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**Databasing 44 years of New Zealand Lepidoptera observations to
assess large-scale changes in moth and butterfly diversity**

A Dissertation
submitted in partial fulfilment
of the requirements for the Degree of
Bachelor of Science (Honours)

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Lincoln University

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Abstract of a Dissertation submitted in partial fulfilment of the requirements for the Degree of Bachelor of Science (Honours).

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by

Davena Watkin

The order Lepidoptera is an ecologically important insect group which undertake a range of ecosystem services, including herbivory, decomposition, and most notably pollination. Numerous studies on Lepidoptera abundance and diversity in the Northern Hemisphere have revealed large, sustained declines in population numbers and alterations to range size over an alarmingly high proportion of species for several decades. The overwhelming trend is one of ongoing net loss of biodiversity at a global scale. Land-use changes resulting in a lack of nectar sources, a loss of critical host plants, and the interaction of these impacts with the increasing pressures wrought by climate change on already vulnerable taxa are thought to be the main drivers behind the temporal patterns of decline being seen.

New Zealand's Lepidoptera fauna is globally significant for its unique assemblage of endemic moths and butterflies. Despite this, population trends of New Zealand's moths and butterflies are so far largely undocumented, as the long-term monitoring regimes responsible for recording declines in other countries is lacking in New Zealand. To begin to fill this gap in knowledge, databasing methods are being undertaken on 44 years' worth of expert Lepidopterist Brian Patrick's personal records, in order to achieve a workable dataset conducive to statistical analysis and ongoing use. Preliminary results of observations spanning 10 years indicate declines in Lepidoptera at lower elevation sites and in agricultural areas. This has significant implications for the future of conservation for our native pollinator species. Refinement of the database is needed, and ongoing exploration of the dataset with the addition of earlier observations will be valuable for strengthening trends. It is hoped that these results will inform the conservation of a key order of New Zealand's biota and serve as a case study for the value of curiosity driven, unfunded data-collection in achieving much-needed long-term datasets.

Keywords: biodiversity loss, conservation, lowland species, long-term monitoring.

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Chapter 1

Introduction

1.1 The significance of New Zealand Lepidoptera

1.1.1 Ecological importance

Adult moths and butterflies are nectar feeders whose primary importance in worldwide ecosystems is their role in pollinating flowering plants. Studies on pollination systems in New Zealand primarily focus on the role of native birds and lizards, and there is a lack of knowledge about specific Lepidoptera-plant interactions (Gillespie, 2010; Newstrom & Robertson, 2005). Plant mutualisms with Lepidoptera based on scent are possible; for example, flowers of the native tree *Dysoxylum spectabile* release a sweet scent at night and provide small amounts of nectar that appear suitable for moths. Adult moths from the Micropterigidae family are able to feed on fern spores and pollen due to specialised mouthparts and this may accidentally pollinate plants (Newstrom & Robertson, 2005). In general, a significant portion of the New Zealand flora show characteristics of entomophily, growing flowers that are conducive to 'unspecialised, imprecise' pollination by insects (Newstrom & Robertson, 2005). Studies on the foraging habits of native moths and butterflies suggest that most species are capable of pollinating a wide variety of both exotic and native plants, and have no preferences other than high availability at any one site (Gillespie, 2010). Native plants that benefit from the visits of New Zealand's moths and butterflies include species of *Muehlenbeckia*, *Hebe* (Gillespie, 2010), *Pittosporum* and *Dracophyllum* (Newstrom & Robertson, 2005).

The contribution of moths and butterflies to the food chains of the habitats they occupy is also an important component of their role in ecosystems. Moths in particular make up a substantial portion of the diet of flying predators such as bats (Black, 1972) and birds. The passerine bird species of Europe rely on the availability of Geometrid larvae for survival and reproduction at many times of the year (Thomas et al., 2007). Recent declines of some bird species in Britain is thought to be partially due to the loss of available moth larval food sources for British birds (Groenendijk & Ellis, 2011). In New Zealand, known native predators of moths include species of forest skinks and geckos (Department of Conservation, 1999) and the lesser short-tailed bat (Department of Conservation, 2005; McCartney, Stringer & Potter, 2007), all of which are organisms of high conservation concern.

Larvae also contribute to the list of ecosystem services Lepidoptera provide. New Zealand has a high number of detritivorous larvae and many of these help to break down leaf litter and recycle nutrients

(Hodgson et al., 2014). Classical biological control provides numerous examples of the effectiveness of Lepidoptera herbivory for suppressing weed populations. The larvae of the Hawkmoth, *Agrius convolvuli*, feed on Convolvulaceae (Newstrom & Robertson, 2005), which can be a difficult weed in many gardens. However, climate warming is predicted to shift the impacts that insect herbivory has on vegetation (Groenendijk & Ellis, 2011), and land use change can result in homogenisation of Lepidoptera communities due to a lack of larval host plants (Ekroos et al., 2010), all of which threaten biodiversity nationally and globally.

1.1.2 Biodiversity value

Aside from the ecological importance of Lepidoptera for New Zealand in general, the unique assemblage of Lepidoptera in New Zealand is globally significant (Patrick, 2004). New Zealand is host to the highest proportion of endemic moths and butterflies in the world (Dugdale, 1988) and many of these species also show high regional endemism (Patrick, 1994). Further, the New Zealand assemblage of Lepidoptera is remarkably butterfly depauperate, with only 20 native species of butterfly compared to over 1800 native moths; a characteristic that sparked interest in biogeographical research (Dugdale, 1988). However, these few native butterfly species are highly diverse; the extreme example, the New Zealand copper butterflies from the genus *Lycaena*, contains a diversity that is unparalleled anywhere else (Patrick & Patrick, 2012). In keeping with the characteristics of other New Zealand native animals, the number of Lepidoptera species with flightless females is higher than most countries, though not particularly pronounced (Stringer et al., 2012). Finally, New Zealand's natural moth assemblage contains an unusually high proportion of brightly coloured, day-flying species (Dugdale, 1988).

1.2 Overseas trends

Evidence for unprecedented rates of decline in the world's pollinator invertebrates is increasingly being brought to light by overseas studies on invertebrate groups. Countries recording declines include Spain (Stefanescu, Torre, Jubany & Páramo, 2011), Finland (Ekroos, Heliölä & Kuussaari, 2010; Hunter et al., 2014; Kozlov et al., 2010), the Netherlands (Groenendijk & Ellis, 2011), Great Britain (Conrad, Warren, Fox, Parsons & Woiwood, 2006; Dennis & Sparks, 2007; Fox et al., 2014; Wilson & Maclean, 2011) Japan (Nakamura, 2011; Sibatani, 1992) and Australia (Williams, 2011). Studies reveal impacts on butterflies and moths alike.

