The State of Britain's Larger Moths 2021

Butterfly Conservation

Saving butterflies, moths and our environment

Keith Tailby

Scarce Silver Y *Syngrapha interrogationis* is a moorland moth of northern and western Britain. Its abundance has decreased by 69% (1968–2017) and its distribution by 71% (1990–2016).

Executive summary

- Long-running data on insect populations are scarce globally, hampering attempts to assess how these extremely diverse and ecologically vital creatures are faring in the current biodiversity crisis. Larger (macro-) moths in Great Britain are an exception, providing insights into the trends of a species-rich group of invertebrates during a time of unprecedented human pressure on the natural world.

- This report summarises current knowledge of the state of Britain's c.900 species of larger moths, presenting analyses of long-term change based on millions of records gathered through the Rothamsted Insect Survey (RIS) and National Moth Recording Scheme (NMRS).

- The total abundance of larger moths caught in the RIS light-trap network in Britain decreased by 33% over 50 years (1968–2017). Losses were greater in the southern half of Britain (39% decrease) than in the northern half (22%).

- Long-term abundance trends were calculated for 427 species of which 41% (175 species) had decreased and only 10% (42 species) increased, with the remaining 49% (210 species) having trends that did not show statistically significant change. Thus, four times as many moth species decreased in abundance than increased.

- Distribution trends revealed a different picture. Of 511 larger moth species for which long-term trends could be calculated from NMRS data, 32% (165 species) decreased in distribution and 37% (187 species) increased, while 31% (159 species) had non-significant trends. More moth species increased in distribution than declined.

- A multi-species distribution indicator increased in extent by 9% over a 47-year period (1970–2016) and the northern range margins of moths have, on average, shifted northwards by 5km per year (1995–2016).

- Moths that breed in woodland and open grasslands increased in distribution, by an average of 12% and 8% respectively (1970–2016). Species that breed on moorland decreased significantly in distribution, by an average of 13%.

- The pattern of change is complex. The decline in abundance of larger moths is clear, yet the distributions of many species are increasing. It must also be remembered that we do not have trends for most scarce and rare species.

- The warming climate is causing many moth species to emerge earlier in the year compared with the 1970s and some are having larger and more regular additional generations. Research indicates that early emergence benefits moths that have more than one generation each year in Britain, but not those with a single annual brood.

- Extinctions are still occurring but the rediscovery of some moth species and natural recolonisation by others has reduced the number believed to have become extinct in Britain since 1900. The total now stands at 51 species (including micro-moths).

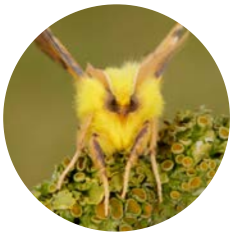
- Many more moth species have colonised Britain. Since 1900, 137 moth species (including micro-moths) have become (and remain) established, including 53 this century. Some have arrived naturally, expanding their European range in response to climate change, while others have been unwittingly imported through the global trade in plants.

- The precise causes of all these changes remain unclear. Habitat destruction and deterioration remain pressing concerns, driven by land-use change and chemical pollution. Artificial light at night has negative effects on moth development and behaviour, but links to population-level decline are yet to be proved. Climate change is the principal driver of range expansion, but there is also growing evidence of negative impacts, particularly on moths that are adapted to cooler conditions in northern, western and upland Britain.

- Despite the enormous challenge of halting moth declines, there are some signs of hope. Given the necessary resources and the determination and skill of conservationists, landowners and volunteers, moths can be saved from the brink of extinction. Fine-tuned management of individual sites, bold landscape-scale conservation projects and the long-term commitment required to recreate biodiverse habitats are forging a brighter future for some of our rarest moths.

- The decline of moths and other insects, both in Britain and elsewhere, is clear and demands an urgent response. We do not need to wait for robust global trends or scientific proof of causes of change. The existing evidence is compelling and clear policy pathways have already been identified; we can and should act now. In Britain, expanding, restoring, connecting and creating habitats that support rich arrays of moths and other wildlife, that improve human wellbeing and that deliver ecosystem services such as carbon storage, flood prevention and cleaner air, is the key to reversing moth declines and confronting the biodiversity and climate crises.

Cover image: Small Elephant Hawk-moth *Deilephila porcellus*. The distribution of this moth has increased by 147% in Britain (1970–2016). (Bob Eade)



Iain H Leach

Canary-shouldered Thorn *Ennomos alniaria* has decreased in abundance by 72% (1968–2017) but increased in distribution by 15% (1970–2016).

Introduction

The world is facing a biodiversity crisis. An estimated one million species are threatened with extinction[1], vertebrate populations decreased by 68% on average between 1970 and 2016[2] and globally agreed targets to reduce the pressures on biodiversity have not been met[3]. The trends of insects, which make up at least 60% of all species on Earth[4] and contribute vital and valuable ecosystem services, such as decomposition, pest control and pollination, remain poorly understood.

Recently, there has been great public concern about impending 'insect Armageddon', that is the catastrophic loss of insects across the whole world. This concern was ignited by the mass media reporting of recent studies such as those at sites in Germany[5] and Puerto Rico[6]. Global and continental assessments for insects (and other invertebrates) have generally shown overall declines in abundance of terrestrial species[7], but the available evidence is heavily biased towards Europe and North America. Long-term, continuous records of insect abundance and distribution are very rare elsewhere in the world, particularly in the tropics. Even where data exist, analyses are fraught with difficulty[8]. Thus, while there is considerable evidence for insect declines[9], the data are insufficient to support extrapolated conclusions about the scale of the worldwide decreases across all insect groups[10].

However, insect biodiversity trends are also complex. Headline figures of decline hide a multitude of winners and losers, as well as variation in trends between different geographical areas and time periods. Sometimes there are conflicting signals from different measures of change (such as abundance and distribution). This complexity in insect trends is shown in analyses of moths from around the world[11]. Overall declines in abundance or diversity, or both, have been reported at national, regional or site scales in several European countries including Finland[12], Germany[13], Hungary[14], the Netherlands[15], Sweden[16] and the United Kingdom (UK)[17].

The previous *State of Britain's Larger Moths* reports in 2006 and 2013 showed that total moth abundance had decreased, but that around one-third of widespread species had increased, and there was no overall change in the northern half of Britain[18]. In addition, more recent assessments of British moths over the same decades found that species had, on average, increased in distribution[19]. Similar findings have come from Finland, where moth species' richness has increased but abundance has declined[20], and Hungary, where moth diversity has decreased but total abundance has not[14].

The few studies of moth populations outside Europe also reflect this heterogeneity, with decreases in caterpillar abundance and diversity at a site in Costa Rica[21], but no overall decline at monitored sites in Ecuador, Arizona (USA) or Missouri (USA)[22].

Given this complex picture and the paucity of long-term data on moths in many parts of the world, *The State of Britain's Larger Moths 2021* report offers a new opportunity to assess patterns of biodiversity change for this ecologically important group using the most comprehensive moth datasets in the world.

DEDICATION

This third assessment of *The State of Britain's Larger Moths* is dedicated to Dr Kelvin Conrad who passed away in 2018 at the age of 56. His work on moth population trends at Rothamsted Research was the key driver for the first such report in 2006, which he co-authored. It is also dedicated to all of the RIS light-trap operators/identifiers and NMRS County Moth Recorders, without whose dedication, expertise and hard work such assessments would not be possible.

[1] Díaz *et al.* 2019
[2] WWF 2020
[3] Secretariat of the Convention on Biological Diversity 2020
[4] Eggleton 2020
[5] Hallmann *et al.* 2017
[6] Lister & Garcia 2018
[7] Dirzo *et al.* 2014, Pilotto *et al.* 2020, van Klink *et al.* 2020, but see Crossley *et al.* 2020
[8] Didham *et al.* 2020
[9] Sánchez-Bayo & Wyckhuys 2019, Wagner 2020
[10] Montgomery *et al.* 2020, Saunders *et al.* 2020
[11] Wagner *et al.* 2021
[12] Mattila *et al.* 2006, Antão *et al.* 2020
[13] Habel *et al.* 2019a
[14] Valtonen *et al.* 2017
[15] Groenendijk & Ellis 2011
[16] Franzén & Johannesson 2007
[17] Conrad *et al.* 2006, Fox *et al.* 2014, Dennis *et al.* 2019
[18] Fox *et al.* 2006, Fox *et al.* 2013
[19] Outhwaite *et al.* 2020
[20] Antão *et al.* 2020
[21] Salcido *et al.* 2020
[22] Marquis *et al.* 2019, Wagner *et al.* 2021

Paul Kirkland

The evidence base

The UK is fortunate in having a long history of moth recording undertaken by skilled amateur naturalists as well as the most comprehensive data on moth abundance in the world from the Rothamsted Insect Survey (RIS). The latter has been the focus of previous assessments of the state of Britain's larger moths, which showed abundance trends from RIS data for 35-year (1968–2002)[23] and 40-year (1968–2007)[24] periods. In this new report, we reanalyse the RIS data, extending the time period to 50 years (1968–2017), but also present distribution (occupancy) trends based on sightings collated through the National Moth Recording Scheme. In both cases, the trends presented are for Great Britain (i.e. England, Scotland and Wales) plus the Isle of Man. Utilising these two different data sources provides separate but complementary insights into how species of larger moths have fared.

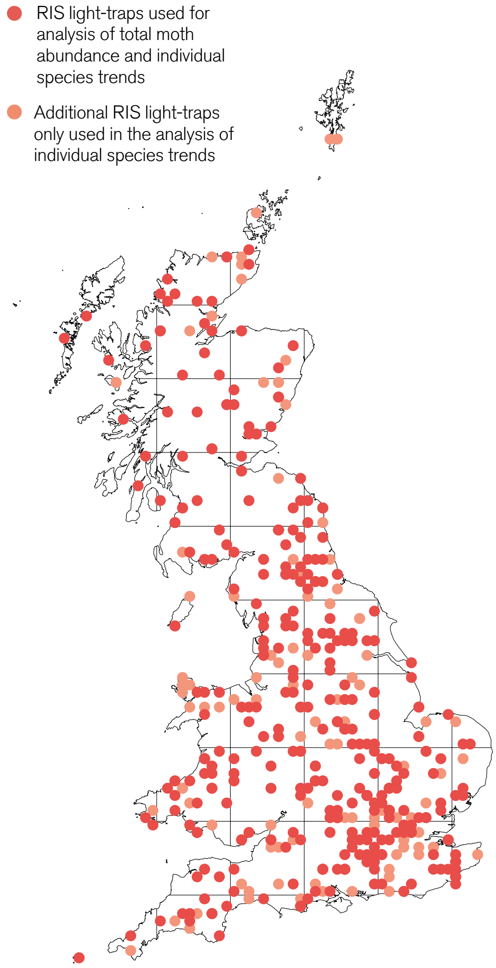
ROTHAMSTED INSECT SURVEY ABUNDANCE TRENDS

This network of standardised, automated light-traps is the longest-running, large-scale time series of data on insect populations in the world. The first RIS light-trap was operated at Rothamsted Research in Hertfordshire in the 1930s, where analysis has revealed a 71% reduction in average numbers of larger moths at that site between pre-1950 catches and 1960–1979[25]. Since the 1960s, nightly sampling has taken place at sites across the UK to monitor the relative abundance of nocturnal larger moths[26].

Long-term abundance trends for Britain were calculated from the RIS dataset for 427 larger moth species (90 species more than in the previous *State of Britain's Larger Moths* reports) and also for the total abundance of all larger moths. In most cases these trends cover 50 years (1968–2017), but shorter time periods were used for 30 species (mainly pugs *Eupithecia* spp.) due to identification or taxonomic problems early in the series. The shortest trends are for 1986–2017 and cover 32 years.

The analysis techniques used here to calculate trends differ from those used in previous reports, due to statistical advances in recent years. For individual species, new techniques enable more realistic estimates of missing counts where there are gaps in sampling[27], trends to be based on the full site-level data[28] and estimates of uncertainty provided for each trend[29].

For the analysis of total abundance of all larger moths caught in the RIS network[30], two different trend assessments were carried out, one to estimate the long-term change over the whole 50-year time period and the other using non-linear trends to identify significant year-to-year changes[31].



The locations of 527 RIS traps that contributed to the 50-year assessment (1968–2017) of moth abundance trends in Britain.

[23] Fox *et al.* 2006
[24] Fox *et al.* 2013
[25] Woiwod & Gould 2008
[26] Conrad *et al.* 2007

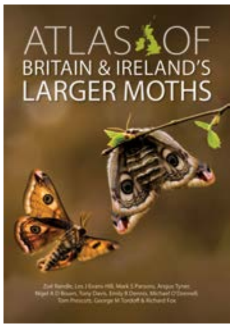
[27] The Generalised Abundance Index (GAI) approach (Dennis *et al.* 2016) was used to model annual species flight curves, which were then used to estimate missing count values. All 527 sites in the RIS were included in the species trend analysis.
[28] A Poisson generalised linear model was fitted to the imputed annual site totals from the GAI, with site identity as a categorical effect but year as a continuous variable, allowing the species trend to be estimated from the full site-level data (thereby incorporating as much of the original variability as possible), rather than by simply fitting a standard linear model to the final yearly indices.
[29] Bootstrapping was used to evaluate the uncertainty associated with each trend and thereby determine statistical significance of the abundance trends. Unreliable trends resulting from insufficient RIS data were excluded.
[30] Only 386 RIS sites with one or more years of 'complete' data (few or no substantial gaps in counts during the year, following Conrad *et al.* 2004) were used for the total abundance analyses. Including sites with larger within-year gaps in recording or only using sites with at least five years of data made no major differences to the results.
[31] Following the approach of Bell *et al.* 2020, the long-term trend was estimated by fitting a log-linear model with a quasipoisson distribution using restricted maximum likelihood. Non-linear trends to assess year-to-year change were calculated from a generalised additive mixed model using generalised cross validation. Bootstrapping was used to estimate uncertainty around trends.

NATIONAL MOTH RECORDING SCHEME DISTRIBUTION TRENDS

The National Moth Recording Scheme (NMRS) was launched by Butterfly Conservation in 2007 to create a UK database of moth records to support conservation[32]. The database has grown rapidly and was recently used, in collaboration with MothsIreland, to publish the first complete set of distribution maps for all larger moth species across Britain and Ireland[33]. Sampling for the NMRS is not standardised – participants can record wherever and whenever they choose using a variety of techniques. Most records are of nocturnal adult moths attracted to light-traps, but sightings of any life cycle stage at any time of day can be contributed. Thus, in contrast to the RIS, the NMRS gathers data on all moths, not just nocturnal species that are attracted to light. NMRS records are collated and verified locally by County Moth Recorders.

Over 24 million NMRS records for Britain and the Isle of Man have been used to calculate the fine-scale, long-term distribution (occupancy) trends presented in this report. Because recording varies considerably from place to place and over time, a simple analysis of species distributions (e.g. the number of grid squares in which a species has been recorded in two different time periods) will be biased by changes in recording effort[34]. A statistical approach called occupancy modelling was used to account for variation in recording and, therefore, estimate the underlying real changes in species distribution[35].

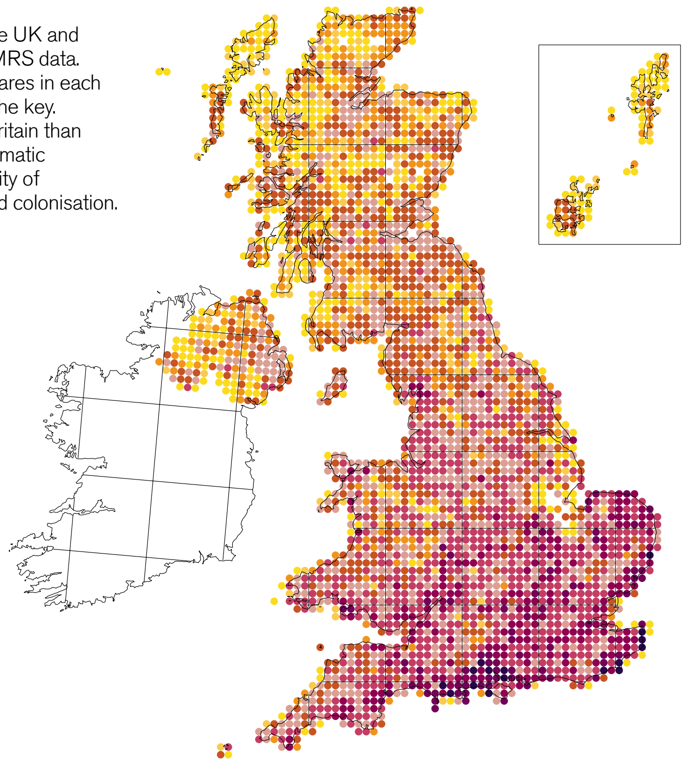
This is the first time that distribution trends have contributed to the *State of Britain's Larger Moths* assessment. NMRS records for 1970–2016 were used to calculate species distribution trends at 1km × 1km grid square resolution. After excluding species with insufficient data to generate reliable trends[36], change was calculated for 390 larger moths since 1970, a further 58 species since 1980 and an additional 63 since 1990, giving a total of 511 species with long-term distribution trends. Each species trend was then converted to an average change over 10 years, so that species could be directly compared despite change being measured over different time periods.



Published in late 2019, the *Atlas of Britain & Ireland's Larger Moths*[33] is the first-ever atlas covering all larger moths in Britain, Ireland, the Isle of Man and the Channel Islands.

