Threatened Species Recovery Hub

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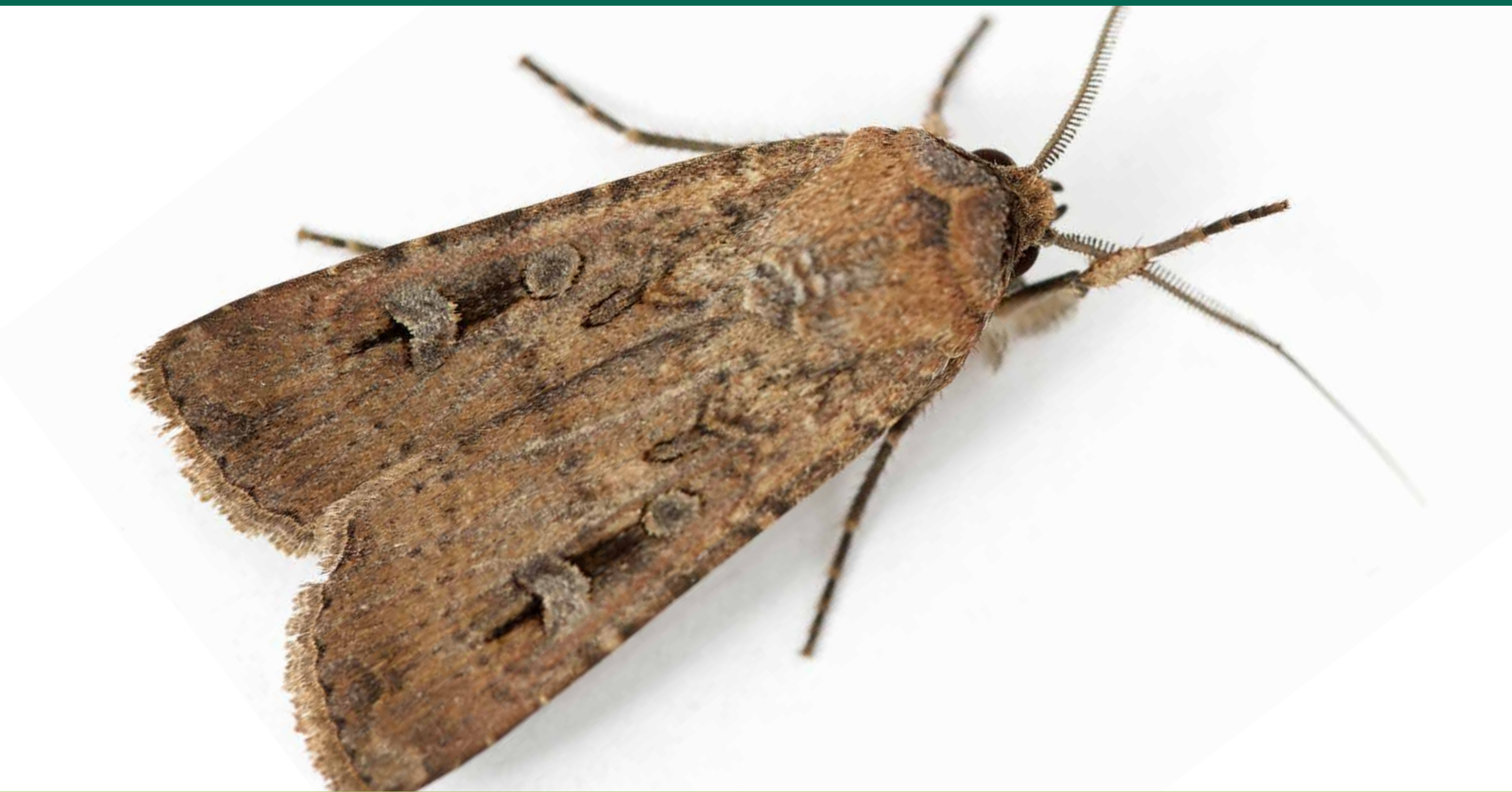

The Bogong moth, *Agrotis infusa*: cultural context, knowledge gaps, conservation and monitoring options

Interim Report*

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Cover image: Bogong moth. Image: Ajay narendra, Macquarie University

EXECUTIVE SUMMARY

The Bogong moth (*Agrotis infusa*) is a unique and iconic Australian species. It remains one of just two insects known, along with the monarch butterfly, to navigate over a thousand kilometres to its summer aestivation sites without ever having been there. It is a truly unique and wonderful species whose navigation and biology remain an inspiring mystery.

The Bogong moth is of immense cultural significance and a central part of the Dreaming for many Indigenous peoples of south-eastern Australia. Significant ritual, law, and rites of passage are associated with the seasonal occupation of the Bogong high plains and other alpine areas of NSW to which the Old people travelled and for whom the harvest of the Bogong moth was so critical.

The Bogong moth is of immense ecological importance in the alpine regions where it is a crucial source of summer protein for birds, mammals, lizard, and frogs. It is well-known as a key source of sustenance for the critically endangered mountain pygmy possum, *Burramys parvus*. The fates of the two species are inextricably linked.

In much of its winter range, where the species reproduces and the larvae grow into adult moths prior to migration in spring and summer, the Bogong moth is known as a ‘common cut worm' and considered an agricultural pest due to the damage it can occasionally cause to commercial crops.

There have been a number of recent studies, reports and public presentations that indicate the Bogong moth has undergone a dramatic decline in abundance since Europeans invaded Australia. Deep Traditional Knowledge combined with a patchy combination of local scientific and citizen science monitoring efforts provide evidence of decline. Evidence compiled in recent studies has been sufficient to prompt the International Union for the Conservation of Nature (IUCN) to enter into an extinction risk assessment for the species. The findings of that assessment are currently pending.

However, significant uncertainties about the exact timing of change, the drivers of change, and the current state and trends of moth populations exist. Uncertainties preclude clear and agreed strategies to mitigate pressures on the species and to maximise the chances of its long-term persistence and recovery. Therefore, the aims of this report are:

1. To summarise the current state of knowledge about state and trends in Bogong moth populations, including documenting the pressures that may be causing declines.
2. To identify potential key uncertainties that most impact on our ability to prioritise conservation interventions, and that could be resolved through targeted scientific research or nationally coordinated monitoring.
3. To identify opportunities for researchers, agencies and Traditional Owner groups to address key research gaps with targeted research.

4. To identify opportunities for researchers, agencies, Traditional Owner groups, citizen and community groups to contribute to a coordinated monitoring program that would help to resolve key uncertainties about the state, trends and drivers of change in the moth population.

We conducted a series of conversations about Traditional Knowledge, existing western science knowledge, knowledge gaps, and priorities for future studies and monitoring of the moth. The perspectives presented in this report reflect the content of those conversations.

The authors of this report posit that significant land use changes for agriculture following European occupation have contributed to the decline of the moth. More recent climatic changes, including increasing temperatures and failure of autumn rains, particularly during prolonged drought, are now thought to be the predominant driver of population declines observed since the 1980s, though the relative contribution of each of these factors is not known. Other stressors such as light pollution interfering with the migration of the species and direct adult mortality from bushfire smoke and increased predation by feral predators (e.g., wild pigs) in their summer range may be adding pressure but are not yet confirmed as major impacts.

Key knowledge gaps were identified that authors agreed should be addressed as a matter of urgency through a combination of targeted studies and coordinated seasonal monitoring. High priority knowledge gaps that impact on the development of targeted and informed conservation strategies include:

- A lack of knowledge about the geographic distribution of (winter) breeding habitats and whether and how their location varies from year to year.
- The metabolic tolerance of adults to increasing temperatures in summer aestivation sites and winter breeding grounds.
- The ability of the moth to locate productive breeding grounds, from intensely farmed land to semi-arid or even arid areas following good rains, and the contribution this has made to their persistence despite significant modification to their “preferred” breeding grounds.