Lepidoptera appear to be undergoing the fastest rates of decline in Britain, with half of Britain's butterfly species threatened or extinct (Warren & Bourn, 2011), and a rate of loss from original habitat of 13% per 10 km² (Dover, Warren & Shreeve, 2011). Declines of species have been across-

the-board: rare species are becoming rarer, but even common and once widespread species are diminishing in number (Conrad, Woiwod, Parsons, Fox & Warren, 2004). The common blue butterfly *Polyommatus icarus* declined in Wales by 75% over the last 100 years (Léon-Cortés, Cowley & Thomas, 1999) while one of the most widespread butterflies in Britain, the common copper *Lycaena phlaeas*, is estimated to have undergone at least a 46% decline in abundance over the same time period (Léon-Cortés, Cowley & Thomas, 2000). Five years after a sudden decrease in abundance, *Artica caja*, a common garden moth in Britain, could only be found in 70% of the sites it once occupied (Conrad et al., 2002).

The magnitude of change being documented in British Lepidoptera is corroborated by studies of moths in the Netherlands, and grassland butterflies in Japan, with declines of 37% since the 1980s and 80% in 40 years respectively (Groenendijk & Ellis, 2007; Nakamura, 2011). There are some exceptions: for example, Salama et al. (2007) recorded an increase in the abundance of four common moths in agricultural pasture in Scotland over a 35 year period, while a study of 80 subantarctic moth species in Finland found that only 6 species were declining in number (Hunter et al., 2014). Nevertheless, the dominant trend is one of wide-spread loss, initiating concern that the globe is undergoing an insect biodiversity 'crisis' (Conrad et al., 2006).

1.3 Causes of decline

Ongoing declines in global Lepidoptera are understood to be the result of multiple drivers of environmental change. Habitat loss, degradation and fragmentation, agricultural and woodland management, chemical pollution, urbanisation, light pollution and climate change all have the potential to alter moth populations (reviewed by Fox, 2013); most of these also apply to butterflies. These environmental drivers can be divided into two categories: land use change and climate change. As both types of change are either directly or indirectly anthropogenic in origin, ongoing biodiversity loss is ultimately due to human activity.

1.3.1 Land use change

Agriculture

Intensification of agriculture is largely recognised as the main driver of biodiversity declines worldwide (Ekroos et al., 2010). In the conversion of natural habitat to managed pasture, direct loss of habitat, and fragmentation of remaining habitats (Öckinger, Dannestam & Smith, 2009), has a detrimental effect on species that require certain plants to complete their lifecycle. Grassland moth species, for example, are naturally more abundant in agricultural margins than woodland species

(Field et al., 2005, 2007). However, habitat quality is an often forgotten consideration of Lepidoptera health over habitat quantity (Field et al., 2006; Williams, 2011). For habitats to support an abundance of Lepidoptera, a minimum viable area for population persistence is needed (Williams, 2011), while for habitats to support a diversity of Lepidoptera, host plant requirements for larvae and sufficient nectar sources for adults are also required (Pywell et al., 2011). A lack of quality remnant habitats after agricultural expansion may be perpetuating patterns of decline.

In Finland, butterfly biodiversity loss is linked to processes of homogenisation which stem from the landscape structure of intense agricultural pastures (Ekroos et al., 2010). Because agricultural management relies heavily on mono-cultures, only some butterfly species are capable of exploiting the remaining habitat. Further, decline of the common blue butterfly *Polyommatus icarus* in Wales was linked to the decline of its host plant, *Lotus corniculatus* (Leon-Cortes et al., 1999), while host plant density was found to be an important predictor of site occupancy and abundance in Australian butterflies and day-flying moths (Williams, 2011). Thus, a loss of critical host species from agricultural sites reduces Lepidoptera populations, with specialist species often more adversely affected due to greater host plant constraints.

Agricultural practices are also a potential cause of decline in Lepidoptera. Use of agro-chemicals has been implicated in colony collapse disorder of bee pollinators but the effects of chemicals on butterfly and moth pollinators are unknown (Fox, 2013). However, eutrophication resulting from fertiliser use may act as an environmental filter in remnant habitats by promoting fast growing, high-nitrogen plant species. In England, high butterfly diversity was associated with slow-growing, nutrient poor plants (Hodgson et al., 2014). Soil nitrogen may therefore ultimately shape the composition of Lepidopteran diversity in areas around agricultural land.

Urbanisation

The increase of urbanisation in the western world may also be responsible for the ongoing decline in Lepidoptera abundance and diversity. The abundance of Lepidoptera species generally declines greatly in urban areas (Blair & Launer, 1997) and urban areas are often depauperate, fragmented or lacking critical host plants and habitat for native moths and butterflies. Further, nocturnal moth assemblages may be altered by light pollution (Fox, 2013) which increases with increasing urbanisation. A higher diversity of moths can be found at lights emitting shorter wavelengths and moths that are attracted to lights may experience greater predation (van Langevelde, Ettema, Donners, WallisDeVries & Groenendijk, 2011) so artificial lighting may also shape the composition of moth diversity in areas around human settlement.

1.3.2 Climate change

Climate change is increasingly being factored into studies on changes to Lepidoptera distributions (Wilson & Maclean, 2011) and many studies favour the interaction of climate effects with the effects of land use as an explanation for declining Lepidoptera biodiversity (e.g. Warren et al., 2001). Insects depend on temperature for the timing of larvae development and all species function within a temperature tolerance range. Climate warming may be increasing competition or predation due to the range expansion of other species, or disrupting the synchronisation of moth and butterfly phenology with host plants (Stefanescu, Penuelas & Filella, 2003), heightening larvae mortality and altering population dynamics. Further, extreme weather events may also increase mortality rates of adult moths and butterflies. Warm, dry summers tend to coincide with greater abundance of most butterfly species (Conrad et al., 2002; Pollard, Moss & Yates, 1995), while moths that overwinter in the egg stage tend to show greater average declines than those that overwinter as adults (Conrad et al., 2004; Groenendijk & Ellis, 2011). Periods of unseasonably heavy rainfall also correspond to decreases in the abundance of common moth species such as *A. ajax* (Conrad et al., 2002). Under current climate predictions, Lepidoptera species decline is expected to continue.

1.4 Assessing the state of New Zealand Lepidoptera

Are the wider temporal trends of New Zealand Lepidoptera also one of decline? The scale at which changes in Lepidoptera abundance and distributions have been documented in populated, temperate countries around the world gives good reason to suppose that similar declines may be occurring in New Zealand (Gillespie, 2010). Since European colonisation, the New Zealand landscape has been drastically altered; lowland areas in the South Island are particularly modified. Ninety percent of indigenous cover has been lost below 400 m on the eastern South Island since European settlement and up to 75% of the Canterbury region, for example, consists of exotic forest, agricultural land or urban areas (Environment Canterbury, 2008). Further, there is evidence that the New Zealand climate is also shifting in response to rising global temperatures. Average national temperatures have increased by approximately 0.9°C since 1990 and significant impacts are expected in as little as 6 years' time (New Zealand Climate Change Centre, 2014). Native ecosystems have been identified as one of New Zealand's most vulnerable sectors with alpine areas particularly at risk, increasing the probability of species extinction (New Zealand Climate Change Centre, 2007). While in Europe, declines of certain butterfly species in some countries have been offset by increases in other parts of Europe (Groenendijk & Ellis, 2011), this is unlikely to be the case for endemic invertebrate pollinators of an isolated island country such as New Zealand.