Species richness of larger moths in the UK and Isle of Man 2000–2016 based on NMRS data. The number of 10km x 10km grid squares in each species richness category is given in the key. There are more species in southern Britain than further north, principally because of climatic differences but also due to the proximity of continental Europe for immigration and colonisation.

- 1–25 (359)
- 26–50 (218)
- 51–100 (325)
- 101–200 (588)
- 201–300 (614)
- 301–400 (553)
- 401–450 (191)
- 451–500 (68)
- 501–548 (16)



[32] Fox *et al.* 2011
[33] Randle *et al.* 2019
[34] Isaac & Pocock 2015

[35] The occupancy modelling approach followed Dennis *et al.* 2019 and the trends presented are those published in Randle *et al.* 2019. For a given species and year, occupancy probability was estimated for each 1km x 1km grid square, using records for all species to account for recording effort and phenology to estimate detection probability. The average of these values formed an annual occupancy index for each species, from which linear trends over time were calculated to assess changes in distribution.
[36] See Randle *et al.* 2019 for more details.

Dan Lombard

Over the course of less than 100 years, Clifden Nonpareil *Catocala fraxini* has colonised Britain, become extinct and recolonised.

Colonisations and extinctions

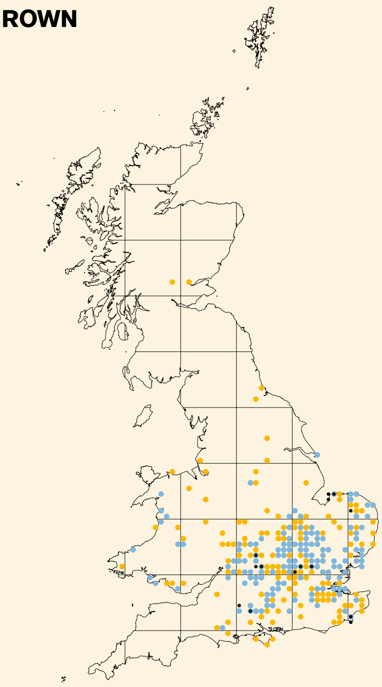
The moth fauna of Britain is not static. Many native species are under pressure, with their habitats destroyed or altered by human activity[37], and some have sadly been lost as resident species. On the other hand, drivers such as climate change, cultivation of non-native plants and the global horticultural trade have provided opportunities for moth species from continental Europe and much further afield to colonise. Most of these are innocuous additions to our biodiversity, but a few present potential problems, such as Oak Processionary *Thaumetopoea processionea* and Box-tree Moth *Cydalima perspectalis*.

The number of moth species (including micro-moths) considered extinct in Britain since 1900 now stands at 51[38], which is considerably lower than reported in the previous assessment (63 species)[39]. This reduction is due to the rediscovery of some species thought to be extinct in Britain, including *Aproaerema vinella* (recorded after a gap of 23 years since the last British sighting) and *Hypercallia citrinalis* (after a 40-year gap). Furthermore, some species previously lost from Britain have recolonised (e.g. Clifden Nonpareil *Catocala fraxini* and Flame Brocade *Trigonophora flammea*).

Extinctions have continued though. In the last 10 years, there have been no further records of Brighton Wainscot *Oria musculosa*, Bordered Gothic *Sideridis reticulata* or Stout Dart *Spaelotis ravida,* which are now considered extinct in Britain. Three additional species have now been highlighted as potentially extinct: *Aproaerema albipalpella*, *Scythris siccella* and Pale Shining Brown *Polia bombycina*[38]. Grave concerns for the continued resident status of Speckled Footman *Coscinia cribraria*, which had not been seen at any of its remaining Dorset sites since 2014 despite extensive searches, were tempered when a single adult was recorded in June 2020.

PALE SHINING BROWN
Polia bombycina

- Pre-1970
- 1970–1999
- 2000–2016



Keith Tailby

A very severe distribution decline, especially since the 1970s, reduced the Pale Shining Brown to small areas of Hertfordshire, Norfolk, Oxfordshire and Wiltshire. A lack of sightings from any of these areas since 2017, despite targeted surveys, has raised concerns that the moth may have been lost from Britain as a resident species.

[37] Hayhow *et al.* 2019
[38] Parsons 2020
[39] Parsons 2010

While the number of moths considered extinct in Britain has decreased, the number of new colonists continues to rise and the rate seems to be increasing. Since 1900, 137 moth species have colonised Britain and are still extant here, 53 (39%) of which have become established this century (31 in 2000–2009 and 22 in 2010–2019)[40]. The total from the last decade is expected to rise as there are several other species that require more data to either determine when they first colonised (e.g. Cryptic Fern *Horisme radicaria*[41]) or whether they are, as yet, established as a breeding species (e.g. Golden Twin-spot *Chrysodeixis chalcites* and Radford's Flame Shoulder *Ochropleura leucogaster*).

Among those recent colonists that appear to have arrived naturally, some, such as Black-spotted Chestnut *Conistra rubiginosa*, had never been recorded in Britain before while others are long-standing migrants or vagrants that have now also become established in certain parts of the country (e.g. *Catoptria verellus* and Dusky Hook-tip *Drepana curvatula*). Climate change, which is causing the distributions of many taxa to expand polewards[42], is the likely driver of such colonisations.

The other major factor responsible for the establishment of non-native insect species is the global plant trade[43]. The importation of plants (both native species and exotics) into Britain provides a direct pathway for the increasing arrival of new insect species[44]. Oak Processionary, for example, had occurred as a scarce immigrant to these shores but all records had been of male moths so the chance of establishment was considered low. However, in the mid-2000s, it was accidentally introduced into London, probably as eggs, with imported oak trees. The species, which can cause allergic reactions in humans and animals, has spread rapidly in spite of a substantial control programme, and climate change modelling suggests that much of Britain will become suitable for the moth by 2050[45]. Butterfly Conservation has objected to the Forestry Commission over the widespread use of pesticides that are toxic to many moth and butterfly caterpillars for control of Oak Processionary, including in Sites of Special Scientific Interest. Less damaging methods of control (removal of larval nests) should be used where necessary. In addition, Butterfly Conservation is working with Defra to highlight the occurrence of scarce species and rich communities of moths (based on NMRS data) in affected areas to support informed decisions about control measures.

Nigel Jarman

Keith Tailby

Neil Sherman

Three recent colonists: Dusky Hook-tip *Drepana curvatula* became established in Kent c.2012, Rosy Underwing *Catocala electa* in Dorset in 2013 and Ringed Border *Stegania cararia* also in Kent in 2017. All three have reached Britain naturally (having previously occurred as immigrants or vagrants) and use native larval hostplants. Time will tell whether they expand from these small footholds and become a widespread and long-term part of the resident moth fauna.

[40] Parsons 2020
[41] Smith & Clancy 2019
[42] Chen *et al.* 2011
[43] Liebhold *et al.* 2016
[44] Smith *et al.* 2018
[45] Godefroid *et al.* 2020

Overall trends in moth abundance and distribution

Bob Eade

Scorched Wing *Plagodis dolabraria* shows no long-term change in abundance, but a 71% increase in distribution (1970–2016).

Over the past five decades the abundance of nocturnal larger moths decreased by 33%, with a greater decline in southern Britain (39%) than in the north (22%). In contrast, larger moths increased in distribution, by an average of 9%, likely driven mainly by climate change.

ABUNDANCE

The total abundance of all larger moths caught in the RIS light-trap network in Britain over a 50-year period (1968–2017) decreased significantly by 33% (Fig. 1). This rate of decline is consistent with previous *State of Britain's Larger Moths* reports[46], which measured change over 35 and 40 years, and other studies[47]. The use of a non-linear trend analysis (Fig. 2) shows that large short-term increases and decreases in moth abundance are common events. Particularly large increases occurred between 1975–1976 and 1994–1996, and these were followed by major decreases between 1976–1978 and 1996–1998. Trends in the total abundance of all larger moths recorded in the RIS were also calculated separately for the northern and southern halves of Britain, defined by the 450km N line of the Ordnance Survey National Grid (which runs from Fleetwood on the west coast of Lancashire, through York to Hornsea on the east coast

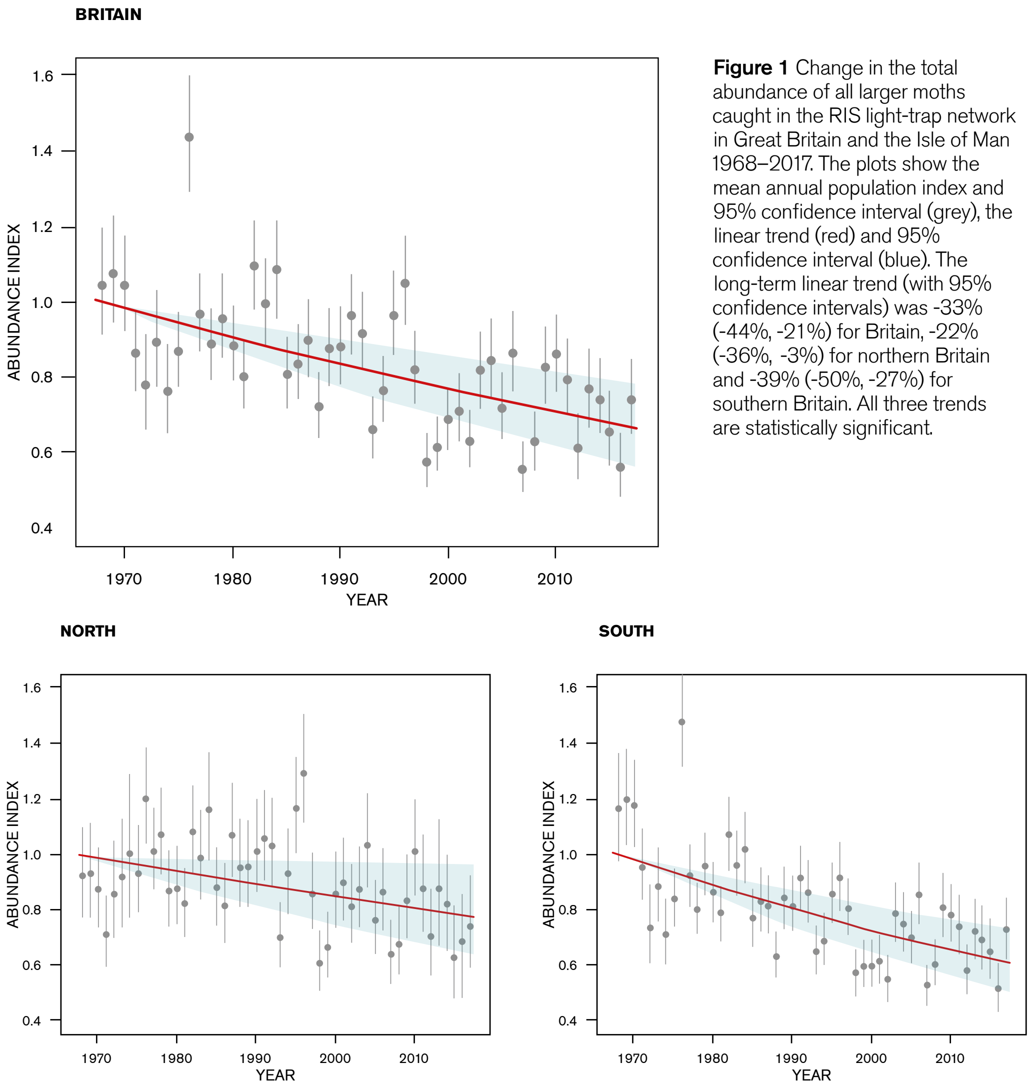


Figure 1 Change in the total abundance of all larger moths caught in the RIS light-trap network in Great Britain and the Isle of Man 1968–2017. The plots show the mean annual population index and 95% confidence interval (grey), the linear trend (red) and 95% confidence interval (blue). The long-term linear trend (with 95% confidence intervals) was -33% (-44%, -21%) for Britain, -22% (-36%, -3%) for northern Britain and -39% (-50%, -27%) for southern Britain. All three trends are statistically significant.

[46] Fox *et al.* 2006, Fox *et al.* 2013
[47] Bell *et al.* 2020

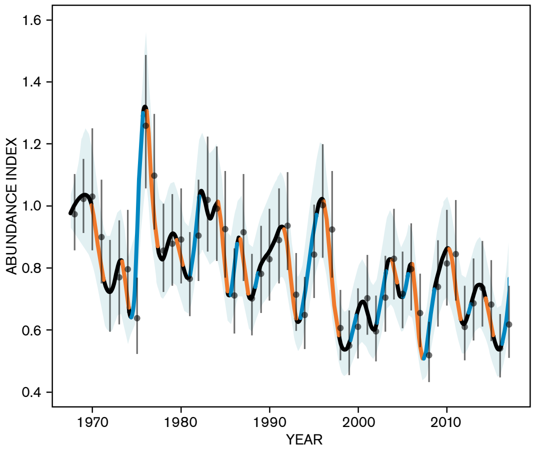


Figure 2 Change in the total abundance of all larger moths caught in the RIS light-trap network in Great Britain and the Isle of Man 1968–2017 assessed using a flexible non-linear model. Statistically significant short-term increases (dark blue) or decreases (orange) in abundance are superimposed on the long-term trend (black) with 95% confidence intervals (light blue).

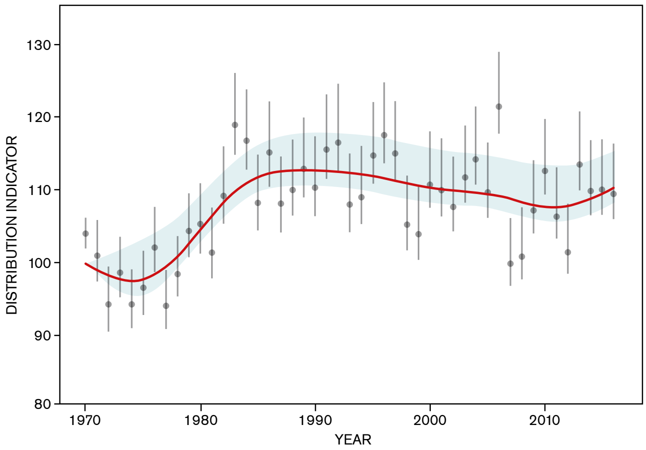


Figure 3 Multi-species indicator of change in distribution of larger moths in Great Britain and the Isle of Man 1970–2016, with smoothed indicator (red) and its 95% confidence interval (blue). The long-term trend (with 95% confidence intervals) was 9% (7%, 13%).

of Yorkshire). Moths decreased over the 50-year period, by 22% in northern Britain (113 RIS sites) and by 39% the south (273 sites) (Fig. 1). The finding that moth numbers have decreased in northern Britain is particularly important because previous analyses over 35 and 40 years showed no overall decline for this region.

DISTRIBUTION

A multi-species indicator based on NMRS data provides an overall picture of the changing distribution of larger moth species in Britain. The occupancy models for each of the 511 moth species for which individual long-term trends were produced (see p.5) were combined to produce a single averaged index for each year. A smoothed indicator with confidence intervals was then generated from these annual indices and the distribution trend over time calculated[48].

This distribution indicator shows that larger moth species in Britain increased in extent by an average of 9% over the 47-year period (1970–2016) (Fig. 3). This mirrors the pattern of northward shift in range margin and consequent increase in distribution seen among many insect and other arthropod groups in response to climate change[49]. The moth indicator shows that there was a large increase in distribution from the mid-1970s to mid-1990s, but little overall change in the last 20 years. The trend was similar when calculated only from the subset of 390 species with distribution trends for the full time period[50]. In addition, a separate analysis of the NMRS data, using a different occupancy modelling approach, also concluded that the larger moth distribution indicator had increased by 9%[51].

COMPLEX PATTERNS OF CHANGE

The total abundance trends and moth distribution indicator provide different summary measures of how larger moths have fared in Britain. They suggest that moths have declined in abundance while simultaneously expanding their distributions.

This seemingly paradoxical pattern has also been noted in Finland, where a significant decrease in moth abundance over 20 years occurred in parallel with a significant rise in species richness[52]. It might arise simply from variation in trends between species, from dissimilar responses of particular species in different parts of their range (e.g. declines in one area but increases in another, perhaps due to spatially variable impacts of drivers such as intensive land-use and climate change) or from the scale at which trends are measured (populations can decrease hugely in abundance while still appearing as 'present' in a distribution model).

Whatever the causes, the complex overall patterns of change for Britain's larger moths make the development of effective policies to address the biodiversity crisis even more challenging.

[48] Following the approach of Dennis *et al.* 2019, the multi-species indicator of moth distribution change was constructed from the geometric mean of annual occupancy indices for 511 individual species. A smoothed indicator was produced posthoc by fitting a generalised additive model to these annual indices. The trend over time was then calculated as a linear regression through the smoothed indicator, with 95% confidence intervals estimated using a parametric bootstrap.
[49] Hickling *et al.* 2006, Mason *et al.* 2015
[50] The distribution indicator trend (with 95% confidence intervals) based on only those 390 species with robust occupancy indices over the full period (1970–2016) was an increase of 6% (5%, 7%). Thus we retained the extra species (58 with trends 1980–2016 and a further 63 with trends 1990–2016) in the indicator to make it as representative as possible of GB larger moths.
[51] Outhwaite *et al.* 2020
[52] Antão *et al.* 2020

Moth species trends

LONG-TERM ABUNDANCE TRENDS

Using standardised counts from the RIS light-trap network, long-term population trends were calculated for 427 species. These tend to be relatively common and widespread species, because scarcer moths are not caught in sufficient numbers across the network to enable robust assessment of population change. Overall, 296 (69%) larger moths had negative trends and 131 (31%) positive trends (Fig. 4). However, because sampling is incomplete and because moth populations vary greatly from year to year, it is prudent to focus on those species trends that are statistically significant. In such cases, we can have high confidence that these species have genuinely changed in abundance over time.