There was strong agreement across the author group that a consistently applied national monitoring program is required to clarify the status and trend in Bogong moth population density in both breeding and aestivation habitats. In particular, time-series monitoring data, in combination with targeted experiments, are required to disentangle the effects of climate and land use change drivers on population fluctuation in order to sensibly identify conservation opportunities in the winter breeding grounds. Monitoring of moth migration pathways may also provide crucial information about feeding behaviour, from where the largest populations of moths appear in any given year and how this varies in relation to the amount and geographic distribution of autumn rainfall. Monitoring of navigation habitats, in which adults get food for summer aestivation may also be valuable as adults may spend up to 3 months at these locations because there is little suitable food at high altitudes

There exists significant opportunity and need for Traditional Owners to lead monitoring and recovery of Bogong moths in both their winter and summer ranges. In particular, there is an opportunity for strong leadership in Bogong moth monitoring that can assist with improved understanding of Bogong moth ecology and promote reconnection with Country.

However, there remains significant technical and resource challenges to implementing a culturally relevant, statistically rigorous national monitoring program, particularly in breeding habitats. While current monitoring of migration and aestivation sites is at best patchy, monitoring of moths, eggs, and larvae in their winter/breeding range is currently non-existent. There is no agreed methodology for reliable and feasible sampling of moth populations in their breeding habitat. Monitoring of the summer range population currently utilises ad-hoc counts in caves, and light traps in open country. Significant technical work is required to improve monitoring methods. The development, testing and refinement of winter, migration, and summer range monitoring methods is a key national priority for informing conservation strategies for the Bogong moth.

Significant additional public investment in improved knowledge about Bogong moth population ecology, distribution and abundance, and feasibility of conservation opportunities is urgently needed. The most direct benefits arise from targeted studies to refine monitoring methods for the species, with particular focus on resolving the significant uncertainties about the geographic location of winter breeding grounds and how the locations vary with local annual variation in rainfall and temperature. There is also an urgent need for targeted experiments to better understand the relative impacts of agricultural practices on Bogong moth recruitment, and the feasibility of conservation options at key breeding locations.

We provide an example summer range monitoring design in Victoria that represents a viable option for immediate deployment of monitoring effort in pursuit of basic understanding of annual Bogong moth population fluctuations. We reiterate the importance and urgency of designing a nation-wide monitoring program that also tackles the question of breeding range and breeding success. Urgent work is required to refine monitoring methods and strategies, including targeted experimentation to expedite understanding of the drivers of declines and feasible conservation options throughout the species range.

Part 1. Review: drivers of decline, conservation opportunities, and key knowledge gaps

INTRODUCTION

Moth ecology & biology

The Bogong moth, *Agrotis infusa*, is a medium-sized, nocturnal noctuid moth, found primarily in south-eastern Australia (Fig. 1c). The breeding grounds and larval stages occur mostly in the soil of lowland southern Queensland, NSW, northern Victoria, SA and – in favourable conditions – as far as WA (Green *et al.* 2021; Rawat 1957; Fig. 1a&b). In spring, most newly emerged adult moths migrate to the Australian Alps via the ACT, southern NSW, and central Victoria. In the alps they aestivate in caves and boulder fields over the hot summer months. As the weather cools and the dicotyledonous annuals that the larvae feed on start to grow, the moths return to the lowland to breed and lay eggs, and the cycle begins again (Common 1954). A detailed biological and morphological study of each life stage of *A. infusa* is outlined in Rawat (1957) and a more recent description of Bogong moth biology, ecology, threats and population trends is provided by Warrant et al. (2016) and Green *et al.* (2021).

The seasonal migration of Bogong moths is globally unusual in the distance it covers (>1000km) and is often compared to the annual migration of the North American Monarch butterfly, *Danaus plexippus*. Two notable differences are that the Bogong moths travel at night – making their mechanism for navigation more complex as it uses the Earth's magnetic field (Dreyer *et al*. 2018) – and that they are thought to do the return migration in a single generation. While some uncertainty exists as to whether the migration always occurs in a single generation (Gibson *et al.* 2018), the migration ecology is remarkable by any measure. However, uncertainty about the location of Bogong breeding grounds is material to conservation strategies that seek to identify important places or regions in which to enhance Bogong moth protection.

Key summer aestivation sites are generally found above 1,500m asl, in the caves, boulder fields and tors of the Australian Alps (Green 2010). These sites are scattered across the south-eastern Australian alpine areas (Keaney 2016). The winter range is thought to be primarily in the areas of grey/black, cracking, "self-mulching" clays of lowlands inside the Great Dividing Range, primarily in NSW and southern Queensland. There are also summer (adult) and winter (larvae and adult) records of the species in South Australia, south-west Western Australia, and Tasmania. It is unknown whether any or all of these populations are self-sustaining and if they migrate (Drake *et al.* 1981).

The life cycle of the Bogong moth begins in the clay soils, where eggs hatch in autumn or early winter and larvae feed on the young shoots of dicotyledonous plants. The later stage (older) larvae sever plants at their base and draw them into their soil tunnels for consumption during the day. After passing through six instars, the larvae pupate over several weeks and the adult moths emerge, ready for migration in early- to mid-spring. Not all *A. infusa* moths return to the inland breeding grounds; some remain on the eastern side of the Great Divide over winter and apparently complete their life cycle there (Common 1954). There are two colour morphs of adults – light hindwings and dark hindwings – and it is postulated that the dark morphs are predominantly the migratory individuals, although both can be observed in the summer aestivation grounds and in Victorian light trap catches (G. McDonald *pers. comm.*). The spring/summer migration occurs with the prevailing winds, and moths travel by the millions to the alpine regions over the course of a few weeks.

Although the mechanics of the moths' navigational abilities are not entirely known, it appears that they use the Earth's magnetic field and stars, combined with visual cues on the horizon (and perhaps temperature cues) to navigate to the Alps, and then olfactory cues to locate temporary camps and aestivation caves once there (Adden (2020); Dreyer *et al.* 2018; Warrant *et al.* 2016, E. Warrant *pers. comm.*).

The *en masse* migration and the moths' attraction to artificial lights along the route has caused numerous high-profile instances of moth "infestations" in public memory (e.g., the 2009 Australian Open finals; the Sydney Olympics closing ceremony (Rigby 2011); periodically at Parliament house (McCormick 2005)). The impact of artificial light on the survival of migrating Bogong moths is not well understood (see "*Key Threats and Stressors Facing Bogong Moths*" below for further discussion). Along their migration, moths have been observed feeding on the nectar of a variety of native plants in spring bloom, predominantly species of *Eucalyptus*, *Grevillea* and *Epacris.*