1.4.1 Conservation status

The large majority of New Zealand endemic Lepidoptera are threatened based on an evaluation of species life history traits, spatial extent and habitat preference (McGuinness, 2001). One hundred and fourteen species are documented as 'at risk' of extinction (Patrick, 2004), and over half of all threatened taxa are confined to the eastern South Island of New Zealand (Stringer et al., 2012). The majority of concern lies with species from the taxonomically larger macro-moth families, such as the nationally vulnerable *Kupea electilis*, the nationally endangered *Maoricrambus oncobolus* and the nationally critical *Orocrambus fugitivellus* (Landcare Research, 2014). Threatened taxa also span a variety of habitats, with 16 threatened species known from shrublands, 13 species from dynamic coastal margins and 13 from a range of non-forest habitats (Stringer et al., 2012).

The number of threatened Lepidoptera species have increased in recent years (Patrick, 2004). However, changes to conservation status do not give an accurate indication of temporal trends for certain species (Lewis & Senior, 2011), as most changes to conservation status are due to an increase in understanding of the conservation requirements of a species over the intervening period between conservation assessments (McGuinness, 2001); many species are still data deficient or imperfectly understood (Stringer et al., 2012). Anecdotal evidence of temporal declines in Lepidoptera numbers have been obtained (B. Patrick, personal communication, 2014) and there are grounds to believe that declines or even extinctions may have occurred in isolated cases; such as the once-common geometrid *Asaphodes obarata*, which has only been collected twice in the last 50 years (Stringer et al., 2012). However, as of yet, there has been no exploration of the wider temporal trend of New Zealand's moths and butterflies.

1.5 Long-term monitoring

1.5.1 The importance of temporal datasets

Such considerations build a strong case for the need to explore the abundance and diversity of moths and butterflies in New Zealand over a temporal scale matching those of overseas studies.

Determining if New Zealand Lepidoptera are undergoing similar changes in species abundance and richness as those of other countries is an important first step for both the conservation of New Zealand biodiversity and for achieving environmentally sustainable management of New Zealand's lowlands. Studies on the Lepidoptera order of New Zealand itself is not especially lacking, but the focus has mostly been on identifying species (Patrick, 1990; Patrick, 1994) and documenting their distributions (e.g. Dugdale, 1989; Emerson et al., 1997; Lyford, 1994). While both are important

precursors to understanding change, monitoring over a substantial number of years is also needed. Temporal studies are able to resolve year-to-year variability in insect populations (Groenendijk & Ellis, 2011; Kozlov et al., 2010), and ecological time lags and climatic effects from the last few years means that in some cases, changes are only recently becoming apparent (Bedford, Whittaker & Kerr, 2012).

1.5.2 Current initiatives

Great Britain has had long-term monitoring projects in place for Lepidoptera since the 1970s. The Rothamstead Light Trapping Scheme is in practice across the UK and gathers data on the species richness of nocturnal moth species (Salama et al., 2007). These studies contribute to records in the National Moth database (Fox et al., 2014). The Butterfly Monitoring Scheme is a similar initiative responsible for tracking the other Lepidoptera types. In the Netherlands, the Dutch Butterfly Conservation and the Working Group Lepidoptera Faunistics has assembled 'Noctua', a database containing Lepidoptera observations since the 1800s (Groenendijk & Ellis, 2011). Of note is the contribution made by enthusiasts and amateurs to the compilation of wide-spread, long-term data (Groenendijk & Ellis, 2011). Citizens taking part in 'MothCount', a project under the UK's National Moth Recording Scheme, have recorded over eight million observations (Fox et al., 2011). Moreover, initiatives such as the Countryside Stewardship Scheme (CSS) (Field, Gardiner, Mason & Hill, 2006) and the Agri-environment Scheme (AES) regularly review gathered data on butterfly species richness in managed areas in response to already perceived declines in moth and butterfly abundance (Dover et al., 2011; Field, Gardiner, Mason & Hill, 2005, 2007).

Despite the unique scientific and conservation value of the Lepidoptera in New Zealand, long-term monitoring of this magnitude in New Zealand is sorely lacking (Gillespie, 2010). It has only been comparatively recently, with the development of NatureWatchNZ in 2012, and its NZ Bio-Recording precursor in 2005, that wide-spread records have been publicly available and open to ongoing citizen contribution (<http://naturewatch.org.nz/>). Most of the extensive studies on Lepidoptera in New Zealand are restricted to the work of a select few experts, notably John Dugdale (e.g. Dugdale, 1988, 1989), Graeme White (e.g. White, 2004) and Brian Patrick (e.g. Patrick, 2004). In particular, Graeme White's work on New Zealand Lepidoptera culminated in the creation of the Tussock Grassland Moth database in 2004. Spanning from 1961 to 2000, the database is an amalgamation of light trapping records from 43 sites around Canterbury. To date, this is the most comprehensive database on New Zealand Lepidoptera. Being internet-based makes it widely available for other researchers (White, 2004). Nevertheless, spatially this data covers only a tiny portion of New Zealand and it still leaves butterflies and other New Zealand moth taxa unexplored.

1.5.3 Brian Patrick's Lepidoptera records

Brian Patrick, one of New Zealand's leading Lepidopterists, has collected data on Lepidoptera species numbers from over 3,500 trips to various locations around New Zealand over the last 44 years, keeping record of his observations through a combination of field notebooks and, more recently, typed documents. As one of the few individuals in New Zealand undertaking observations in this field, and as the only dataset of its kind that comes close to the spatial, temporal and taxonomic scales of overseas studies, these notebooks are a valuable repository of Lepidoptera knowledge. The exploration of such a dataset presents a unique opportunity to contribute to the science of New Zealand's moths and butterflies. Until now, no analysis has been attempted with Brian's dataset. This is mostly due to its public unavailability and the practicality of extracting data from handwritten notes.

Chapter 2

Aims & Objectives

2.1 Aims

Building a modern database containing all of Brian Patrick's Lepidoptera promises to provide much-needed insight into the state of New Zealand's moth and butterfly fauna. The necessity of getting this data to the point where it is available for statistical analysis is urgent. The data required extensive reworking into an electronic format and statistical exploration to extract meaningful information.

The foremost aim of this project was to extract the Lepidoptera data contained in 44 years' worth of field observations and collate it in a format that is accessible to statistical analysis and conducive to the on-going addition of Lepidoptera observations. The long-term vision of such a database is aimed at determining if Lepidoptera are undergoing patterns of decline in the South Island and represents an endeavour to add to the global literature on Lepidopteran biodiversity trajectories.

2.2 Objectives

The short and long-term objectives were as follows:

- Build a database with sufficient structural complexity to contain all of Brian's data in a platform amenable to analysis.
- Copy and digitise Brian Patrick's observations and field notebooks into the database
- Begin analysis of this data to test for declines and assess whether they are most pronounced in modified lowland landscapes.

With continuous additions to the database, this project is and will continue to be a work in progress. What follows is a documentation of the processes leading towards the realisation of these aims and objectives, a preliminary analysis of the data with what has been achieved thus far, and an appraisal of the future of Lepidoptera studies in New Zealand.

