al., 2007; Beck et al., 2018) occupied
- Nature of Köppen-Geiger climate zones occupied
- Level of threat to preferred habitat
- Habitat specificity
- IUCN listing
- IUCN population trend

We accept that some of these characters overlap and interact to some degree. Nevertheless, we believe they provide a robust basis upon which to derive for the Guloninae a three-way classification of relative vulnerability to the CEE. We explain our reasoning below.

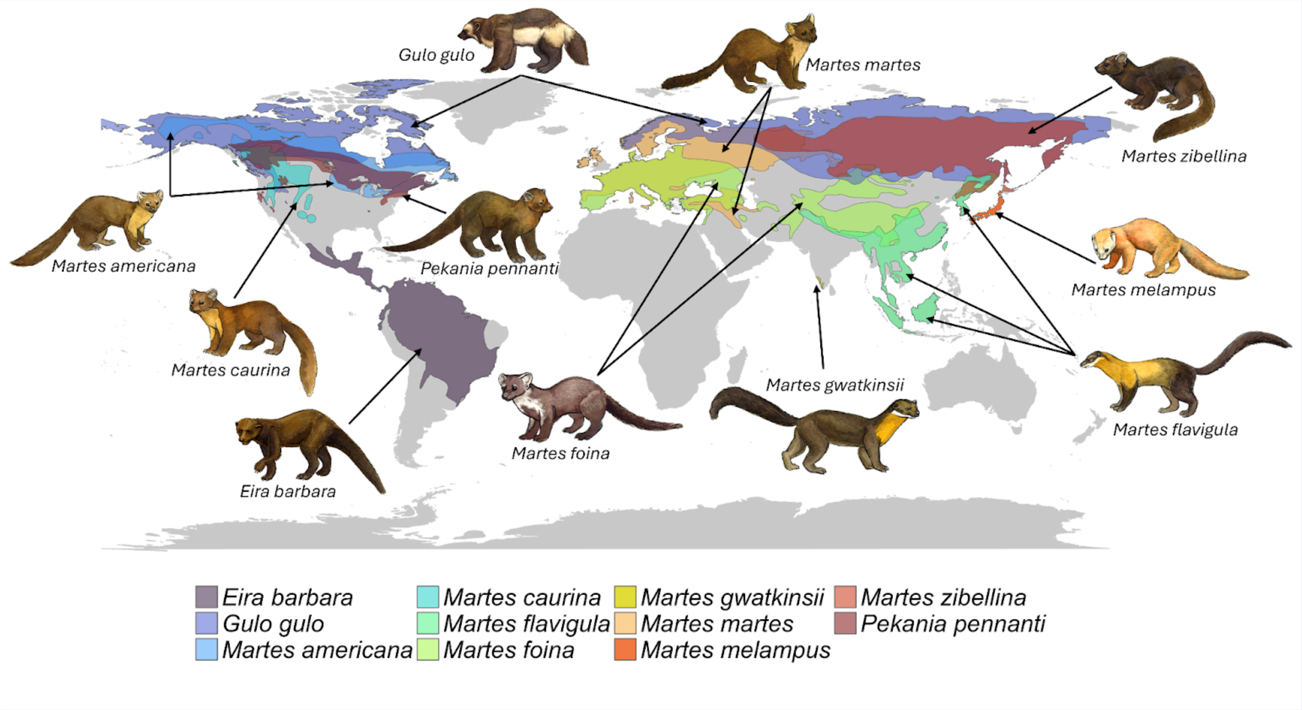

Figure 2. *Global distribution of the eleven Guloninae species (Burgar et al., 2025), reproduced with permission from the authors. For up to date ranges, refer to the Martes Working Group website www.marteswokinggroup.org.*