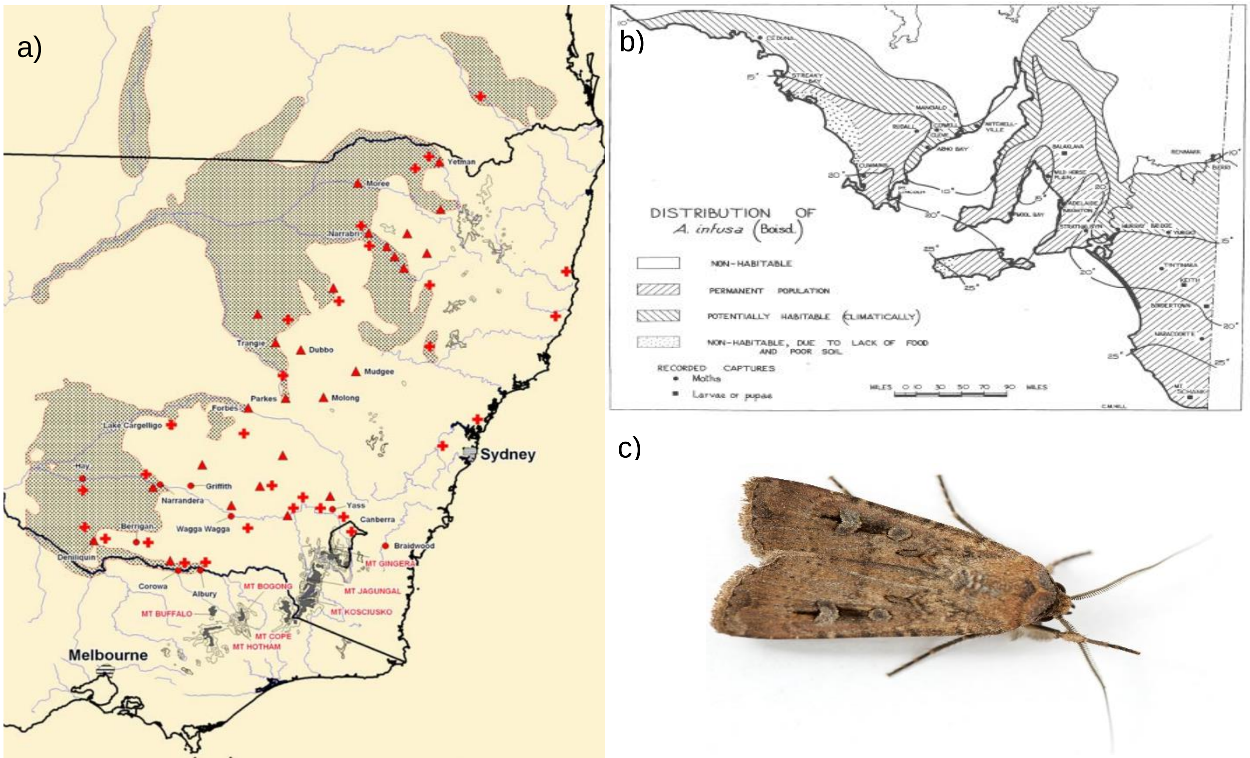

Figure 1. a) Map produced by McCormick (2005 – reproduced with permission) based on data by Common (1954) and Froggatt (1900). It shows locations of larval records by Froggat (1900 – red triangles) and Common (1951-1953: red crosses). Proposed (by Common 1954) key inland breeding locations on the 'self-mulching soils' are given in dark hatching, though observations of larvae have been made further west along the Darling River (Fig 1. in Green *et al.* 2021). Key alpine regions occupied by *A. infusa* in the summer months are given in grey shading in the region of the map between Melbourne and Canberra. b) Map produced by Rawat (1957) indicating regions permanently and potentially habitable by *A. infusa* in South Australia. c) Adult *A. infusa* specimen, photo credited to Dr. Ajay Narendra, Macquarie University, Australia.

The moths' arrival in the alps represents a huge nutrient transfer to the area just as the snow melt begins (Green 2010). The critically endangered mountain pygmy possum, *Burramys parvus*, emerges from hibernation in spring and depends, at least in part, on the nutrient-dense moths to regain their body condition following their period of dormancy. This dependency appears to vary by time of season and across pygmy possum populations (Gibson *et al.* 2018; Heinze *pers. comm.*). Australian and Little Ravens, *Corvus coronoides* and *Corvus mellori* respectively, and currawongs *Artamidae spp.*, also feed on the adult moths during the day, with microbats feeding at dusk, when a proportion of moths leave their aestivation sites to fly.

There is evidence that the timing of moth arrival in the alps has shifted over recent decades (Green *et al.* 2021). This is likely to have flow-on impacts to every stage of the moth's life cycle, as well as the species that depend on them.

Cultural importance

The name “Bogong moth” has its origins in the south-eastern Australian Indigenous language groups (Love 2010). The Bogong moth is listed as having Indigenous cultural values as part of the Australian Alps National Parks (AANP) National Heritage Listing. Adult moth aestivation was the basis for large-scale annual gatherings of different Aboriginal groups for ceremonies through history, and this is recognised as an exceptional part of cultural heritage (Stephenson *et al.* 2020; Keaney 2016). Aboriginal groups from the surrounding lowlands and foothills across the whole range of the Australian Alps had estates that extended into the high peaks of the alpine regions. There are reports from settlers in the 1830s in the northern area of the Bogong Peaks of Aboriginal people stupefying the aestivating moths with smoke while they gathered in the caves, cooking them in a coal-less fire, and creating a long-lasting cake from the ground bodies (Bennett 1834, as reported in Stephenson *et al.* 2020). Under a historical period of genocide and dispossession, Aboriginal people in the area stopped gathering for the moth “festival” within 30 years of European invasion, reviving it late in the twentieth century. The tradition was reinterpreted into the annual Ngan Girra Festival, held each year in Albury, New South Wales (and initially called the “Bogong Moth Festival”) (Love 2010). More recently, Jaithmathang owners of the Bogong moth aestivation grounds have begun to reconnect with their country, providing an opportunity for healing of Country that may bring benefits to Bogong moths and many other species.

Agricultural context

Eggs of *A. infusa* hatch and spend their larval stages predominantly in the “self-mulching” soils inland of the dividing range with strong breeding sites frequently observed in Queensland and NSW, and less well described breeding locations in South Australia and Victoria (Fig. 1). Post-European invasion, these areas have been heavily modified and used for cropping and grazing. *A. infusa* larvae are considered an occasional agricultural pest, as they kill young plants, severing them at their base before consuming them. The magnitude of this issue for farmers is not well understood, as the larval phase is virtually indistinguishable from other native species of “cutworms”. As such, it is likely that they are either targeted with pesticides, or likely more often, incidentally treated as part of wider pest control, to reduce damage to young and maturing crops (Kreisner & Weeks 2019). It remains unclear how much of an impact these pesticides are having on the larval (cutworm) stage and thus on Bogong moth populations.

Management of broad-acre crops has changed greatly in the past 40 years, with a move to minimum- or zero-till cropping systems, the extensive use of herbicides for the eradication of agricultural weeds and the reduction to the grazing (pasture) phase of wheat/sheep enterprises. The highly effective control of in-crop weeds with herbicide application is a key feature of this system, not only to reduce competition, but also to remove the “green bridge” that enables insect pest species to persist over the cropping cycle. These practices are likely to be reducing the availability of feed plants to larvae and making less of the environment available to Bogong moth recruitment.

The impact of pastoralism on bogong moth recruitment is less clear. In rangeland areas, the introduction of sheep was followed by the near removal of palatable species (Caughley 1987), with possible negative consequences on bogong moth larva that prefer the more palatable dicotyledonous annuals. Within improved pastures, introduced *Medicago* spp. feature prominently, and appear to be important hosts for *A. infusa* (Common 1954).

Population decline

Recent studies show that insect biomass and species richness is in decline globally (IPBES 2019, Wagner *et al.* 2021). The implications of insect decline are profound. Wild insect pollination is responsible for pollination of 70% of crops, and pollination services are estimated to be worth around $US560B/year to the global economy (IPBES 2019). Insects form the basis of food chains, and provide many other ecosystem services, including biodegradation. 10% of all insect, and 30% of all bee, species assessed by the International Union for the Conservation of Nature (IUCN) are identified as at high risk of extinction.

Bogong moths appear to have declined severely and rapidly in recent years. A recent paper that examines a suite of local monitoring efforts, indicate a dramatic overall decline in the species that is commensurate with anecdotal reports (Green *et al.* 2021). The most dramatic declines appear to have occurred since the 1980s, however, these more recent declines are likely to have compounded declines throughout the past 150 years following colonial land clearing and agricultural intensification. While the longer-term declines are most likely because of land use change, the drivers of more recent precipitous declines are less easily identified, with climate change – particularly warming and drying – increased pesticide use, invasive species, and even city lighting all considered possible drivers.

Purpose of this report

The primary aim of this report is to synthesize expert advice on the drivers of decline, and to identify knowledge gaps and opportunities for the conservation of the Bogong moth. The report is based on a series of conversations between the report authors, *A. infusa* experts, Traditional Owners, and managers, and iterated report drafts. Conversations were focused on key threats to the species, the most immediate research priorities to fulfil knowledge gaps, and the potential for a coordinated national monitoring program to help fill knowledge gaps and provide greater clarity about the dynamics and drivers of population fluctuations.

Contemporary views of Bogong moth experts

1. Key Threats and Stressors Facing Bogong Moths

Bogong moths are now acutely threatened due to ongoing pressures from changing climatic conditions and impacts from agricultural practices in the breeding grounds/larval range. These key drivers affect the species across all life stages and throughout their geographic range, although stressors on the larval range appear to be the least well understood but arguably most closely linked to post-European declines. A series of other potential factors have been suggested, the impacts of which remain largely unknown and warrant further investigation (Green *et al.* 2021).