Chapter 3

Materials & Methods

3.1 Brian's Collection Methods

3.1.1 Day trips

Lepidoptera observations were primarily made during the day. These observations were the result of both deliberate collecting excursions and chance observations during daily life. For any deliberate excursion, sweep-netting was used to obtain Lepidoptera counts. Searching vegetation and rocks by hand were also used to obtain counts of moth pupae and larvae, and other invertebrates seen during trips were also documented when appropriate. Site variables such as weather and duration of searching were usually recorded and co-ordinates were provided for some of the digitised later sites.

3.1.2 Light Trapping

Light trapping was carried out at night using 8W, 12V self-ballasted mercury vapour lamps (B. Patrick, personal communication, April 2014), though incidental observations of moths were made in rare cases by means other than light trapping, such as by car headlights.

3.2 Format of original data

Lepidoptera observations of trips from November 1977 to September 2004 were held in six notebooks containing handwritten field entries. All pages of these books were photographed and saved in portable document format (PDF) for ongoing consultation during the data-basing process (Figure 3.1). Photographing Brian's field notebooks also provides a valuable backup of an important and otherwise irreplaceable historical record.

Trips from 2004 to 2012 were held in Microsoft Office Word® documents (Figure 3.2). These were converted by hand into digital spreadsheets by Morgan Jones, an external collaborator.

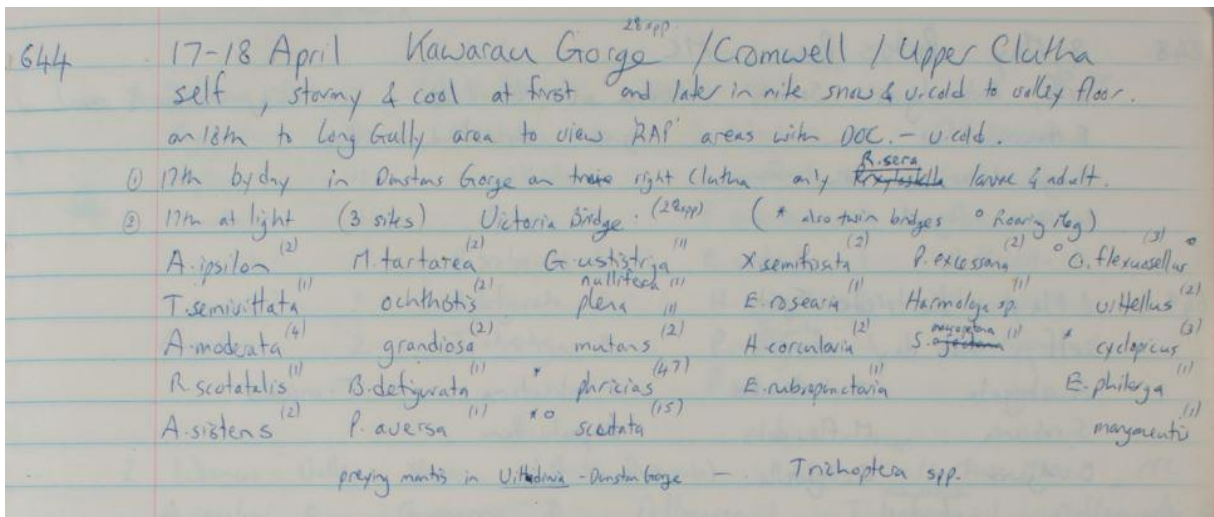


Figure 3.1 A trip entry from 1990 taken from a page of Brian Patrick's field notebooks

8 April 2006 Merton Arm, Waikouaiti Estuary, Karitane DN
 with Haruna - sunny to 20 degrees
Vanessa itea Liothula omnivora cases Helastia corcularia Orocrambus vulgaris Merophyas paraloxa
Pieris rapae Asaphodes abrogata cyclopicus Cydia succedana
Zizina oxlevi Scopula rubraria aegrota Eudonia leptalea
 Tiger beetle spp. blue damselfly

Figure 3.2 A trip entry from 2004 taken from Brian Patrick's field documents.

3.3 Database Building

3.3.1 File Maker Pro Advanced

The File Maker platform, developed by FileMaker Inc., is an information managing solution which is used for streamlining, analysing and sharing a wide range of management functions (FileMaker Inc., 2014). The database building software File Maker Pro Advanced 13.0v3 Windows version 6.1 was used to hold and structure the Brian Patrick Lepidoptera Database. The following contains a brief overview of the Brian Patrick Lepidoptera Database and rationale of the information and structure contained therein.

3.3.2 Data Entry

All parts of Brian's original data were preserved in separate layers and all records in all tables were assigned a unique ID so that no data was duplicated and all original elements of the data were preserved (see Figure 3.3). Spreadsheet data manually created from Brian's Word documents from 2004-2014 were imported directly into the database, while trip details from notebooks were entered

into the database manually. Handwritten data entry and manual fixes to the database information is still ongoing. Digital data also continues to be received from Brian.

