What is known about terrestrial insect population trends in Aotearoa New Zealand?

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Abstract

A scoping study was undertaken to determine what is known about terrestrial insect population trends in Aotearoa New Zealand in a way that is informative and strategic for policy making. The study aimed to explore key themes for insect population health, to capture expert perspectives on how to better understand this issue and recognise what key barriers to work exist. A mixed methods approach was used through the analysis of threat classifications, key informant interviews, an expert panel, targeted engagement, and input from Māori, alongside the scoping of literature.

Interviewed experts agreed that there are insufficient data to determine the overall state and trend of insect populations in Aotearoa New Zealand, and that the base knowledge of our insect fauna is less well established than that in Europe and the United States, for example, although considerable baseline data are available. Key knowledge gaps of state and trend information for insect populations, including habitats occupied by insect species and the relative compositions of insect species assemblages, such as pollinators were identified. Overall, there is limited trend or driver evidence that is suitable for guiding policy making. There are good opportunities to fill these gaps, including through undertaking metadata analyses of existing information and building on previous survey work largely undertaken by a small number of dedicated entomologists. Opportunities also exist to explore Māori values and mātauranga Māori of te/nga aitanga-a-pepeke (the insect world). The findings of this work and the suggested ways forward for Aotearoa New Zealand are consistent with those recently discussed in the Australian context, and the recent roadmap set out by an international consortium of experts.

The following steps are suggested to address the knowledge gaps: 1. capitalise and build on historic insect datasets and collections; 2. identify and utilise state of the art technologies to enable cost-effective monitoring; 3. commit to inclusive monitoring approaches including citizen science efforts; and 4. develop a research programme that is supported by key government agencies, crown research institutes, museums and universities, and that is consistent with the goals of the NZ biodiversity strategy and a te ao Māori approach to undertaking the required work.

Keywords: terrestrial insect population health, New Zealand, native species, exotic species, research priorities in entomology, conservation, primary industry

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Introduction

The notion of widespread and potentially global 'insect decline' has been widely publicised in recent years. This publicity is typically linked to two field studies (Hallmann et al., 2017, Lister and Garcia, 2018) and to a literature review (Sánchez-Bayo and Wyckhuys, 2019). The field studies reported large decreases in flying insect biomass in Germany over 27 years (estimated >70%) (Hallmann et al., 2017) and in arthropod biomass in Puerto Rico over 40 years (decreases of 4 to 60 times depending on sampling type) (Lister and Garcia, 2018), respectively. The literature review concluded that the current rate of decline may lead to the extinction of 40% of the world's insect species over the next few decades. However, there has been some disagreement in the scientific community with these studies, despite their widespread coverage. In particular, requests have been made for more conservative conclusions based on robust evidence for the Puerto Rico study (Willig et al., 2019) and literature review (Simmons et al., 2019, Thomas et al., 2019, Komonen et al., 2019). Regrettably, this ongoing debate clouds the wider understanding of insect population health in Europe and the Americas, as well as for other continents with less established baselines (Braby, 2019). An effort to clarify this issue has been made through the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) (2019) which estimates that around 500,000 insect species (10%) are threatened with extinction. This report has given further cause for global awareness and potential concern regarding insect population trends in Aotearoa New Zealand.

The declines reported by these studies were putatively associated with multiple drivers of change such as: landscape changes and climate change (Hallmann et al., 2017); climate warming (Lister and Garcia, 2018); habitat loss through agriculture and urban intensification, pollution, including synthetic pesticides and fertilisers, biological factors including pathogens and introduced species, and climate change (Sánchez-Bayo and Wyckhuys, 2019); and land-use change, direct exploitation [of natural environments], climate change, pollution, invasive alien species and others (IPBES, 2019).

Given the level of global awareness regarding state and trend of insect populations we sought to understand what is known about terrestrial insect population trends in Aotearoa New Zealand with the intention that findings would drive a considered policy response, including for ongoing research and monitoring needs. We begin with a summary of why insects are important. We then describe our approach, present an analysis of the state of knowledge, and suggest an inquiry-based strategy for moving forward.

Terrestrial insects and their 'value' context in Aotearoa New Zealand

Ecosystem services and economic values

Ecosystem services are the direct and indirect benefits that humans gain from ecosystems (MA, 2005). Insects provide primary ecosystem services, such as pollination, nutrient cycling, pest control and wildlife nutrition (Losey and Vaughan, 2006). Due to these services, insects and the roles they play are fundamental for the overall health of ecosystems. The global monetary value of animal pollination services (>80% by insects) was estimated to be $US235-577 billion/year, or 5-8% of global crop production (IPBES, 2016). The benefits that pollination services provide, however, go beyond food provisioning and include benefits to medicines, biofuels, fibres, construction materials, bioinspiration (technology inspired by nature) and many cultural components (IPBES, 2016). The economic value of insects and the ecosystem services they provide in Aotearoa New Zealand is not well understood. Furthermore, it is not yet clear how changes in trends of in insect populations could disrupt ecosystem service benefits in Aotearoa New Zealand.

The conservation value of insects in Aotearoa New Zealand

As a result of being an isolated group of islands, Aotearoa has a high proportion of endemic species (species that are not found elsewhere in the world). An estimated 20,000 insect species occur in Aotearoa New Zealand (c.90% of which are terrestrial) (Macfarlane et al., 2010), and c.18,000 of these species are thought to be endemic (Gibbs, 2016). For terrestrial insects c.11,000 species (c.60%) are documented (Macfarlane et al., 2010). Orders Coleoptera (beetles, pītara), Diptera (flies, ngaro), Lepidoptera (moths and butterflies, pēpepe), Hymenoptera (wasps, bees and ants, wāpi, pī and pōpokoriki) and Hemiptera (bugs, pītara) are the most species rich (Macfarlane et al., 2010).

Multiple factors make Aotearoa New Zealand's insects of special conservation interest. These include the high rates of endemicity (c.90%), the uniqueness of many of our species (Gibbs, 2016) and the often high levels of genetic divergences (Buckley et al., 2015). The unusual rates of endemicity can be exemplified by the fact that in some orders the highest taxonomic levels are only found in Aotearoa New Zealand. This includes four beetle families, namely Agapythidae, Chalcodryidae, Cyclaxyridae, and Metaxinidae, the primitive moth family Mnesarchaeidae and unusual batflies Mystacinobidae (Buckley et al., 2015). The isolation of Aotearoa New Zealand without land-based mammalian species also led to insects filling non-typical niches and evolving unique characters, such as relative 'gigantism', as expressed in several wētā species and the giraffe weevil (tūwhaipapa, *Lasiorhynchus barbicornis*). During expert interviews it was noted that three Coleoptera (beetles, pītara) families diverged as far back as the Cretaceous period; this rivals some of the biological heritage of our endemic vertebrate species (Buckley et al., 2015).

Māori and insects

Tangata whenua (Māori) experts (see Methods for details) emphasised the importance of whakapapa (genealogy) as a lens to understand and appreciate te/nga aitanga-a-pepeke (the insect world). Whakapapa describes the interwoven relationships among nature, where all parts are linked, including humans as kaitiaki (environmental stewards) (Timoti et al., 2017, Walsh et al., 2013). These interwoven relationships are evident in the roles that insects play in the environment (e.g. pollination, nutrient cycling, pest control and wildlife nutrition) (Losey and Vaughan, 2006). Through these relationships, insects can support Taonga species, including kiwi (*Apteryx sp.*) (nutrition) and mānuka (*Leptospermum scoparium*) (pollination). Insects may also threaten Taonga species; for example, in the case of mosquito transmission of avian malaria to hoiho (yellow-eyed penguin, *Megadyptes antipodes*) populations. Insects support human needs through mahinga kai (food provisioning) or culturally important materials, such as rongoā (medicinal uses). A Ngāi Tahu proverb exclaims that te/nga aitanga-a-pepeke (the insect world) makes a point to remind humans of its importance throughout the day and night; it is namu (sand flies) that take the day shift while waeroa (mosquitoes) take the night shift. Because of their foundational importance in ecosystems, insects are often considered harbingers of seasonal change or indicators of environmental health (Lyver et al., 2017). Opportunities exist to further explore the cultural values that iwi/hapu/whanau have for specific insect species, as has been done for bird species such as the kererū (New Zealand Pigeon, *Hemiphaga novaeseelandiae*) (Timoti et al., 2017).