Climate change

Changing climatic conditions are an important, underlying stressor on Bogong moths. Warming summer temperatures are putting pressure on suitable aestivation sites, “season creep” (the change in timing of the seasons as the climate changes) could be misaligning larval emergence and moth migration with key food resources along the migration pathway (e.g., nectar availability from flowering plants), and decreasing, or failure of, autumn rainfall (the “autumn break”) is likely to be impacting food resources and, therefore, egg and larval survival in breeding locations. Less certain impacts of climate include an increasing tendency towards drought in south-eastern Australia (CSIRO 2020) that appears likely to change timings of breeding cycles and impact larval survival.

There remains significant uncertainty about the importance of the marginal (less frequently utilised) semi-arid breeding grounds further west of the better understood Murray–Darling basin breeding locations. It is hypothesised that these western (or inland) breeding grounds could be crucial for the survival of the species given the large and ongoing changes that have occurred in the Murray-Darling basin due to agriculture and agricultural intensification. However, the western, semi-arid breeding grounds are likely only viable in wet years, which appear to be occurring less frequently. A medium/long-term impact of changing climates could be the loss of viability in the western breeding grounds that could have, over the past 70 years, served to bolster the moth population in good years. This could somewhat compensate for the agricultural impacts on the population in breeding habitats further east. Australian migratory noctuids, of which *A. infusa* is one, are specialist exploiters of the annual variances in the Australian climate. They display a number of exploitative behaviours common to other migratory noctuids, evolved to survive in Australia’s relatively dry and often erratic and/or ephemeral environment (Farrow and McDonald 1987). However, increasing climatic uncertainty, drying autumns and early winters seem like to impact even this species adapted to seasonal variability. Understanding the scale of the landscape and the relative contribution of its subregions (e.g., rangelands, ephemeral flood plains, croplands, etc.) make to *A. infusa’s* habitat within these, should be important avenues of exploration.

There is strong consensus that the severe drought in the Murray–Darling Basin beginning in early 2017 (BoM 2020) played a significant role in the sharp decline in Bogong moths observed migrating and in the aestivation sites in that, and subsequent, years (Green *et al.* 2021). There are mixed views about how much climatic changes had impacted the species prior to that and contributed to the dramatic decline observed in the species since the 1980s. While it seems likely that there has been a climatic signature in the current decline, the is consensus that ongoing climatic changes are the main future threat, given that the bulk of the agricultural impacts relating to land clearing and conversion to agriculture are already manifest.

Agricultural practices

A range of agricultural practices are thought to threaten larval recruitment in their primary breeding grounds. European agriculture converted much of the grey cracking clay soil ecosystems into farmland, possibly resulting in loss of the moth’s native plant hosts. The severity of these historical impacts is not well documented, though the extent of land use change, cultural knowledge and anecdotal evidence indicates that these impacts have dramatically reduced the potential of the Bogong moth to reproduce and flourish in normal to poor years. In good years (wet autumn), large populations may emanate from regions further west of the most suitable, heavily farmed areas such as the Darling Downs, to some extent masking impacts of losses in optimal habitats.

In agricultural areas in which suitable, nutrient-rich broadleaf crops can provide adequate food resources, and residual natural habitats support larval growth, Bogong moth recruitment continues to occur. Recent observational studies based on moth light trapping around Canberra on the migration routes from prime habitats in the Murray–Darling Basin toward the NSW and Victorian Alps indicates that the prime breeding areas in the agricultural zone are still producing significant numbers of recruits. However, in the absence of systematic monitoring data, it can only be assumed that the contribution of these areas to the migrating population is a small proportion of what they once provided prior to clearing for agriculture and the subsequent agricultural intensification and routine use of pesticides. Bogong moth larvae were most likely a generalist herbivore prior to European crop introduction and would have had little trouble switching to feeding on newly established agricultural crops. However, the use of pesticides and herbicides and the introduction of less suitable crops such as wheat and rice has probably contributed to ongoing declines in concert with increased drought frequency.

There remains significant uncertainty about the population-level impacts on Bogong moths of pesticide application, particularly neonicotinoids. Published evidence in Europe indicates neonicotinoids have sub-lethal effects on honeybees, *Apis mellifera*, impacting their navigation abilities (Matsumoto 2013). This alone warrants targeted research on the impacts of such chemics on Bogong moths given that navigation is so central to their ecology.

The scale of impact of weed management is also somewhat uncertain. The destruction of agricultural weeds prior to cropping, often through use of herbicides, likely denies the hatching neonate larvae with the young food plant options they need; many small larvae with limited mobility are likely to starve. It is possible that other weed management actions, like efforts to remove “green bridges” between crops so that insects can’t persist from one crop rotation to the next, also impact *A. infusa* larvae to some extent, although the scale of such effects seems unlikely to constitute a significant impact.

A shift in the Murray–Darling region to growing more rice and cotton (Green *et al*. 2021) could pose a threat for larval recruitment, as inundated rice fields leave no habitat for larvae, and cotton monocultures, depending on weed and pest management regimes, may leave no room for suitable Bogong moth larvae food plants.

Some experts posited that increased competition from introduced herbivores could be placing pressure on larval food resources, particularly in areas where grazing is more prevalent than cropping. Issues of soil compaction by hooved grazers may also play a role, though there is currently no strong data or evidence on which to base an estimate of this impact. Zero till practices may also be implicated in Bogong moth declines due to the high use of herbicide and removal of suitable vegetation (P. Caley *pers. comm.*).

<u>Other factors</u>

A suite of other threats or stressors have been proposed as potentially influencing Bogong moth populations (Green *et al.* 2021). Changing fire regimes and increasing frequency of significant smoke impacts in summer aestivation could lead to population losses given the observed negative effects that smoke has on individuals of the species (K. Green *pers. comm.*).

Migrating moths may be distracted from their migration route by artificial lights (Knop et al. 2017), although some experts felt that this distraction was temporary for most individuals and that there have been no strong observed correlations between years of large moth inundations in cities and 'poor' population numbers in summer aestivation sites (E. Warrant *pers. comm*.). Thus the scale of this impact on Bogong moths is unknown, though we suspect that moths may be only briefly waylaid before continuing. However, the possibility that they may be permanently unable to navigate onwards, or they may be distracted for long enough that it impacts their energy levels is worthy of examination with targeted research trials.

Predation by introduced and native predators may be impacting the adult moth populations during aestivation. Large numbers of moths have been observed falling prey to feral pigs in alpine caves in NSW/ACT (Caley & Welvaert 2018), and Australian and Little Ravens, and introduced foxes (*Vulpes vulpes*) are known to track large aggregations of Bogong moths (L. Broome and K. Green *pers. comm.*). The total loss of Bogong moths by all predators in the mountains has been calculated to be close to one billion individuals annually (Green 2011).

2. Key opportunities to address threats through on-ground or policy action

Significant gaps in knowledge about the species biogeography (where they exist, in what densities, at what times/following which rainfall events) and ecology generate significant uncertainty about the most critical threats to the population and how to act on them.

While there was a general agreement that current and future changes in climate are, and will continue to impact on the species, there are no precise or reliable predictions about exactly how and where those impacts will manifest. This is a result of uncertainty about where key breeding grounds are in years of varying rainfall and temperature. It is thought that the species is capable of breeding in a greater number of geographic areas when autumn rainfall is strong. Without better data on the whereabouts of the most critical breeding areas and how that varies with annual weather patterns, policies or incentives to reduce pressure on the species through protection of breeding habitats are difficult to design, evaluate or target.

Contingent on gaining a better understanding of the locations of key breeding grounds and how their location may vary depending on contemporary climates, a suite of potential conservation actions could be deployed:

- Action on climate change: All experts agreed that strong policy action on climate change is vital to alleviating the underlying climatic pressures on the moths, particularly drought impacts. The Bogong moth could be a flagship species for action on climate change.
- Designed experiments to resolve the impact of pesticides and crop management practices on larval recruitment: Given the known impacts on other flying insects, some experts felt that restricting neonicotinoid use in Australia would be a positive step. Neonicotinoids are currently under review by the Australian Pesticides and Veterinary Medicines Authority[1]. If the target species of pesticides are largely other agricultural pests, there may be some potential to help farmers coordinate spraying until after the Bogong moths begin their migration.
- Conserving habitat in breeding grounds: Areas that consistently form viable breeding habitat could be conserved and enhanced through the promotion of known feed plants.

Undertaking crucial research to understand the impact of possible bushfire smoke during the moths' migration, including smoke from controlled burning that occurs along the migration route.