Global range size

We took the view that species with large global ranges were likely more resilient to CEE impacts than those with small global ranges. Global range location and size of maximum range extent in square kilometers were derived from the most recent IUCN listings. These represent the limits of the current known distribution from occurrence data along with knowledge of habitat, elevation limits and expert knowledge of the species and its range. However, the polygons displayed on the distribution maps communicate that the species probably only occurs within the polygon but it is not necessarily distributed equally nor does it occur everywhere within that polygon (IUCN, 2018). We categorized global range sizes of Guloninae as Small (<1 million km^2), Medium (1-10 million km^2) or Large (>10 million km^2). Species' global range sizes may be determined extrinsically by their tolerances to environmental conditions, but also by a species' capacity to breed, disperse and establish new populations. Comparatively small populations may have lower genetic diversity and, therefore, a lower intrinsic adaptive capacity as well as likely being isolated in space, and with less potential for range shift. Therefore, we determined that the smaller the global range size, the more sensitive a species will be to the impacts of the CEE.

Number of Köppen-Geiger climate zones occupied

We used the Köppen-Geiger system (Peel et al., 2007; Beck et al., 2018) that classifies global climate into five main zones: Tropical; Arid; Temperate; Continental; and Polar (Figure 3). We compared the global range of each species with the distribution of the five main climate zones to identify the nature and number of zones they currently occupy. We assumed that those species confined to just one climate zone would be more sensitive to climate change than those occupying two or more zones because of their lower intrinsic adaptive capacity and their inability to shift their range across multiple climate zones. Accordingly we chose the following categories: one climate zone occupied = High sensitivity; two climate zones occupied = Medium; and three climate zones occupied = Low.

Nature of Köppen-Geiger climate zones occupied

In light of evidence of regional differences in current rates of global heating and the strong association of cold-adapted Guloninae species with the faster-warming Polar and Continental climate zones, we assumed that there are differences in their vulnerability to global heating linked to the nature of the zone that each species predominantly occupies as follows: range predominantly in the Polar zone = High vulnerability; range predominantly in the Continental zone = Medium; range not in the Polar or Continental zones = Low.