During expert interviews te āwheto (vegetable caterpillar fungus, *Cordyceps robertsii*) was given as an example of whakapapa owing to the connections that can be observed between the caterpillars, fungus, humans and their surrounding environments. Forest porina caterpillars (genus: *Dumbletonius* and *Aoraia*) live and forage on the forest floor, eating leaf litter, forest grasses and seedlings. In this environment, spores of the *Cordyceps robertsii* fungus can infect and consume the caterpillars to leave behind the dormant shell (sclerotium) and a fruiting fungal stem (stroma) to continue the life cycle (SLH, 2018). These dormant shapes were called te āwheto by Māori and vegetable caterpillars by Europeans. Te āwheto is interwoven into Māori customs as it was used as an ink ingredient for tā moko (Higgins, 2013), and sometimes as a food source. It is these relationships which relate forest porina caterpillars to the forest floor, the plants it eats, the fungus that preys on it and the humans that benefit from te āwheto. The loss of these types of relationships, through the extinction of species, threatens Māori with a risk of losing cultural identity (Black et al., 2019).

Methods

A mixed methods approach was used to identify a prevailing narrative for insect populations internationally, then to explore these themes and what is known for Aotearoa New Zealand, primarily using expert perspectives This involved analysis of threat classifications, key informant interviews, an expert panel, and targeted engagement and input from Māori, alongside the scoping of literature. The methods for these aspects are described following sections outlining ethics, scope, limitations and metrics below.

Ethics

Interviews with experts in a given field do not typically require Human Ethics Committee approval at most New Zealand universities. This work was carried out consistent with the Auckland University Human Participants Ethics Committee (UAHPEC) guiding principles (Section 3.1.1, Page 6) which state that no ethics approval is needed from the UAHPEC under the relevant exception: "discussions of a preliminary nature that will assist in the development of a research protocol or instrument, but will not provide data to be incorporated into the research dataset". In addition, all interviewees and reviewers were asked if they would like to be acknowledged in this work, to which all persons agreed.

Scope

To limit the review scope, only terrestrial insect species were considered. The definition of 'terrestrial' relies on that reported in the 'New Zealand Inventory of Biodiversity' (Macfarlane et al., 2010) or as assigned in conservation threat assessments using the New Zealand Threat Classification System (NZTCS). Gordon (2010, p236) defines *Hexapod* species' environments as: "for any significant part of their lifecycle; 'marine' pertains to individuals or hosts that are regularly living or feeding in or on the sea or below the high-tide mark. 'Freshwater' means fully submerged, as in the case of larvae, not merely riparian" and terrestrial species are those that are neither 'marine' or 'freshwater'".

Endemic and introduced species are considered, however, only introduced species generally considered 'beneficial' were in scope. 'Beneficial' exotic species are defined as a species that provide one or more ecosystem service benefits and/or they contribute economic or cultural benefit to Aotearoa New Zealand. The definition of 'benefit' is subjective and relevant examples were guided by expert perspectives.

Limitations

This work was undertaken over a three-month timeframe and captures important themes but was not intended to be a comprehensive review of a complex topic. Rather it is designed to be informative and strategic for policy making.

Metrics

Three ecological quantification metrics are useful to help understand the state of insect populations, namely: 1) presence or absence (if a specific species is or is not observed at a defined location); 2) biomass and density abundance (how many individuals are observed) and 3) metrics of community ecology, such as species richness (total number of species) and species evenness (how abundance is distributed for all species). The reproductive nature of insects also needs to be considered when measuring state and trend of the described ecological metrics. Generally, insect reproduction can have multiplicative responses to the environment, so in times with contrasting seasonal temperatures or rainfall, populations can rapidly increase or decrease (Kingsolver, 1989, Gherlenda et al., 2016). To account for these types of effect and 'inter-annual variation', sampling is often made over three- to five-year time periods and running averages are sometimes used.

Scoping national studies

Scoping literature searches were carried out for Aotearoa New Zealand relevant findings. These used a combination of general search terms, such as "insect", "population", "health" and "survey", and aimed at insect population metrics. Additional literature was suggested by experts, and this tended to be especially relevant for findings in Aotearoa New Zealand.

New Zealand Threat Classification System (NZTCS)

The NZTCS (URL) is used by the Department of Conservation (DOC) to assess the risk of extinction of species in Aotearoa New Zealand (DOC, 2019). NZTCS assessments were analysed to explore the current threat status of insect species and to explore the assessment trends overtime for some ground beetle species (family: *Mecodema*). The method of analysis is explained in detail in **Supporting Information - Appendix 1,** with appropriate references and an additional graph. In short, a non-archived NZTCS version downloaded on 21-06-19 and filtered by 'Environment'='Terrestrial' for the relevant insect orders was used. This allowed an overview of 'data deficient', 'threatened', 'at risk' and 'not threatened' assessments for the Insecta class.

Māori interviews

Contact was made with five individuals for Māori perspectives on the value of insects – two initial individuals were suggested by the Chief Science Advisor authors of this work and the three additional individuals were suggested from the initial interviews. An opportunity arose to speak, specifically, about this topic with three Ngāi Tahu kaitiaki; therefore, there is a strong incorporation of the Ngāi Tahu context. The two other interviewees were associated with Māori contexts in the upper North Island. The examples provided are indicative only of the diverse roles and values of insects in the wider Māori context. Māori names are included as found in Miller (1952) and in the online Māori Dictionary (Moorfield, 2019).

Entomology or ecology expert interviews

Initial contact was made with five entomology or ecology experts based on specific areas of expertise. Recommendations from these initial contacts and discussions guided further expert identification and subsequent interviews. Interviews ultimately occurred with 21 experts and sometimes involved follow-up contact. While broad ranging, given the exploratory scope of this work the sample of experts interviewed does not represent the full range of relevant science expertise in Aotearoa New Zealand.

The general questions presented to interviewees have been included in the **Supporting Information - Appendix 4**.

Entomology and ecology expert panel

An expert panel was convened at Lincoln University to identify methods that could be used to gather the evidence required to determine what widespread population trends may be occurring in New Zealand. This panel consisted of 11 experts who were primarily invited based on expertise and their relative proximity to Lincoln. As such, they included members from Lincoln University, University of Canterbury, the Entomological Society of New Zealand, BioProtection Research Centre, Plant and Food Research, AgResearch and Manaaki Whenua – Landcare Research. The general questions presented to the group have been included in the **Supporting Information - Appendix 4**.

Findings and discussion

The mixed methods approach elicited findings in the following areas: knowledge gaps, examples from the literature of po, means of improving knowledge, considerations for fostering Māori knowledge in research and barriers to work in this area. Each area is discussed in the following sections.

