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Recent butterfly extinctions in Sweden reveal the inadequacy of site-based protection and the need for landscape-scale management

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Abstract

Recent extinctions of protected butterflies in regions with strong conservation frameworks raise concerns about biodiversity loss in northwestern Europe. Using historical records, citizen science data and systematic surveys, we documented the local extinctions of three butterfly species (*Parnassius mnemosyne* ssp. *argiope*, *Melitaea britomartis*, and *Plebejus argyrognomon*), which are high-priority conservation targets in Sweden and beyond. *Parnassius mnemosyne* is further protected under the EU Habitats Directive, Swedish national regulations, and the Bern Convention. While some European butterflies are expanding northward with climate change, these three diet and habitat specialists show range contractions across their distributions. Following the severe drought in 2018, *M. britomartis* was last observed in Sweden that same year, *P. argyrognomon* persisted until 2019, and *P. mnemosyne* ssp. *argiope* until 2023. Despite Sweden's environmental protection measures, species action plans, and monitoring programs, these extinctions highlight the vulnerability of isolated populations on northern margins to land-use intensification and extreme weather events. Conservation success now hinges on coordinated efforts by universities, environmental authorities, and conservation organizations to not only manage remaining grassland specialists but also restore and reconnect habitat at the landscape scale.

KEYWORDS

biodiversity, butterflies, climate change, conservation, habitat fragmentation, local extinction, northwestern Europe

1 | INTRODUCTION

Terrestrial insect biomass and diversity are declining at unprecedented rates, jeopardizing ecological functioning and the delivery of ecosystem services (Cowie et al., 2022; Wagner et al., 2021; Wepprich et al., 2019). In Europe, long-term butterfly monitoring has shown a decline in mean abundance of approximately 30% since 1990, with grassland specialists experiencing an even larger decline (Maes et al., 2019; van Swaay et al., 2022). Similar patterns are emerging in North America, with two-thirds of species showing population decreases (Edwards

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et al., 2025). The 2018 pan-European mega-drought, an event of historic severity (Buras et al., 2020), exemplified how extreme weather can amplify insect population declines (Betzholtz et al., 2025; Johansson et al., 2022; Weiss et al., 2024). Metapopulation theory predicts that such stochastic events become extinction triggers when habitat networks are small, fragmented, and homogeneously managed (Hanski, 1998; Kindvall, Forsman, et al., 2022).

Sweden is often cited as a legislative frontrunner in insect conservation (Jönsson et al., 2021). Eight butterfly species receive strict protection under the Species Protection Ordinance; 33 are on the national red list (Eide et al., 2020); and over 4000 Natura 2000 sites are present (Spiliopoulou et al., 2023). Management is supported by agri-environment payments and by a national biodiversity strategy (Kindvall, Forsman, et al., 2022). Complementing these instruments, the National Inventory of Landscapes in Sweden and the Swedish Butterfly Monitoring Scheme provide comprehensive datasets (Ståhl et al., 2011). Paradoxically, however, 44% of the country's resident butterflies have suffered local or regional extirpations since 1900 (Nilsson et al., 2008). This discrepancy between policy ambition and ecological outcome raises concerns about whether existing frameworks can buffer habitat specialists against the dual pressures of land-use intensification and climatic extremes (Franzén & Johannesson, 2007; Maes et al., 2019).

The present study focuses on three such specialists formerly confined to species-rich grasslands in southern Sweden: the clouded Apollo *Parnassius mnemosyne* (southern metapopulation historically referred to as ssp. *argiope*), Assmann's fritillary *Melitaea britomartis*, and Reverdin's blue *Plebejus argyrognomon*. All are nationally Red-Listed (Eide et al., 2020); *P. mnemosyne* is additionally listed in Annex IV of the EU Habitats Directive and Appendix II of the Bern Convention. Since 2023, none of these taxa have been recorded despite targeted surveys—an observation that, if verified, would represent the first Swedish butterfly extinctions since the 1950s (Eliasson et al., 2005).

Our objectives are therefore to:

1. Verify the extirpation status of these populations by collating structured monitoring data, targeted search effort, and opportunistic citizen-science records from 2010 to 2024;
2. Situate these disappearances within the context of recent climatic events by assessing the temporal alignment of the population collapses with the documented 2018 mega-drought; and
3. Critically evaluate the adequacy of existing conservation instruments by examining their scale and management prescriptions in relation to the ecological requirements of the target species.