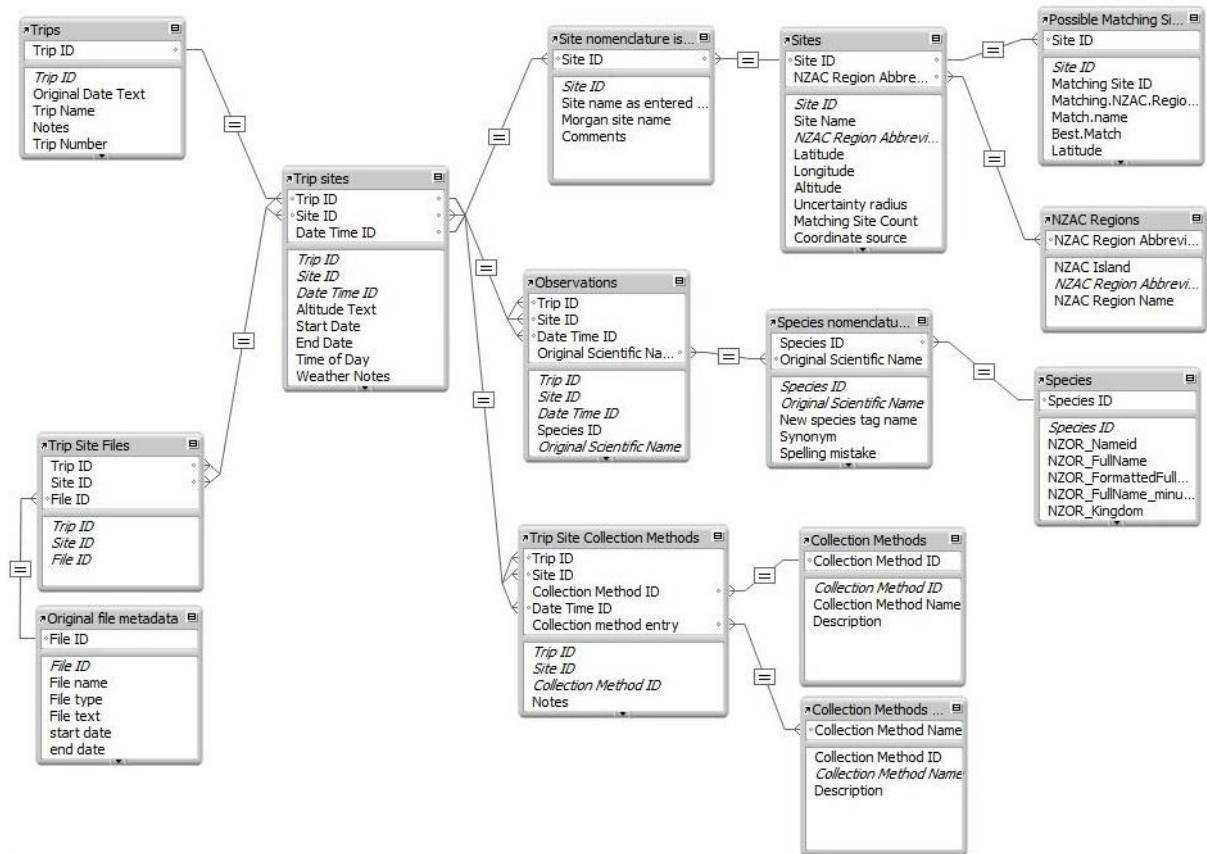


Figure 3.3 Relationships from Brian Patrick's Lepidoptera Database. Note that some tables and fields are temporary inserts necessary for data processing.

Trips and trip sites

Trips were Brian's original reference by which observations were ordered. Linked to trips at one conceptual end of the database was the original source file of Brian's observations for that trip (a PDF scan of a notebook or an original Word document) and a record of the pages on which each trip could be found. On the other side of trips were trip sites, an intermediate table which allows the linking of multiple sites with multiple trips. Variables such as time of day, weather notes and start and end dates were all important contributions to an assessment of which species might be encountered. These were recorded in trip sites, since these were not a fixed feature of each site, but could vary at each site for any one trip. Similarly, multiple collection methods could be used at any one site on any one trip, so these were also allocated to a separate table accessible through an intermediate ID.

Sites

Sites were used as the primary spatial reference by which observations were ordered. Sites were assumed to be the same location each year unless stated otherwise and a 10 km error in site location was assumed unless additional notes, such as elevations, or more precise descriptions written by Brian, indicated otherwise. This was a reasonable assumption for the most part, as Brian does try to visit the same sites when in the area where possible (B. Patrick, pers. comm. 2014). With few exceptions, Brian described each site he visited by name, including a formal site name from a standard New Zealand map. As most trip names included the names of the sites visited on that trip, site names for the database were extracted from the names of each of Brian's documented trips using the statistical analysis program R (R Development Core Team 2014). Extracted site names were assigned the Crosby code region abbreviation from Brian's trip names in order to match to the names in the formal New Zealand place names databases. Site names for all sites from 1977 to 2012 were then manually edited in Microsoft Excel. Manual editing primarily fixed sites missing Crosby codes, separated trips missed by the R code and altered names of sites or region abbreviations that contained obvious spelling mistakes. Brian's Crosby code abbreviations were then linked to an official list of New Zealand Regions.

Brian's site names only very infrequently included map coordinates. Providing coordinates for all sites visited on Brian's more than 3,500 trips was a time consuming challenge. Edited site names and Crosby codes were matched to the place names available for the New Zealand Map Series NZMS 260 and The New Zealand Gazetteer of Official Geographic Names in multiple passes of regular expressions data wrangling in R. Matched site names ultimately allowed co-ordinates to be brought into the database. Both mapping services were used to give co-ordinates for sites, as each service gave slightly different co-ordinates due to differences in the way in which each map service allocated their co-ordinates. Site names that did not match with either map service's site names were re-run with code that allowed for fuzzy matching, and a best match index was designed and assigned to each site. All fuzzy-matched site names and co-ordinates were imported into the database for manual editing. This process was aided by incorporating a portal link into the database to OpenStreetMap, an online open source mapping database (<http://www.openstreetmap.org.nz/>).

Manual editing of co-ordinates was undertaken for cases when site co-ordinates had several official co-ordinates, or when sites spanned more than one region. These sites were commonly roads, rivers, and ranges. A best guess was assigned to such cases and flagged for checking with Brian. Sites were also plotted in Google Earth with the aid of the online interactive NZ Topo Maps website (<http://www.topomap.co.nz/#>) and DOC Maps (<http://maps.doc.govt.nz/mapviewer/index.html?viewer=dto>), which provided co-ordinates for un-matched names. Certain geographical identifiers that were included in Brian's site name but were not part of the official list of New Zealand localities,

such as saddles and spurs, were able to be estimated more precisely by manual plotting in Google Earth. Google Earth plots allowed a preliminary assessment of the spatial extent of Brian's observations and replicated sites that might merit statistical exploration (Figure 3.4). A combination of QGIS and R with the packages *mapproj* and *foreign* were used to process KML files for importation into the database.

Observations

The species names of all observations from all digitised trips were matched in R to the New Zealand Organisms Register (NZOR). Not all species matched, due to synonym usage and spelling mistakes, and for the hand-written notebooks, species were often hard to read. These required manual cleaning, which was undertaken using fuzzy match searching on the NZOR website (<http://demo.nzor.org.nz/search>), trial and error searching in Google, and conferring with Brian. All encountered synonyms and spelling mistakes have been retained in the database both for future reference and so that changes made to Brian's original data have been documented in case of translation errors.