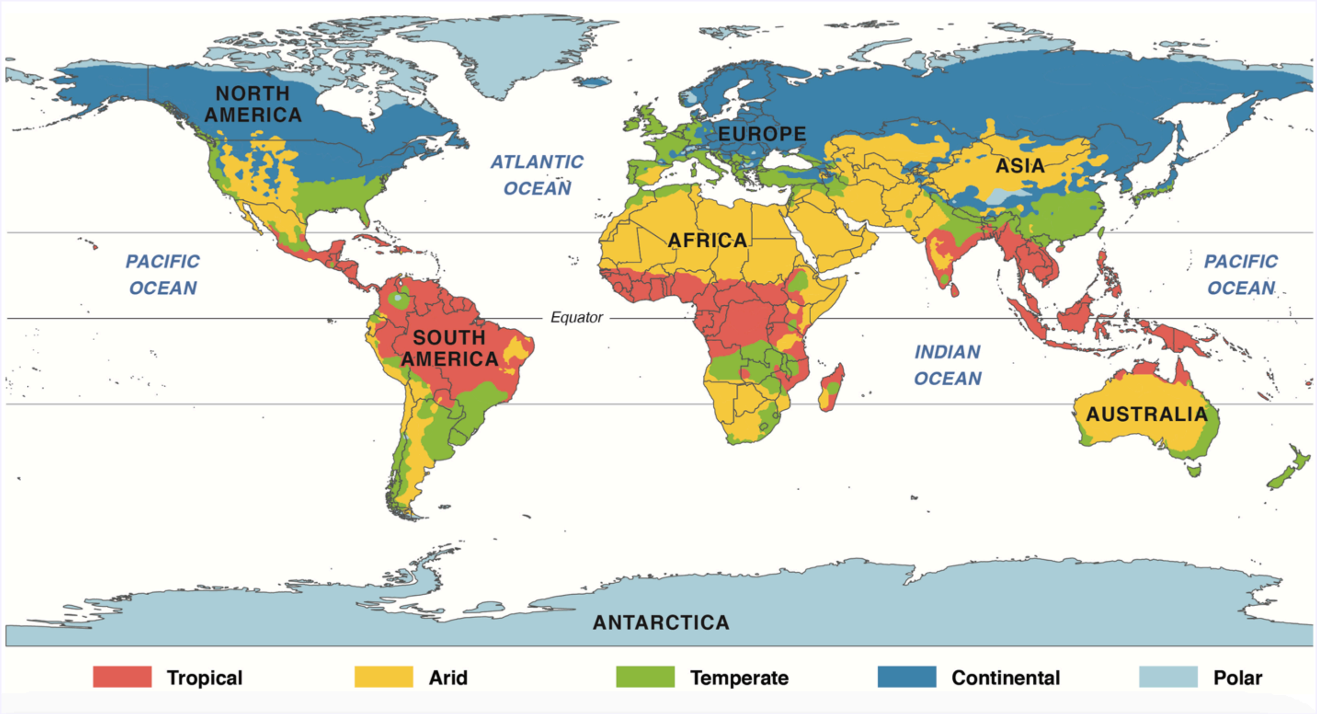

Figure 3. *The current global distribution of the five main climate zones defined and described by the Köppen-Geiger system (Peel et al., 2007; Beck et al., 2018). Image credit: Emily Eng, Smithsonian Institution https://ssec.si.edu/sites/default/files/other/climate/ClimateZoneMap-.pdf.*

Level of threat to preferred habitat

In light of evidence of marked differences in current rates of forest loss between the tropics and other bioclimatic zones we assigned a level of exposure to the CEE based on the level of threat to the forested habitat that each species occupies as follows: High = species occupying tropical forests; Medium = species occupying non-tropical forests; Low = species showing no strong preference for occupying forested habitat. We derived information on forest occupancy for each of the eleven species from a combination of expert opinion and interpretation of the current literature.

Habitat specificity

The degree of habitat specificity for the Guloninae species was also derived from expert opinion and interpretation of the current literature. We used the habitat specificity of each species as a measure of their adaptability to changing conditions in their preferred habitat as follows: High = species rarely recorded outside their preferred habitat demonstrating low adaptability; Medium = species demonstrating tolerance of moving through a heterogeneous habitat matrix; and Low = species recorded throughout heterogeneous habitat outside of their preferred habitat demonstrating high adaptability. Species identified as having a high degree of habitat specificity were deemed to be less adaptive and therefore have a higher vulnerability to the CEE than those demonstrating greater adaptive capacity with a medium or low degree of habitat specificity.

IUCN listing

We recognized that current IUCN listings may not all be accurate because the latest assessment was completed in 2015. For example, it does not separate the genetically distinct Pacific marten *M. caurina* and American marten *M. americana* (Carr & Hicks, 1997; Dawson et al., 2012). We assumed that those species listed by IUCN as ‘Endangered’ are the most sensitive to the CEE (= High sensitivity) followed by those that are listed as ‘Vulnerable’ (= Medium) and as ‘Least Concern’ (= Low) respectively.

IUCN population trend

We considered the IUCN population trends of each of the eleven species to assess their current sensitivity to the CEE. Informed by Pearson et al. (2014), we assumed that species whose populations are already decreasing as a result of existing and historical threats (such as habitat loss, over harvesting and non-native invasives) will be more sensitive to the impacts of the CEE than those species that are currently not experiencing decline as a result of pre-existing threats. Accordingly, we assumed that those species with a ‘Decreasing’ population trend are more sensitive to the CEE (= High sensitivity) than those with a ‘Stable’ (= Medium) or ‘Increasing’ (= Low) population trend respectively.

Having categorized and/or quantified the factors as explained above, we identified the contribution each factor made to the overall relative vulnerability of species to the CEE as shown in Table 1. This process involved a quantification of overall vulnerability based upon the total scores for each species, where High factors scored 3, Medium factors scored 2 and Low factors scored 1.