Four times as many moth species declined significantly in abundance than increased significantly in Britain over 50 years. In all, 175 species (41% of the total) had statistically significant decreases compared with only 42 species (10% of the total) with significant population increases (Fig. 4). The remaining 210 species (49%) had non-significant trends.

LONG-TERM DISTRIBUTION TRENDS

Occupancy modelling was used to produce long-term distribution trends for 511 larger moth species. In total, 227 species (44%) had decreased and 284 (56%) had increased (Fig. 5). Those species trends that were statistically significant showed a similar pattern with 165 species (32% of the total) having significant long-term declines in distribution and 187 (37% of the total) significant increases (Fig. 5). Thus, slightly more species had increased in distribution than decreased, while 159 species (31%) had non-significant trends. More moth species have increased in distribution in Britain than have declined since 1970.

Again, this highlights the complexity of biodiversity change over recent decades. While larger moth abundance in Britain has decreased significantly, raising grave concerns for the species themselves and for knock-on impacts on other wildlife, a substantial proportion of moths are bucking that trend, becoming more widespread and, in some cases, also increasing dramatically in numbers.

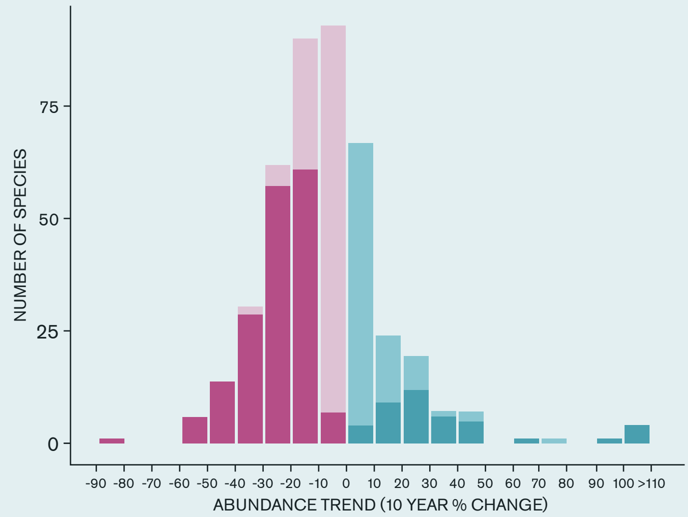


Figure 4 Long-term abundance trends of 427 species of larger moth. For each species, the size of the abundance change is given as the average 10-year rate of change across the time period assessed, which varies from 32–50 years depending on the species. Statistically significant trends are shown in darker shades and non-significant trends in paler shades.

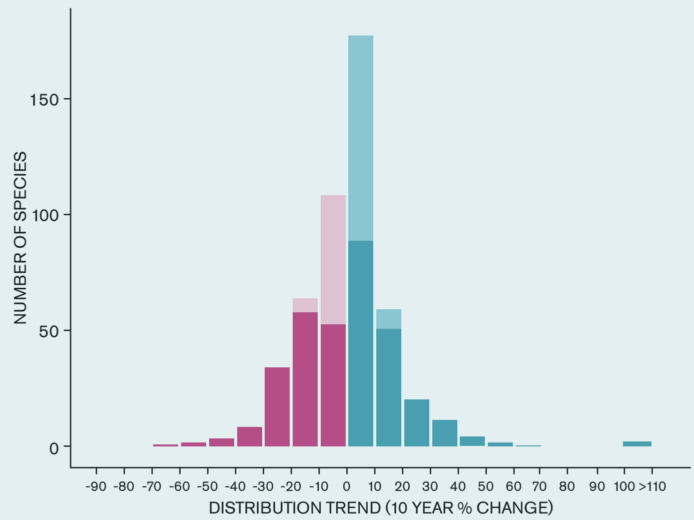


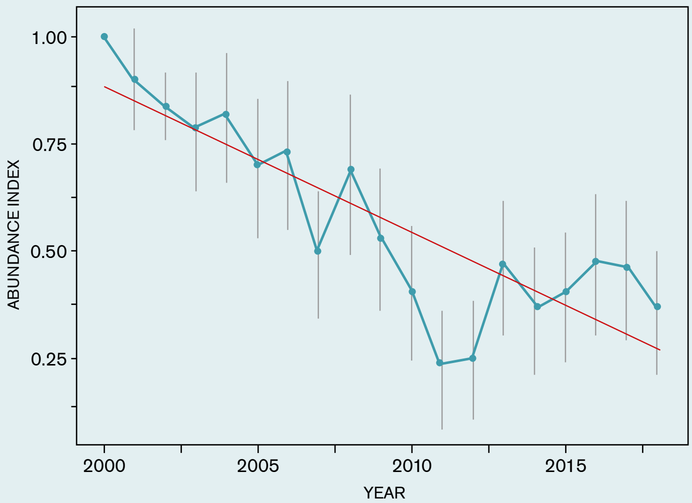
Figure 5 Long-term distribution trends of 511 species of larger moth. For each species, the size of the distribution change is given as the average 10-year rate of change across the time period assessed, which varies from 27–47 years depending on the species. Statistically significant trends are shown in darker shades and non-significant trends in paler shades.

MONITORING BRITAIN'S RAREST MOTHS

In addition to trends derived from the long-running data of the RIS and NMRS, population monitoring has been carried out on a small number of rare moths in Britain, mainly since the year 2000. Data for some of these species contribute to a UK government indicator of priority species[53] and can be used to calculate individual species trends. Currently, annual monitoring takes place for at least some populations of 14 rare moth species, using a variety of methods including transects and timed counts of adults (e.g. for Bright Wave *Idaea ochrata* and Dark Bordered Beauty *Epione vespertaria*), counts of larvae or larval cases (e.g. *Eudarcia richardsoni* and Marsh Moth *Athetis pallustris*), and egg counts (Fiery Clearwing *Pyropteron chrysidiformis*).

Butterfly Conservation aims to increase the coverage and quality of rare moth monitoring and has recently identified 40 additional species that could be included[54]. For some of these, little extra effort is required on top of existing work, but for others monitoring methods will have to be designed and trialled, volunteers recruited and trained, and sufficient resources made available. It is likely to take several years for good coverage to be achieved for many of the species. Despite the difficulties of carrying out fieldwork in 2020, as a result of the Covid-19 pandemic, monitoring work started on a few species (e.g. Mountain Burnet *Zygaena exulans*) and trials were conducted on several others (e.g. Kentish Glory *Endromis versicolora* and Four-spotted *Tyta luctuosa*).

SUSSEX EMERALD



NETTED CARPET

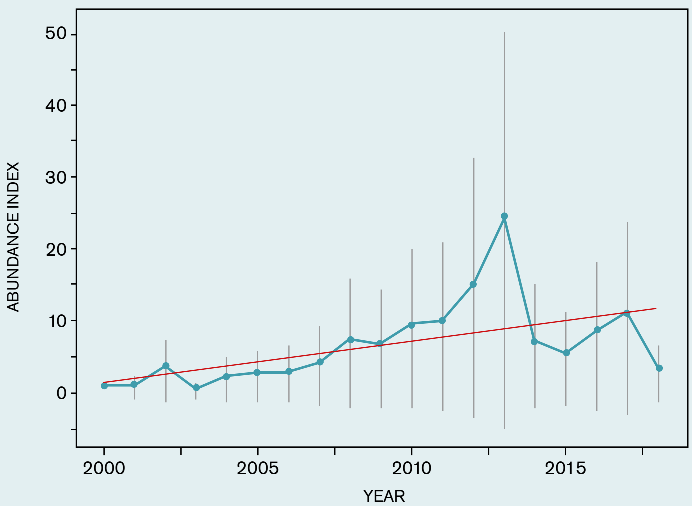


Figure 6 Abundance trends from larval monitoring of Sussex Emerald *Thalera fimbrialis* at Dungeness, Kent (significant decrease of 66% in abundance 2000–2019) and Netted Carpet *Eustroma reticulata* across its Lake District and north Lancashire colonies (significant increase of 906% in abundance 2000–2018).

[53] Eaton *et al.* 2015
[54] Tordoff 2020

Moths in decline

Patrick Clement

Rosy Minor *Litoligia literosa*: 92% decrease in abundance (1968–2017) and 21% decrease in distribution (1970–2016).

Many species of larger moths have declined in Britain over the past five decades. Long-term trends show that 41% of species decreased significantly in abundance and 32% suffered significant reductions in distribution.

Tables 1 and 2 show the 30 species with the most severe rates of abundance and distribution decrease. These are expressed as rates of change over an average 10-year period, so that valid comparisons can be made between species with trends measured over different durations. The full percentage change over the whole time period assessed is given, for example species, elsewhere in the text but with the full date period shown.

Some species have high rates of decline in both abundance and distribution, such as Golden Plusia *Polychrysia moneta*, Garden Dart *Euxoa nigricans* and Lappet *Gastropacha quercifolia,* but others show large decreases in only one of the two measures. This is in part because not all species have trends for both abundance and distribution – Stout Dart *Spaelotis ravida*, for example, has the highest rate of abundance decline but, while it has clearly suffered a catastrophic distribution decrease (and may be extinct in Britain, p.6), there are insufficient data to calculate a long-term trend. Alternatively, a species' abundance and distribution trends may differ substantially for reasons including time lags between population-level decline and reduction in distribution or different responses around Britain (e.g. abundance decline in the core part of the species' distribution, but range expansion at the northern edge).

TABLE 1

Thirty species of larger moths with the highest (statistically significant) rates of decrease in abundance measured over an average 10-year period.

Species	Abundance trend Average 10-year % change
Stout Dart *Spaelotis ravida*	-81
Golden Plusia *Polychrysia moneta*	-58
Garden Dart *Euxoa nigricans*	-54
V-Moth *Macaria wauaria*	-54
Large Thorn *Ennomos autumnaria*	-53
Lappet *Gastropacha quercifolia*	-53
Oak Lutestring *Cymatophorina diluta*	-52
Figure of Eight *Diloba caeruleocephala*	-48
Lead Belle *Scotopteryx mucronata*	-48
Dusky-lemon Sallow *Cirrhia gilvago*	-47
Spinach *Eulithis mellinata*	-47
Dusky Thorn *Ennomos fuscantaria*	-47
Double Dart *Graphiphora augur*	-45
Hedge Rustic *Tholera cespitis*	-44
Juniper Pug *Eupithecia pusillata*	-44
Large Nutmeg *Apamea anceps*	-44
Small Autumnal Moth *Epirrita filigrammaria*	-44
Maple Pug *Eupithecia inturbata*	-44
Brindled Ochre *Dasypolia templi*	-42
Anomalous *Stilbia anomala*	-41
Beaded Chestnut *Agrochola lychnidis*	-41
Dot Moth *Melanchra persicariae*	-40
Dark-barred Twin-spot Carpet *Xanthorhoe ferrugata*	-40
Broad-barred White *Hecatera bicolorata*	-40
White-line Dart *Euxoa tritici*	-39
Satyr Pug *Eupithecia satyrata*	-38
Lackey *Malacosoma neustria*	-38
Red Carpet *Xanthorhoe decoloraria*	-38
Larch Pug *Eupithecia lariciata*	-38
Broom-tip *Chesias rufata*	-38

TABLE 2

Thirty species of larger moths with the highest (statistically significant) rates of decrease in distribution measured over an average 10-year period.

Species	Distribution trend Average 10-year % change
Netted Pug *Eupithecia venosata*	-64
Ruddy Carpet *Catarhoe rubidata*	-57
Plain Pug *Eupithecia simpliciata*	-54
Brown-veined Wainscot *Archanara dissoluta*	-50
White Colon *Sideridis turbida*	-42
Northern Deep-brown Dart *Aporophyla lueneburgensis*	-41
Orange Moth *Angerona prunaria*	-40
Ruddy Highflyer *Hydriomena ruberata*	-38
Bilberry Pug *Pasiphila debiliata*	-36
Mocha *Cyclophora annularia*	-35
Scarce Silver Y *Syngrapha interrogationis*	-35
Lead-coloured Drab *Orthosia populeti*	-31
Garden Dart *Euxoa nigricans*	-31
Juniper Carpet *Thera juniperata*	-30
Clouded Buff *Diacrisia sannio*	-30
Crinan Ear *Amphipoea crinanensis*	-30
Grass Wave *Perconia strigillaria*	-30
Sand Dart *Agrotis ripae*	-29
Shore Wainscot *Mythimna litoralis*	-29
Larch Pug *Eupithecia lariciata*	-29
Angle-barred / Ash / Tamarisk Pug *Eupithecia innotata*	-29
Gold Swift *Phymatopus hecta*	-29
Blossom Underwing *Orthosia miniosa*	-29
Cloaked Carpet *Euphyia biangulata*	-29
Crescent Striped *Apamea oblonga*	-28
Ochreous Pug *Eupithecia indigata*	-28
Grey Mountain Carpet *Entephria caesiata*	-28
Golden Plusia *Polychrysia moneta*	-28
Barred Hook-tip *Watsonalla cultraria*	-28
Double Dart *Graphiphora augur*	-26

Keith Tailby

Lappet *Gastropacha quercifolia*: 98% decrease in abundance (1968–2017) and 61% decrease in distribution (1980–2016).

Peter Maton

Dark Spinach *Pelurga comitata*: 90% decrease in abundance (1968–2017) and 52% decrease in distribution (1970–2016).

DOUBLE DART

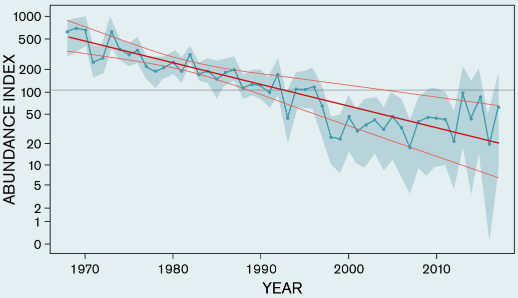
Graphiphora augur

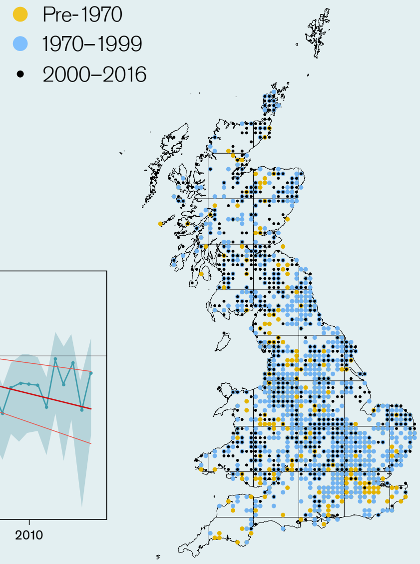
-96% abundance (1968–2017)

-79% distribution (1970–2016)

Double Dart has decreased severely over the past 50 years, particularly in southern Britain. Its abundance declined sharply until the late 1990s, by which time it was very scarce in the RIS network, and has remained so. It is a moth of broadleaved woodland and scrubby habitats, where its caterpillars feed on common trees such as willows, Blackthorn and birches, as well as herbaceous plants. The causes of its decline are unknown.

Keith Tailby





RED CARPET

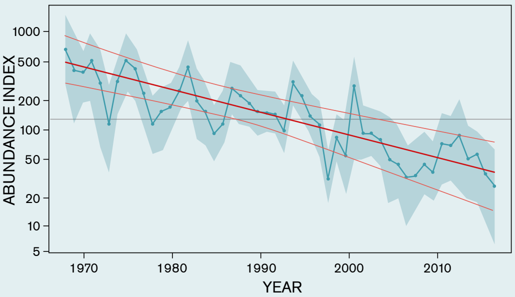
Xanthorhoe decoloraria

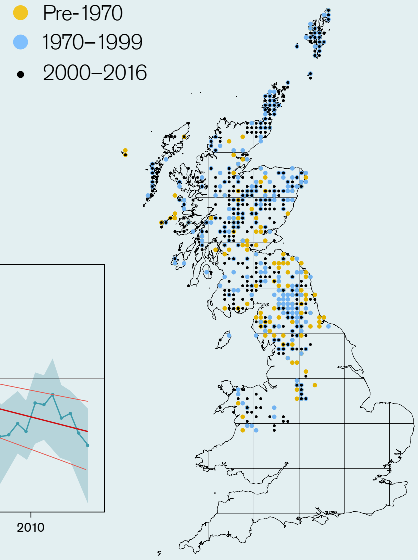
-92% abundance (1968–2017)

-62% distribution (1970–2016)

Red Carpet is a northern species, restricted to higher altitudes in Britain, except in Orkney and Shetland where it occurs at lower elevations. It typically occurs on grassy hillsides with rocky outcrops and the larvae feed on lady's-mantles. The steep declines of this moth are most pronounced in the southern half of its range, which is consistent with a negative response to climate change.