By integrating ecological evidence with a policy audit, we aim to inform the redesign of agri-environment and protected-area measures, ensuring that remaining grassland specialists in northern Europe are better insulated from future extreme climate events.

2 | MATERIALS AND METHODS

2.1 | Study species and conservation status

This study focuses on three specialist butterfly species of high conservation concern in Sweden.

2.2 | *Parnassius mnemosyne* (clouded Apollo)

In Sweden, this species is traditionally classified into two subspecies based on phenotype: *P. m. argiope* in the south and *P. m. romani* in the north (Eliasson et al., 2005). However, it should be noted that recent genomic analyses do not support this subspecific division (Talla et al., 2023). The southern metapopulation, historically representing the northern margin of a range extending through Denmark and Germany, is dependent on *Corydalis* spp. as host plants for its larvae. In Sweden, *P. mnemosyne* is listed as Endangered, receiving strict protection under the EU Habitats Directive (Annex IV), the Bern Convention (Appendix II), and the Swedish Species Protection Ordinance (Eliasson et al., 2005).

2.3 | *Melitaea britomartis* (Assmann's fritillary)

Occurring at its northern range limit, the last known Swedish populations of this species were in Kalmar County. This habitat specialist requires warm, sheltered mosaics of semi-natural grassland and sparse woodland where its larval host plant, *Plantago lanceolata*, grows. *M. britomartis* is classified as Critically Endangered in Sweden but lacks specific international legal protection, making it reliant on national conservation initiatives (Eliasson et al., 2005).

2.4 | *Plebejus argyrognomon* (Reverdin's blue)

The Swedish populations of this species, also at their northern range margin, have experienced a dramatic decline. It exhibits strict ecological requirements, relying exclusively on its larval host plant, *Astragalus glycyphyllos*, which is found in warm, calcareous grasslands. Despite its Critically Endangered status in Sweden, *P. argyrognomon* receives no specific protection under EU legislation (Eliasson et al., 2005).

2.5 | Biogeographical context

All three species occur at their northern range margins in southern Sweden. Such range-edge populations typically exhibit smaller sizes, greater isolation, and reduced genetic diversity, increasing their sensitivity to environmental stochasticity (Thomas et al., 1994). Range-edge environments generally have higher severity and frequency of extreme climatic events relative to the range core (Hampe & Petit, 2005), while populations at range edges often face environmental extremes that impose physiological limits and impact population growth (Sexton et al., 2009). This positioning makes them exceptionally vulnerable to the impacts of extreme weather events and climate change (Franco et al., 2006; Hargreaves et al., 2014).

2.6 | Study area and occurrence data

The study was conducted across the historical and recent ranges of the target species in southern Sweden, with comparative data from Denmark and southern Norway (latitudes 54–60°N). This region is characterized by a fragmented landscape of intensive agriculture and commercial forestry, interspersed with remnant patches of semi-natural grassland.

We systematically compiled occurrence records from 1900 to 2024 from four primary sources selected for reliability and temporal coverage: (1) museum and literature records providing a historical baseline (1900–1955) (Nordström et al., 1955); (2) the European butterfly atlas for continental context (1970–2006) (Settele et al., 2008); (3) systematic monitoring data (2010–2024) from the Swedish Butterfly Monitoring Scheme; and (4) quality-controlled citizen-science observations from Artportalen, Sweden's national biodiversity database. Records lacking photographic or expert validation were excluded.

2.7 | Survey design and effort quantification

For detailed extinction assessments, we focused on recent records (2014–2024), coinciding with the initiation of coordinated surveys under Swedish species action plans. We mapped historical distributions at a 50 × 50 km resolution and recent records at a 1 × 1 km resolution to track population declines precisely. While intensive monitoring focused on the last known localities, surveys were extended to include all historical sites and suitable habitat patches within a 50 km radius.

To distinguish genuine absences from insufficient survey coverage, we quantified survey effort using two metrics derived from all butterfly observations reported to Artportalen: (1) person-days, the number of unique observer-date combinations per 1 × 1 km grid during the target species' flight period; and (2) spatial coverage, the number of 1 × 1 km grid cells surveyed annually. This approach assumes that high levels of general butterfly recording activity indicate adequate survey effort for detecting the target species.