Knowledge gaps

The interviewed experts and the expert panel agreed that for most insect taxa, information on the current state and trend of ecological metrics is not available. This is consistent with the Parliamentary Commissioner for the Environment's report (PCE, 2019) which found that there is an incomplete understanding of our native arthropod biota, which contains insects, and that this is compounded by the paucity of data. For a small proportion of specific taxa there are state and trend metrics that show declines. However, it is not clear if these trends are occurring across the insect fauna or if they are isolated to specific species or species-location interactions. Based on expert feedback there are good opportunities to fill these gaps and the following subsections explore both contentions.

Threatened species analysis

The conservation status of c.1,400 terrestrial insect species (approximately 13% of the total number of documented terrestrial insect species in Aotearoa New Zealand (c.11,000) (Gibbs, 2016)) have been assessed (Error! Reference source not found., and **Supporting Information - Appendix 1** for further d etails). This assessment was made by a diverse range of professional and non-professional taxonomists (Leschen et al., 2012, Andrew et al., 2012, Stringer et al., 2012, Ward et al., 2014, Hoare et al., 2017, Buckley et al., 2012, Trewick et al., 2014). Of the assessed species, c.750 or 54% of species are considered as 'Threatened' or 'At Risk'. Of the subset of insect species that have been reassessed (between 2010 and 2017, depending on insect order), 21 had an improved status and 37 had a worsened status[1]. All improved ratings were based on new data or reinterpretation of existing data, rather than on observed improvements in populations. Ten of those with 'worse' conservation state assessments were based on actual declines of populations. Of the species assessed as 'Not Threatened', 'At Risk' and 'Threatened', seventy-five are considered data poor, meaning their threat assessment has been made with limited data. Finally, there are around 400 species which are data deficient; this means there is not enough information to make a satisfactory threat classification. The

[1] 12 'Not Threatened', 6 'At Risk-Sparse', 3 'At Risk-Naturally Uncommon', 5 'At Risk-Range Restricted', 1 'At Risk-Recovering', 2 'At Risk-Declining', 3 'Threatened-Nationally Vulnerable', 5 'Threatened-Nationally Endangered' → 11 'At Risk-Naturally Uncommon', 1 'At Risk-Recovering', 3 'At Risk-Declining', 4 'Threatened-Nationally Vulnerable', 7 'Threatened-Nationally Endangered', 11 'Threatened-Nationally Critical'

around 1000 species that have a threat classification are short of the approximately 11,000 terrestrial species that have been documents and the 20,000 estimated species in Aotearoa New Zealand (Macfarlane et al., 2010). However, for specific taxa assessments and related literature are informative and this is exemplified below.

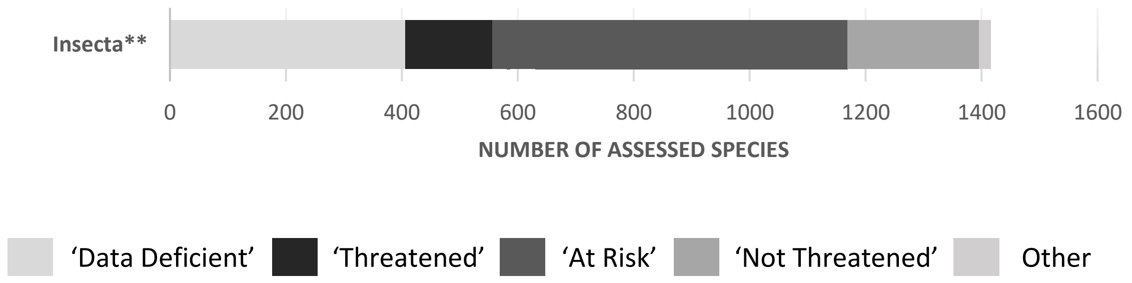

Figure 1 *Threat assessment categories for terrestrial insect species in Aotearoa. NZTCS data (DOC, 2019) 21-06-19 and reviewed by Jeremy Rolfe (Technical Adviser, DOC). 75 species are listed as data poor and these species are distributed within assessments in the 'Threatened', 'At Risk' and 'Not Threatened' categories, while 400 species are data deficient*.

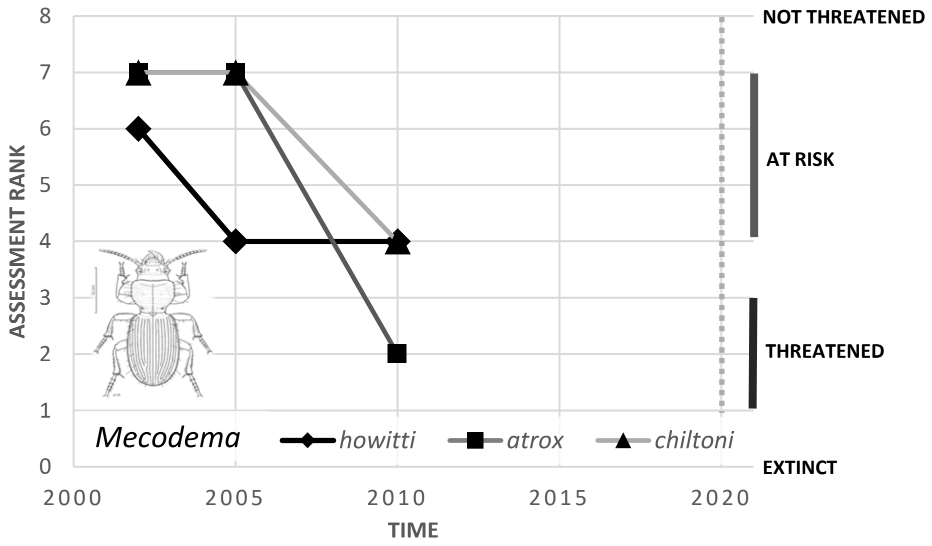

Figure 2 *Threat classifications for three ground beetle species: M. howitti, M. atrox and M. chiltoni in the Mecodema genus through time. This data was collated from published assessments (Hitchmough et al., 2007) and current NZTCS assessments accessed 21st July 2019. The grey dotted line represents the expected updated Coleoptera threat classification in 2020. Insert illustration is of the Mecodema genus, credit: Des Helmore © Manaaki Whenua – Landcare Research, CC BY 4.0 (URL).*

The threat classification for three ground beetle species (genus: *Mecodema*, family: Carabidae) can be tracked over time (**Figure 2**). These species are vulnerable to predation by rodents as they are flightless, slow moving, and large (10-32mm). While these three species are found in three different locations (*M. howitti* - Banks Peninsula, *M. atrox* – Volcanic Plateau and eastern North Island, and *M. chiltoni* – Central Otago to eastern Fiordland), the threat status for all three species has deteriorated over the assessment period (2002-2010). For *M. howitti*, the removal or burning of rotting hardwood from pastureland resulted in decreased abundance (Anderson et al., 2003); the lowland forest habitat of *M. atrox* was reduced (Seldon and Leschen, 2011); and for *M. chiltoni,* a continued decline has been recorded, though the species can be relatively common locally (Barratt, 1993). Presence reduction or range contraction can be a symptom of population decline (Caughley and Gunn, 1996). In Aotearoa New Zealand, range contraction involves species loss on a widely distributed scale (national) to loss on regional and local scales - given many species are regional or local endemics then this occurrence could have very important conservation significance. If declines are unabated, the species may be limited to a very small geographic habitat, like the Mahoenui giant wētā (*Deinacrida mahoenui*) which is restricted to an area of 240 hectares on public conservation land (Watts et al., 2013), and thus, at a greatly increased risk of extinction.