In order to define overall relative vulnerability based upon the sum of the seven factor threshold scores we used the following thresholds:

- Low overall vulnerability (9-11)
- Medium overall vulnerability (12-14)
- High overall vulnerability (15-17)

Table 1. *A summary of the three-way categorisation of each of seven factors assumed to define relative vulnerability to the Climate and Ecological Emergency (CEE). Species are classified as having High, Medium, or Low overall vulnerability to the CEE based on the scored thresholds of the seven contributing factors.*

Factor	**Contributions of factor thresholds to overall relative vulnerability to the CEE**		
	High (3)	**Medium (2)**	**Low (1)**
Global range size	Small	Medium	Large
Number of climate zones occupied	1	2	3
Nature of climate zone occupied by main range	Polar	Continental	Neither Polar nor Continental
Threat to preferred habitat	High	Medium	Low
Habitat specificity	High	Medium	Low
IUCN Listing	Endangered	Vulnerable	Least Concern
IUCN Population Trend	Decreasing	Stable	Increasing

Results

Details of the contribution of the seven factors to the overall vulnerability to the CEE of the eleven Guloninae species and their overall relative vulnerability score are presented in Table 2. Three of the eleven Guloninae species were assessed as having high overall vulnerability to the CEE, comprising the American, Pacific and Nilgiri martens. Six species were assessed as having medium overall vulnerability to the CEE: Sable; yellow-throated marten; Japanese marten; pine marten; fisher; wolverine and tayra. Only the stone marten was assessed as being of relatively low overall vulnerability to the CEE.

Direct impacts of climate change on Guloninae

Whilst our assessment indicates that most of the Guloninae are moderately or highly vulnerable to the CEE, some impacts of rising temperatures are difficult to predict in the absence of data on the thermal niche of each species. Nevertheless, the knowledge that eight of the 11 Guloninae species are cold-adapted and associated with the Polar and/or Continental Köppen-Geiger climate zones, together with evidence that the Arctic is warming four times faster than the global average (Rantanen et al., 2022), suggests that these species may already be experiencing significant effects.

Increasing temperatures will likely drive the northward and upslope range contraction of cold-adapted species; this may induce increased range fragmentation and isolation of sub-populations given limited connectivity of suitable habitat, and potential risks of increased intra- or inter-specific conflict (Elsen & Tingley, 2015; Vergara et al., 2016). Where more thermophilic species are sympatric, such range shifts may involve the replacement of one species by another. For example, modeling of Guloninae responses in Europe have predicted northward range contraction of the cold-adapted pine marten and northward range expansion by the more habitat-generalist and adaptable stone marten (Vergara et al., 2016; Lawler et al., 2012). Similarly, modeling predictions by Spencer et al. (2015) indicate that Pacific marten in the Sierra Nevada is likely to suffer from habitat loss and fragmentation under climate change, with upslope shrinkage of habitat; in contrast, future predictions for fisher varied between climate scenarios, with some predicting habitat loss and others habitat gain. Zielinski et al. (2017) affirm the uncertainty of outcomes where responses to climate change of competing Guloninae at their range edge are difficult to predict.

Table 2. *A summary of the contribution of each of the seven factors to the overall vulnerability of the 11 Guloninae species to the Climate and Ecological Emergency (CEE) based on the threshold classifications described above. Relative vulnerability scores are shown as bold numbers (see Table 1 for definitions). Note that the threat level number in the preferred habitat column relates to the threat to that habitat (see Table 1). Note that the IUCN gives no population trend for Fisher, so we have assigned this factor a 'Medium' score. Also, because the IUCN does not separate the Pacific marten from the American marten, we have assigned the same IUCN factor scores to each of these species.*