3. Key scientific uncertainties that impact on our ability to motivate and implement on-ground or policy options

The geographic extent and yearly variation in the location of the larval range is a key uncertainty that permeates and undermines other theories about impacts of drought, agricultural practices, and artificial light. Without knowing where the animals breed, it is extremely difficult to estimate the impacts of past and current agricultural practices nor the benefits of possible changes in those practices or targeted conservation actions and incentives. A lack of clarity about the larvae's native food resources remains an impediment to targeted protection and restoration actions. Without knowing the extent of the range over which juvenile moths may emerge, it is not possible to properly understand their migration pathways and hence the potential impacts of city lights. Resolving basic biogeography of the species will underpin a much more complete ecological understanding and knowledge about viable conservation options.

A key element of uncertainty about the species' biogeography is the location of the western boundary of the productive breeding grounds and how that varies with annual rainfall in the region. There is some hypothesising that adults returning from aestivation track rainfall (G. McDonald *pers. comm.*), though the mechanism of that tracking and the extent to which it occurs remains untested and other schools of thought posit that moths simply head in the direction from which they arrived, regardless of rainfall. An ability to predict the most likely breeding grounds for the moth each year, depending on the location and amount of autumn rainfall could potentially help to target payments to land holders for ecosystem services (Jack *et al.* 2008), including the provision of crops that promote Bogong moth larvae, and reduction in application of pesticides. Better understanding the relationship between Bogong moth breeding

[1] https://apvma.gov.au/node/57031

success and annual and decadal climate and weather patterns would help to interpret historical and more recent declines. For example, it remains unclear whether the immense migrations that took place in living memory will be repeated or whether they are a thing of the past, driven down by the combined effects of increasing temperatures, decreasing rainfall, and broad-scale land clearing for agriculture.

Related questions that warrant further investigation because of the potential for improved knowledge leading to improved conservation effectiveness include:

- Resolving the exact impacts of insecticides, especially neonicotinoids. This question could be resolved with lab studies.
- Understanding the individual and combined effects of different land-use practices including the landscape-scale use of insecticides and herbicides, the impact of a range of grazing regimes and associated food plant loss and soil compaction, habitat loss from inundation, the removal of ‘vegetation bridges’ (the residual vegetation between crops that can act as small refuges for cutworm). Most of these studies would require as a starting point an improved understanding of the range of Bogong moth larvae in the autumn/winter months.
- There remains significant uncertainty about the moths’ movement and behaviour during migration to and occupation of aestivation sites. For example, it is unclear whether and to what extent moths are feeding in the evenings when they emerge from aestivation caves. The implications of this are that preservation and promotion of feed plants around aestivation caves and boulder fields may aid survival during summer aestivation. It is also unclear how important to the species’ survival are the stop-over points between the winter breeding grounds and summer aestivation sites (e.g., Mt Gingera), again with strong implications for the management of potential impacts at all of those sites such as feral pigs (Caley and Welvaert 2018). Other moth trapping data (Green et al. 2021; G. McDonald *unpubl.*) suggest that the breeding sources and return destinations of Bogong moths throughout eastern Australia go well beyond the alluvial, self-mulching clays of the Murray–Darling Basin. Further, Victorian and South Australian (Rawat 1957) trap catches throughout summer revealed populations of non-aestivating moths. Collections of moths from ephemeral native plants in arid environments and in a diversity of coastal environments indicates a complexity to the migration process, potentially involving cycles that play out over multiple years. The importance of these lesser-known breeding and aestivation locations remains uncertain.
- A better understanding of the thermal tolerances of adults and larvae would help provide a basis for evaluating the medium–long term viability of current breeding and aestivation locations, and where suitable locations may exist in the future. This uncertainty could be resolved with laboratory studies. This work would build on some initial, foundational work done on adults and larvae in the 1950s and 70s by Rawat (Rawat 1970; 1957). A start has been made on updating this work with current climatic predictions in mind (E. Warrant *pers. comm.*)
- Understanding the population-level impacts of artificial light attraction on the migration pathway would help determine whether and how much to prioritize certain actions (e.g. dimming, light curfews, limiting spectral content) at certain times of the year (and the

efficacy of those actions), though some authors felt the artificial light is unlikely to be generating significant population-level impacts.

- There remains significant uncertainty about the impact of smoke on moths. There are ethnohistories of local Aboriginal Peoples using smoke to stupefy and collect the moths for consumption, but the impacts of smoke from wildfire (and smoke-level tolerance) haven't been studied, though there are anecdotal reports of moth deaths due to smoke entering caves (E. Warrant *pers. comm.*).

4. Important scientific uncertainties requiring a nationally coordinated monitoring program.

There is widespread support for the implementation of a national monitoring program for Bogong moths, with manifold benefits identified. The existence of fundamental ecological and biogeographical knowledge gaps both challenge and necessitate a monitoring program. For example, in the absence of reliable mapping or modelling of Bogong moth breeding grounds, there are significant challenges in establishing monitoring of the larval range. Moreover, Bogong moth larvae are very difficult to distinguish from other cutworms, indicating that a specialist, rather than community and citizen, monitoring approach would be required for larval stage monitoring, making it a more expensive proposition unless cheap genetic testing methods can be developed and deployed. Nonetheless, without consistent measurement of larval productivity over multiple seasons in multiple locations, it will not be possible to properly understand the range dynamics of the species in response to changing climate and rainfall.

However, not all of the important uncertainties require a national monitoring program to address. For example, targeted research could well be a more viable way to build and improve understanding about the impacts of various agricultural practices, including the effects of various cropping and grazing systems, pesticide application or landscape scale increases in inundation. Building on past work around fundamental questions of species thermal tolerances in larval and adult phases could well be best addressed in the laboratory. Some laboratory testing is currently underway (E. Warrant *pers. comm.*).

Nonetheless, the fundamental question about how the species is responding (range and population change) to changing climate, including the increasing preponderance of drought, can only really be addressed through systematic, broad scale monitoring in both the summer and winter ranges. Compared with winter range monitoring, summer range monitoring is relatively easy and cheap to implement. While winter range monitoring will require substantial technical development and refinement (see other noctuid surveys (larvae and adults) of agricultural and ephemeral environments which illustrate the complexity and time-consuming nature of this work e.g., Gregg *et al.* (2019) [Helicoverpa surveys]; McDonald *et al.* (1995) [Mythimna surveys]), summer range monitoring could be implemented immediately through an alps-wide network of standardized light-trapping, airborne LiDAR bathymetry (ALB), and cave count surveys. Much of the technical detail about how best to standardize summer surveys has already been addressed (see Part 2), though opportunities to improve analysis remain.

5. Key attributes of a nationally coordinated monitoring program

The primary objectives of a monitoring design would be to:

1. Disentangle and diagnose causes of decline, and
2. Identify the most critical places in throughout the range of the moths to conserve in order to bolster the population, particularly in poor (low Autumn rainfall) years.

A range of necessary monitoring design attributes were identified that reflected key objectives for a monitoring program. Given the long-term nature of the population fluctuations driven by interactions between changing climate and land use pressures, it would be necessary for the monitoring program to be carefully designed and committed to long-term before definitive signals would emerge from the data. The monitoring program would need to be complemented by a series of carefully designed experiments to determine optimal conservation management strategies, particularly around agricultural practices in the larval range of the species.

The geographic scope of the monitoring program would need to be wide enough to understand range changes occurring at the extremities of the breeding range in good (wetter) and poor (drought) years. This creates significant challenges to the implementation of the program given the immense geographic range over which the moth exists.

Partnerships will be crucial in the development and implementation of the program. In the summer portion of the range, opportunities to engage Indigenous ranger groups in the design and implementation of monitoring will build and increase local knowledge and two-way sharing. The opportunity to support reconnection and healing of Country through a national program such as this are exciting. Skills and will exist in some key Traditional Owner groups in the summer range of the species but resourcing of peer-to-peer training would be required. Aestivation-range light-trap or ALB sampling and monitoring designs need to be refined in collaboration with Traditional Owners and a range of groups that would be involved and funded to undertake monitoring.