2.8 | Data analysis and limitations

While detailed quantitative habitat and climate modeling was beyond the scope of this study, surveyors documented key environmental changes, including habitat succession, intensified grazing, and visible drought impacts. Our analysis, therefore, focuses on trends in occupancy and relative abundance. As our data comprises observation counts rather than mark-recapture estimates, we use maximum daily count—calculated as the highest number of individuals recorded at a site on any single day within a year—as a standardized index of local abundance.

The three focal species are conspicuous habitat specialists, facilitating high detection rates. For *P. mnemosyne*, empirical data show a high detection probability per visit, yielding a cumulative likelihood of >99% after three visits (Johansson et al., 2017). Similar high detectability is documented for related specialists, including a 92% detection probability for the Marsh Fritillary (*Euphydryas aurinia*), a close relative of *M. britomartis* (Norman et al., 2024), strengthening the conclusion that observed absences in well-surveyed sites represent genuine extirpations.

To verify that the observed population declines were not an artifact of varying search effort, we analyzed temporal trends in population metrics against survey effort metrics for the period 2014–2024. Due to the correlation between year and search effort, we performed a simple linear regression of maximum daily counts against person-days and searched 1 × 1 km grids separately for each species. All analyses were performed using the lm() function in R version 4.4.3 R Core Team (2024).

3 | RESULTS

All three studied butterfly species disappeared from their last known localities in southern Sweden between 2018 and 2023 (Figure 1). The data show a clear pattern of