Literature evidence provides some insight into potential declines of specific insect fauna

There is some literature that demonstrates decline and cause for concern. For example, White (1991) reported that moth abundance decreased between the periods 1961-63 and 1987-89 in two inland central-Canterbury sites. The site with the largest loss of endemic herbs also had the largest declines of abundances in common herb- and grass-feeding moth species (88% and 74%, respectively). By contrast, the site that had the smallest loss of endemic herb species had a smaller decline in abundance of grass-feeding moths (56%). Watkin (2014) undertook a preliminary 'meta-analysis' of a comprehensive and widespread Lepidoptera collection, and reported a decline of moth and butterfly species richness in human-modified landscapes in Aotearoa New Zealand over time. Generally, in native plant habitats there were slight increases in the number of endemic species, except for tussock grasslands where declines were reported In addition, Bowie *et al.* (2019) identified an overall decrease of Carabidae (ground beetle) species richness between 1977-78 and 2007-08 in the Ahuriri Scenic Reserve in Port Hills, Banks Peninsula. There also appeared to be an overall decrease of abundance (17%), when considering catches across 14 sampling sites, but this was not statistically significant. Nevertheless, the abundance for one species, *Mecodema oregoides*, decreased significantly by 63%. As noted above, it is not clear if these trends are occurring across the wider insect fauna or if they are isolated to specific species or species-location interactions identified in this study.

'Beneficial' exotics should be considered too

As an exemplar exotic species, the domestic honeybee (*Apis mellifera*) provides benefit directly from honey related products and provides pollination to crops such as clover, pip/stone fruit and kiwifruit (MPI, 2020, Evans et al., 2019). In 2019, the net pure honey price reached NZ$44.0 per kilogram (10% increase on 2018), the total number of hives reached 918,000 (4% increase on 2018) and the net pure honey export value was NZ$355 million (MPI, 2020) (**Supporting Information - Appendix 2**).

Threats to the domestic honeybee are well documented internationally (Genersch, 2010). While feral bee colonies have been decimated (Newstrom-Lloyd, 2013), managed colonies show a low overwintering colony loss rate (Stahlmann-Brown et al., 2020) compared to other countries (Bruckner et al., 2019, Laurent et al., 2014). In 2019, the rate of loss was 10.5% which is statistically indistinguishable from the estimated loss for 2018 (10.2%), but statistically distinguishable and higher than estimated losses for 2017 (9.7%), 2016 (9.6%) and 2015 (8.4%). The surveyed median 'economic injury level' or economically sustainable level for 2019 was 10% and identical to that for 2018 (Stahlmann-Brown et al., 2020).

Given the economic importance of this species, there is an increasing body of work and a monitoring program that helps identify the drivers of these losses, such as queen problems (Stahlmann-Brown et al., 2020) and pathogens such as varroa mite and wasp predation (Gallagher et al., 2018, Stahlmann-Brown et al., 2020). Mitigation tools can be developed when a good understanding of drivers is established. For example, miticides are currently used to control varroa mites in colonies and new solutions are developing that may address miticide resistance and other issues (Kanga et al., 2010). In the case of American Foul Brood, a honeybee disease, regional coordination of apiarist management behaviours is of high importance (ApicultureNZ, 2017).

Methods to address knowledge gaps

The interviewed experts and expert panel suggested several approaches to address the knowledge gaps with respect to state and trend evidence. These involve capitalising on historic datasets, investing in new tools and exploring the drivers of trends.

There is a wealth of information or metadata available in the literature, unpublished datasets and in insect collections (both private and public). The expert panel suggested the first step of working with historic datasets is to review all available datasets to appreciate strengths or weaknesses and prioritise some for future work. To assist with the preliminary review of datasets, an online inventory has been initiated and is hosted by the Entomological Society of New Zealand (NZIDI, URL). Ongoing development of this inventory towards and easily accessible resource is highly advantageous, and could be based the Coral Trait Database (URL) which is a similar effort for coral datasets globally. The recommended datasets can be explored using metadata analysis techniques and resampling efforts, as discussed below. It should be noted that the use of historical records and the replication of surveys were recently identified as primary approaches to appreciate the population trends of insects in Australia (Braby, 2019) and in the roadmap set out by an international consortium of experts (Harvey et al., 2020). Example datasets collated by experts are provided in the **Supporting Information - Appendix 3.**

The 'metadata-analysis' method for trend assessment

The metadata-analysis method is an information science approach that mines available data fields. With respect to insect population trends these data may include: species/taxon presence/absence, abundance, date of collection, and location and relevant habitat information from the collection site. Data from comprehensive entomological collections throughout Aotearoa New Zealand is particularly relevant for this type of analysis. This method can provide indicator and community ecology metrics, such as species richness; however, it has not been widely considered for the study of insects in Aotearoa New Zealand. To explore this approach, an exemplar study of pollinators is noted (Bartomeus et al., 2018). Using various sources of information in Aotearoa New Zealand (including universities, research institutes, museums and private collections) a dataset was curated that reflected no obvious biases in geographical or taxonomic coverage. The data entries, covering 100 years of collection, were filtered down to records which showed suitable representation through time and included native bees (clade: *Anthophila*) and fly (family: *Calliphoridae* and *Syrphidae*) species, both of which contain important fly pollinators. From these, rarefied species richness values were calculated. For native bees, the richness measure was stable; however, for exotic flies there was an increasing trend of richness, while for endemic fly species there was a decreasing trend in richness. This study demonstrates the usefulness of historic collections and datasets to show how ecological metrics have changed over time.

Interviewed experts noted that one advantage of this technique is that analysis can start immediately and make use of collection and literature metadata that is already digitised in internationally standardised formats. Continued digitisation of Aotearoa New Zealand's datasets and collections will further enhance this approach to evaluate faunal changes through time. There are many opportunities for digitisation and renewed support in this area. For example, only c.10% of the New Zealand Arthropod Collection is digitised. If the remaining c6.3 million specimens were digitised, this would considerably increase the knowledge that could be gained through the metadata-analysis method.

Digitisation also assists with other primary functions of collections such as improved recall of data or specimens for biosecurity purposes. It should be noted that some datasets may already be digitised but are not publicly available, and there are calls by experts to increase the openness of such datasets (Saunders et al., 2020).

The 'resample' method for trend assessment

The resampling method is simply repeating a detailed field survey a decade or more later to compare species and 'species assemblage' data over time. Robust resampling datasets would be those where normal 'inter-annual variation' in insect populations was accounted for by pooling data across three- to five-year or longer periods. This type of approach is best suited to studies that interpret close to species level information and have well defined sampling methods that could be replicated accurately.

One advantage of resampling is that baseline measurements are already available and therefore trends in community and species metrics can be explored more rapidly than for new studies. They may also show changes that have already taken place, and correlation to potential drivers could be explored. A weakness of resampling is that the sampling method should ideally replicate the original study method; but this may be outdated, cost prohibitive or inefficient. Resampling undertaken over several time periods should be a priority to improve resolution of trends and drivers; however, if a large number of resample efforts with two data points are undertaken across different taxa, habitats and regions, it is likely that general trends will emerge (Braby, 2019). Careful selection of datasets may allow for extrapolation of trends for other taxonomic groups too.

Some historic data sets are particularly valuable for resampling. For example, samples and documentation collected around 100 years ago by George V. Hudson provide a unique baseline measure of old forest in Karori, Wellington. Resampling efforts in this area began recently involving members of the Entomological Society of New Zealand, Zealandia and the Department of Conservation. Additionally, datasets that retain specimens (i.e. collections) are especially valuable for resampling efforts as these specimens provide verification for taxonomic assessments and if suitably stored, they may be applicable for future genetic studies.

In addition to resampling based on previous datasets, the use of long-term study sites across environmental gradients has been recently shown to provide high quality datasets and evidence for determining insect population state-and-trend (Seibold et al., 2019, Cardoso and Leather, 2019). This type of approach is ideal for purpose-built long-term monitoring.