Keith Tailby





FLOUNCED CHESTNUT

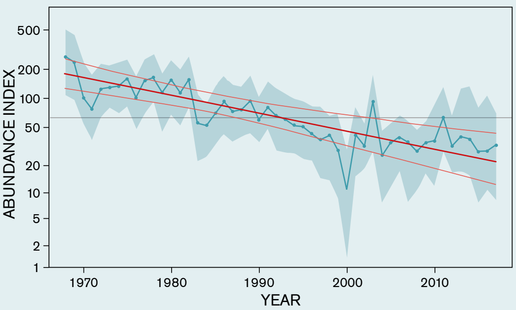
Agrochola helvola

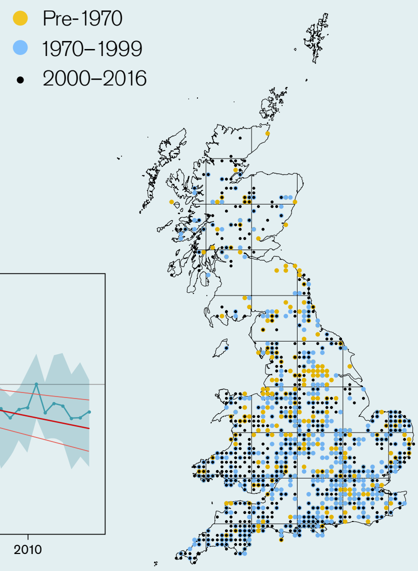
-87% abundance (1968–2017)

-55% distribution (1970–2016)

Although it does not feature in the 30 most rapidly decreasing species for abundance or distribution, Flounced Chestnut has undergone severe declines. Its numbers at RIS sites decreased steeply until the turn of the century, but have since shown little overall change. Recent distribution declines seem to be concentrated in south-east England and the Midlands. It is associated with woody plants and is found in broadleaved woodland and scrub, as well as on heaths and moors.

Neil Sherman



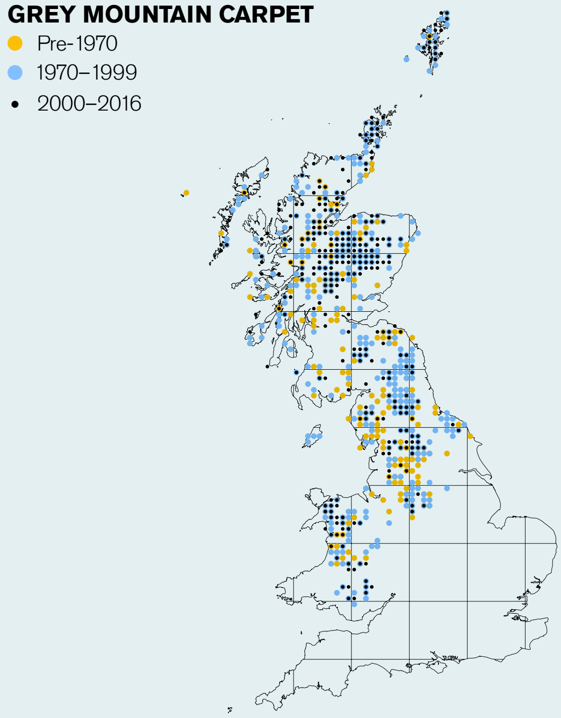


These plots show the annual abundance indices (blue points and line) and their 95% confidence intervals (blue shading) and the trend (bold red line) and its 95% confidence intervals (pale red lines). The grey horizontal line shows the average annual abundance index across the entire time period. The vertical axis is on a log scale.

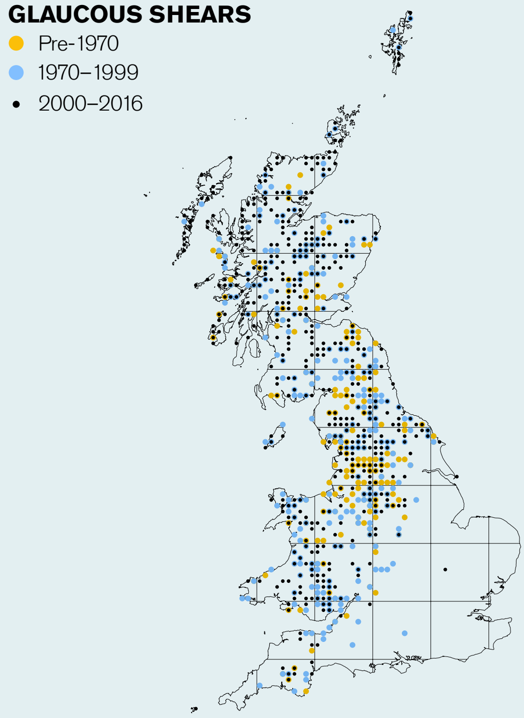
STAYING COOL

Many larger moths that have a northern and western distribution in Britain, and are associated with cool, damp climates, appear to be retreating. Examples include Grey Mountain Carpet *Entephria caesiata* (81% decrease in distribution 1970–2016) and Glaucous Shears *Papestra biren* (38% decrease 1970–2016) (both shown below), Autumn Green Carpet *Chloroclysta miata* (38% decrease 1970–2016), Grey Chi *Antitype chi* (57% decrease 1970–2016) and Brindled Ochre *Dasypolia templi* (76% decrease 1970–2016). Most of these species also appeared to be shifting to higher altitude in a study in Yorkshire[55]. While the causes are not known with complete certainty, these distribution declines are in keeping with expected responses to climate change.

GREY MOUNTAIN CARPET



GLAUCOUS SHEARS



All of the species with long-term RIS and NMRS trends are relatively common and widespread, or at least were for a substantial part of the time period assessed. In general, reliable trends cannot be calculated for scarcer species, unless specific population monitoring has been carried out (e.g. for rare, conservation-priority species p.11). However, the decrease of widespread larger moths is perhaps more worrying than declines of scarce species, and certainly presents a greater conservation challenge, as it suggests a pervasive, insidious deterioration of the environment.

Abundant and widespread species contribute disproportionately to both biomass (i.e. food for other organisms) and ecosystem functioning (e.g. pollination), so their declines may have severe impacts on other species[56]. In addition, because most interactions between people and moths occur with widespread species, these declines are a factor in the 'extinction of experience'[57], whereby people are no longer familiar with moths that used to be common. Writing more than a century ago, Richard South observed that the Garden Tiger *Arctia caja* was a moth that "few persons living in the country, and at all interested in the natural objects around them, will fail to recognize"[58]. Sadly, after a 90% decline in abundance since the late 1960s, as well as a significant reduction in distribution (24% decrease since 1970), many people are no longer familiar with this spectacular moth or its "woolly bear" caterpillars.

This disconnect is linked with another phenomenon called 'shifting baseline syndrome', whereby people who did not experience higher levels of wildlife abundance in the past accept the current depleted populations as the norm[59]. Together, these have negative implications for conservation; people who are detached from nature or unaware of the scale of change are unlikely to support ambitious efforts to restore it.

[55] Fletcher 2018
[56] Kleijn *et al.* 2015, Winfree *et al.* 2015
[57] Soga & Gaston 2016
[58] South 1907
[59] Soga & Gaston 2018

Keith Tailby

Coronet *Craniophora ligustri*: 220% increase in abundance (1968–2017) and 54% increase in distribution (1980–2016).

Moths on the increase

While there is clear evidence of decline among Britain's larger moths over the past 50 years, a substantial number of species have bucked the trend; a modest 10% of species had statistically significant increases in abundance, but 37% had significant, positive distribution trends.

Some of the most rapidly increasing species are recent colonists, such as Cypress Carpet *Thera cupressata*, which was first recorded in Sussex in 1984, and White-point *Mythimna albipuncta*, which became established in the 1980s, or immigrant moths (e.g. Gem *Nycterosea obstipata*). Most, however, are long-term resident species that have undergone dramatic increases in abundance and/or distribution over recent decades.

Particularly interesting are species that were formerly highly restricted in their British distribution, but have expanded into many new areas. Devon Carpet *Lampropteryx otregiata* and Jersey Tiger *Euplagia quadripunctaria*, for example, were historically restricted to south-west Britain, while Webb's Wainscot *Globia sparganii* was principally a coastal species.

Tables 3 and 4 show the 30 species with the greatest rates of abundance and distribution increase (measured as rates of change over an average 10-year period so that species with trends of different durations can be compared). Total rates of change over the whole time period assessed are given elsewhere in the text but always with the full date period shown.

TABLE 3

Thirty species of larger moths with the highest (statistically significant) rates of increase in abundance measured over an average 10-year period.

Species	Abundance trend Average 10-year % change
Buff Footman *Eilema depressa*	237
Least Carpet *Idaea rusticata*	131
Orange Footman *Eilema sororcula*	115
Dingy Footman *Eilema griseola*	110
Spruce Carpet *Thera britannica*	92
Straw Dot *Rivula sericealis*	64
Small Rufous *Coenobia rufa*	49
Red-green Carpet *Chloroclysta siterata*	45
Treble Brown Spot *Idaea trigeminata*	44
Broad-bordered Yellow Underwing *Noctua fimbriata*	43
Devon Carpet *Lampropteryx otregiata*	40
Scarce Footman *Eilema complana*	38
Dotted Chestnut *Conistra rubiginea*	36
Oak Nycteoline *Nycteola revayana*	32
Dingy Shell *Euchoeca nebulata*	32
Green Carpet *Colostygia pectinataria*	31
Double-striped Pug *Gymnoscelis rufifasciata*	31
Peacock Moth *Macaria notata*	30
Satin Beauty *Deileptenia ribeata*	30
Blair's Shoulder-knot *Lithophane leautieri*	28
Rosy Footman *Miltochrista miniata*	28
Juniper Carpet *Thera juniperata*	28
Copper Underwing *Amphipyra pyramidea*	27
Vapourer *Orgyia antiqua*	27
Grey Shoulder-knot *Lithophane ornitopus*	26
Lesser Cream Wave *Scopula immutata*	25
Dwarf Cream Wave *Idaea fuscovenosa*	25
Coronet *Craniophora ligustri*	24
Clay Triple-lines *Cyclophora linearia*	20
Black Arches *Lymantria monacha*	19

TABLE 4

Thirty species of larger moths with the highest (statistically significant) rates of increase in distribution measured over an average 10-year period.

Species	Distribution trend Average 10-year % change
Cypress Carpet *Thera cupressata*	273
Marsh Oblique-barred *Hypenodes humidalis*	137
Jersey Tiger *Euplagia quadripunctaria*	119
Orange Footman *Eilema sororcula*	66
Buff Footman *Eilema depressa*	58
Webb's Wainscot *Globia sparganii*	52
Red-green Carpet *Chloroclysta siterata*	49
Cream-bordered Green Pea *Earias clorana*	45
Spruce Carpet *Thera britannica*	45
Scarlet Tiger *Callimorpha dominula*	44
Pinion-streaked Snout *Schrankia costaestrigalis*	42
Festoon *Apoda limacodes*	39
White-point *Mythimna albipuncta*	39
Six-spot Burnet *Zygaena filipendulae*	37
Dingy Footman *Eilema griseola*	37
Humming-bird Hawk-moth *Macroglossum stellatarum*	35
Old Lady *Mormo maura*	33
Edinburgh / Freyer's / Mere's Pug *Eupithecia intricata*	33
Blair's Shoulder-knot *Lithophane leautieri*	32
Dotted Chestnut *Conistra rubiginea*	32
Black Arches *Lymantria monacha*	32
Golden-rod Pug *Eupithecia virgaureata*	32
Gem *Nycterosea obstipata*	31
Maiden's Blush *Cyclophora punctaria*	30
Straw Dot *Rivula sericealis*	27
Burnet Companion *Euclidia glyphica*	27
Vine's Rustic *Hoplodrina ambigua*	26
Treble Brown Spot *Idaea trigeminata*	25
Scarce Footman *Eilema complana*	24
Varied Coronet *Hadena compta*	24

Iain H Leach

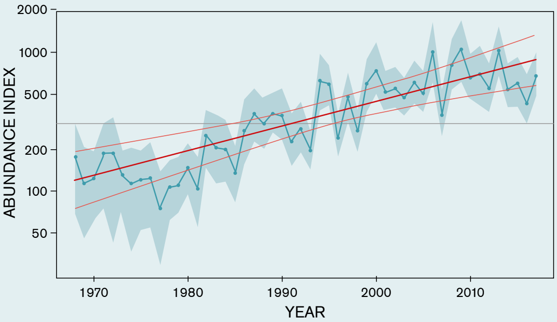
Black Arches *Lymantria monacha*: 161% increase in abundance (1968–2017) and 307% increase in distribution (1970–2016).

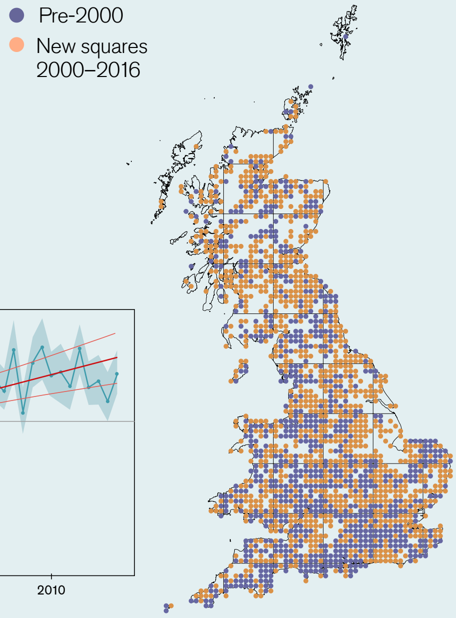
Patrick Clement

Dotted Chestnut *Conistra rubiginea*: 439% increase in abundance (1968–2017) and 124% increase in distribution (1990–2016).

RED-GREEN CARPET
Chloroclysta siterata
653% abundance (1968–2017)
667% distribution (1970–2016)
Red-green Carpet has fared extremely well in Britain over recent decades. Its abundance started to increase rapidly at RIS sites from the early 1980s and the moth has been recorded much more widely across Britain, particularly this century. This is predominantly a woodland species, using a wide range of broadleaved trees as larval foodplants, but it also occurs in more open places including gardens.

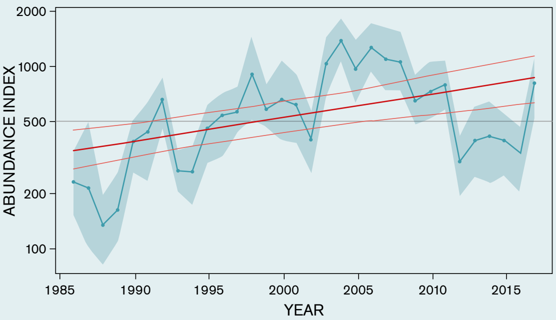

Peter Maton

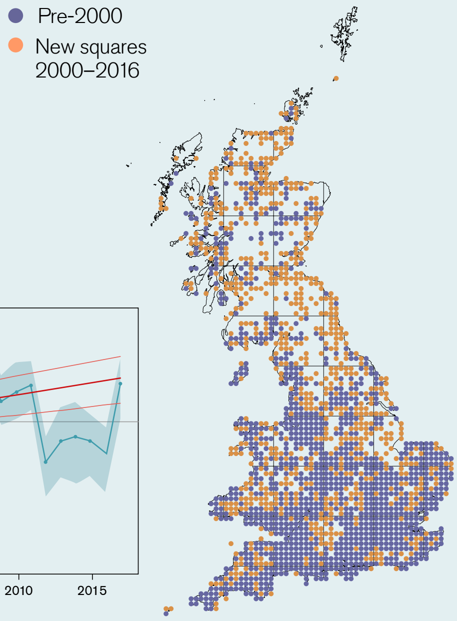




DOUBLE-STRIPED PUG
Gymnoscelis rufifasciata
151% abundance (1986–2017)
165% distribution (1970–2016)
Pug species were not assessed in the previous *State of Britain's Larger Moths* reports, but some, such as Double-striped Pug, have undergone major changes over recent decades. This species, which occurs in a wide range of habitats from gardens to upland moors, has increased in distribution, particularly in Scotland and northern England. It has also become regularly double-brooded in the north and partially triple-brooded in the south, which will have contributed to the large increase in abundance.


Patrick Clement





These plots show the annual abundance indices (blue points and line) and their 95% confidence intervals (blue shading) and the trend (bold red line) and its 95% confidence intervals (pale red lines). The grey horizontal line shows the average annual abundance index across the entire time period. The vertical axis is on a log scale.

SPREADING NORTH

The distributions of larger moth species that reach a northern limit to their range within Britain have, on average, expanded northwards at an increasing rate since the 1960s[60]. Using NMRS data, we re-examined range margin shifts over recent years, using only heavily recorded 10km squares to minimise bias caused by variation in recording effort[61]. Of 487 larger moth species with sufficient data and the potential to spread northwards, the mean range margin change was a northward shift of 5.1km per year over the period 1995–2016 (Fig. 7). In all, 346 species (71% of the total) had statistically significant rates of northward expansion.

Patrick Clement

Devon Carpet *Lampropteryx otregiata* has undergone a rapid range expansion from south-west Britain northwards to reach southern Scotland. Its northern range margin has shifted northwards at 16km per year (1995–2016). The distribution of this moth has more than doubled (118% increase 1980–2016) and its abundance increased greatly (526% increase 1968–2017).