In the winter range, partnerships with Indigenous ranger groups and other landholders and managers would also be crucial to monitoring program success. However, because of the lack of existing standardized sampling methodologies for Bogong moth larvae, successful implementation of this element of a monitoring program will require substantial development in concert with Traditional Owners who may well hold crucial knowledge about the species that may be shared if appropriate IP agreements can be struck. With the recent encoding of the Bogong moth genome, it may be possible to deploy automated e-DNA sampling methods in the larval range, presenting a key research priority.

There has been a history of LiDAR use in Bogong moth surveys, and now with significant recent developments in both radar and LiDAR insect monitoring that may be particularly valuable for better understand the timing and direction of migrations (Kirkeby *et al.* 2016). In concert with detailed density monitoring in breeding and aestivation sites, automated methods may add significant extra information to a monitoring program and warrant investigation for potential future application.

6. Important scientific uncertainties to address through targeted research

There is a strong need for targeted, smaller-scale experiments to understand the impacts of land management practices on the Bogong moth. For example, the impact of grazing stocking levels, or cropping methods on larvae would require a detailed replicated design. While such studies would require at least seasonal or annual sampling of larval density, the extent of that sampling would be smaller than required to address the larger questions of climatic influences and long-term patterns addressed through national monitoring.

Targeted social science surveys of local landholders and managers may also prove useful in understanding current land management practices that may threaten or conserve Bogong moths. The degree to which landholders and managers might consider alternative crop and land management practices to foster and promote moth recruitment, with or without incentives, could also be investigated to help inform and target conservation strategies in key areas.

A suite of key research priorities pertain to development, testing and refinement of observation methods to support monitoring. There is an urgent need to evaluate e-DNA sampling in the larval range and LiDAR and radar approaches to monitoring moths during migration. Optimising the precision of light-trapping or ALB methods and sampling strategies for summer range monitoring also requires methodological research.

Improved knowledge about the diet of adult and larval moths, obtained through targeted studies would help tailor restoration and vegetation protection priorities in key breeding and migration sites.

Synthesis

There exist significant, hitherto to unexplored opportunities to conserve Bogong moths throughout their range, including through targeted protection and enhancement of breeding and recruitment habitats, protection of key migration feeding sites, and protection of aestivation sites. However, conservation efforts will be inefficient until critical knowledge gaps are filled, particularly around the location and variation in autumn–winter Bogong moth breeding grounds and the impacts of various land management practices, including the use of insecticides. Because conservation actions will need to be deployed over large geographic areas, involving many actors and agencies including Traditional Owners groups, public and private landholders and managers, there is strong motivation to improve knowledge to optimise deployment of policies, actions, and incentives.

Bogong moth decline is a national problem with immense implications for several ecosystems and other species, particularly the Victorian and NSW alps. We strongly encourage key state and national agencies to urgently resource the actions that are viable now (protection and management of known key sites and habitats) and to invest in rapid and coordinated knowledge gain that will facilitate more effective, wide-spread management of decline in the poorly understood autumn and winter range.

The Bogong moth is a globally significant species with unique biology, ecology, and cultural significance. Its rapid and seeming ongoing decline toward extinction foreshadows an impending cultural and conservation tragedy. Unless we act now, we may be too late.

Further reading and current initiatives

A small number of recent papers and reports have been published that tackle the state of knowledge on Bogong moths and investigate reasons for population declines. A recent paper uses a collection of published and unpublished data to posit causes of population decline (Green *et al.* 2021), as well as providing an excellent introduction to the biology and ecology of the species. Modelling of mountain pygmy-possum diet and bogong moth relative abundance at sites in Kosciuszko National Park monitored since 1994 suggests growth conditions across bogong moth breeding grounds influenced their abundance recorded in the alps in spring, which in turn was reflected in *B. parvus* diet (Gibson *et al*. 2018).

Part 2. Example monitoring design to detect changes in Victorian summer range of the Bogong moth, *Agrotis infusa*

Introduction

There is strong anecdotal and cultural evidence for modern (post-1980) population decline in Bogong moths (Part 1; Green *et al.* 2021). However, the link to climatic variation, including drought and higher temperatures in summer and winter range remains unclear. Current observational data do not provide a robust basis on which to analyse the proximal drivers of annual population fluctuations changes.

There is an urgent need for more robust data on population fluctuations such that a statistical relationship between population change and seasonal drivers can be established. Clear statistical inference will require data over several years so that interacting effects of warming, drying, rainfall seasonality, and land management practices can be analysed.

It is not clear whether the stressors driving the putative declines in the moth population play out primarily on the larval phase of the species life cycle that takes place in the northern part of the species range, or the on the adult phase that migrates from the northern and western part of its range to cooler, predominantly alpine environments for aestivation for the summer months (Green *et al.* 2021).

Ideally, monitoring would take place in both winter (larval) and summer (aestivation) range sites to help clarify the relative contributions of stressors on both life stages. Unfortunately, there are no larval sampling and mapping methodologies that could be viably applied across a large enough area to provide the data for reliable biogeographic and population analysis. Conversely, there are relatively well-specified protocols for summer (adult) range sampling using cave counts and light trapping methodologies that allow easy identification and relative abundance sampling of adult moths.

There remain concerns about the susceptibility of light trapping and cave count methodologies to high sampling variation (K. Green *pers. comm.*). However, these concerns could be addressed in part by utilizing extensive spatial and temporal replication of sampling effort, as well as new, cheaper monitoring methods such as ALBs. An extensive monitoring effort is plausible given the relatively low cost and ease with which the method can be deployed by a wide range of ranger groups, agency staff, volunteers, and researchers.

Here we set out the basic ingredients for a Bogong moth summer range monitoring program. We present a map of summer range moth relative abundance derived from systematic light trapping surveys conducted over the summer of 2019/20 in the Victorian alpine region and augmented with some historical survey data. We utilize mapping of predicted relative abundance in the SPOTR (Spatial Power analysis of Occupancy Trends in R) software to analyse the statistical power of monitoring designs of varying cost to detect population changes of interest over the next 10 years. We conclude that a monitoring design, implemented largely by ranger groups and citizen science groups could be sufficiently powerful to detect change of practical concern in the moth population within plausible public and philanthropic funding resources.

Methods

The monitoring design case study took place the Victorian Alpine subset of the Bogong moth summer range (Figure 1). The Victorian Alps contain large areas of high altitude, rocky and shrubby habitats that attract large numbers of moths during the summer aestivation.

Unfortunately, existing light trapping data for Bogong moth summer range in Victoria is extremely patchy and ad-hoc, having been collected primarily at mountain pygmy possum sites for the purposes of understanding food availability. A few other moth surveys, including cave counts at particular locations, have been undertaken in Victoria over several years, though only in one or two places (Green *et al.* 2021).

In order to build a sufficiently reliable summer range map of key Victorian Bogong moth sites, we undertook a more wide-ranging summer field survey during the summer of 2020/21. Data from the 2020/21 surveys were combined with previously collected light trap data (Kreisner & Weeks 2019; Monk, N. 2021) to use as a basis for developing a species distribution model (SDM) for the moth.

The SDM formed the basis of a random, stratified monitoring design for the moth. The statistical power of the monitoring design to detect population fluctuations in Bogong moths over the next decade was evaluated using the SPOTR software (Southwell *et al.* 2019).

2020/21 Field data collection

One hundred sites were identified across the Victorian alpine region for light trap surveys with the aim of filling significant gaps in the existing Bogong moth survey data between December 2020 and February 2021. The number of sites surveyed was the maximum that could be covered with the available budget and within the tight timing of the Bogong moth aestivation. COVID-19 lockdowns impacted on the field collection season, preventing some of the key geographic gaps in moth survey data being filled (e.g., in the far north-eastern part of the Alps toward the NSW border, including Mt Benambra, the Cobberas and the peaks around the upper Snowy River). Nonetheless, surveys did dramatically expand the systematic survey coverage for the Bogong moth in Victoria and provided a sound basis for SDM construction.

The light trap used in surveys is a simple globe-and-bucket trap with the light source a 300mm, 8-watt fluorescent black light UV tube that produces a 320-420nm wavelength that runs on a 12-volt battery (Fig. 2a). The total weight of the trap is less than 2kg, making it very portable for long hikes into survey locations. The traps consist of three sections: a white poly bucket (26cm diameter, 27cm height) in which funnels are fitted, the 8-watt black light fluorescent tube which is attached to three clear plastic vanes, allowing a 360-degree light emission. Three stretch cords are placed at equal distance apart from the top edge of the bucket to the metal ring at the top of the vanes to hold it in place. The third section of the trap includes the solid-state electronic components.