Genetic sequencing

Genetic sequencing techniques involve a set of tools that use DNA to identify organisms in a complementary way to classical taxonomy based on morphology (Hebert et al., 2003). Some high throughput techniques limit the number and type of DNA/RNA sequences interpreted and can be generally categorised as genetic 'barcoding'. This approach can also help identify cryptic species not easily distinguished by classical means (Burns et al., 2008, Velasco-Castrillón et al., 2014). 'Meta-barcoding' enables the simultaneous identification of multiple organisms or groups (Thomsen and Willerslev, 2015, Dopheide et al., 2019). This can be interpreted from environmental samples of DNA (named eDNA), where genetic tracers from multiple insect species are left behind as a result of biological activity (e.g. in water, soil, excrement or leaf litter) (Thomsen and Willerslev, 2015). The key to interpretation of barcoding and eDNA for insect species is the building of a library with genetic data reference to morphological taxonomy. However, incompletely-referenced eDNA sequencing can also provide a plethora of insightful correlations relating to environmental factors such as land restoration

(Fernandes et al., 2019) or forest-stand composition (Barsoum et al., 2019), biodiversity measures (Douglas et al., 2012) and also to identify sequences which could be useful as bioindicators (Carew et al., 2013). There is much work to be done in this area, including method standardisation, robust eDNA field studies and using insect collections to record genetic identifiers for each species which can be used to reference sequences as they become available. Typically, any new field sample will contain new, previously unrecorded species to document and build the library. Interviewed experts agree there is considerable power to detect and explain insect faunal change by investing in this approach. Some specific suggestions include:

1) genetic diversity (often described as the gene pool) within isolated populations may be measured from a small number of individuals via genotyping. This measures species population health (state) and is sensitive to genetic bottlenecks via declines in population sizes (Allendorf et al., 2010, Elshire et al., 2011).
2) presence or absence of cryptic or hard to find/identify species that are mobile can be measured by meta-barcoding eDNA (Deiner et al., 2017).
3) species richness of many insect groups can be rapidly determined by meta-barcoding of homogenised samples from large-scale environmental samples, collected by techniques such as malaise traps (Morinière et al., 2016) or soil samples (Dopheide et al., 2019).

Classical species taxonomy is still needed to link genetic identity with actual insect species to make sense of the environmental associations as well as helping determine faunal state and trend.

Enhancement of citizen science/engagement

Most insect citizen science contributions in Aotearoa New Zealand are ad-hoc and this impacts the usability of these data to generate community metrics. There have been calls by experts to standardise citizen science (Saunders et al., 2020) and possible ways to standardise these contributions were suggested during expert interviews. The first is to develop a standardised national survey like the New Zealand 'Garden Bird Survey' (MW-LCR, 2019), which provides presence and relative abundance data on native and endemic birds each year. Such an initiative in Aotearoa New Zealand could leverage the momentum of the 'Big Backyard Butterfly Count' which is run by the Moths and Butterflies of New Zealand Trust and has been running since 2015 (MBNZT, 2015). The second is to enable citizen scientists to develop large publicly available audio, video or still image datasets and use artificial intelligence (AI) to mine these for community and species metrics with geospatial tags (Zilli, 2015, Gurgel-Gonçalves et al., 2017). Such datasets can be generated by citizen scientists efficiently (e.g. with smartphones) and can be stored at relatively low cost. Interviewed experts suggest there are distinctive insect opportunities with cicada or wētā locating and mating calls and wingbeat recognition for beetles and many flying insects. A proof of principle for this type of citizen science technology has been implemented in England (the 'Cicada Hunt' app, URL, URL), and was designed to detect their only native cicada (the New Forest Cicada, *Cicadetta montana*). The app was installed by c.5,000 people.

The way citizen science is implemented is also important for uptake and for the relevance of findings and engagement (UKEOF, 2012). Interviewed kaitiaki emphasised the importance of accessibility and strong feedback loops in citizen science efforts. This will allow communities to get involved easily and will allow those communities that contribute data to benefit from the scientific findings. This means effective communication of what the scientific findings are and how they affect the community ecosystems for which they are kaitiaki. For example, the Environmental Protection Agency has recently started work with Te Tini o Hākuturi, a group of kaitiaki, who are developing a monitoring programme for streams and catchments in their rohe, beginning with the Zealandia Ecosanctuary.

Citizen science allows the empowerment of a wider populace and specific communities to make observations on scales that cannot typically be achieved by institutional research (Theobald et al., 2015). This type of work would ideally leverage social media and the growing fondness for insects. This fondness in Aotearoa New Zealand is exemplified by the two insect social media groups (URL and URL), each of which has greater than 5000 members, and the public campaign that committed c.NZ$4000 for research of the 'At-Risk – Relic' Forest Ringlet Butterfly (*Dodonidia helmsii*). Interviewed kaitiaki recommended an insect/invertebrate public awareness campaign aimed to engage the hearts and minds of the public and to further foster public appreciation of insects in Aotearoa New Zealand. This goal is shared by the Entomological Society of New Zealand, which aims to stimulate interest, encourage amateurs, and promote the profession of entomology.

Table 1 *Potential drivers raised during expert interviews. These have been arranged into the classes of 'direct drivers' (land-use change, climate change, pollution, invasive species and other) that have been linked to global biodiversity trends (IPBES, 2019).*

LAND-USE CHANGE	CLIMATE CHANGE	POLLUTION	INVASIVE SPECIES	OTHERS
Agricultural and urban intensification	Changing envelopes	Pesticide use	Predation	Stochastic events
Homogenisation	Changing temperature regime	Non-pesticide chemical use	Competition	Parasitism
Fragmentation	Changing frequency of extreme events	Light pollution	Loss of food source	Wide-scale pest interventions
Hydrology changes			Habitat change	
Refuge destruction				
Soil compaction				

Exploring potential drivers

Interviewed experts raised various potential drivers that could contribute to pressures on insect populations (summarised in **Table 1**). These suggestions are consistent with the well-established literature on drivers which can degrade insect population health such as habitat change (Samways, 2005, Tscharntke et al., 2005, Potts et al., 2010), pesticide use (Goulson, 2013, Whitehorn et al., 2012, Henry et al., 2012), mammalian predators (Gibbs, 2009, St Clair, 2011, Watts et al., 2008, Watts et al., 2011) and climate change (Addo-Bediako et al., 2001, Terblanche et al., 2010). Typically, two or more interacting drivers, such as those presented in **Table 1**, would lead to pressures on populations. The mentioned drivers are generally consistent with global 'direct drivers' of biodiversity trends (land/sea use change, direct exploitation, climate change, pollution, invasive alien species and others) raised by the IPBES (2019) report on global biodiversity, and drivers identified when assessing threat classification of invertebrates (habitat loss or modification, and introduced predators) (Stringer and Hitchmough, 2012). By carrying out meta-analysis and field-based resample studies these drivers and their associated mechanisms can be explored; furthermore, through use of simulations, field areas of high endemicity could be identified for new sampling efforts (Milar et al., 2017). For example, a preliminary metadata analysis has indicated that temperature and climatic changes may be a driver for the migration of *Lepidoptera* community structures to higher altitudes (Watkin, 2014). In addition, unique opportunities arise for data collected on predator-free islands (Sinclair et al., 2005) or from within predator-free ecosanctuaries (Watts et al., 2014), as these datasets could approximate minimally altered habitat or 'baseline' metrics to investigate drivers for endemic insect fauna in those specific ecosystems. Furthermore, by investigating the state-and-trend of native species found in Aotearoa New Zealand, for which there is also reliable data in other countries, comparisons can be made internationally. By better understanding the trends and their drivers, remedial action can be implemented as needed.