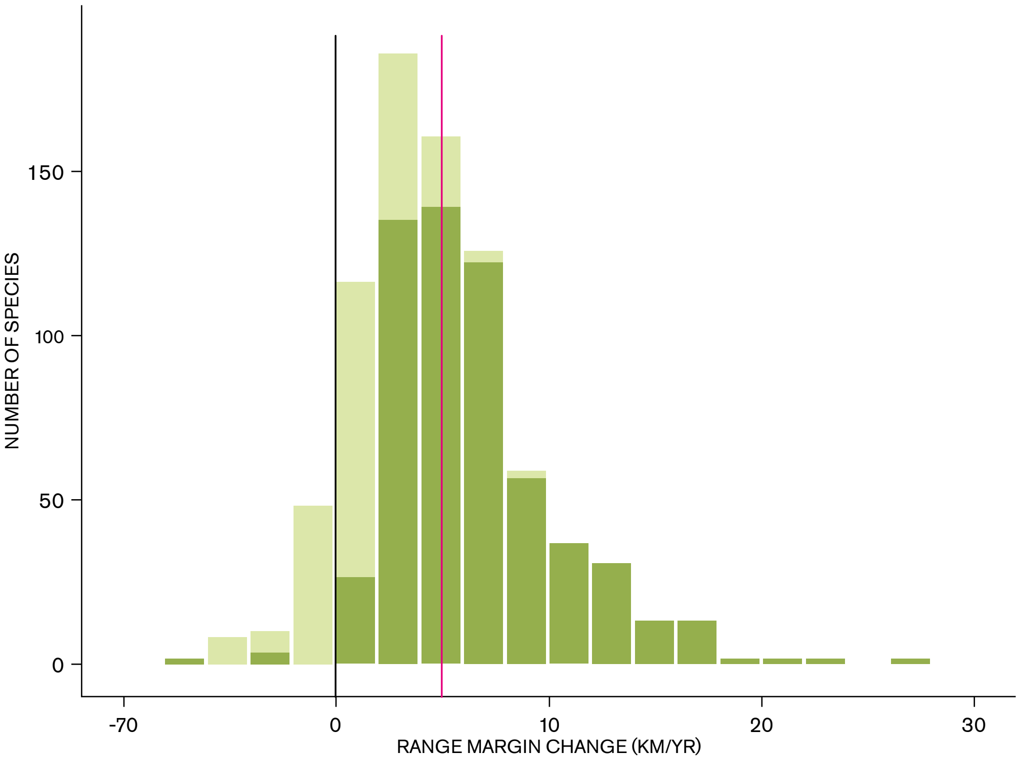


Figure 7 Annual rates of latitudinal shifts in the northern range margins of 487 larger moth species in Britain and the Isle of Man (1995–2016). Statistically significant trends are shown as a darker shade and non-significant trends as a lighter shade. Positive values equate to northwards shifts, negative values to southward shifts. The mean response was a northward shift of 5.1km per year (red line).

[60] Mason *et al.* 2015

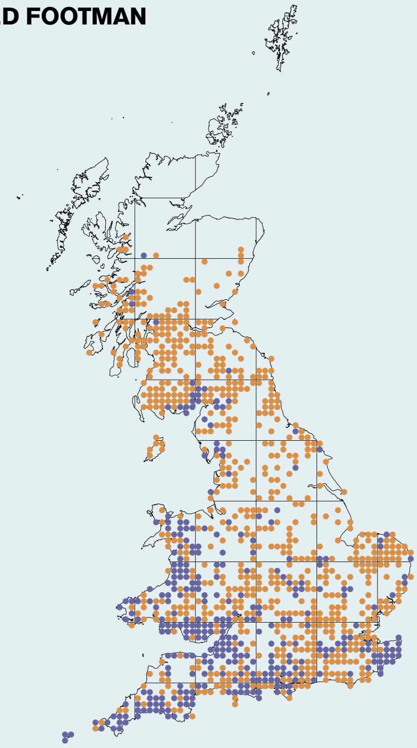
[61] Our methodology followed Macgregor *et al.* 2019a. Only data from 501 heavily recorded 10km squares were included in the analysis and species were excluded if they had been recorded in <20 squares during the period, if their range margin in 1995–1999 occurred within 100km of the northern tip of mainland Britain, or if their distribution had a mean elevation of >200m (as upland species might shift uphill rather than north). The northern range margin of each species was calculated each year as the mean latitude of the 10 most northerly occupied squares.

FOOTMEN MARCH ON

Previous *State of Britain's Larger Moths* reports have highlighted the large increases in abundance of many of the footman species, which have larvae that feed on lichens and algae. These trends have continued and the assessment of distribution change shows that they have also expanded their ranges greatly in recent decades, probably in response to reduced air pollution and climate change (see p.26). The maps below show the historical distributions of four footman species up to 1999 and the new 10km squares where the species has been recorded for the first time from the year 2000 onwards. The total increases in distribution are: Red-necked Footman *Atolmis rubricollis* 66% increase (1990–2016), Buff Footman *Eilema depressa* 524% (1980–2016), Dingy Footman *E. griseola* 391% (1970–2016) and Orange Footman *E. sororcula* 330% (1990–2016).

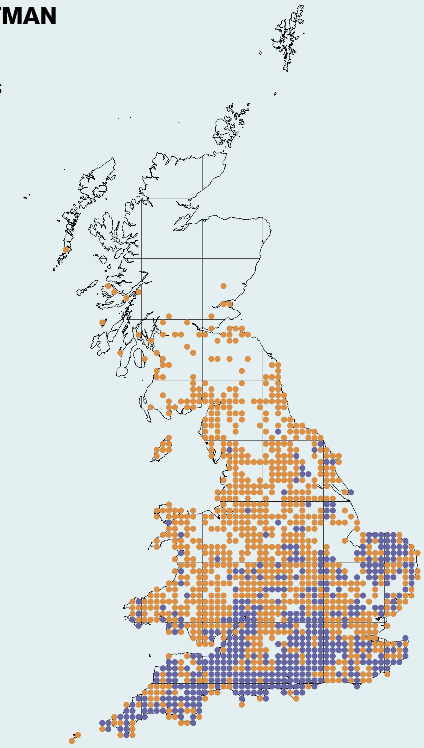
RED-NECKED FOOTMAN

- Pre-2000
- New squares 2000–2016



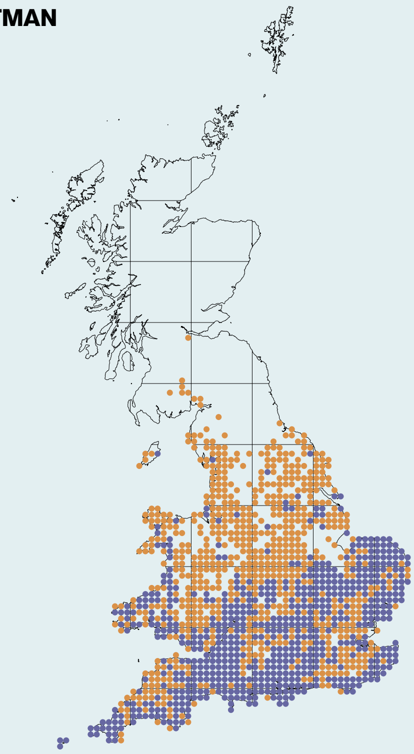
BUFF FOOTMAN

- Pre-2000
- New squares 2000–2016



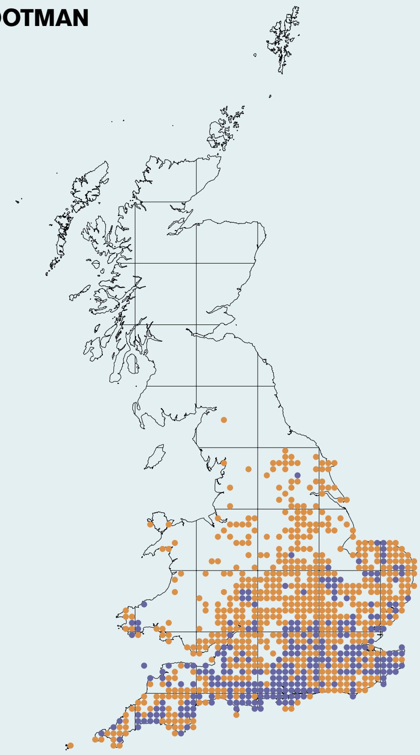
DINGY FOOTMAN

- Pre-2000
- New squares 2000–2016



ORANGE FOOTMAN

- Pre-2000
- New squares 2000–2016



Pale Prominent *Pterostoma palpina* abundance has decreased by 40% (1968–2017).

Patrick Clement

Peter Creed

Beautiful Yellow Underwing *Anarta myrtilli* is a moth of moorland and heaths, which has decreased in distribution by 62% (1980–2016).

Patterns of change

Considering the inherent characteristics (often termed 'traits') or ecological preferences that are shared by species exhibiting similar changes in abundance or distribution can reveal patterns that improve our understanding of the causes of trends. They also provide information on the likely implications for ecosystems and enable predictions to be made about which other species might be similarly affected. This approach is widely used in ecological studies of insects[62] and moths are no exception, although the results can present a complex and sometimes contradictory picture.

The most frequently reported correlation is between species trend and number of larval foodplants; highly specialised moths with caterpillars that only eat a small range of plant species are more likely to have decreased or to be at risk of extinction, while more generalist species tend to have fared well[63]. Large wingspan was found to be the best predictor of moth declines in studies in Britain and Finland[64], although urbanisation seems to favour larger moths[65]. Some studies found that moth species overwintering as eggs tended to have fared badly over recent decades, while those spending the winter as adults have done well on average[66]. Other traits linked to moth declines include univoltinism (having a single generation each year), short flight seasons and low dispersal ability. Noctuid moth species in which wing patterns vary between individuals had lower risks of extinction in Sweden[67]. However, to complicate matters, this trait is also correlated with several others previously associated with positive species trends, including a greater number of larval hostplants, although not with overwintering stage[68]. These interrelationships (the fact that many traits are correlated with each other) make it very challenging to determine which aspects of traits are the causal factors of trends in moth distribution or abundance.

To examine patterns of change in moth distribution according to different habitat preferences, multi-species indicators were constructed (following the method used on p.9) and long-term trends estimated for the period 1970–2016. Moth species were classified according to whether they breed in different broad habitat types in Britain and the distribution trends of individual species combined to produce indicators for woodland, open grassland, moorland and heathland (Fig. 8). Some species that breed in a range of habitats were included in multiple indicators, but species that are dependent on non-native hostplants were excluded.

Moths that breed in woodland (which includes those associated with more open vegetation in clearings and rides) increased significantly in distribution by an average of 12%. This trend remained almost identical when species that use coniferous trees as larval hostplants were excluded. Moths that breed in open grassland habitats also increased significantly in distribution, by 8% on average. In contrast, moth species that breed on moorland in Britain decreased significantly in distribution, with an average 13% reduction over the period 1970–2016. The heathland indicator showed no significant change (Fig. 8).

Given that the overall indicator of distribution change (Fig. 3, p.9) shows a significant increase, the decrease among moths that breed on moorland is notable. More research is required to understand the causes, especially since some of the species in the moorland indicator may also breed in other habitats such as heathland and woodland. However, climate change is one possible driver, given that much of Britain's moorland habitat occurs in cooler, damper areas and at moderate to high altitude. Increased nitrogen deposition is another possible cause,

[62] Wong *et al.* 2019
[63] Mattila *et al.* 2008, Öckinger *et al.* 2010, Betzholtz *et al.* 2017, Valtonen *et al.* 2017
[64] Mattila *et al.* 2009, Coulthard *et al.* 2019
[65] Merckx *et al.* 2018
[66] Conrad *et al.* 2004, Groenendijk & Ellis 2011
[67] Betzholtz *et al.* 2017
[68] Forsman *et al.* 2020

given that moorland plant communities on nutrient-poor soils may be severely impacted by this chemical pollution[69]. Changes in moorland management, including the intensity of livestock grazing and frequency of burning, may also be a factor. A recent RSPB analysis showed that moor burning was the biggest identified cause of damage to Sites of Special Scientific Interest in England[70]. There is evidence that high levels of livestock grazing on moors have negative effects on moth communities[71], but the impact of moorland burning has not been studied in Britain, although fire has caused declines in moth abundance and species richness in other habitats around the world[72]. Research is needed to identify the extent to which management by burning is linked to the distribution decreases of moorland moths.

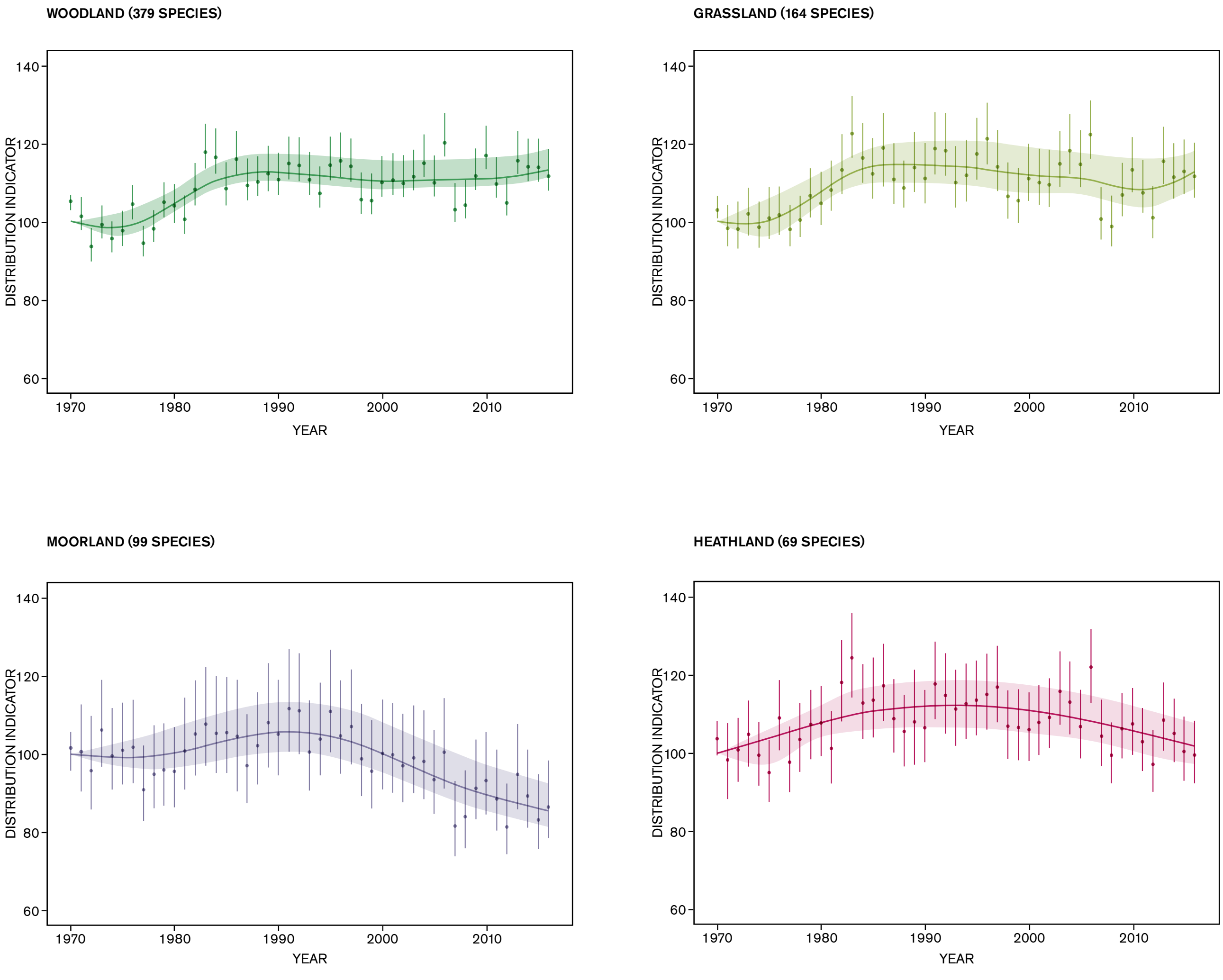


Figure 8 Multi-species indicators of change in distribution of moths that breed in various broad habitat types in Britain and the Isle of Man (1970–2016). The line and shading on each plot shows the smoothed indicator and 95% confidence interval. The long-term trends (with 95% confidence intervals) were: woodland 12% (11%, 17%), grassland 8% (5%, 13%), moorland -13% (-17%, -7%), heathland 1% (-3%, 7%).

[69] Field *et al.* 2014
[70] rspb.org.uk/about-the-rspb/about-us/media-centre/press-releases/new-analysis-shows-that-burning-of-moorlands-is-the-biggest-threat-to-englands-most-important-places-for-wildlife/
[71] Littlewood *et al.* 2006
[72] e.g. Banza *et al.* 2019

Phenology change

Iain H Leach

The second generation of Burnished Brass *Diachrysia chrysitis* has become more numerous and occurred further north since the 1970s.

Changes to phenology, the timing of life cycle events, have been widely documented as species respond to rising temperatures[73]. In Britain, moth flight periods have, on average, shifted earlier in the year over time, with the largest advances among species that fly in the first half of the year[74]. For example, the mean flight dates of species such as Water Carpet *Lampropteryx suffumata*, Oak-tree Pug *Eupithecia dodoneata*, Grey Birch *Aethalura punctulata* (Fig. 9), Great Prominent *Peridea anceps* and Common Quaker *Orthosia cerasi* have advanced by at least 13 days since the 1970s[75]. Mirroring this change, some autumn-flying moths, such as Anomalous *Stilbia anomala* and Pink-barred Sallow *Xanthia togata*, are now flying later in the year compared with the 1970s. Recent research found that emerging earlier in the year appeared to benefit some moth and butterfly species in Britain but not others[76]. In species that have more than one generation each year, the earlier emergence of the first generation led to greater abundance in the second brood and was associated with long-term population increases. In contrast, there was no evidence of a positive relationship between earlier emergence and abundance trends for univoltine (single-brooded) species. Indeed, for those univoltine species that are also habitat specialists, earlier emergence was correlated with decreasing abundance.