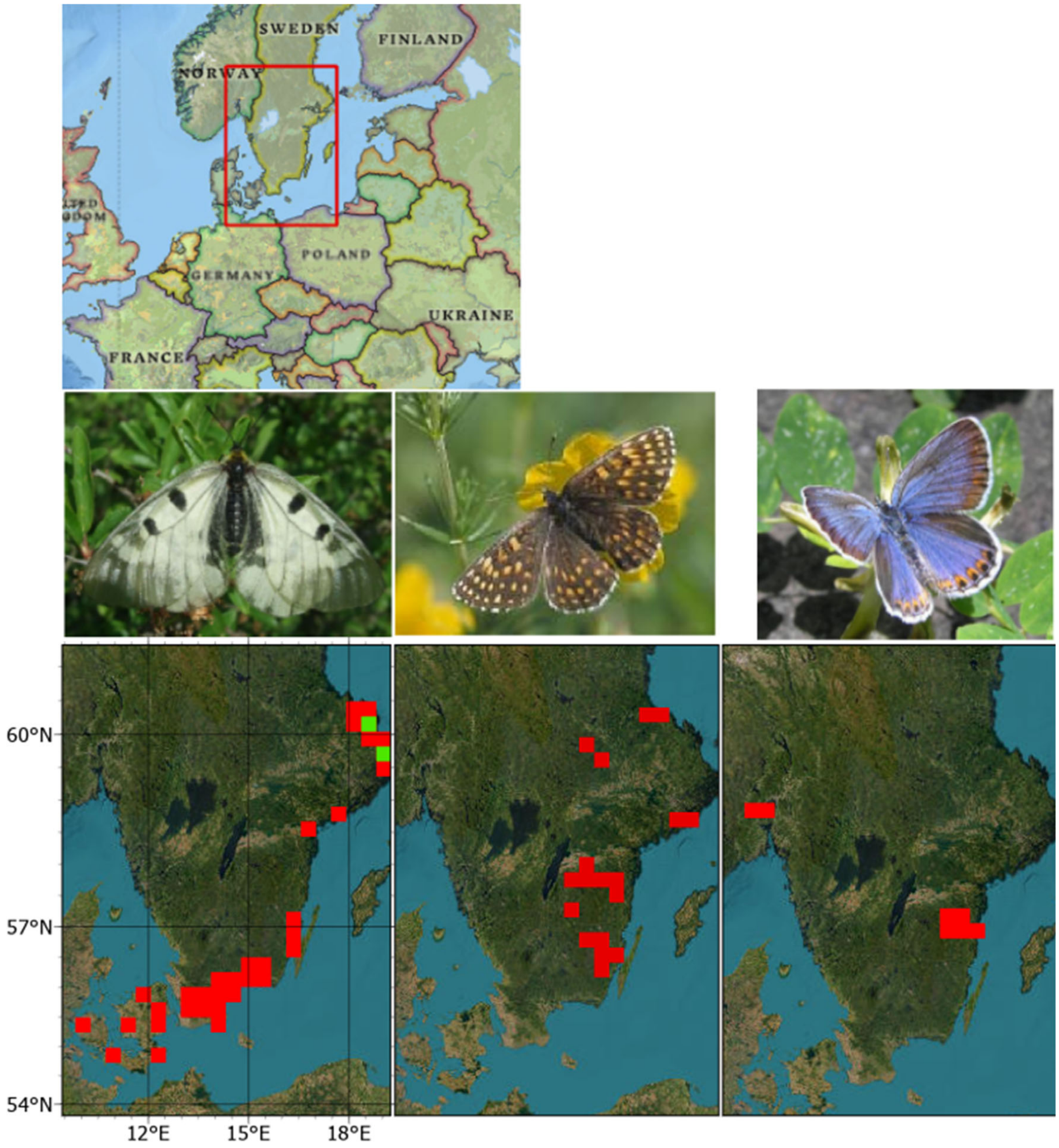

FIGURE 1 Historical range contraction and recent extinction of three conservation-priority butterfly species in southern Scandinavia. The maps display historical occurrences from 1900 to 2024 within 50 × 50 km grid cells. Red grid cells denote areas where a species was historically present but is now considered regionally extinct. Green grid cells indicate areas with extant populations as of 2024. An inset map shows the location of the study area within northwestern Europe. (a) Range contraction of the clouded Apollo (*Parnassius mnemosyne*), showing the extinction of the southern subspecies (*P. m. argiope*) last observed in 2023. The remaining green cells in northern Sweden represent the extant subspecies *P. m. romani*. (b) Extinction of Assmann's fritillary (*Melitaea britomartis*) from Sweden, last observed in 2018. (c) Extinction of Reverdin's blue (*Plebejus argyrognomon*) from Sweden and Norway, last observed in 2019—photographs by Markus Franzén and Tommy Karlsson (*P. argyrognomon*). The inset map shows the study area in red rectangle.

declining observations and occupied grid cells, even as the survey effort dedicated to finding them increased.

3.1 | Population and occupancy declines

The three species exhibited sequential declines, ultimately leading to their final extirpation—*Parnassius mnemosyne* ssp. *argiope* was the last to disappear; in Ronneby municipality, its maximum daily count fell from 14 individuals across two 1 × 1 km grids in 2014 to four individuals in a single grid cell in 2023, the final year it was observed. *Melitaea britomartis* showed the steepest decline; in Högsby municipality, counts fell from a maximum of 68 individuals across three grid cells in 2014 to nine individuals in one grid cell in 2018, after which it was no longer detected. *Plebejus argyrognomon* persisted for 1 year longer in northern Västervik and southern Östergötland, with maximum daily counts declining from 11 individuals across six grid cells in 2014 to just two individuals in one grid cell in 2019, its last year of observation (Figure 2 and Table 1).

3.2 | Survey effort trends

The survey effort for all three species intensified over the study period as they became rarer. For *P. mnemosyne*, the annual number of person-days spent searching ranged from 21 in 2015 to 78 in 2023.