Commonly cited drivers should be investigated

Land-use change was commonly identified as a potential driver during expert interviews, and this is one of the largest drivers of wider biodiversity trends globally (IPBES, 2019). Such changes can be evaluated from satellite imagery (Weeks et al., 2012, Cieraad et al., 2015) and these data are available from the late 1980s. For areas that have, or are currently undergoing land-use changes, insect community and species metrics could be collected, and correlations made between the state and trends of these metrics and the changes in land-use. There may be some unique opportunities where historical insect datasets and land-use changes detectable by satellite imagery overlap. In these cases, this type of analysis can identify land-use as a potential driver for changes in state or trend of insect community and species metrics over time.

Controversial potential drivers such as pesticide use (DiBartolomeis et al., 2019) would likely require focused research, and it should be noted that an interviewed expert expressed plans for work in this area starting in the short term. For example, the community metrics and correlations with pesticide use could be compared between closely located native bush, organic farms and conventional farms. An important caveat that was raised by interviewed experts is that few pesticide uses are indiscriminate. Furthermore, population health can be benefited by pesticide use, e.g., protection of beehives from mites (Kanga et al., 2010). For endemic insect fauna, there are examples of pesticide tools reversing and reducing harm for the fauna found on islands and in many other situations. These include bait station control of insect predators such as exotic pest wasps (Edwards et al., 2017) and rat species (Towns et al., 2012).

The fostering of Māori values and mātauranga Māori in research

Interviewees emphasized the importance of complementing biophysical measurements with Māori values and incorporating mātauranga Māori (knowledge). Partnering with communities enriches research and conservation as co-designed projects capitalise on the strengths of both approaches (Galla et al., 2016). Researchers in Aotearoa New Zealand are directed to engage with Māori communities to conserve indigenous knowledge and manage Taonga (treasured) species (Anon., 2011). This work is linked to implications of the WAI 262 Treaty of Waitangi claim to address acknowledgment of intellectual property (IP) of Māori communities and peoples, with regard to indigenous biodiversity and related knowledge. This is especially important for how genetic information is managed and for intellectual property ownership considerations. As the genetic knowledge of Aotearoa New Zealand's insects increases, so too should an awareness of how this resource can benefit local communities (Galla et al., 2016). It should be noted that interviewed kaitiaki indicated that there are opportunities to explore Māori values and mātauranga Māori of te/nga aitanga-a-pepeke (the insect world), and these opportunities should be explored alongside biophysical research.

Barriers to researching state and trend

Insect population trends are typically interdecadal. To explore the state and trend of insect populations, continuous and coherent research and monitoring is required on interdecadal timescales. Interviewed experts and the expert panel agree that work in this area is fragmented due to a lack of strategy and integration between institutions. This has been identified as a major barrier as it limits the efficiency of resource use, expertise and, in some cases, can lead to competition for funding. Furthermore, robust and consistent biodiversity monitoring generally has limited science 'stretch' and has long timeframes; these limit funding opportunities through conventional research funding streams. This is compounded by the challenges faced in measuring ecological community metrics for insects. Currently there are no, cost effective, sufficiently rapid and standardised tools and systems in place to allow widescale monitoring of insect ecological metrics, although genetic tools such as eDNA are considered by interviewed experts and in the literature as a good prospects for this work. These tools and systems would need to be robust enough to measure across the unique insect fauna and terrestrial landscapes found in Aotearoa New Zealand.

The interviewed experts and the expert panel also emphasised that taxonomy and taxonomic collections underpin the community and species metrics needed to understand state and trend of insect populations. The capacity and capability to identify species is proportional to the ability to progress understanding in this area. There are several challenges that taxonomy and taxonomic collections in Aotearoa New Zealand currently face and these and have been well documented in a recent Royal Society of New Zealand (RSNZ) report (Nelson et al., 2015). Some key findings were the erosion of resourcing and a fragmentation of taxonomic research. These are particularly relevant to the taxonomic collections in Aotearoa New Zealand. The recent Conservation and Environment Science Roadmap strongly emphasized the need for up-to-date taxonomic collections and taxonomic expertise (DOC, 2017). The required steps to work towards this are identified in the RSNZ report, and are laid out in the Decadal Plan for Taxonomy and Biosystematics in Australia and Aotearoa New Zealand (RSNZ, 2018). These recommendations are generally consistent with recommendations, specific to entomology, identified during this work and recommendations made in the literature (Lester et al., 2014). It should be noted that the new tools proposed in this work are complementary to, and enhance, classical taxonomic approaches.

Conclusions

This scoping work has determined that little is known of state or trend for terrestrial insect fauna in Aotearoa New Zealand. Not enough is known to undertake assessments like those done in Europe and the United States, although good examples of baseline data are available. We have identified knowledge deficiencies relating to the state and trend of insect populations, occupancy of insect species and the relative compositions of insect species assemblages, such as pollinators. The current structure of research and monitoring in this area lacks integration and likely appears inconsistent with the objectives of the recently released Biodiversity Strategy (DOC, 2020). Furthermore, the current understanding of insect community metrics is not well suited to guide policy making, as recommended in the Conservation and Environment Science Roadmap (DOC, 2017). This stands as a barrier to requests from experts to incorporate genetic and ecological data for better informing of policy and management for a better understanding of human impacts on insect population health (Saunders et al., 2020).

Around half of the estimated species in Aotearoa New Zealand have been documented (c.11,000 of c.20,000), and around 13% (c.1,400) of these have been assessed for their conservation threat status under the NZTCS. This indicates that significant work is needed to determine what species are present, their habitat needs and conservation status. Given that 54% of the total number of species currently assessed are considered as either 'threatened' or 'at risk', it is imperative to establish if this level of threat is representative of the wider insect fauna which have not yet been identified and then assessed.

There are good opportunities to fill the identified knowledge gaps by exploring state and trend of insect fauna and the drivers of trends (including the associated spatial contexts). There are also opportunities to explore Māori values and mātauranga Māori of te/nga aitanga-a-pepeke (the insect world). By better understanding the state and trends of the wider insect taxa in Aotearoa New Zealand, remedial action can be implemented if, where and when it is needed. Our results and the suggested ways forward for Aotearoa New Zealand are consistent with those recently discussed in the Australian context (Braby, 2019) and the roadmap set out by an international consortium of experts (Harvey et al., 2020).

Based on the above, the following steps are proposed to address knowledge gaps: 1. Undertake a strategic metadata analysis of existing data to capitalise and build on historic insect datasets and collections; 2. identify and utilise state-of-the-art technologies to enable cost-effective monitoring; 3. commit to inclusive survey and monitoring approaches including citizen science efforts; and 4. develop a research programme that is supported by key government agencies, Crown research institutes, museums and universities, and that is consistent with the goals of the NZ biodiversity strategy. But above all, this approach needs to be consistent with te ao Māori principles, be co-designed with Māori, and fulfil Treaty of Waitangi obligations.