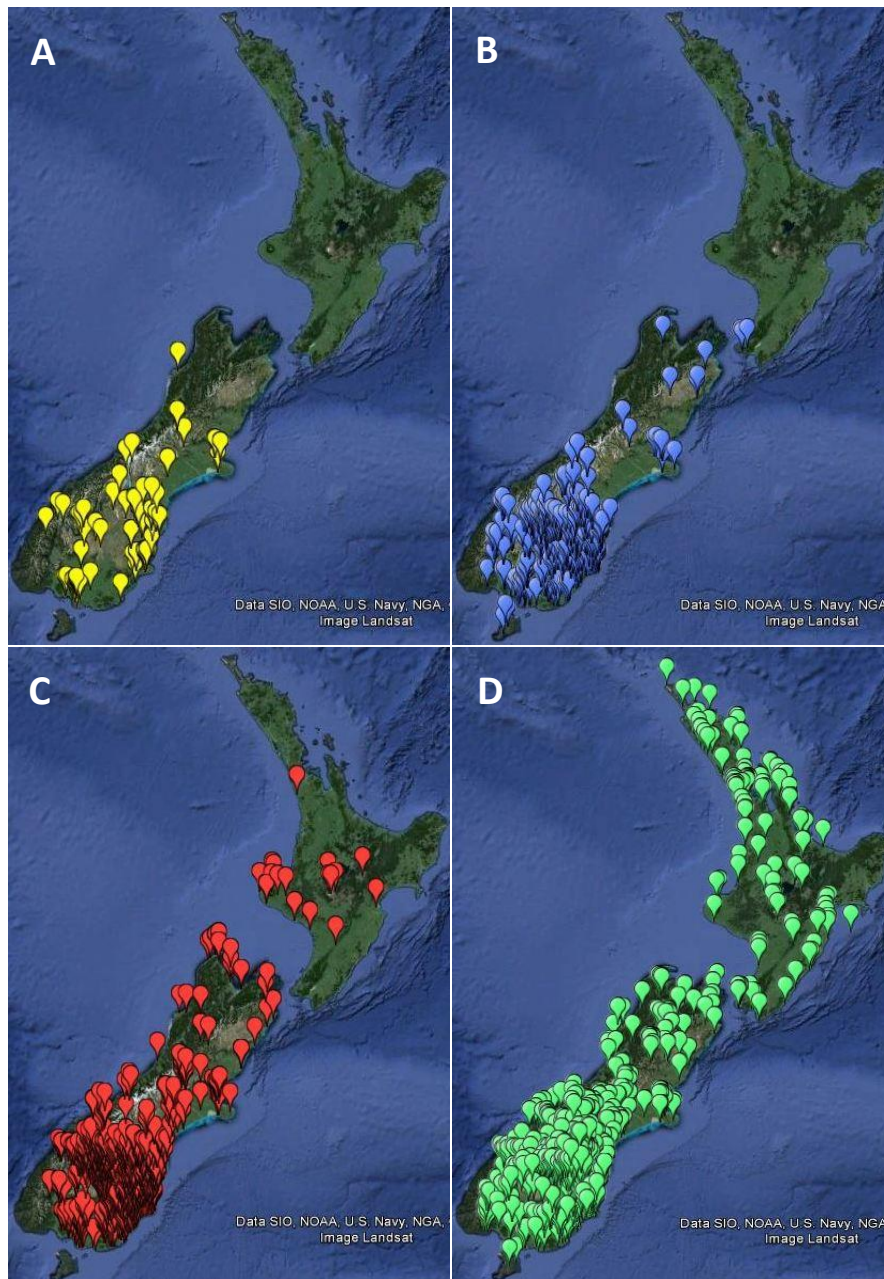


Figure 3.4 Spatial distribution of study sites by decade. A = 1977-1979, B = 1980-1989, C = 1990-1999, D = 2000-2009.

3.4 Data Analysis

Analysis was undertaken in R on species richness of completed database sites from 2004 to 2014 using the packages RJDBC, sp.raster, shapefiles, grid and RGDAL. Sites chosen for analysis were the sites that contained greater than ten species of moth, on the assumption that these sites had completed data entry and that this indicated a complete list of moths encountered. The 273 sites that matched this prerequisite showed distributions across both North and South islands (Figure 3.5).

The species richness of endemic, non-endemic native, and naturalised exotic species were calculated for each site, based on the biostatus recorded in NZOR.

Land cover categories for sites were extracted from New Zealand's Land Cover Database v3.0 (LCDB3) in order to analyse species numbers by land use. Land classification resolution was converted to a 1 km x 1 km raster; the most dominant land cover category from the LCDB3 polygons within each 1 km x 1 km grid was taken as the land classification for the whole grid. Sites were then assigned a land cover category based on the 1 km x 1 km square it occurred in. This gave a measure of the dominant land use surrounding each site. This gave 37 different types of land cover across the study sites which were simplified to 14 classifications for the purposes of analysis (Table 3.1). Co-ordinates of study sites from the database, initially in WGS84 Latitude Longitude, were transformed to the New Zealand Transverse Mercator (NZTM) co-ordinate system for comparison with LCDB3. QGIS was used to convert the LCDB3 vector layer to a raster and site-matching to the raster was completed in R with the packages *RGDAL* and *raster*.

Elevations were also obtained for sites from site co-ordinates using a digital elevation model provided by the LRIS system of Landcare Research, which gave 25 m x 25 m resolution over all of New Zealand. The elevation of each site was extracted from this raster layer using the same method as LCDB3. Elevations were used to analyse the relationship between species number and altitude. These elevations were screened so that Brian's elevations were used when Brian had provided a site elevation; GIS-extracted elevations were used for all other sites.

Dates were extracted from the database in order to analyse species richness by seasonality. These dates were transformed using the cosine of the day of the year in order to provide a season index adjusted for the effect of modelling summer seasonality as occurring at either end of the yearly spectrum. Mid-summer became 1 and mid-winter -1; all other days of the year fell between these two extremes.

3.4.1 Statistical modelling

Three generalised linear models were fitted for three species categories: endemic, exotic, and non-endemic native. A Poisson distribution was used for counts of species and all landscape variables hypothesised to be important (season, year, elevation, latitude, and land use) were modelled. A quadratic term was included for elevation to allow for a curved relationship with species richness. Interactions were included between year and elevation, and between year and land use. Fitted lines on the graphs gave model predications for the year 2005, the mean latitude (NZTM northing), mid-summer, mean elevation, and the land use of low production grassland (the most common land use

in the dataset). Drop1 tables were also generated to confirm the significance of each variable in explaining the distributional data.

Table 3.1. Number of sites with >10 species by land use classification. Original Land cover categories extracted from LCDB3 are listed next to the simplified land classifications used in analysis.

LCDB3 land cover category	Simplified land use classification	Number of Sites
Alpine Grass/Herbfield Permanent Snow and Ice Sub Alpine Shrubland	Alpine vegetation	3
Coastal Sand and Gravel Estuarine Open Water Herbaceous Saline Vegetation Mangrove	Coastal vegetation	3
Gorse and/or Broom Herbaceous Saline Mixed Exotic Shrubland Vegetation	Exotic dominated shrubland	9
Deciduous Hardwoods Exotic Forest Forest – Harvested	Exotic forest	5
Herbaceous Freshwater Vegetation Lake and Pond River	Freshwater Wetland	0
Grassland High Producing Exotic	High producing exotic grassland	19
Orchard Vineyard & Other Perennial Crops Short-rotation Cropland	Horticulture	1
Depleted Grassland Low Producing Grassland	Low producing exotic grassland	24
Fernland Flaxland Manuka and/or Kānuka Matagouri or Grey Scrub	Native dominated shrubland	5

Broadleaved Indigenous Hardwoods Indigenous Forest	Native forest	9
Tall Tussock Grassland	Native tussockland	14
Transport Infrastructure Surface Mines and Dumps Roads and mines Landslide	Rock and landslides	4
Built-up Area (settlement) Urban Parkland/Open Space	Urban built up	2