It is important to note that the changing phenology of moth life cycles is not happening in isolation. The phenology of their foodplants, predators and parasitoids is also changing, but rates vary from species to species, creating the potential for temporal mismatches[77]. For example, while Winter Moth *Operophtera brumata* eggs hatch earlier in warmer springs to remain synchronised with the earlier appearance of oak leaves[78], insectivorous birds have not adjusted their egg-laying dates sufficiently to keep up with shifts in the peak of caterpillar biomass[79]. Despite numerous examples of phenological mismatches across a wide range of species, there is insufficient evidence at present to link such divergence to impacts on populations[80].

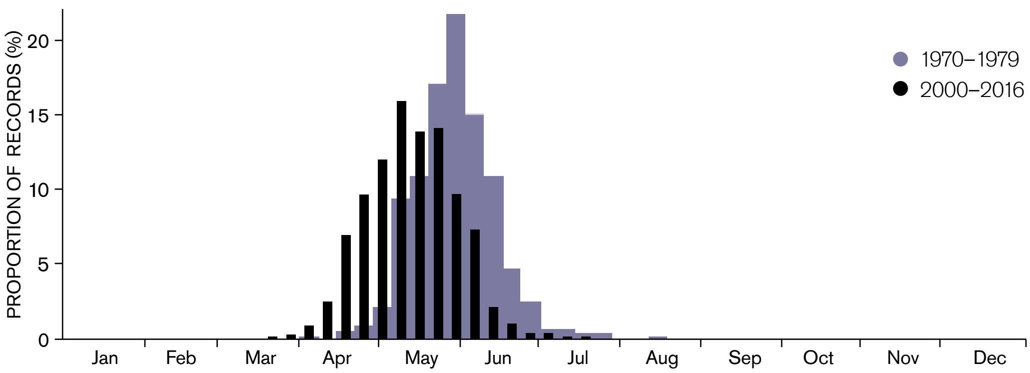
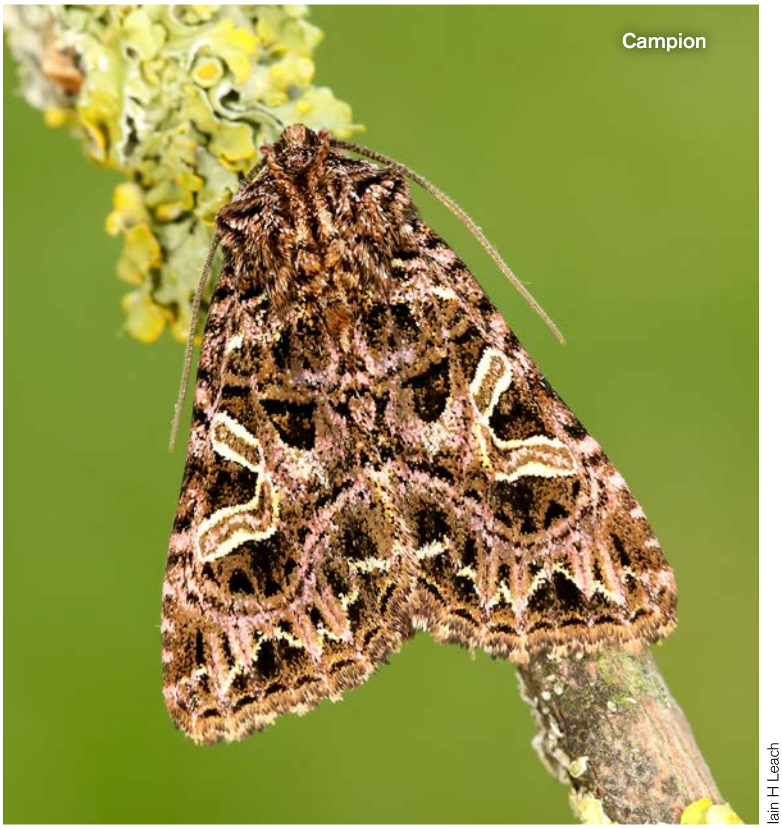


Figure 9 The flight period of Grey Birch *Aethalura punctulata* has advanced considerably since the 1970s.

[73] Cohen *et al.* 2018
[74] Bell *et al.* 2019, Randle *et al.* 2019
[75] Randle *et al.* 2019
[76] Macgregor *et al.* 2019a
[77] Thackeray *et al.* 2016, Tougeron *et al.* 2020
[78] Buse *et al.* 1999
[79] Both *et al.* 2009, Burgess *et al.* 2018
[80] Samplonius *et al.* 2021



Patterns of voltinism among moths are also changing in response to climate change, with increased incidence of multiple broods per year[81]. There has been an increase in the size of second generations (relative to the first brood) since the 1970s for species such as Green Carpet *Colostygia pectinataria*, Sharp-angled Peacock *Macaria alternata* (Fig. 10), Lilac Beauty *Apeira syringaria*, Burnished Brass *Diachrysia chrysitis*, Campion *Sideridis rivularis* and Common Wainscot *Mythimna pallens*. In many cases, these second generations are also occurring further north than they did previously. In other species, traditionally considered to be single-brooded in Britain, a small second generation has become evident or more frequent over recent decades (e.g. Buff Arches *Habrosyne pyritoides*, Swallow-tailed Moth *Ourapteryx sambucaria* and White-line Snout *Schrankia taenialis*). The consequences of such changes are not yet understood but could form 'development traps', as individuals contend with lower-quality foodplants and deteriorating climatic conditions later in the year[82].

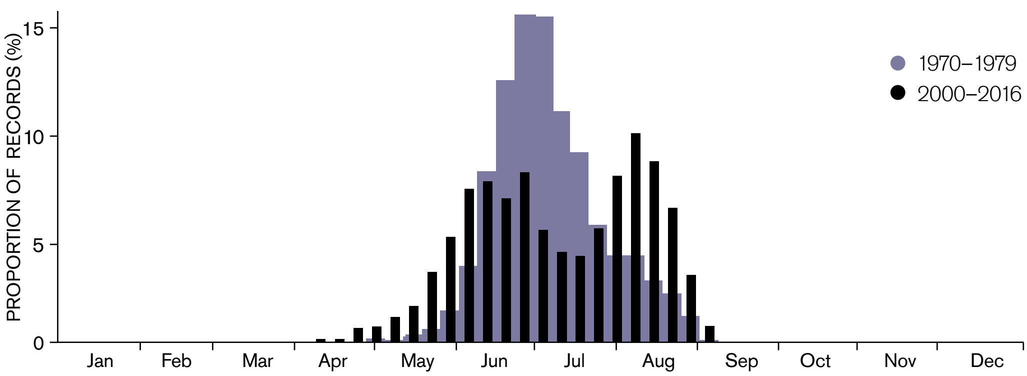
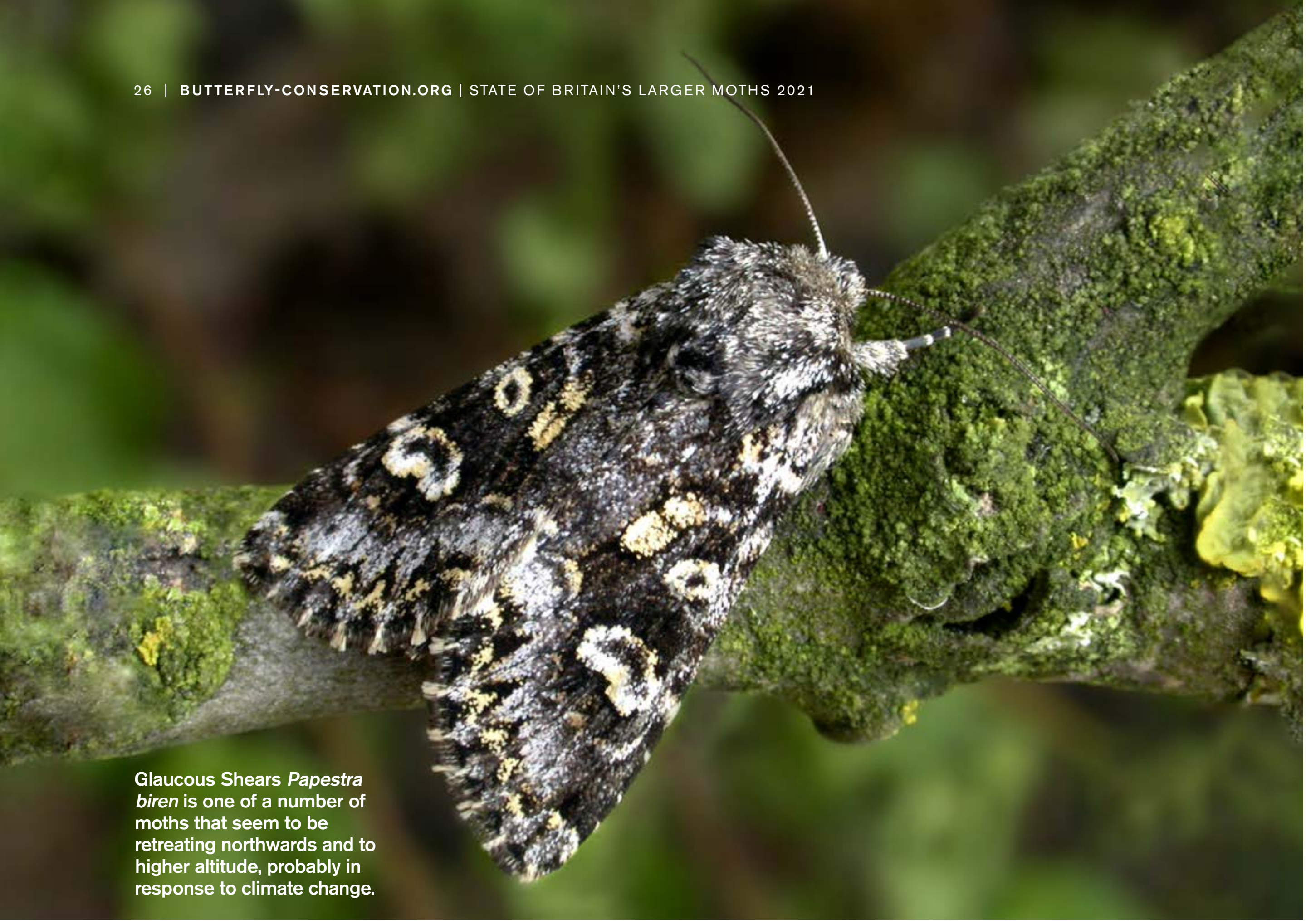


Figure 10 The second generation of Sharp-angled Peacock *Macaria alternata* has become relatively more abundant since the 1970s.

[81] Altermatt 2010, Pöyry *et al.* 2011
[82] Van Dyck *et al.* 2015, Kerr *et al.* 2020



Glaucous Shears *Papestra biren* is one of a number of moths that seem to be retreating northwards and to higher altitude, probably in response to climate change.

Keith Tailby

Oliver Dixon; cc-by-sa

Drivers of change

Much remains to be discovered about the factors driving the changing state of Britain's moths, the relative importance of each and how they interact with each other. Nevertheless, progress has been made in recent years, particularly in understanding the potential impacts of artificial light at night and nitrogen pollution.

LAND USE

Both the destruction of habitats and major changes in management intensity are considered the key drivers of long-term moth declines[83], particularly those associated with the intensification of agriculture[84]. More sympathetic management (e.g. through agri-environment schemes) often leads to increased abundance and species richness. For example, reduced frequency and intensity of hedgerow cutting in GB agricultural landscapes benefited Lepidoptera communities[85]. Urbanisation is linked to reductions in moth numbers and diversity, particularly the loss of habitat specialist species, but also favours larger, more mobile moths[86].

CLIMATE CHANGE

Substantial effects of climate change on moths, butterflies and other insects are evident in Britain and around the world[87]. New species have colonised (see p.7) and moths with northern range margins in Britain have spread northwards at an increasing rate since the 1960s[88]. A climatic risk assessment predicted that >60% of 422 moth species could increase in distribution this century due to climate change[89]. However, the extent to which species are able to expand through fragmented British landscapes is limited by habitat availability[90]. Other studies have found evidence of negative climatic impacts on moth abundance[91] and distribution[92].

CHEMICAL POLLUTION

The UK's soils and water bodies are increasingly enriched with mineral nutrients emanating from chemical fertilizers, farm and urban effluent and pollution from vehicles and industry. Nitrogen enrichment, in particular, is expected to affect moths via changes to the chemistry, structure and composition of plant communities[93].

[83] Fox 2013
[84] Burns *et al.* 2016, Mangels *et al.* 2017
[85] Staley *et al.* 2016, Froidevaux *et al.* 2019
[86] Merckx *et al.* 2018, Merckx & Van Dyck 2019
[87] Wilson & Fox 2020
[88] Mason *et al.* 2015
[89] Pearce-Higgins *et al.* 2017
[90] Platts *et al.* 2019
[91] Martay *et al.* 2017, Palmer *et al.* 2017
[92] Fox *et al.* 2014, Fletcher 2018
[93] Nijssen *et al.* 2017, Stevens *et al.* 2018

Moths with larval hostplants that thrive in high-nutrient conditions tend to have more positive trends in Britain[94] and Finland[95] and are spreading northwards more rapidly in Sweden[96] compared to those using plants adapted to nutrient-poor environments. Increased larval mortality of Blood-vein *Timandra comae* and Straw Dot *Rivula sericealis*, as well as several widespread butterfly species, has been recorded when hostplants were given nitrogen fertilizer in quantities typically applied in agriculture[97].

Reduced air pollution in Britain may also be indirectly driving some positive species trends. Moths with larvae that feed on lichens, e.g. Brussels Lace *Cleorodes lichenaria*, Dingy Footman *Eilema griseola* and Marbled Green *Nyctobrya muralis*, have fared well and this has been linked to the recovery of lichen populations following air-quality improvements, particularly the reduction in sulphur dioxide pollution[98].

There is currently very little evidence of impact on moths for other chemical pollutants. Insecticides and herbicides clearly have the potential to damage moth populations, at least locally, but disentangling such effects from other aspects of intensive management is challenging, particularly given the lack of toxicity information for non-target Lepidoptera[99]. One short-term field experiment found negative effects of insecticide application on moth caterpillar abundance in field margins, but no effect of herbicide treatment[100].

ARTIFICIAL LIGHT AT NIGHT

The global extent and intensity of artificial light are both increasing at c.2% per year[101] and 83% of the human population now lives under light-polluted skies[102]. Research into the impacts of artificial light on wildlife has proliferated in recent years[103], revealing diverse direct effects on moths throughout the life cycle[104] as well as potentially via changes to the growth and phenology of larval hostplants[105].

Artificial light can disrupt pheromone production in Cabbage Moth *Mamestra brassicae*[106], reduce mating in Winter Moth *Operophtera brumata*[107], decrease larval growth in Rustic Shoulder-knot *Apamea sordens*[108] and inhibit feeding in adult moths including Common Marbled Carpet *Dysstroma truncata*[109]. It has also been shown to alter nocturnal pollination by moths[110]. As yet there is limited evidence for a direct causative link between artificial light and population change in moths; experimental illumination of woodland edges with LED lighting caused a 14% decrease in total moth abundance but only after several years[111].

SHINING A LIGHT

Butterfly Conservation has been involved in and helped to fund research into the impacts of artificial light at night on moth populations and ecosystem functioning through two NERC PhD research projects in partnership with Newcastle University and the UK Centre for Ecology & Hydrology. The first project, undertaken by Callum Macgregor, found impacts of artificial light on pollen transport by nocturnal moths[112] and pollination of White Campion[113], as well as discovering that between 23% and 34% of moths were carrying pollen in farm field margins in Oxfordshire and Yorkshire respectively[114]. In the second project, which is ongoing, Douglas Boyes is investigating the impacts of light pollution on the abundance, development and behaviour of moth caterpillars and their parasitoids.

Douglas Boyes

Surveying nocturnal moth caterpillars as part of research to understand the impacts of street lighting.

[94] Fox *et al.* 2014
[95] Pöyry *et al.* 2017
[96] Betzholtz *et al.* 2013
[97] Kurze *et al.* 2018
[98] Pescott *et al.* 2015
[99] Braak *et al.* 2018
[100] Hahn *et al.* 2015
[101] Kyba *et al.* 2017
[102] Falchi *et al.* 2016
[103] Sanders *et al.* 2021
[104] Boyes *et al.* 2020
[105] Bennie *et al.* 2016, ffrench-Constant *et al.* 2016
[106] Van Geffen *et al.* 2015a
[107] Van Geffen *et al.* 2015b
[108] Grenis & Murphy 2019
[109] Van Langevelde *et al.* 2017
[110] Macgregor *et al.* 2019b, Giavi *et al.* 2020
[111] van Grunsven *et al.* 2020
[112] Macgregor *et al.* 2017
[113] Macgregor *et al.* 2019b
[114] Macgregor *et al.* 2019c

Extinction risk and conservation priority

Dave Green

Straw Belle *Aspitates gilvaria* is an endangered species with a declining distribution that is restricted to Kent and Surrey.

The resources available for conservation are limited and should be targeted at the species that are most in need and where we have the knowledge and ability to make an effective difference. Assessing the status of species is the starting point for this process of prioritisation. Population and range size (rarity), abundance and distribution trends (such as those described in this report) and threats all help to inform species status. The Red List process developed by the International Union for Conservation of Nature (IUCN) provides an international standard for assessing the extinction risk of species at global, continental, national and even regional scales[115].