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Appendices

Appendix 1

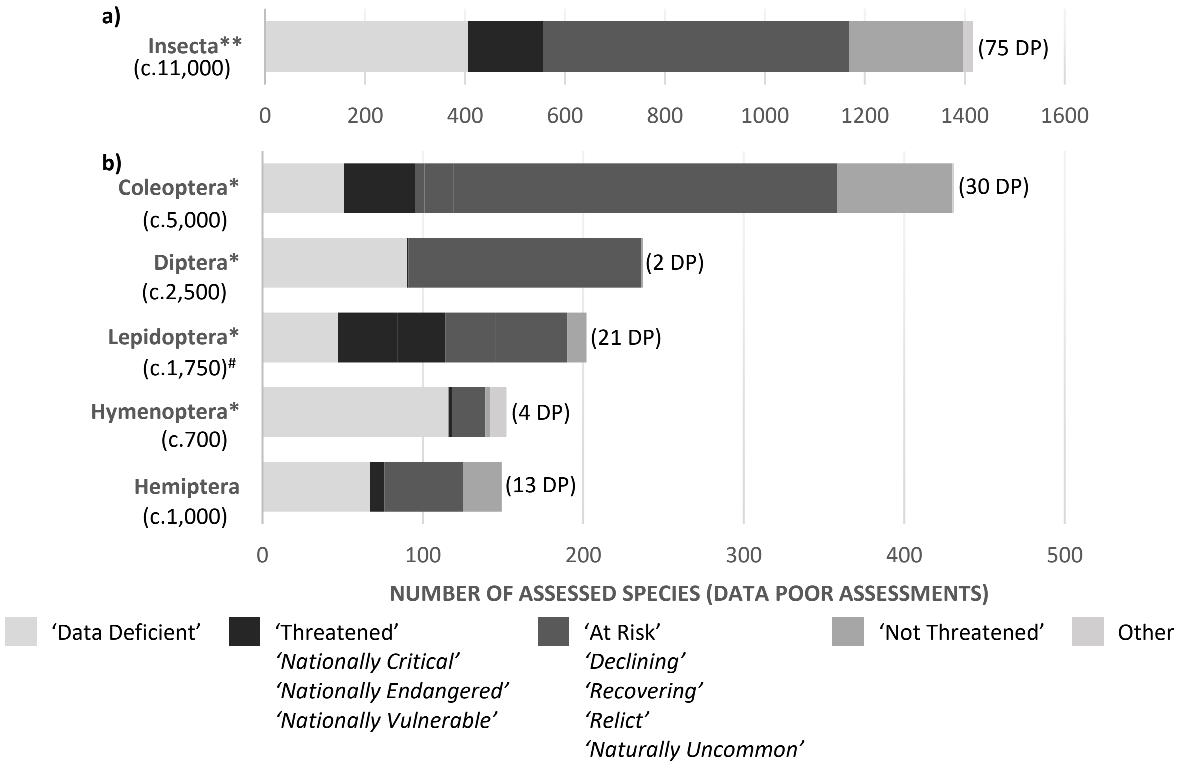

Figure A1 Threat assessments a) across terrestrial insect species and b) within the five largest orders. Total described species are shown in parenthesis under the taxa label and were taken from Macfarlane et al. (2010) except for Lepidoptera which was taken from Hoare et al. (2017).

Table A1i Threat classification rank for each classification report as used in **Figure 2**.

	2002		2005		2010	
Rank	**Category**	**Status**	**Category**	**Status**	**Category**	**Status**
8	Not Threatened	-	Not Threatened	-	Not Threatened	-
7	At Risk	Sparse	At Risk	Sparse	At Risk	Naturally Uncommon
6	At Risk	Range Restricted	At Risk	Range Restricted	At Risk	Relict
5					At Risk	Recovering
4	Chronically Threatened	Gradual or Serious Decline	Chronically Threatened	Gradual or Serious Decline	At Risk	Declining
3	Acutely Threatened or Chronically Threatened	Nationally Vulnerable or Serious Decline	Acutely Threatened or Chronically Threatened	Nationally Vulnerable or Serious Decline	Threatened	Nationally Vulnerable
2	Acutely Threatened	Nationally Endangered	Acutely Threatened	Nationally Endangered	Threatened	Nationally Endangered
1	Acutely Threatened	Nationally Critical	Acutely Threatened	Nationally Critical	Threatened	Nationally Critical
0	Extinct	-	Extinct	-	Extinct	-

Table A1ii Threat assessments for terrestrial insect species in the class Insecta and a break-down of the five largest orders within Insecta.

	Threat Assessments for Various Insect Taxa					
	Insecta	Coleoptera	Diptera	Lepidoptera	Hymenoptera	Hemiptera
'Data Deficient'	406	51	90	47	116	67
'Threatened'	**150**	**44**	**1**	**67**	**2**	**9**
'Nationally Critical'	83	34		25	2	9
'Nationally Endangered'	21	7		12		
'Nationally Vulnerable'	46	3	1	30		
'At Risk'	**613**	**263**	**145**	**76**	**21**	**49**
'Declining'	25	6	1	13	2	
'Recovering'	6					
'Relict'	43	18		18		1
'Naturally Uncommon'	539	239	144	45	19	48
'Not Threatened'	227	72	1	12	3	24
Other	20	1			10	
Total	**1416**	**431**	**237**	**202**	**152**	**149**

NZTCS analysis used a non-archived NZTCS version downloaded on the 21-06-2019. All results are filtered by 'Environment'='Terrestrial' and 'Report Name'='Aphids 2010 (Stringer et al, 2012)' or 'Coleoptera 2010 (Leschen et al, 2012)' or 'Diptera 2010 (Andrew et al, 2012)' or 'Hemiptera 2010 (Stringer et al, 2012)' or 'Hymenoptera 2014 (Ward et al, 2017)' or 'Lepidoptera 2015 (Hoare et al, 2017)' or 'Minor invertebrate groups 2010 (Buckley et al, 2012)' or Orthoptera 2014 (Trewick et al, 2016)' or 'Stick insects 2014 (Buckley et al, 2016)' statements. For the specific orders the appropriate 'Report Name' value was used except for Hemiptera where the 'Aphids 2010 (Stringer et al, 2012)' and 'Hemiptera 2010 (Stringer et al, 2012)' 'Report Names' are used. It should be noted that specifying for the terrestrial environment will exclude insect groups such as dragonflies (suborder:*Anisoptera*) and damselflies (suborder:Zygoptera), which are sometimes defined as terrestrial.

Table A1ii details data used to plot **Figure 1** and **Figure A1** in the report and focus on the categories: 'Threatened', 'At Risk, 'Not Threatened', and 'Data Deficient'. For the Insecta orders, the 'Status' values were not detailed with patterning for visual clarity. The Other category was used in the report for brevity (not including extinct species or exotic species, for example) and contains entries which satisfy 'Category' = 'Introduced and Naturalised' or 'Non-resident Native'.

About the NZTCS data:

Direct quotes from Statistics New Zealand (URL) are included here as they are effective descriptions of the NZTCS, the data it contains and the way it should be used.

"Conservation status is a representation of the threat classification of resident indigenous plant and animal species. The Department of Conservation (DOC) developed the New Zealand Threat Classification System (NZTCS) to provide a national system that is similar to the International Union for Conservation of Nature and Natural Resources Red List. Experts assign a threat of extinction status through a DOC-led process, based on criteria of abundance, distribution, and change in population over time. The criteria are used to monitor the status of individual species and report on the state of indigenous biodiversity (Townsend et al, 2008). In the context of this indicator, we use the word 'species' to describe the collective grouping of species, subspecies, varieties, and forms.

To date, the conservation status of fewer than 10,000 indigenous terrestrial species in New Zealand has been assessed, and these species are a small fraction of the total thought to exist. Of the species assessed, nearly 30 percent cannot be assigned a conservation status because we lack sufficient information about them (classified as data deficient), and confidence in the quality of data is low for the assessments of many other species. Numerous species in the invertebrates group have not been assessed. Furthermore, most of the groups of organisms that have not yet been assessed are poorly understood. … . For the other species we do not and should not make assumptions about overall conservation status without further research."

"The subcategories within the 'threatened' conservation status category are:

- nationally critical: most severely threatened, facing an immediate high risk of extinction
- nationally endangered: facing high risk of extinction in the short term
- nationally vulnerable: facing a risk of extinction in the medium term.