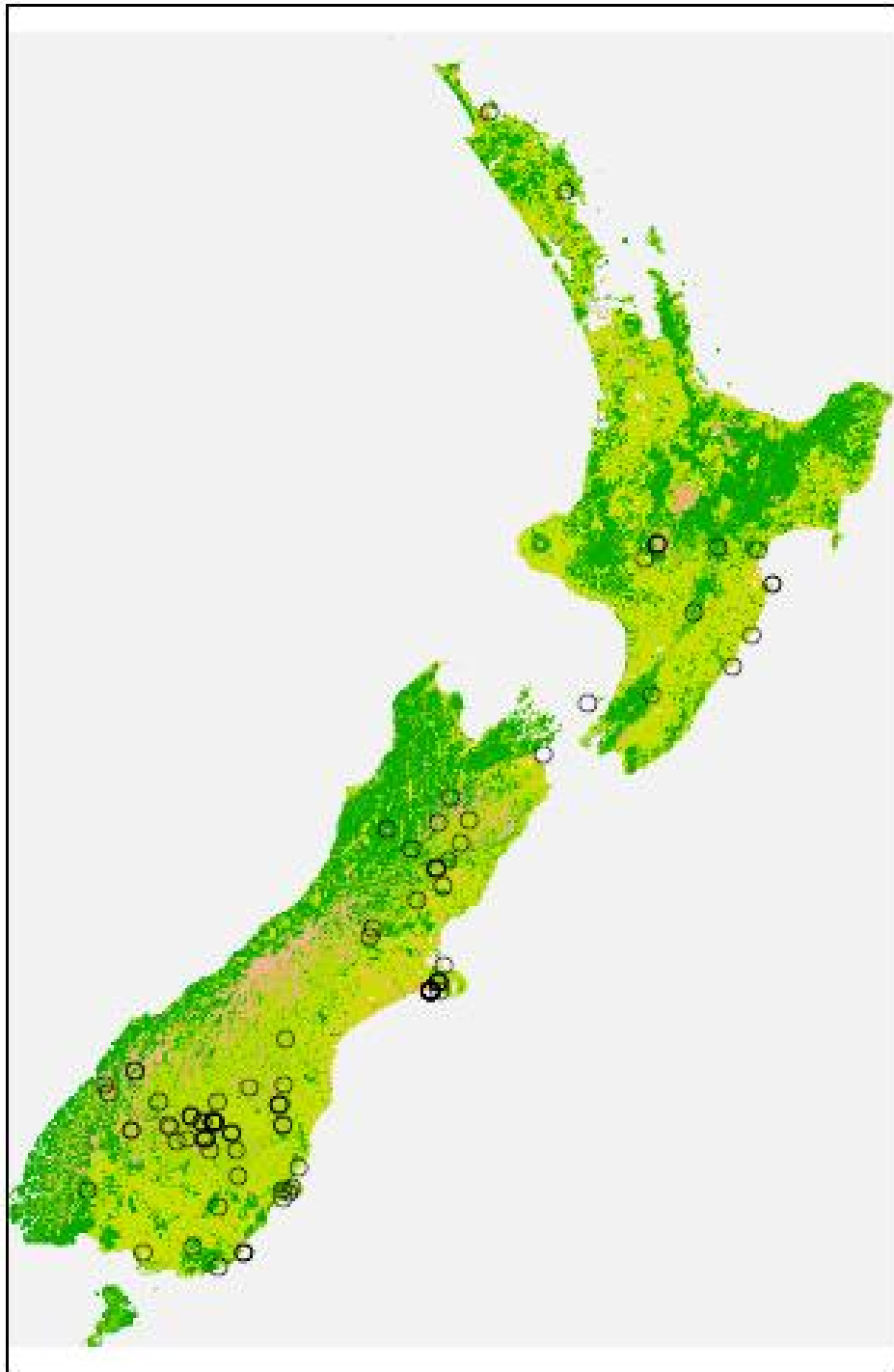


Figure 3.5 Distribution of sites used in analysis

Chapter 4

Results

4.1 Database Summary

One thousand, five hundred and fifty-seven study sites were nested within 3430 trips from around New Zealand, the majority of which are concentrated in the South Island regions of Canterbury, Otago and Southland (Table 4.1). The database currently holds records for 1649 moth and butterfly species, and a total minimum of 15,056 individual observations. Ten years' worth of data was available for analysis, summaries of which can be found in Table 4.2 and Table 4.3.

Table 4.1 Number of sites surveyed in each region by decade

Region	1970s	1980s	1990s	2000s	2010s
Auckland	0	2	9	31	31
Bay of Plenty	0	0	4	8	8
Buller	2	0	15	30	40
Central Otago	48	272	463	434	517
Coromandel	0	0	0	10	10
Dunedin	46	425	699	264	270
Fiordland	4	46	16	37	48
Hawkes Bay	0	0	6	14	43
Kaikoura	0	2	4	1	3
Mackenzie	5	28	25	58	67
Marlborough	0	2	5	19	20
Marlborough Sounds	0	0	2	5	5
Mid Canterbury	9	23	53	44	133
Nelson	0	1	18	13	20
North Canterbury	2	1	9	9	22
Northland	0	0	1	20	23
Otago Lakes	8	26	109	82	89
Rangiteki	0	0	1	1	2
South Canterbury	5	0	22	33	40
Southland	93	287	141	59	83
Stewart Island	1	15	3	3	3
Taranaki	0	0	12	3	3
Taupo	0	1	13	8	28
Waikato	0	0	1	18	18
Wairarapa	0	0	3	4	4
Wanganui	0	0	5	0	0
Wellington	0	3	10	14	18
Westland	0	0	37	22	23

Table 4.2. Distribution of total sites and species available for analysis by land use

Land use	Endemics	Non-endemics	Exotics	All species	Site visits
Alpine vegetation	129	3	2	142	8
Coastal vegetation	35	5	3	52	5
Exotic dominated shrubland	143	9	20	188	18
Exotic forest	112	4	18	142	11
Freshwater wetland	30	4	7	43	9
High producing exotic grassland	373	20	34	460	60
Horticulture	17	2	14	35	3
Low producing exotic grassland	336	22	23	408	97
Native dominated shrubland	219	9	13	253	10
Native forest	319	14	11	365	21
Native tussockland	373	16	7	430	35
Rock and landslides	188	5	5	216	10
Urban built up	83	4	9	102	17

Table 4.3 Distribution of total sites and species available for analysis by region

Region	Endemics	Non-endemics	Exotics	All species	Site visits
Auckland	4	1	4	12	5
Buller	93	1	2	104	8
Central Otago	486	26	34	623	173
Dunedin	195	13	17	247	22
Fiordland	136	0	0	138	6
Hawkes Bay	247	15	32	298	13
Kaikoura	19	3	7	32	1
Mackenzie	175	8	10	205	11
Marlborough	131	2	8	152	12
Marlborough Sounds	10	1	4	16	1
Mid Canterbury	310	21	35	428	80
Nelson	17	2	2	22	2
North Canterbury	137	4	4	154	9
Northland	11	1	18	30	4
Otago Lakes	283	14	11	313	25
Rangiteki	92	5	4	101	1
South Canterbury	11	2	1	15	5
Southland	156	8	4	176	18
Taupo	172	7	6	188	9
Wellington	30	3	6	42	2
Westland	30	0	0	31	4

4.2 Modelling Outputs

For the endemic moths species model, latitude was one significant response variable of the model (Table 4.4, Table 4.8). The species richness of exotic and non-endemic moths was not significantly correlated with site variables (Table 4.6). Drop1 tables suggested that the model interactions were not co-dependent as no differences were found between initial and dropped models (Table 4.5, Table 4.7, Table 4.9).

Endemic species richness was found to be greatest at mid altitudes and showed declines at altitudes below 500 m and above 1000 m (Figure 4.1A). Species richness also trended towards higher richness towards lower (more northern) latitudes (Figure 4.1B) and increasing richness from winter to summer (Figure 4.1C). Further, the number of endemic moth species per site increased over time at higher altitudes though of the lowland altitudes, slight increases over time were seen at sea level (Figure 4.2). Endemic species richness increased over time for three out of four non-modified land use sites, while all urban and agricultural sites showed declines in species richness over time (Figure 4.3).