Figure 2. (a) The light trap used in all moth surveys (Image from Australian Entomological Supplies), (b) a Bogong moth aestivation cave (Warrant et al. 2016), and (c) deployment in a Victorian alps survey location indicating boulder field aestivation habitat (photo: Ingrid Crossing).

Light trap surveys took place predominately in the two hours following sunset and two hours prior to dawn, which are known to be peak activity times for the moth (Common 1954). Light traps were set on automatic timer to switch on and off to fix a 2hr survey duration for each survey (note: only a 1hr duration was used at Falls Creek and Mt Hotham sites). The number of moths caught in the light trap at each sampling session were then manually counted. Counts ranged from very low numbers up to over 700 at some of the most productive moth locations on Mt Hotham.

Species distribution model (SDM)

A total of 142 moth counts were available for modelling comprised of 101 collected in light traps through the summer of 2020/2, nine sites collected by Mt Hotham, Buller and Falls Creek Resort Management (Monk, N. 2021), and a further 32 data points were obtained from the Victorian Biodiversity Atlas, primarily collected by Kreisner in 2019/20 (*unpubl*).

Independent environmental variables considered likely correlates of moth counts were obtained and processed for use in regression modelling (Appendix 1). These included climatic, topographic, land cover and vegetation type variables. Independent variables were sampled at survey locations using the ‘sample’ command in the R GIS library ‘raster’ (Hijmans & van Etten 2012) to create a modelling matrix for use in regression model selection.

Pairwise correlations between environmental variables were computed in order to identify and remove variables with high linear correlation with other independent variables. For each pair of correlated (R^2 >0.7) predictor variables (Appendix 1), only the variable with the highest correlation with moth counts was retained to avoid parameter estimation instability in regression models.

Regression models that described the variation in moth counts as a function of independent environmental predictors were fitted in the function ‘glm’ in the statistical freeware R (R Core Team 2020). The performance of competing models was evaluated using Akaike’s Information Criterion (AIC: Akaike 1973) that seeks to find a balance between explanatory power and simplicity. A range of model structures were explored using a backward-selection method that starts with a full model and iteratively removes least explanatory independent variables (i.e., simplifies the model) until the simpler model has a worse AIC than the larger model, at which point the selection algorithm stops.

The AIC-best distribution model was used to create a one-hectare resolution map that shows the predicted nightly count of moths at all areas in the Victorian Alps. The predicted count can be used as an index of the relative suitability of each hectare cell.

Power analysis using SPOTR

The AIC-best Bogong moth SDM was used as a basis for the design of a candidate monitoring program for the Victorian aestivation range. Two monitoring designs were developed and tested for their power to detect changes of 10% and 30% in moth occupancy of alpine areas over the next 10 years. The two candidate designs were comprised of two site-stratification strategies: (i) randomly stratified across all levels of habitat suitability as described by the SDM, and (ii) weighted toward including more sites within higher quality habitat strata, as defined by the SDM. A range of different annual sampling efforts were deployed to provide a picture of the minimum sampling effort required for acceptable power, based on the other assumptions about background variation and effect size.

All computer (R) code for model fitting and SPOTR analysis are available at Appendix 1.

Results

Surveys conducted in the summer of 2020/21 showed a wide and highly skewed distribution of counts, with most surveyed locations yielding zero or very low counts, and a few survey locations yielding extremely high numbers of trapped moths (400–800) in a 2-hour trapping session. This indicates that while Bogong moths are widespread across the alpine region and do persist in low densities in rocky habitats, they do also congregate in extremely high numbers at the most favourable locations. The highest-density observations in our surveys were the loose boulder fields on Mt Hotham. Some relatively high densities were detected at other sites including Mt Bogong and Falls Creek, though those numbers tended to be in the tens rather than the hundreds.

The species distribution model (SDM) fitted to the summer Bogong moth count data included a negative relationship with maximum temperature, and positive relationship with elevation, and higher expected density in rocky areas with shrubby vegetation. The model explained 42% of the variation in moth counts and achieved an adjusted R^2 of 0.72 under bootstrap evaluation. Model predictions were mapped onto the alpine region to produce a map of highly suitable areas for use in developing a candidate monitoring sampling design (Fig. 3).

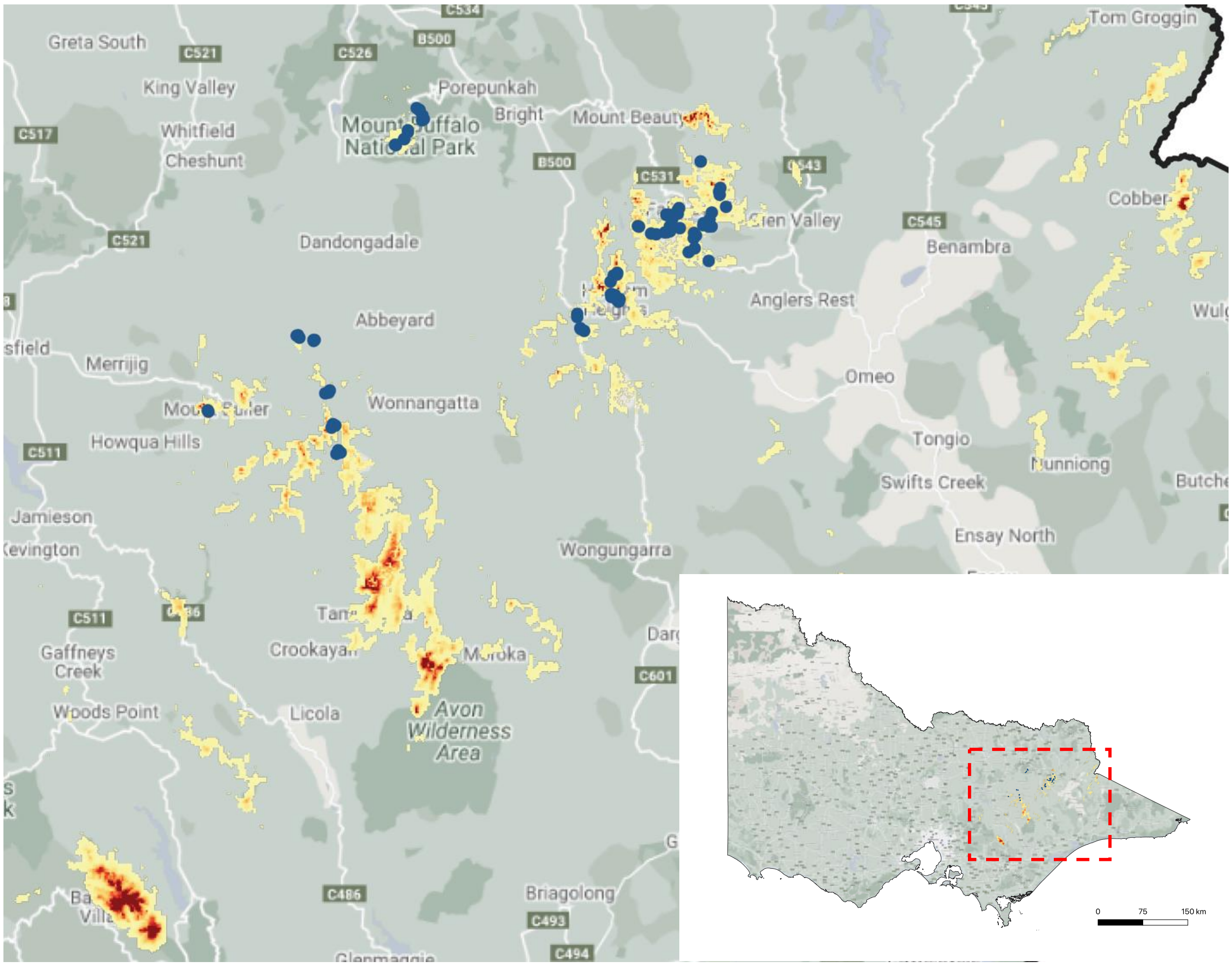

Figure 3. A map of predicted moth counts in the Victorian alps based on the AIC-best SDM. The predicted count can be thought of as a surrogate for habitat suitability. Blue dots indicate 2019–2021 survey locations with positive counts. Yellow shading indicates areas of moderate predicted counts and red indicate areas of high predicted counts.