The subcategories within the 'at risk' conservation status category are:

- declining: population declining but still abundant
- recovering: small population but increasing after previously declining
- relict: small population stabilised after declining
- naturally uncommon: naturally small population and therefore susceptible to harmful influences.

Species are classified as 'data deficient' if we lack information on the species, making threat classification assessment not possible."

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R.J.B. Hoare, J.S. Dugdale, E.D. Edwards, G.W. Gibbs, B.H. Patrick, R.A. Hitchmough and J.R .Rolfe (2017). Conservation status of New Zealand butterflies and moths (Lepidoptera). New Zealand Threat Classification Series 20. www.doc.govt.nz.

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Appendix 2

Table A2 Annual change of selected apiculture (honeybee keeping) key parameters from 2014 to 2019. Export volumes and prices are for pure honey and are 'at free on board'. Data taken from Apiculture 2019 report by MPI.

		2014	**Δ%**	**2015**	**Δ%**	**2016**	**Δ%**	**2017**	**Δ%**	**2018**	**Δ%**	**2019**	**Δ%**
Num. hives		507247	12%	575872	14%	684046	19%	795578	16%	881185	11%	918026	4%
Yield per hive	kg/hive	34.7	-12%	34.2	-1%	29.1	-15%	18.7	-36%	22.7	21%	25.1	11%
Export volume	Tonnes	8702	8%	9046	4%	8831	-2%	8450	-4%	8692	3%	8065	-7%
Export value	NZ$ Mil.	187	29%	233	25%	315	35%	329	4%	348	6%	355	2%
Export price	NZ$/kg	21.5	19%	25.8	20%	35.6	38%	38.9	9%	40.0	3%	44.0	10%

Appendix 3

Some example datasets for resampling have been included in **Table A3**. These were collected Barbara Barrett and Stephen Goldson to survey available datasets. To facilitate the collating of datasets, a freely accessible form and database was made by the lead author of this report. This resource is called the New Zealand Insect Data Inventory (NZIDI, URL) and provides a central inventory which insect datasets can be listed to raise awareness in a clear and transparent way. Once the inventory is populated this will facilitate the prioritisation of resampling and metadata analysis of the best available datasets. This inventory also has the potential to record current and ongoing research which is often not well publicised. The recommended datasets can be explored using metadata and resampling efforts discussed in the sections 'the 'meta-analysis' method for trend assessment' and 'the 'resample' method for trend assessment'.

Table A3 Some example datasets collated by Barbara Barrett and Stephen Goldson that could be useful for metadata analysis and/or resampling efforts. Please note these entries included here are to serve as examples only and are not representative of the 'best' datasets available in Aotearoa New Zealand. A full inventory of datasets is needed and should be followed by a prioritisation of research questions to guide which datasets are best suited for answering these questions. This process was the direct recommendation from the expert focus group in Lincoln.

Collector	Location and habitat	Dates	Frequency of collections	Collection method	Taxa included	Specimen Avail.	Data Avail.	Ref
David Teulon	Various	1981-2018	Various	Suction trap	aphids, thrips, other	yes	yes	Some data: Teulon, D. A. J., Stufkens, M. A. W., & Fletcher, J. D., 2004, New Zealand Plant Protection, 57, 227-232.
Barbara Barratt et al.	Mt Benger and Deep Stream, Otago tussock grassland	1998-2013	quantitative annual sample in Jan	Turf samples heat extracted	all	yes	yes	Barratt, B. I. P., Ferguson, C. M., Barton, D., Johnstone, P. D., 2009, Science for Conservation 291, Mosgiel. 75Pp.
"NZAC Litter Samples"	NZ wide	mostly 1960-1980	often 1 visit per location	various	all	various		unpublished. >2000 individual litter leaf samples
Brian Patrick	NZ wide	1977-present	many datasets including year-long collections from many sites	light trapping, hand collection	mainly Lepidoptera	species	yes	Watkin D, 2014, BSc (Hons) Thesis, Lincoln University

Appendix 4

For expert interviews the following context and questions were presented, and feedback was uses to guide the themes explored in the main text.

Context: "We would like to understand what the key issues of 'terrestrial insect biodiversity' are in the New Zealand setting, and what is the available evidence to understand this."

Questions:

1. In your expert opinion, what are the key issues for understanding insect biodiversity in New Zealand?
    a. Given the key issues, how can these issues be explored and addressed?
2. How can these issues be effectively managed by various key players – i.e the government departments, CRIs, universities, companies, the public?
3. What about Māori key players – how do we form partnerships so that the viewpoints and voices of Māori are clearly appreciated and defined?
4. There has been discussion of terrestrial endemic 'bioindicators' to make wider inferences (given data deficiency). Do you think bioindicators are useful, and what might you want to indicate?
5. If so, do you think some species, genera, families or orders are especially useful to as bioindicators for this?
6. There has been discussion of 'beneficial' roles or ecosystem services that they provide, and there are many examples of exotics. How would you evaluate 'benefit' that an exotic insect provides?

For the expert group a general context was presented (as above), and a discussion based of the following questions was opened.

<u>Questions:</u>

1. In your expert opinion, what are the key issues for understanding insect biodiversity in New Zealand?
    a. Given the key issues, how can these issues be explored and addressed?
    b. Can the 'bioindicator' approach be used to make wider-scale inferences and if, so what groups would make 'good' bioindicators?

Appendix 5

The expert interviews were conducted with the following people, and their areas of expertise are included as listed on institutional websites.

Name	Expertise	Location
Interviewees		
Eric Edwards	Ecologist, invertebrates	Wellington
Jeremy Rolfe	Botanist, NZTCS lead	Wellington
Stephen Goldson (reviewer)	Entomologist, biological control	Lincoln
Stephen Wratten	Entomologist, biological control	Lincoln
Danielle Shanahan	Conservation biologist	Wellington
Thomas Buckley	Geneticist, systematics	Auckland
Brian Patrick	Entomologist, Lepidoptera	Christchurch
Darren Ward	Entomologist, ecologist, Hymenoptera	Auckland
Richard Leschen	Entomologist, Coleoptera	Auckland
Steven Pawson	Entomologist, Coleoptera	Lincoln
John Early	Entomologist, biological control	Auckland
George Gill	Ecologist, insect-plant interactions	Wellington
John Marris	Entomologist, Coleoptera	Christchurch
David Pattemore	Entomologist, Hymenoptera	Hamilton
Jason Tylianakis	Ecologist, Hymenoptera	Christchurch
Robert Hoare	Entomologist, Lepidoptera	Auckland
Rachelle Binny	Ecological modeller	Lincoln
Warren Chinn	Ecologist, invertebrates	Christchurch
Cor Vink	Taxonomist, invertebrates	Christchurch
Johnathon Ridden	Ecologist, invertebrates	Christchurch
Panel members		
Steven Pawson	Ecologist, Coleoptera	Lincoln
Barbara Barratt (reviewer)	Ecologist, Curculionidae, biological control	Dunedin
Tara Murray (reviewer)	Entomologist	Christchurch
Ronny Groenteman	Ecologist, biological control	Lincoln
Robert Brown	Entomologist, Hymenoptera	Lincoln
David Teulon	Ecologist, aphids and thrips	Lincoln
Brad Howlet	Entomologist, pollination	Lincoln
Stephen Goldson	Entomologist, biological control	Lincoln
Stephen Wratten	Entomologist, biological control	Lincoln
Mike Bowie	Entomologist, ecologist	Lincoln
Jon Sullivan	Ecologist, plant-insect interactions	Lincoln