Species	Global Range (km^2) (IUCN)	No. of Climate Zones Occupied	Main Climate Zone	Preferred Habitat and Threat Level	Habitat Specificity	IUCN Status	IUCN Population Trend	Overall Vulnerability Score	References
American marten *Martes americana*	6,987,000 (**2**)	1 (**3**)	Continental (**2**)	Late successional, closed-canopy forests with complex structure near ground level (**2**)	Avoids areas with >25% open habitat, even with connectivity (**3**)	LC (**1**)	Decreasing (**3**)	16 (**High**)	Buskirk & Powell, 1994; Hargis et al., 1999; Helgen & Reid, 2016.
Pacific marten *M. caurina*	651,000 (**3**)	2 (**2**)	Continental (**2**)	Late successional, closed-canopy forests with complex structure near ground level (**2**)	Highly sensitive to landscape change from wildfire and timber harvest (**3**)	LC (**1**)	Decreasing (**3**)	16 (**High**)	Volkman & Hodges, 2022; Volkmann et al., 2020; Helgen & Reid, 2016.
European pine marten *M. martes*	9,930,000 (**2**)	3 (**1**)	Continental (**2**)	Late successional, closed-canopy forests with complex structure near ground level (**2**)	Also uses hedged farmland and smaller woodlands (**2**)	LC (**1**)	Stable (**2**)	12 (**Medium**)	McNicol et al., 2020; Mergey et al., 2023; Herrero et al., 2016.
Stone marten *M. foina*	12,454,000 (**1**)	3 (**1**)	Temperate and Continental (**1**)	Landscape mosaics with large forest patches and cropland (**1**)	Shifts to rural and urban areas where it coexists with pine martens (**2**)	LC (**1**)	Stable (**2**)	9 (**Low**)	Otte, 2021; Fonda et al., 2021; Abramov et al., 2016.
Sable *M. zibellina*	10,082,000 (**1**)	1 (**3**)	Continental (**2**)	Late successional, closed-canopy forests with complex structure near ground level (**2**)	Responds negatively to the absence of tree canopy, of large live trees, and of coarse woody debris (**3**)	LC (**1**)	Increasing (**1**)	13 (**Medium**)	Miyoshi & Higashi, 2005; Buskirk et al., 1996; Monakhov, 2016.

Yellow-throated marten *M. flavigula*	6,698,000 (**2**)	1 (**3**)	Temperate and Tropical (**1**)	Tropical and subtropical forests, subalpine and alpine environments (**3**)	Occupies diverse habitats, including forests, plantations, gardens. Recorded traveling on roadsides and trails (**2**)	LC (**1**)	Decreasing (**3**)	13 (**Medium**)	Proulx & Aubry, 2017; Hon et al., 2016; Chutipong et al., 2016.
Japanese marten *M. melampus*	280,000 (**3**)	2 (**2**)	Temperate and Continental (**1**)	Deciduous and evergreen broad-leaved forests (**2**)	Low habitat preference and widespread detection (**2**)	LC (**1**)	Stable (**2**)	13 (**Medium**)	Tatara, 1994; Tanigawa et al., 2022; Abramov et al., 2015.
Nilgiri marten *M. gwatkinsii*	31,000 (**3**)	1 (**3**)	Tropical (**1**)	Medium to high elevation evergreen forests and montane shola grassland areas (**3**)	Prefers forest edges near high-elevation shola habitats (**3**)	V (**2**)	Stable (**2**)	17 (**High**)	Balakrishnan, 2005; Shameer et al., 2023; Mudappa et al., 2015.
Fisher *Pekania pennanti*	3,721,000 (**2**)	2 (**2**)	Continental (**2**)	Forests of diverse types and variable ages (**2**)	Occupies diverse landscape, including forests, agriculture and urban areas. High use of corridors linking forest patches (**2**)	LC (**1**)	Unknown (population trend varies by region; some declining, others recovering) (**2**)	13 (**Medium**)	Pauli et al., 2022; LaPoint 2013; Helgen & Reid, 2018.
Wolverine *Gulo gulo*	24,394,000 (**1**)	2 (**2**)	Continental (**2**)	Boreal forest and high elevation talus (2)	Expanding southward in Sweden from alpine areas to boreal forests. Increasing breeding records in snow-free areas (**3**)	LC (**1**)	Decreasing (**3**)	14 (**Medium**)	Caroll et al., 2021; Persson et al., 2023; Abramov, 2016.
Tayra *Eira barbara*	13,375,000 (**1**)	2 (**2**)	Tropical (**1**)	Forests with intermediate disturbance, such as secondary forest and edge habitats (**3**)	Able to coexist with humans and persist in a variety of habitat types (**2**)	LC (**1**)	Decreasing (**3**)	13 (**Medium**)	Twining et al., 2023; Cuarón et al., 2016.