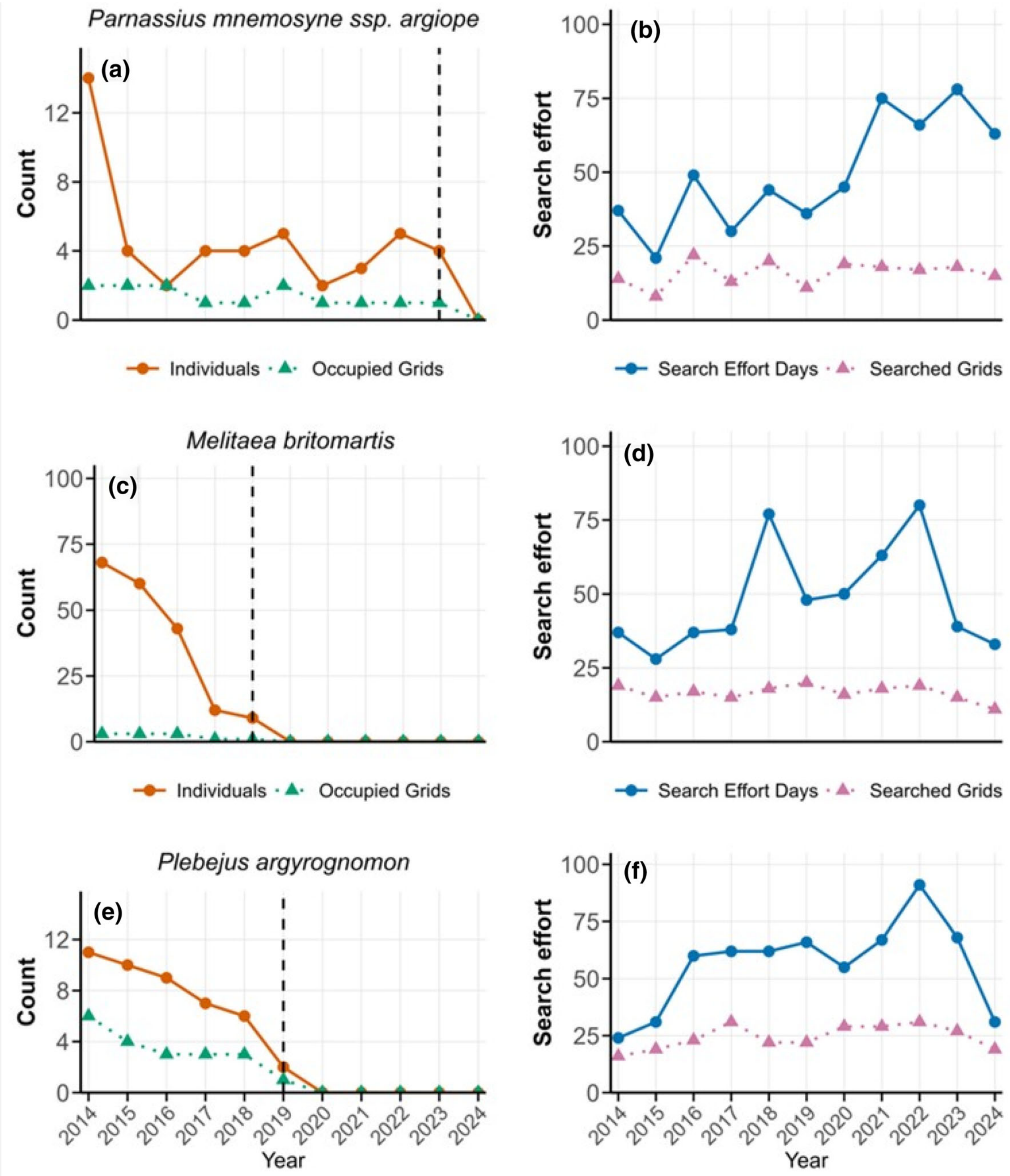

FIGURE 2 (a–f) Trends in population counts and search efforts for three butterfly species between 2014 and 2024. The data are shown for *Parnassius mnemosyne* ssp. *argiope* (panels a, b), *Melitaea britomartis* (panels c, d), and *Plebejus argyrognomon* (panels e, f). Left panels (a, c, e) show the maximum daily count of observed individuals (solid orange lines) and the number of occupied 1 km^2 grids (dotted green lines) per year. Right panels (b, d, f) depict the search effort, measured as the total number of observing days (solid blue lines) and searched 1 km^2 grids (dotted magenta lines) per year. The vertical dashed lines mark each species' last observed year: 2023 for *P. mnemosyne*, 2018 for *M. britomartis*, and 2019 for *P. argyrognomon*.

TABLE 1 Annual monitoring data for three butterfly species (*Melitaea britomartis*, *Plebejus argyrognomon*, and *Parnassius mnemosyne* ssp. *argiope*) across their final Swedish populations.