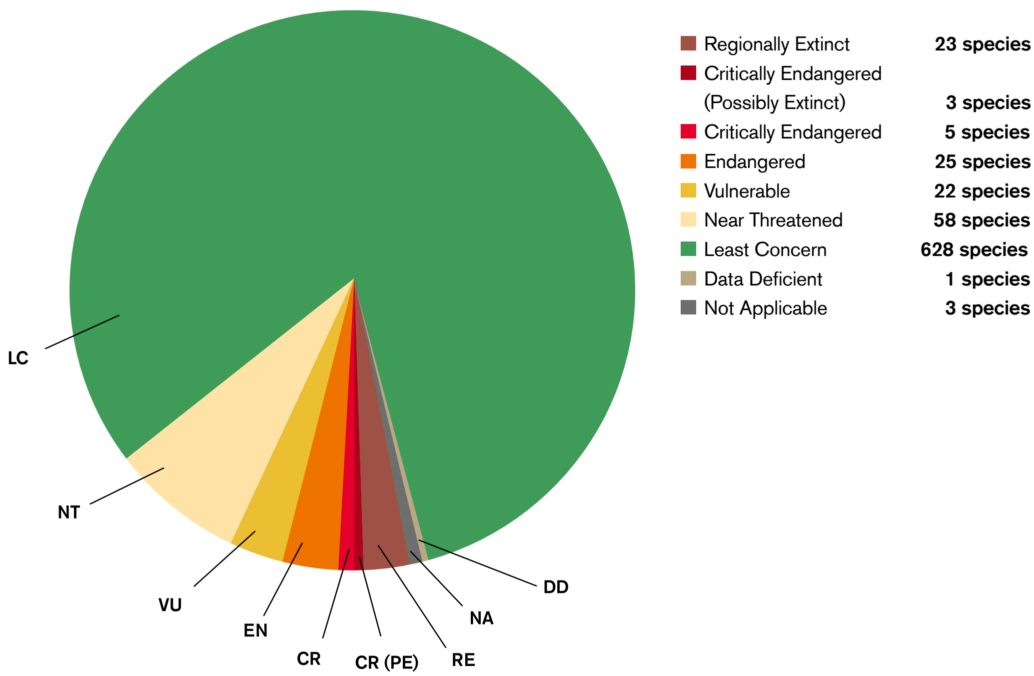
Being listed as threatened in a Red List is not sufficient justification, by itself, for prioritising conservation action for a species[115]. Other factors, such as an understanding of the ecological requirements of species, access to sites, effective habitat management techniques, costs and likelihood of success may all influence the selection of priorities. Thus, the widely held view that Red Listing is equivalent to a conservation prioritisation process is incorrect[116]. Nevertheless, by providing key status information and by generating public and political awareness, Red Lists often catalyse conservation initiatives[117].

RED LIST STATUS OF LARGER MOTHS IN BRITAIN

Over recent years all resident or formerly resident larger moth species in Britain have been evaluated using the IUCN criteria to assess their status[118]. Twenty-three species (3% of the total) were categorised as Regionally Extinct and 55 (7%) listed as threatened, comprising three Critically Endangered (Possibly Extinct) species (Brighton Wainscot *Oria musculosa*, Orange Upperwing *Jodia croceago*, Bordered Gothic *Sideridis reticulata*), five Critically Endangered species (New Forest Burnet *Zygaena viciae,* Black-veined Moth *Siona lineata*, Speckled Footman *Coscinia cribraria*, Reddish Buff *Acosmetia caliginosa*, Stout Dart *Spaelotis ravida*), 25 Endangered and 22 Vulnerable moth species. An additional 58 species (8% of the total assessed) were classified as Near Threatened and 628 (82%) as Least Concern (Fig.11)[119].

RED LIST

Figure 11 The proportion of resident and former resident larger moth species in each Red List category in Britain.



[115] Mace *et al.* 2008
[116] Collen *et al.* 2016
[117] Rodrigues *et al.* 2006, Hoffmann *et al.* 2008, Azam *et al.* 2016

[118] Fox *et al.* 2019
[119] In addition, Fen Square-spot *Diarsia florida* was listed as Data Deficient, as the status of this taxon is uncertain, and three species that became established due to accidental human importation (Common Forest Looper *Pseudocoremia suavis*, Oak Processionary *Thaumetopoea processionea*, Gypsy Moth *Lymantria dispar*) were treated as Not Applicable in accordance with IUCN rules.

James Lowen

Butterfly Conservation now considers Marsh Carpet *Gagitodes sagittata* to be a High Priority for conservation, due to its restricted range, apparent loss from many former sites and declines at remaining sites.

MOTH CONSERVATION PRIORITIES IN BRITAIN

Drawing on the data and trends from the NMRS and RIS, as well as international designations (such as the EU Habitats Directive), Butterfly Conservation has recently reassessed its conservation priorities for larger moths in the UK[120]. Sixty-four species were identified as being High Priority for conservation action. These include 15 species afforded High Priority status for the first time, such as Marsh Carpet *Gagitodes sagittata*, Scarce Blackneck *Lygephila craccae* and Fisher's Estuarine Moth *Gortyna borelii*. A further 45 species have been listed in a new category of Medium Priority for conservation action. This includes some species downgraded from former High Priority status, such as Narrow-bordered Bee Hawk-moth *Hemaris tityus*, Dark Crimson Underwing *Catocala sponsa* and Fenn's Wainscot *Protarchanara brevilinea*. These downgraded species include moths whose known distributions have increased in recent years, as well as others that remain scarce but show no signs of decline.

Within these two Priority categories, species are further divided according to the urgency and geographical extent of the required conservation actions. In addition, a separate group of widespread but rapidly declining moths has been identified as being at high or medium priority for research to better understand the causes of their trends.

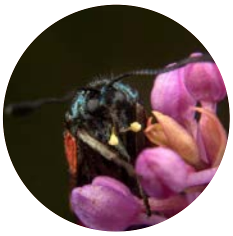
Chris Manley

Dingy Mocha *Cyclophora pendularia* remains a High Priority species for Butterfly Conservation.

[120] Tordoff *et al.* 2020

Moths are essential pollinators of some wild plants, such as this Greater Butterfly-orchid being visited by an Elephant Hawk-moth *Deilephila elpenor*, but their role in the pollination of most plants is poorly known and probably greatly underappreciated.

John Walters



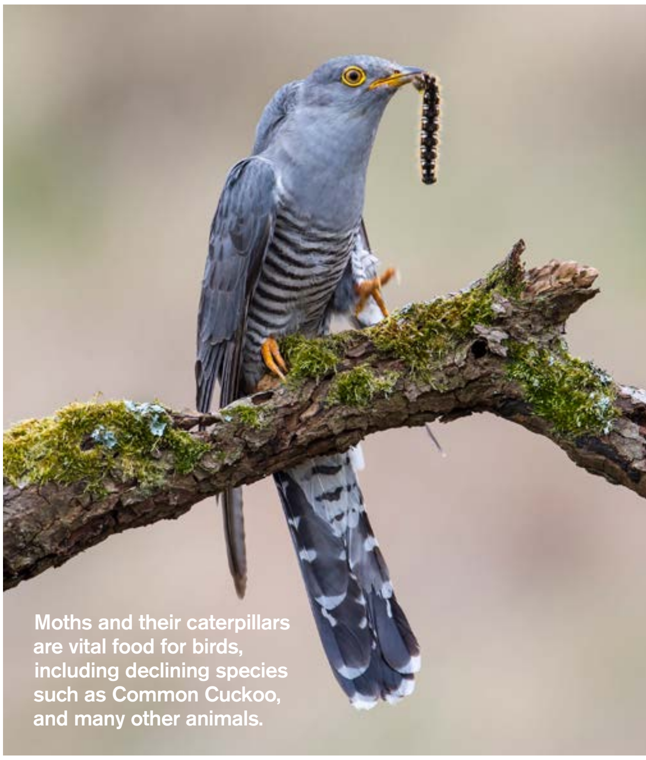
Brian Eversham

Orchid pollinia attached to the proboscis of a Six-spot Burnet *Zygaena filipendulae.*

Conserving moths

In addition to being beautiful, fascinating creatures in their own right, moths play numerous roles in ecosystems and so their conservation is important for maintaining ecological functions. Moths and, in particular, their caterpillars are essential in the diets of a wide range of predators, including bats[121] and many birds[122], and act as hosts for a huge diversity of parasitoid flies and wasps. Moth caterpillars are important herbivores, while adult moths have under-studied and under-valued roles as pollinators of plants[123]. Recent studies in Britain have revealed that moths transport pollen from a wide variety of native and cultivated plants[124] and some wildflowers rely almost entirely on moth pollination, such as Greater and Lesser Butterfly-orchids[125].

Butterfly Conservation has been working hard to conserve the UK's moths over the past three decades, in collaboration with numerous partner organisations, volunteers and landowners. Rare and threatened moths have been the focus of much of this action, but much more work will be required to reverse the declines of widespread species. The following case studies illustrate the variety of different approaches that have been successfully employed to conserve Britain's moths.



Moths and their caterpillars are vital food for birds, including declining species such as Common Cuckoo, and many other animals.

Steve Williams

[121] Vaughan 1997
[122] Denerley *et al.* 2019, Rytkönen *et al.* 2019
[123] Macgregor *et al.* 2015
[124] Macgregor *et al.* 2019c, Walton *et al.* 2020
[125] Nilsson 1983

Fiona Haynes

Planting Barberry to create habitat for the endangered Barberry Carpet *Pareulype berberata*.

Landscape-scale conservation for Barberry Carpet

Over recent decades, the conservation of threatened species has been revolutionised by a shift away from piecemeal work at individual sites to a landscape-scale approach, where habitat management is co-ordinated across networks of sites that either have existing populations or which could be colonised naturally. Butterfly Conservation has pioneered this approach, driven by metapopulation theory, in its work on threatened butterflies in over 50 landscapes across the UK[126]. Landscape-scale conservation is equally applicable to moths and is being implemented in a Back from the Brink project focused on Barberry Carpet *Pareulype berberata*. This endangered species has just 12 remaining colonies in Britain, many of which are vulnerable because they are small and isolated.

Historically, the moth was more widespread, but its sole larval foodplant, Barberry, was systematically removed from farm hedgerows, as it is a host for a rust fungus that can affect cereal crops. Populations of the moth can also be damaged by hedge-cutting in early autumn when the caterpillars are feeding on Barberry leaves.

The project, led by Butterfly Conservation, is creating new habitat for the moth by planting more than 4,000 Barberry bushes in Dorset, Gloucestershire and Wiltshire to increase moth numbers at existing sites and link up colonies through the landscape. The moth appears unable to colonise sites that are distant from source populations. By creating lots of stepping stones of suitable habitat, we hope to facilitate spread by increasing the overall population size and the number of colonies, all of which will reduce the Barberry Carpet's risk of extinction.

The conservation work has been a community effort. Specialist growers have provided the thousands of native Barberry saplings for planting. Community groups, conservation organisations and private landowners have provided locations for habitat creation away from arable fields and volunteers have been heavily involved with the planting and essential aftercare of the delicate new shrubs. These volunteers will be vital to the long-term ambitions of the project and the benefits it will hopefully bring to the Barberry Carpet.

Alex Hyde

Barberry Carpet

Fiona Haynes (inset), Alex Hyde

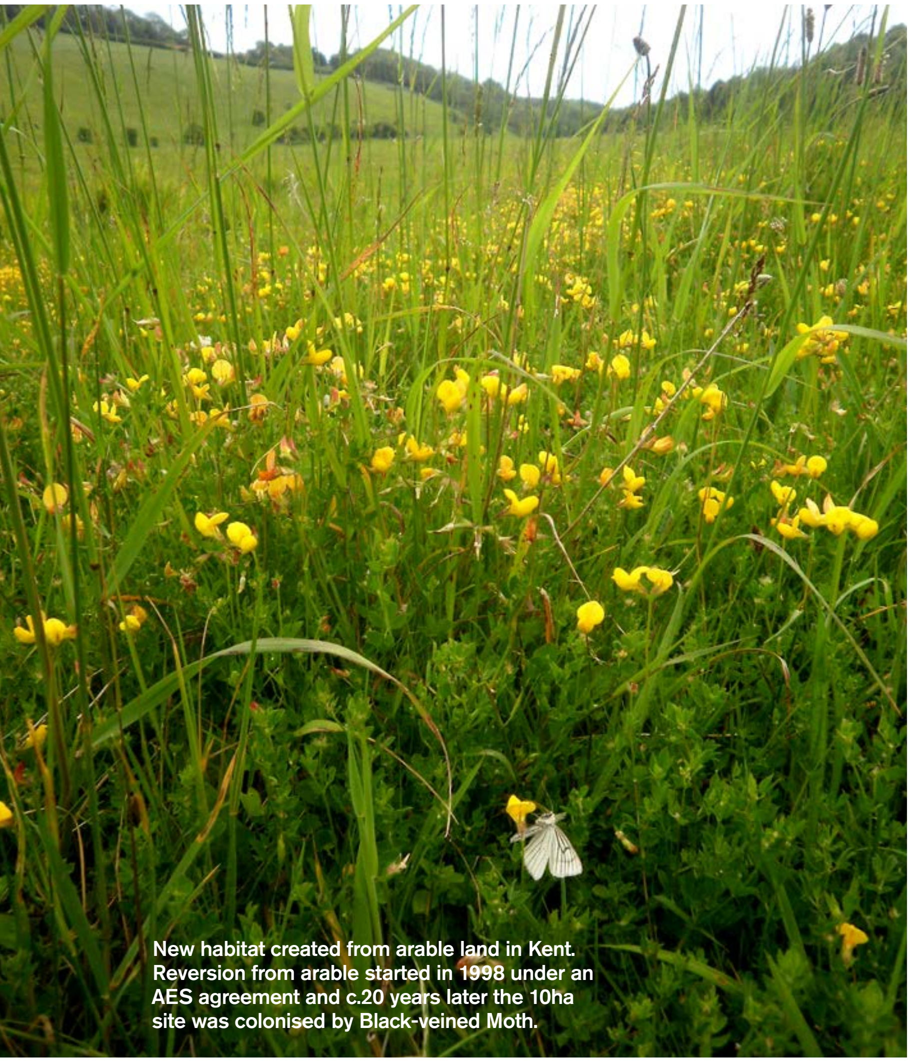
[126] Ellis *et al.* 2011

Mark Parsons

Black-veined Moth *Siona lineata*.

Agri-environment schemes: Black-veined Moth in Kent

Black-veined Moth *Siona lineata* is a critically endangered species restricted to chalk downland in a small area of east Kent. Since the 1990s, when only three remaining colonies were known, Natural England has led intensive conservation efforts to maintain the long-turf conditions required by the moth at its existing sites, supported by annual population monitoring co-ordinated by Butterfly Conservation. Vital though this has been, threats to individual colonies from extreme weather, erratic overgrazing by rabbits and occasional management issues meant that a more ambitious approach was necessary to secure the moth's long-term survival.



New habitat created from arable land in Kent. Reversion from arable started in 1998 under an AES agreement and c.20 years later the 10ha site was colonised by Black-veined Moth.

Dan Tuson

For over 20 years, Natural England's vision has been to create a new generation of species-rich grasslands from intensive farmland using agri-environment scheme (AES) funding for arable reversion and grassland restoration. To date, around 250ha of arable reversion has been instigated under AES agreements, spread across 60 sites on 18 farms in the Stour Valley landscape (with 20 sites in the 'core' moth area). This long-term commitment is beginning to reap rewards, with a suite of new grasslands in the landscape that have developed sufficient plant diversity and structural complexity to provide habitat for the moth and other rare species such as Duke of Burgundy butterfly *Hamearis lucina*. Indeed, two reversion sites have been colonised by Black-veined Moth in the last few years and the greater number of botanically diverse grasslands may also have facilitated the moth's movement through the landscape to colonise existing, isolated areas of downland. The moth now occupies 10 discrete sites, the greatest number of known colonies since at least 1990.

AES funding has been essential, providing farmers with the financial flexibility to achieve this vision of a more wildlife-rich and resilient landscape, as well as paying for one-off costs such as spreading green hay, sowing native provenance wildflower mixes, scrub management and fencing to enable grazing. Long-term, trusted relationships and regular one-to-one contact between advisers and farmers have been critical to success. Bringing in new farms, schemes and reversion/seeding projects each year has enabled a network of developing biodiverse grasslands to be built 'piece by piece' through the landscape.

Other arable conversion projects funded by AES have also produced successful results for moths in Britain[127]. In addition, smaller-scale, more broadly applicable management practices that are encouraged within AES, such as wide field margins[128] and reduced frequency of hedge cutting[129] also benefit moth communities. We hope that greatly increased funding to support targeted wildlife-friendly farming will become available over the next few years through the reshaping of AES. This will provide major opportunities to benefit threatened moths and improve biodiversity generally, consistent with the principle of 'public money for public goods'.

[127] Alison *et al.* 2017
[128] Merckx *et al.* 2012, Alison *et al.* 2016
[129] Staley *et al.* 2016, Froidevaux *et al.* 2019

Volunteers preparing to survey for *Choreutis diana* on the centenary of the species' discovery in Glen Affric.

David Hill

Alan Watson Featherstone

***Choreutis diana*.**

Volunteers and the conservation of rare moths

Volunteers are at the heart of Butterfly Conservation's work and play vital roles in the conservation of many threatened moths across the UK. Whether through recording and monitoring, detailed research into life cycles and ecology, or habitat management and site protection, volunteers have made important contributions to many of the case studies presented in this report. Participants themselves benefit from the positive social, educational, health and wellbeing aspects of volunteering[130] and greater connections with nature foster a stronger commitment to conservation[131].