[1] **LC = Least Concern; V = Vulnerable**

An empirical example of range shift response by a cold-adapted Guloninae is reported in Hiltner's (2022) study of the American marten in Michigan's Upper Peninsula, at the southern edge of the species' US range where an earlier study by Lawler et al. (2012) predicted that climate change would shrink and degrade marten habitat. Harvest data between 2005 and 2020 revealed a gradual decrease in marten occupancy in the southern part of the study area in response to a decline in the area of suitable abiotic conditions, notably deep snow and low mean winter temperatures (Hiltner, 2022). In light of wider predictions of northward range shifts by this species in response to global heating, Hiltner (2022) argues that an understanding of the drivers of change at the southern border will better inform conservation action for American martens. A separate modeling study of American martens in the northern Appalachians (Carroll, 2007) predicted a 40% population decline by 2055 in response to reduced snow cover due to global heating.

Impacts of wildfires on Guloninae

Outside of the tropics, global trends in tree cover loss are driven by fire dynamics in boreal forests (Global Forest Review, 2024a). These events rapidly damage or destroy large areas of habitat, with a variety of context-dependent responses from the carnivores that occupy them (Geary et al., 2020). The frequency, extent and severity of wildfire events are increasing in response to global heating and associated drought conditions (IPCC, 2023; Jolly et al., 2015). For example, 2023 was remarkable for the extent of forest destroyed by wildfires across many countries, damaging the habitat of several northern Guloninae species. Notably, Canada had its worst wildfire season on record, with a fivefold increase in tree cover loss due to fire compared with 2022 (Global Forest Review, 2024b). Research studies on the impacts of changing fire regimes upon carnivores occupying boreal and montane forests in Canada and the USA are undermined by taxonomic bias and inconsistent approaches (review by Volkmann et al., 2020).

Further south, increasingly severe wildfires have impacted the habitat of fisher and Pacific marten in the western USA: movements of Pacific martens revealed complex responses to post-fire forest landscapes, with extreme avoidance of areas subject to salvage logging, the practice of extracting trees from disturbed areas to minimize loss of commercial timber (Volkmann & Hodges, 2021). A study of fishers - a species of conservation concern in the western U.S. - by Green et al. (2022) revealed decreases in fisher abundance following damage to habitat in the Sierra Nevada caused by wildfires and post-fire forest management such as salvage logging; the authors concluded that the increasing severity, frequency and extent of wildfires in the western USA will harm fisher populations and alter the composition of mesocarnivore communities.

Biotic factors driving changes in Guloninae behavior, range and/or abundance

Biotic responses to the CEE will influence the structure and function of ecosystems and their capacity to support healthy populations of Guloninae species. Impacts may range between minor shifts in the availability of resources, to complete ecosystem breakdown. ‘Catastrophic forest ecosystem collapse’ was the highest ranked issue among a majority (64%) of Expert Panel members considering the future of UK forests over the next 50 years (Tew et al., 2023). Inevitably, catastrophic consequences of global climate breakdown for forest habitats will be widespread beyond the UK, with serious impacts upon tree health and forest structure arising from the increasing intensity and frequency of drought, wildfires and storms (IPCC, 2023). The rising impact of pests such as bark beetles on trees rendered more vulnerable by climatic stress has led to predictions of wide scale collapse of boreal forests - important Guloninae habitat and a major global carbon sink - across the northern hemisphere (Greenfield, 2024).

Predicting outcomes for Guloninae is challenging because of the complexity of ecosystem components, interactions and processes involved. Nevertheless, identifying the drivers that stress and threaten populations in an era of rapid environmental change is crucial (Kuntze et al., 2024). The examples below offer some insights into the scale of that challenge.

Some climate-related impacts upon Guloninae are driven by prey populations responding to rapid environmental change. Shifts in prey abundance, distribution and the timing of activity (Saino et al., 2011;

Schweiger et al., 2008) may have profound impacts upon predators. For example, in the Sierra Nevada of California wide-scale climate-induced tree mortality induced a dietary shift from mammals to plants in an endangered population of fishers because of reductions in the availability of preferred mammalian prey (two species of tree squirrel), with likely consequences for the behavior, energetics, demography and fitness of the population (Pilgrim et al., 2023). Other studies have demonstrated effects of tree mortality on physiology, behavior and survival of fishers (Kordosky et al., 2021a; Kordosky et al., 2021b; Kuntze et al., 2024). Changes in forest composition and snow cover regimes have also resulted in northward shifts in important prey populations, with possible implications for American marten populations (Scott et al., 2022).