Species	Year	Observing days	Visited 1-km grids	Individuals observed	Occupied 1-km grids
Melitaea britomartis	2014	37	19	68	3
Melitaea britomartis	2015	28	15	60	3
Melitaea britomartis	2016	37	17	43	3
Melitaea britomartis	2017	38	15	12	1
Melitaea britomartis	2018	77	18	9	1
Melitaea britomartis	2019	48	20	0	0
Melitaea britomartis	2020	50	16	0	0
Melitaea britomartis	2021	63	18	0	0
Melitaea britomartis	2022	80	19	0	0
Melitaea britomartis	2023	39	15	0	0
Melitaea britomartis	2024	33	11	0	0
Plebejus argyrognomon	2014	24	16	11	6
Plebejus argyrognomon	2015	31	19	10	4
Plebejus argyrognomon	2016	60	23	9	3
Plebejus argyrognomon	2017	62	31	7	3
Plebejus argyrognomon	2018	62	22	6	3
Plebejus argyrognomon	2019	66	22	2	1
Plebejus argyrognomon	2020	55	29	0	0
Plebejus argyrognomon	2021	67	29	0	0
Plebejus argyrognomon	2022	91	31	0	0
Plebejus argyrognomon	2023	68	27	0	0
Plebejus argyrognomon	2024	31	19	0	0
Parnassius mnemosyne	2014	37	14	14	2
Parnassius mnemosyne	2015	21	8	4	2
Parnassius mnemosyne	2016	49	22	2	2
Parnassius mnemosyne	2017	30	13	4	1
Parnassius mnemosyne	2018	44	20	4	1
Parnassius mnemosyne	2019	36	11	5	2
Parnassius mnemosyne	2020	45	19	2	1
Parnassius mnemosyne	2021	75	18	3	1
Parnassius mnemosyne	2022	66	17	5	1
Parnassius mnemosyne	2023	78	18	4	1
Parnassius mnemosyne	2024	63	15	0	0

Similarly, the effort for *M. britomartis* rose from 28 person-days in 2015 to 80 in 2022, and for *P. argyrognomon* from 24 in 2014 to 91 in 2022. The spatial coverage of these surveys also expanded, with annual searches covering 8–22 grid cells for *P. mnemosyne*, 11–20 for *M. britomartis*, and 16–31 for *P. argyrognomon* within their historical ranges (Figure 2).

3.3 | Relationship between population indices and survey effort

Linear regression analyses, based on 11 annual records per species, revealed that survey effort did not positively predict population counts. Simple regression models showed predominantly negative, non-significant relationships between counts and effort metrics. For *P. mnemosyne*, person-days ($\beta = -0.055$, $SE = 0.061$, $p = 0.39$, $R^2 = 0.083$) and searched grids ($\beta = -0.23$, $SE = 0.27$, $p = 0.42$, $R^2 = 0.072$) both failed to predict counts. *M. britomartis* showed similar patterns with person-days ($\beta = -0.74$, $SE = 0.43$, $p = 0.12$, $R^2 = 0.246$) and no relationship with grids ($\beta = 1.06$, $SE = 3.39$, $p = 0.76$, $R^2 = 0.011$). *P. argyrognomon* exhibited marginally non-significant negative relationships with both person-days ($\beta = -0.12$, $SE = 0.065$, $p = 0.10$, $R^2 = 0.272$) and grids ($\beta = -0.47$, $SE = 0.24$, $p = 0.084$, $R^2 = 0.295$).

4 | DISCUSSION

The sequential disappearance of *M. britomartis*, *P. argyrognomon*, and *P. mnemosyne* from southern Sweden (2018–2023) provides a cautionary case study of how legally protected species can be lost even from regions with long-standing monitoring schemes and robust legislative instruments. All three butterflies are nationally Red-Listed; *P. mnemosyne* is additionally safeguarded under Annex IV of the EU Habitats Directive and Appendix II of the Bern Convention. Despite these designations, conservation outcomes were inadequate, underscoring structural weaknesses in existing frameworks: policy instruments that prioritize site designation over landscape processes, and conservation budgets that cannot counteract the pace of land-use intensification and climate extremes (Warren et al., 2021).

Multiple interacting drivers—habitat loss, climatic extremes, population isolation, degraded resource quality, and exposure to pesticides — likely contributed to these extinctions (Forister et al., 2019). First, agricultural and forestry policies have promoted uniform, high-stocking grazing and fertilized silage production, systematically eroding the fine-scale habitat heterogeneity—including mosaics of host-plant patches, nectar sources, and microclimatic refugia—required by specialist invertebrates (Kindvall, Forsman, et al., 2022; Tscharntke et al., 2005). Second, extreme weather events now act upon this simplified landscape. The 2018 northern European mega-drought exposed our study area to an accelerated soil moisture depletion (Buras et al., 2020). For *M. britomartis* and *P. argyrognomon*, both restricted to small, fragmented grasslands on thin soils, such an event likely caused host-plant desiccation and triggered an abrupt population collapse. The loss of the southern *P. mnemosyne* metapopulation in 2023 followed five of the warmest years on record, suggesting that chronic habitat degradation combined with extreme heat events drove the population beyond its resilience threshold (Harvey et al., 2023; Thomas & Clarke, 2004).