Over the last decade or so, volunteers have been critical in improving the conservation status of one of our rarest moths *Choreutis diana*. In the UK, this micro-moth is only known from Glen Affric in the Scottish Highlands, where it had been recorded sporadically over the past century, sometimes with gaps of several decades between sightings. A breakthrough came in 2007 when expert volunteer Bob Heckford, an eminent micro-lepidopterist, was the first to discover *C. diana* larvae in the glen and noted the characteristic feeding signs they make on the upper surface of birch leaves[132]. This provided an effective survey method, as well as a better understanding of the moth's habitat requirements. Subsequent searches suggested that *C. diana* was restricted to just a handful of trees around one of the glen's car parks, some of which were inadvertently felled to open up the view and make space for a picnic bench.

Given the moth's great rarity and high conservation priority, Butterfly Conservation Scotland organised volunteer training and survey events in Glen Affric during 2019. Exactly 100 years to the day from the moth's original discovery, these events culminated with over 20 people searching for the day-flying adults. In addition to sightings of adult moths at two locations, searches during the year found evidence of larvae on 42 trees over 10km of the glen, showing the moth to be more widespread than previously thought.

In 2020, transects were established to monitor the moth's population and further surveys are planned to see if *C. diana* occurs in adjacent glens. We continue to work closely with Forestry and Land Scotland who own and manage Glen Affric.

[130] Merenlender *et al.* 2016, Richter *et al.* 2018, Coventry *et al.* 2019
[131] Lewandowski & Oberhauser 2017, Soga & Gaston 2018
[132] Heckford 2010

The 'Bog Squad' in action – volunteers installing a new dam.

Melissa Shaw

Patrick Clement

Grass Wave ***Perconia strigillaria*****.**

Site management for moths

Many rare and threatened moths are now restricted to small, isolated patches of habitat and subject to multiple human impacts such as chemical and light pollution, climate change and radical shifts in farm and forestry management. Mitigating these effects in order to give moth populations the best chance of long-term survival often requires active intervention. Every year, Butterfly Conservation and its partners carry out a huge amount of habitat management to benefit moths, other species and the wider environment.

THE BOG SQUAD

Peat bogs are valuable wildlife habitats and provide important ecosystem services, such as carbon storage and flood prevention. However, many UK bogs are in a poor state having been damaged by peat extraction for horticultural use, planted with conifers or drained leading to scrub encroachment. As well as impacting on specialist species, such damage may cause the release of huge amounts of carbon into the atmosphere, thus exacerbating the climate crisis.

To address these twin issues on lowland raised bogs across Scotland, Butterfly Conservation formed the Bog Squad, a group of volunteers that undertakes practical management to re-wet damaged sites, promoting the growth of sphagnum mosses and restarting the slow process of peat formation. Since 2014, the Bog Squad, supported by NatureScot's Peatland ACTION Fund, has undertaken nearly 100 work parties involving over 280 volunteers at 26 peatland sites. Over 330ha of scrub has been removed and 196 dams installed to block artificial drainage ditches.

At Butterfly Conservation's Wester Moss nature reserve, for example, the open bog habitat has been increased by 15% through the removal of scrub and by blocking old ditches. Moths such as Marsh Oblique-barred *Hypenodes humidalis* and Grass Wave *Perconia strigillaria* are benefiting, along with the Large Heath butterfly *Coenonympha tullia* and a rare spider, the Bog Sun-jumper *Heliophanus dampfi*.

Woodland and scrub has been kept around the fringes of the reserve for moths, including Silvery Arches *Polia hepatica*, Lunar Hornet Moth *Sesia bembeciformis* and Scarce Prominent *Odontosia carmelita* and has the added benefit of screening the reserve from surrounding intensive land-use. Some young birch seedlings are retained on the bog to provide habitat for the nationally scarce micro-moth *Atemelia torquatella*.

The ongoing work of the Bog Squad exemplifies Butterfly Conservation's goal of managing important sites for Lepidoptera to deliver wider benefits for biodiversity and environmental gains such as carbon capture and flood control.

RETAINING OPEN SPACE IN WOODLAND FOR DRAB LOOPER

Woodland is one of the few semi-natural habitat types that has increased in extent in the UK over the past century. However, the amount of open space, such as glades and rides, within woodland has declined dramatically and this has, in turn, driven decreases of insects that require sunny, sheltered conditions[133].

Drab Looper *Minoa murinata* is a scarce day-flying moth that is dependent on Wood Spurge (the only larval foodplant) growing in sunny conditions and, therefore, on the regular woodland management that enables the plant to flourish. One of the moth's remaining strongholds is in the ancient woodlands of south-east Wales, where it occurs at 10 sites. For the past decade, Butterfly Conservation Wales has been working with Natural Resources Wales, which manages most of these woodlands, to increase the breeding habitat for Drab Looper. For example, at Hendre Wood, near Monmouth, scrub and young trees have been cleared (by contractors and volunteers) from 3.6km of rides to create open, sheltered areas where the plant and moth can thrive. Thanks to habitat management at this and other sites, such as Slade Wood near Caldicot and Highmeadow Woods near Monmouth, the status of Drab Looper in Wales is more secure. However, a long-term commitment to regular woodland management is essential to safeguard the moth's future.

Drab Looper

George Tordoff

Habitat creation for Drab Looper in Hendre Woods, with Wood Spurge growing where scrub has recently been cleared.

George Tordoff

Addressing the climate crisis and reversing biodiversity loss – restored bog habitat at Butterfly Conservation's Wester Moss reserve, which is owned by Stirling Council. Restoration work has been supported by the Inner Forth Landscape Initiative and EcoCoLIFE project.

David Hill

[133] Thomas *et al.* 2015

Volunteers carrying out emergency fence repairs following landslips.

Tom Prescott

Tom Prescott

New Forest Burnet
Zygaena viciae.

Emergency action for threatened moths

A few UK moths are restricted to a single known site. Such rarity inevitably puts the species at risk of extinction here (although they survive elsewhere in the world) as a result of human actions or extreme weather. *Scythris siccella*, for example, appears to have been lost from Britain after its only known site on Chesil Beach, Dorset, was inundated with seawater during storms and impacted by an effluent leak. Protecting such populations is not always possible, but emergency action by Butterfly Conservation can make a difference, as in the case of New Forest Burnet *Zygaena viciae*.

Despite its name, the only known UK population of New Forest Burnet is at a remote location on the west coast of Argyll[134]. When discovered in 1963, this Scottish population was quite widespread on the grassy undercliffs, but by 1990, following heavy grazing by sheep, it was restricted to around 15 individual moths on a small ledge inaccessible to livestock. A fence was erected to exclude sheep from the site, allowing the vegetation to recover, and the moth responded impressively – its population fluctuates but peaked at around 12,000 in 2012. Unfortunately, major landslips in 2014 ripped through the perimeter fence, allowing sheep back onto the site. Volunteers from Butterfly Conservation's Highland Branch stepped in and undertook emergency repairs to the fence.

The following year, thanks to funding through the Scottish Landfill Communities Fund and Butterfly Conservation's Match Pot Appeal, a 900m perimeter fence was erected. This huge task, undertaken by a local fencing contractor, required materials to be delivered by helicopter.

In 2018 the population was estimated at 2,800, but declined to just 400 the following year, probably due to poor weather. No counts were possible in 2020 because of Covid-19 restrictions but, thanks to the extraordinary efforts of Butterfly Conservation and others, the colony continues to survive.

Fencing materials to protect the only New Forest Burnet colony in the UK had to be delivered by air.

Tom Prescott

[134] This species was formerly known from the New Forest, Hampshire, but became extinct there in the 1920s.

Dave Green

The only British site for *Coleophora wockeella* is Butterfly Conservation's Oaken Wood nature reserve in Surrey.

Butterfly Conservation's nature reserves

Nature reserves and other protected areas have traditionally been the foundation of biodiversity conservation efforts in the UK and around the world. Although designation of protected areas does not guarantee better population trends or even prevent local extinction[135], nature reserves provide refuges for rare species and wildlife-rich habitats, stepping stones for species responding to climate change[136] and important opportunities for people to interact with the natural world[137].

Butterfly Conservation manages 35 nature reserves across the UK and works in partnership on others. Many of these reserves support populations of rare and threatened moths.

Rough Bank, a Butterfly Conservation nature reserve in Gloucestershire with a high number of scarce and rare moth species.

Rob Wolstenholme

Oaken Wood in Surrey supports the only known British colonies of two micro-moth species: *Coleophora wockeella* and *C. calycotomella*. The latter was only discovered in Britain in 2004 at this site. Recent management work on the reserve has increased the amount of foodplant for both species. Other scarce moths that breed in Oaken Wood include Drab Looper *Minoa murinata*, Light Orange Underwing *Archiearis notha* and Small Black Arches *Meganola strigula*.

Catfield Fen in Norfolk supports a range of specialist wetland moths typical of high-quality habitat in the Broads. Of particular note are *Pseudopostega auritella*, which is extremely local even within the Broads, and *Monochroa divisella*. The remarkable list of nationally rare moths seen at the reserve also includes Reed Leopard *Phragmataecia castaneae*, Scarce Vapourer *Orgyia recens*, Dotted Footman *Pelosia muscerda*, Small Dotted Footman *P. obtusa* and Fenn's Wainscot *Protarchanara brevilinea*. Thanks to major funding from the Environment Agency and Natural England, work is under way to protect and improve the site's biodiversity by increasing the flow of alkaline water into the fen.

Another important reserve for moths is Rough Bank, a limestone grassland in Gloucestershire. Volunteers have recorded 689 moth species on the site, including 39 nationally scarce and four nationally rare species: *Glaucolepis headleyella*, *Epermenia profugella*, *Coleophora niveicostella* and *Phalonidia gilvicomana*. Grazing by Belted Galloway cattle and careful removal of encroaching scrub maintains the flower-rich habitat that supports so many moths.

Nature reserves offer many opportunities and benefits. As well as harbouring important wildlife, Butterfly Conservation's reserves provide real-world demonstrations of habitat restoration success (e.g. chalk downland at Magdalen Hill, Hampshire, heathland at Prees Heath, Shropshire and raised bog at Wester Moss, Stirling), outdoor classrooms for life-long learning, benefits for health and wellbeing, and locations for applied ecological research.

[135] Geldmann *et al.* 2013, Rada *et al.* 2019
[136] Thomas *et al.* 2012
[137] Soga & Gaston 2016

Butterfly Conservation joined with other organisations to prevent the destruction of important habitats and moth populations at Coul Links in Scotland.

Andrew Weston

Protection through planning

Chris Manley

Portland Moth *Actebia praecox* was among many species that faced habitat loss at Coul Links.

In the planning system, the anticipated social and economic benefits of housing and infrastructure development often outweigh resulting damage to wildlife and the environment, despite the plethora of targets and duties to protect biodiversity at UK, national and local levels. This tendency is even greater when the biodiversity interest of a development site is dominated by insects rather than mammals or birds. It is very heartening, therefore, when the presence of important populations of Lepidoptera do prompt mitigation measures or sway the outcome of planning decisions.

Butterfly Conservation opposes any weakening of the environmental protections provided by the planning system. Housing, commercial and infrastructure development is necessary but has been a major contributor to the climate crisis, biodiversity decline and localised problems such as flooding. Moving forward, built development must provide net benefits for the environment, for wildlife and for carbon emissions as part of a green economic recovery.

COUL LINKS

A wide variety of rare habitats and species found in this unspoilt dune system near Embo, in East Sutherland, was threatened by proposals to build a new "world-class" golf course. Butterfly Conservation joined forces with other environmental organisations to form the Coul Links Conservation Coalition and oppose the development.

In addition to national (Site of Special Scientific Interest), European (Special Protection Area) and international (Ramsar site) conservation designations, Butterfly Conservation was able to show that Coul Links holds an important assemblage of Lepidoptera; 227 moth species (and 19 butterflies) had been recorded there by local and visiting enthusiasts, including several rare and scarce species such as *Caryocolum blandelloides, Stigmella spinosissimae, Aproaerema sangiella,* Portland Moth *Actebia praecox* and Lyme Grass *Longalatedes elymi.*

The campaign to save the site and its biodiversity culminated in a month-long public inquiry in March 2019. Dr Mark Young, renowned micro-lepidopterist, County Moth Recorder and former trustee of Butterfly Conservation, stood as an expert witness, making a strong, evidence-based case that the development posed a significant threat to the site's important Lepidoptera communities. Thankfully, the Scottish government refused permission for the golf course and in their letter to the developer, Scottish Ministers specifically cited the adverse impact on important populations of invertebrates, especially the particularly rich range of butterflies and moths.

This notable victory owes its success not only to Mark Young, Butterfly Conservation and others directly involved in the campaign, but also to all of the recorders over the years who took the time to submit their moth and butterfly sightings from Coul Links to County Recorders and into the UK recording schemes. Without the hard evidence of these records, the outcome might have been very different.

SUNDERLAND POINT

At Sunderland Point in Lancashire, plans to install cables to one of the world's largest offshore wind farms risked damaging part of the saltmarsh habitat of the only remaining English colony of Belted Beauty *Lycia zonaria*. Through positive engagement by Butterfly Conservation and Lancashire Moth Group, first with the developers and later also with the Planning Inspectorate, the original plans to cut up to five large trenches across the site were modified to installation by tunnelling under the saltmarsh – a more expensive option but considered far less damaging to the surface habitat and the survival of the moth.

In granting development consent, the Secretary of State mentioned the Belted Beauty and required the cable to be laid by tunnelling. As recommended in the planning decision, the developers commissioned detailed surveys of the moth's population over several years and monitoring by Lancashire Moth Group volunteers has continued. While no short-term impacts were detected following the laying of the cables, Belted Beauty numbers fluctuate considerably from year to year and further studies are needed to determine whether there are any longer lasting impacts on the moth.

Keith Tailby

Belted Beauty male (left) and wingless female (right).

Conclusions

Chris Manley

Chevron *Eulithis testata* is a widespread but declining moth in Britain. Its abundance has decreased by 74% (1968–2017) and its distribution by 40% (1970–2016).

Thanks to the dedication and skill of many thousands of volunteer recorders and the organisations that support them, Britain is one of the few places in the world with long-term data on the abundance and distribution of moths. The analyses presented in this report, based on five decades of distribution recording and population monitoring of larger moths, provide an up-to-date assessment of trends for this species-rich group of insects. Moths are a beautiful and substantial part of our wildlife, vital for the functioning of ecosystems, for example being major nocturnal pollinators of wild plants and playing a central role in many food chains.

As in previous assessments[138] the overall picture is that larger moths have decreased in abundance in Britain, with declines both in the total abundance of all moths caught in the RIS network and in many individual species. However, while moths are decreasing in number, the NMRS data show that many species are increasing in distribution, mainly in response to climate change. A typical moth enthusiast in Britain may be recording a wider range of species on their patch as species become more widespread or colonise from overseas, but may also have noticed a general reduction in numbers. The appearance of a new species is striking and memorable whereas, because the abundance of most moth species fluctuates considerably from generation to generation, declines can easily go unnoticed. Long-term data are essential to detect such trends.

Dr Phil Sterling pioneered the creation of species-rich grassland along the Weymouth Relief Road in Dorset. Through Butterfly Conservation's Building Sites for Butterflies project, similar approaches are being promoted for major developments and landfill sites, as well as existing road verges and green space. In 2020, Highways England said they would adopt these techniques on all major road improvement schemes.

Andrew Cooper

The headline results conceal a complex pattern of change, driven by radical changes to the environment and climate caused by human activity. More ecologically specialised and larger bodied moths are faring badly, while small, generalist species prosper, but there are many exceptions.

These findings do not reflect the recent 'insect Armageddon' narrative or apocalyptic predictions of insect extinction[139], even in the highly modified landscapes of a densely populated island. Nevertheless, the evidence of declines in larger moths and other insects, both in Britain and elsewhere[140], is compelling and demands an urgent policy response[141]. We can and should act now. While some positive steps have been taken, such as Highways England's plan to create biodiverse, low-nutrient grasslands on all new road schemes, much more must be done.

The conservation case studies in this report demonstrate that threatened moth populations and the sites at which they occur can be safeguarded through concerted, evidence-based action that also delivers wider benefits to the environment and to people. Tackling the wider biodiversity and climate crises requires the expansion, restoration and creation of habitats that support wildlife, improve human wellbeing and deliver ecosystem services (e.g. carbon storage and flood prevention). Government commitments for greatly increased woodland cover (although not at the expense of important open habitats) and farm subsidies for environmental benefits, as well as growing interest in the rewilding[142] of land with little biodiversity value, promise a brighter future for widespread and common moths[143].

The broader, global pathway to halting and reversing the decline of moths and other insects has been mapped out[144] but until politicians, policy-makers, communities, land owners and individuals take bold strides along it, moths and a multitude of other insect species will continue to decline, with potentially dire consequences for ecosystems.

[138] Fox *et al.* 2006, Fox *et al.* 2013
[139] Sánchez-Bayo & Wyckhuys 2019
[140] Pilotto *et al.* 2020, van Klink *et al.* 2020, Wagner 2020, Wagner *et al.* 2021
[141] Cardoso *et al.* 2020
[142] Pettorelli *et al.* 2018, Sandom *et al.* 2019
[143] Fuentes-Montemayor *et al.* 2011, Merckx *et al.* 2012, Fuentes-Montemayor *et al.* 2015, Merckx 2015
[144] Dicks *et al.* 2016, Forister *et al.* 2019, Habel *et al.* 2019b, Harvey *et al.* 2020, Samways *et al.* 2020

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Inspiring an interest in moths through engagement projects and public events is key to addressing the biodiversity crisis and creating the recorders of the future.

Robbie Labanowski

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