Drought-induced tree mortality was found to be the main driver of stress levels in fishers in the California population, with associated demographic impacts including reduced survival rates (Kordosky et al., 2021a; Kuntze et al., 2024). The survival of this isolated fisher population at the southern end of the Sierra Nevada mountain range is now uncertain because of the impacts of climate change, including the rapid increase in the size and severity of wildfires driving habitat loss and fragmentation (W. Spencer, pers. comm. [paper presented to Aviemore *Martes* Symposium]; Spencer et al., 2015; Kuntze et al., 2024; Steel et al., 2023).

Differential responses of two North American Guloninae to climate change and forest management have been revealed by trapper interviews in eastern Canada (Suffice et al., 2017): fishers had increased and expanded their range since the early 2000s, while American martens had decreased. Results from interviews suggest that forest management and climate change conferred localized benefits upon fishers, while negatively influencing American martens due to declining habitat and increased predation and competition from fishers and other carnivores. An earlier study highlighted the role of snow in segregating American martens and fishers (Karniski, 2014). Given the similarity between these two species, increased agonistic interactions driven by reduced snow cover are likely to be detrimental to the smaller American martens, which are occasionally killed by fishers (McCann et al., 2010).

In Poland, a global heating-induced increase in primary productivity and woodland rodent populations is believed to have driven a change in skull morphology and increase in pine marten body size since 1980, together with a shift towards a male-biased sex ratio over the same period (Wereszczuk et al., 2023). Moreover, a wider study of both pine and stone martens across continental Europe revealed differential rates of climate warming-induced body mass increase (over the period 1960-2019 pine marten average body mass increased by 24%; stone martens by 6%), with stronger interspecific competition a potential consequence in areas of sympatry (Wereszczuk et al., 2021). These are part of a suite of unpredictable morphological changes reported across many taxa as species respond to new conditions delivered by global heating (Goldenberg et al., 2022; Weeks et al., 2020).

Socio-economic impacts upon Guloninae research and conservation

As human societies around the globe experience the increasingly harmful impacts of the CEE, the likelihood of energy, food and water insecurity, mass migration, international conflict and societal breakdown will grow (Richards et al., 2021). In response, national governments will necessarily change policies and funding priorities in their efforts to avert or minimize economic and societal collapse. Funding for wildlife research and conservation will likely shrink to the extent that most work on Guloninae will lose financial support.

Under a CEE scenario of public funds shifting away from Guloninae conservation, the continuation of such work will depend upon the extent to which higher priority policy areas might be influenced to benefit Guloninae. For example, reforestation is now prioritized by governments because of its role in carbon sequestration (e.g. Forestry Commission, 2022; Cho et al., 2025) and the supply of carbon neutral material for the construction industry (Atkinson et al., 2022; Rapid Transition Alliance, 2021). A further incentive for extensive tree planting arises from new evidence that afforestation contributes to local air cooling and climate mitigation (Barnes et al., 2024). Herein lie opportunities to influence the scale and pattern of afforestation and reforestation to mitigate CEE impacts upon Guloninae (see below).

Mitigating the CEE's impacts upon Guloninae

The collective global failure to address the causes of global heating and biodiversity loss forces wildlife biologists to focus on anticipating and mitigating impacts upon the natural world. In view of the northward and altitudinal range shifts projected for many Guloninae (Lawler & Hepinstall-Cymerman, 2010) and the associated risks of range fragmentation and reduced population viability, mitigation should prioritize the maintenance and enhancement of habitat connectivity. Efforts should focus on establishing viable ecological networks (Lawton et al., 2010), ideally organized to facilitate anticipated directional and elevational range shifts. This approach is most urgently required in those forested countries that currently experience high rates of resource extraction and continuing primary forest loss (Fisher et al., 2022; Global Forest Review, 2024b); as well as in historically deforested countries where Guloninae populations are constrained by poor availability and connectivity of woodland habitat (e.g. MacPherson & Wright, 2021).