The failure of existing conservation instruments can be attributed to three interconnected issues: a mismatch of scale, inflexible management prescriptions, and insufficient enforcement. First, protected sites are often too small to support viable populations; Natura 2000 sites in the region average <50 ha, yet individual *P. mnemosyne* can fly over a kilometer between resources. The viability of these populations is therefore determined by the surrounding matrix, where agricultural subsidies often incentivize management that erodes biodiversity (Kindvall, Forsman, et al., 2022; Kindvall, Franzén, et al., 2022; Pe'er et al., 2022). Second, agri-environment schemes typically prescribe static, uniform grazing from May to September, failing to reduce stocking densities during droughts when livestock consume the scarce green vegetation that provides critical thermal refugia and food resources for insect larvae (Ekroos et al., 2014). Dynamic management, which adjusts grazing pressure to environmental conditions, remains rare (Derner et al., 2023). Finally, County Administrative Boards often lack the resources for robust compliance monitoring, and without credible enforcement, voluntary schemes consistently fail to deliver biodiversity outcomes (Maron et al., 2021). These conservation failures reflect broader systemic challenges in political and intergovernmental frameworks that have proven inadequate to halt biodiversity loss and address the underlying drivers of environmental degradation at the scale and pace required (Cardinale et al., 2012). Therefore, an effective conservation response must be multi-scalar and adaptive. Evidence from the UK and Central Europe indicates that heterogeneous, low-intensity management enhances microclimatic buffering and population persistence during heatwaves (Oliver et al., 2015; Suggitt et al., 2015). At the site scale, this involves reinstating rotational grazing and late-season mowing to create a mosaic of sward structures. Such management would not only support the focal species but also other highly threatened specialists with complex needs, such as the Alcon Blue (*Phengaris alcon*). At the landscape scale, existing reserves must be buffered and connected by negotiating conservation easements on adjacent parcels to create functional habitat networks. The recently announced 21.5 million SEK "Dream Project" fund offers a timely vehicle to pilot such agreements. At the policy scale, the Common Agricultural Policy eco-schemes must be reformed to include outcome-based payments that reward structural diversity and incorporate climate-contingent clauses that permit adaptive management during droughts. However, more broadly, preventing biodiversity decline across northern Europe will require landscape-scale habitat restoration programs that extend beyond grasslands to recreate heterogeneous landscapes capable of supporting entire ecological communities under climate change (Harvey et al., 2020).

While reintroductions may be justified once habitat quality and connectivity improve (Kukkonen et al., 2024; Thomas et al., 2009), our findings first demand a paradigm shift in how we manage agricultural landscapes. The contraction of *P. mnemosyne* in Sweden mirrors declines in Denmark and Germany (Kudrna et al., 2011). Yet, its status elsewhere in Europe highlights that regional outcomes are contingent on management; the species is expanding in the well-connected agricultural landscapes of Estonia (Liivamägi et al., 2013), maintains stable populations where habitat mosaics are maintained (Sielezniew et al., 2023), while being the focus of successful conservation programmes in Finland (Kuussaari et al., 2015).

The loss of these three high-profile species is not an isolated tragedy but symptomatic of a broader crisis. The current 2025 Swedish Red List evaluation found that of the 110 butterfly species assessed, 43 (39%) might be threatened, a stark indicator of the deteriorating status of the nation's biodiversity. This alarming trend underscores that the time for incremental adjustments has passed. Awaiting perfect quantitative models is a luxury we cannot afford, given the clear evidence of systemic failure. Ultimately, while our proposed habitat measures are immediately actionable and essential for safeguarding northern Europe's remaining grassland specialists, mitigating future losses requires their integration into comprehensive policies that address the primary drivers of land use, climate, and pollution. The extinctions we document should serve as an urgent call to action for policymakers, conservation bodies, and researchers to collaborate in implementing and funding the landscape-scale changes required to prevent further collapse of insect diversity.

AUTHOR CONTRIBUTIONS

Markus Franzén conceived and designed the study, performed the experiments, and analyzed the data. Victor Johansson contributed to data collection and analysis. Both authors discussed the results and contributed to the final manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data supporting the findings of this study are available from the correponding author upon request.

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