Based on the predicted moth counts, two candidate summer range Bogong moth monitoring designs were developed based on a random stratification across the full range of predicted counts (or suitability) and a stratification weighted toward more suitable survey locations (Fig. 4). The statistical power of the two monitoring designs was evaluated based on a minimum detectable effect size (change in population size) of 10%, 20% and 30% over ten years. Unsurprisingly, the power to detect the larger (more obvious) change of 30% was much higher than the power to detect just a 10% change. Unfortunately, the statistical power to detect a 10% decline in the species over 10 years was not satisfactory (<0.5) even at large sample sizes of 350 sites per year (Fig. 4, black lines). However, a power to detect a 20% decline of around 0.8 could be obtained with a sampling effort of around 175 sites per year when sampling was biased toward higher quality sites (Fig. 4, panel (b), blue line). This represents a realistic annual survey effort with a budget of around $70K/year. Monitoring design weighting toward more suitable sites tended to provide slightly higher power to detect change than a fully random design that is evenly stratified across predicted counts because differences between larger counts over years are statistically easier to detect than differences between smaller counts (at more marginal locations).

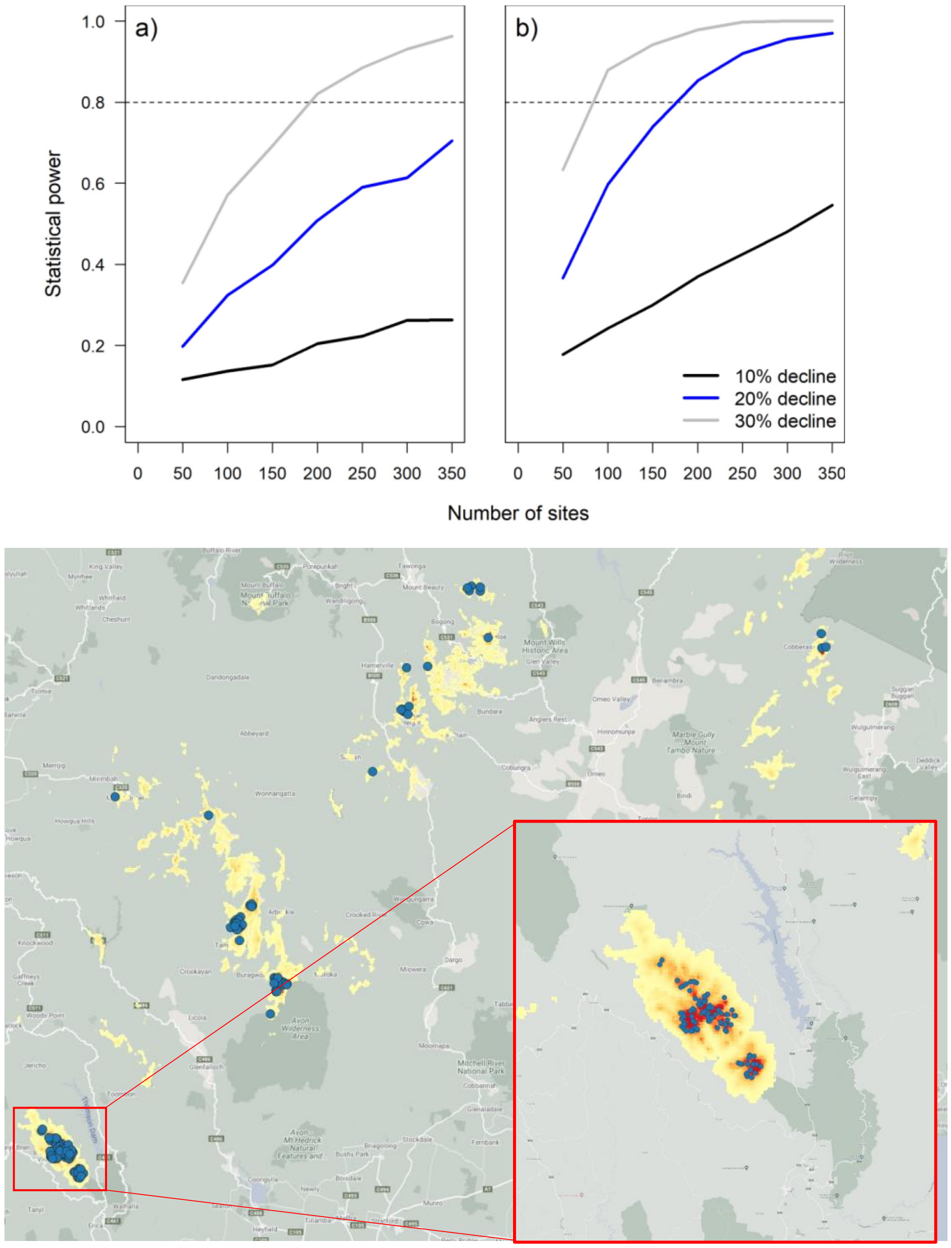

Figure 4. (Top row) Statistical power (y-axis) of detecting 10% (black line), 20% (blue line) and 30% (grey line) declines in occupancy for a given number of monitoring sites (x-axis). The panel on the left (a) randomly selected sites from habitat with >0.1 occupancy; the panel on the right (b) randomly selected sites from >0.3 occupancy. In both scenarios, sites were monitored every year for 15 years assuming perfect detectability, an alpha rate of 0.1 and a two-tailed significance test, with simulations run 1000 times. (Bottom row) A map of a random-stratified monitoring sampling design for the Victorian Alps comprised of 200 sites, weighted toward higher probability locations (more suitable) as defined by the SDM.

Discussion

A monitoring design with a reasonable power (~0.8) to detect moderate to large (20–30%) declines in the Bogong moth population arriving in the alps each is plausible within reasonable annual monitoring budget of around $70–100K/year. However, this is based on a number of assumptions that must be explored in more detail and to which findings may be sensitive. For example, the SPOTR analysis currently assumes a linear change/decline in moth numbers over the 10-year period. However, dramatic yearly fluctuations in moth arrivals have been observed (see Fig 3. in Green et al. 2021). This may not be a problem if such fluctuations correlate strongly with measurable environmental factors such as autumn–winter rainfall in the breeding grounds, allowing those factors to be controlled in statistical analyses of monitoring data.

Given the results presented here for Victoria, there appears little problem in rolling out the design to the NSW Alps, sharing costs, increasing statistical power, and improving the generality of the results.

However, a number of sampling issues need also to be resolved. The timing of surveys would need to be randomised across locations over years, or ideally, surveys would be repeated throughout the summer spring, summer, and early autumn at survey locations. This would have the added advantage of improving understanding about the timing of the arrival and departure of the moths and how that varies with annual weather and climatic variation. Replicating surveys at sites within a season would increase costs and could perhaps be undertaken at a subset of sites. A suite of know aestivation caves should be included in the monitoring set to provide insights into whether numbers are changing at these sentinel sites. Several such sites are already routinely monitored, though the consistency of methods could be more carefully coordinated across research groups.

This report sets out the basic parameters of a summer range monitoring program for Bogong moths in Victoria. Such a program would allow better under of whether trends are worsening, whether conservation actions are working, with some possible insights into the role of seasonal rainfall patterns in larval range on the arrival of moths into the alps. However, summer monitoring must be complemented with winter (larval) range monitoring and targeted experiments to explore in more detail and learn more quickly about the potential effectiveness of conservation strategies.

A key part of the appeal of a national summer range monitoring program is in the opportunity to bring Traditional Owners and citizen scientists onto Country in a cooperative effort to learn more about this amazing species, to develop a shared appreciation of their cultural and ecological significance and contribute to reconnection and healing of Country. This conveys an opportunity but also an obligation for public agencies to help support this reconnection through adequate resourcing, shared management, and reconciliation.

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Further information:

http://www.nespthreatenedspecies.edu.au

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