Opportunities to expand and connect Guloninae habitat to maximize population resilience are provided by the global target to halt forest loss and restore 350 million hectares of lost and degraded forests by 2030 (Global Forest Review, 2024c). This will require strategic, landscape-scale approaches in line with the 'Bigger, Better, More and Joined' Lawton principles of nature conservation (Lawton et al., 2010). Effective delivery will likely depend upon government-driven land use strategies designed to resolve conflicts between different land use interests striving to achieve climate change adaptation whilst meeting the needs of human society (e.g. Forestry Commission, 2022). A likely hindrance affecting large-scale decarbonization tree-planting is provided by the substantial uncertainties surrounding future climate and economic conditions (Cho et al., 2025).

When making the case for designing reforestation plans to benefit Guloninae, arguments should draw upon evidence that biodiverse forest ecosystems are more resilient to the impacts of the CEE (Thompson et al., 2009) and that Guloninae can deliver ecosystem services, including landscape-scale biological control of invasive species (e.g. Twining et al., 2022). Such benefits should be recognized as part of the expanding field of nature-based solutions to the societal challenges of climate breakdown and biodiversity loss (Seddon et al., 2021).

In rising to the challenges presented by the CEE, conservation biologists should recognize the role that tipping elements may play in the earth's climate system, notably where these create uncertainty in projections of environmental change. For example, the Atlantic meridional overturning circulation (AMOC) is one such tipping element that, if it collapses under pressure from oceanic freshwater forcing, would trigger a reversal in the current warming of the northern hemisphere, with the greatest cooling apparent in western Europe (van Westen et al., 2024).

Conclusions

The increasingly catastrophic impacts of the Climate and Ecological Emergency will likely define the work of wildlife biologists through the remainder of this century and beyond. So, efforts must focus on maximizing Guloninae resilience by addressing the following tasks at appropriate geographical scales:

- Understanding the drivers of harm to Guloninae
- Predicting and monitoring Guloninae responses to the CEE
- Reporting impacts upon Guloninae to wider society
- Designing and enacting mitigation for Guloninae
- Securing ways of continuing research and conservation work
- Prioritising research and conservation work on the most vulnerable and/or neglected species.

These actions may provide a foundation for conservation action which, if enacted effectively by wildlife managers, could mitigate the impacts of the CEE upon Guloninae as they increase in severity through the 21st century (Prato, 2009).

In many countries, the future survival of Guloninae will depend upon the forestry industry and its efforts to adapt to the CEE and, thereby, to meet the needs of human society. Those efforts will involve substantial changes in forestry practice – many of which will directly or indirectly impact Guloninae - as adaptive measures are deployed to combat new or elevated risks to forests of windthrow, wildfires, drought, heat stress, flooding, pests and diseases (e.g. Atkinson et al., 2022; Tew et al., 2024). Nevertheless, in an era of likely great reductions in funding for wildlife research and conservation, climate change adaptation commitments to deliver landscape-scale reforestation provide the best opportunities to mitigate CEE impacts upon Guloninae.

Acknowledgments

We are grateful to members of the *Martes* Working Group for valuable discussions around Guloninae and the CEE; notably, we thank Jo Burgar for pre-publication permission to reproduce the Guloninae global range map. We thank three anonymous reviewers for their significant contributions to improving this paper. We thank Stacy Coty for help with access to literature and Bryn Evans for editorial input. JB acknowledges the special contribution - by deepening his understanding of the climate and biodiversity crises - of scientists and fellow activists at Extinction Rebellion and journalists at The Guardian newspaper.

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Data Availability

This manuscript did not generate new data and collated data are presented in Tables 1 and 2.

Transparent Peer Review

Results from the Transparent Peer Review can be found here.

Recommended Citation

Birks, J., Johnstone, S., Snell, E., & MacPherson, J. (2025). What is the future for The *Martes* Complex (Guloninae) in the face of climate change and ecological breakdown? *Stacks Journal*: 25006. https://doi.org/10.60102/stacks-25006

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