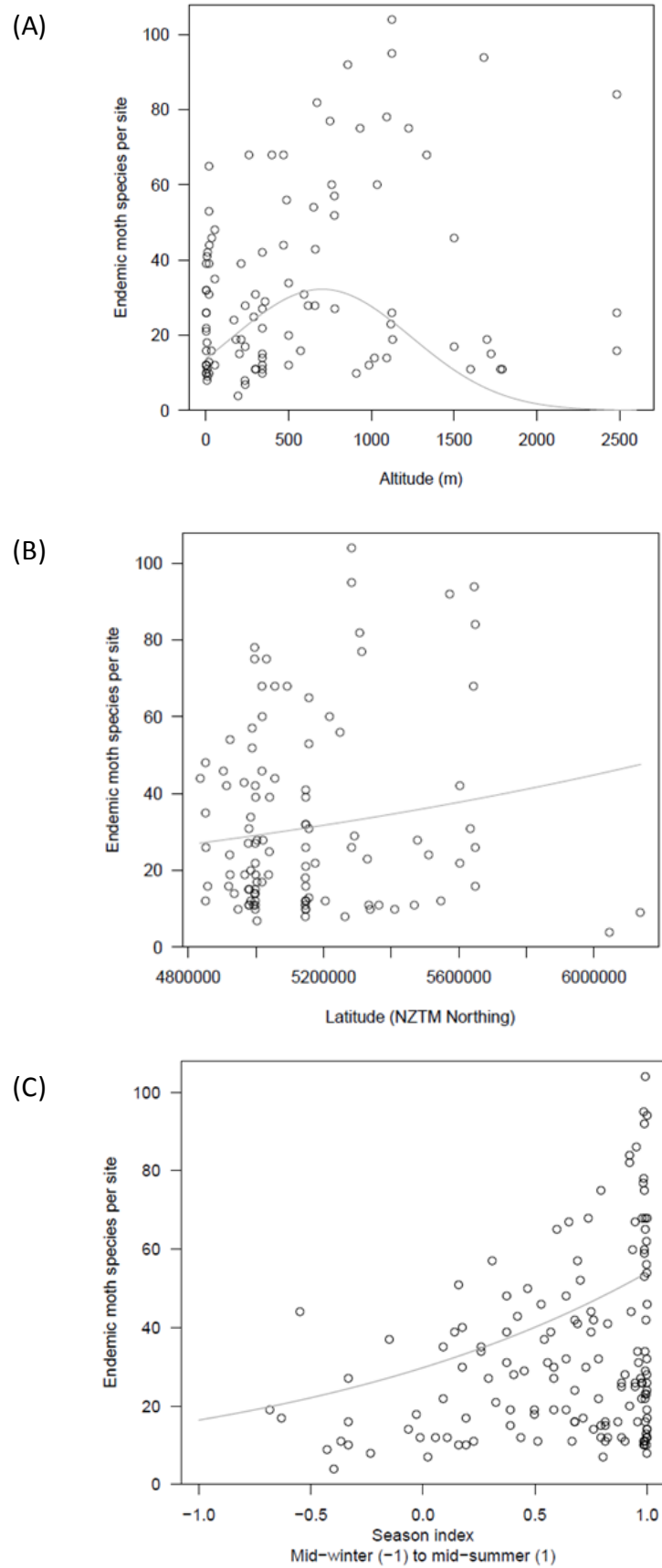


Figure 4.1 Site species richness of endemic moths by a) altitude, b) latitude and c) seasonality. Lines are the model predictions for the year of 2005 and the land use low production grassland.

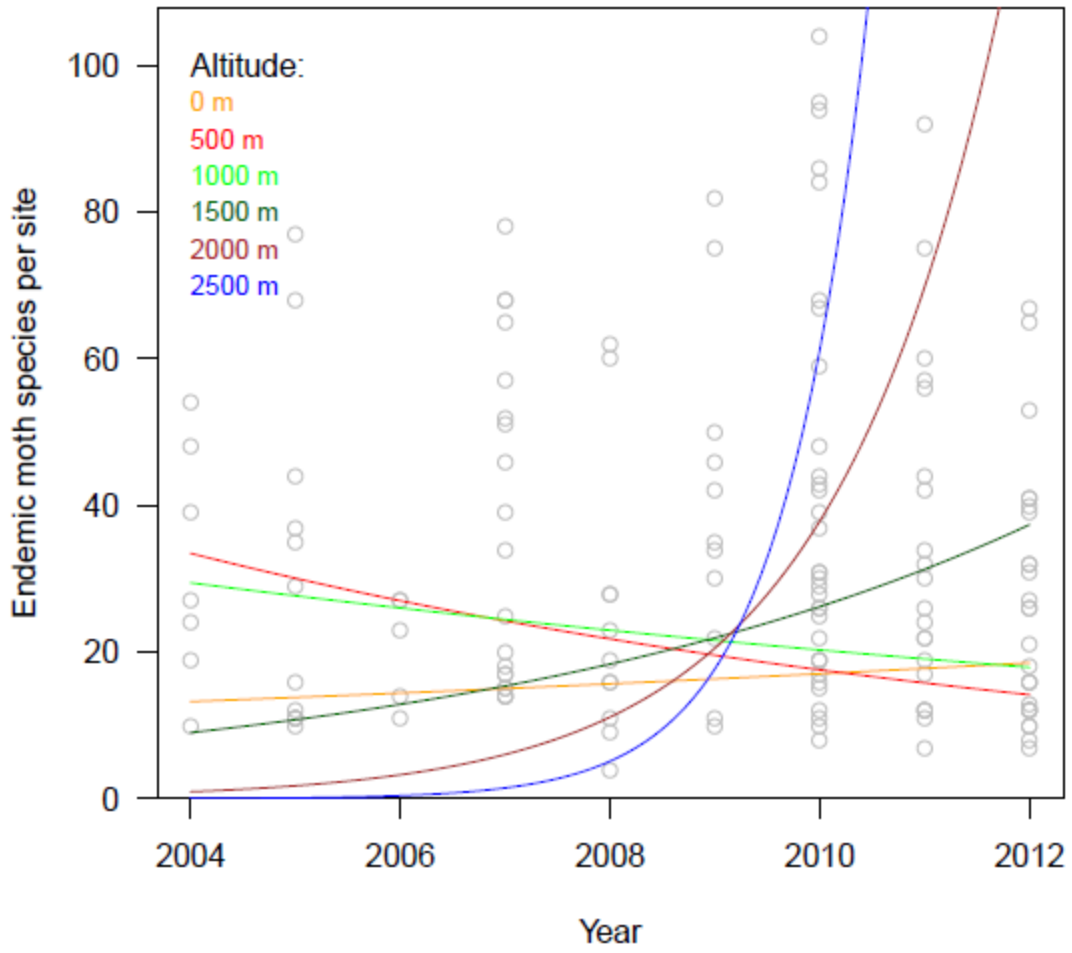


Figure 4.2 Number of endemic moth species and altitude over time.

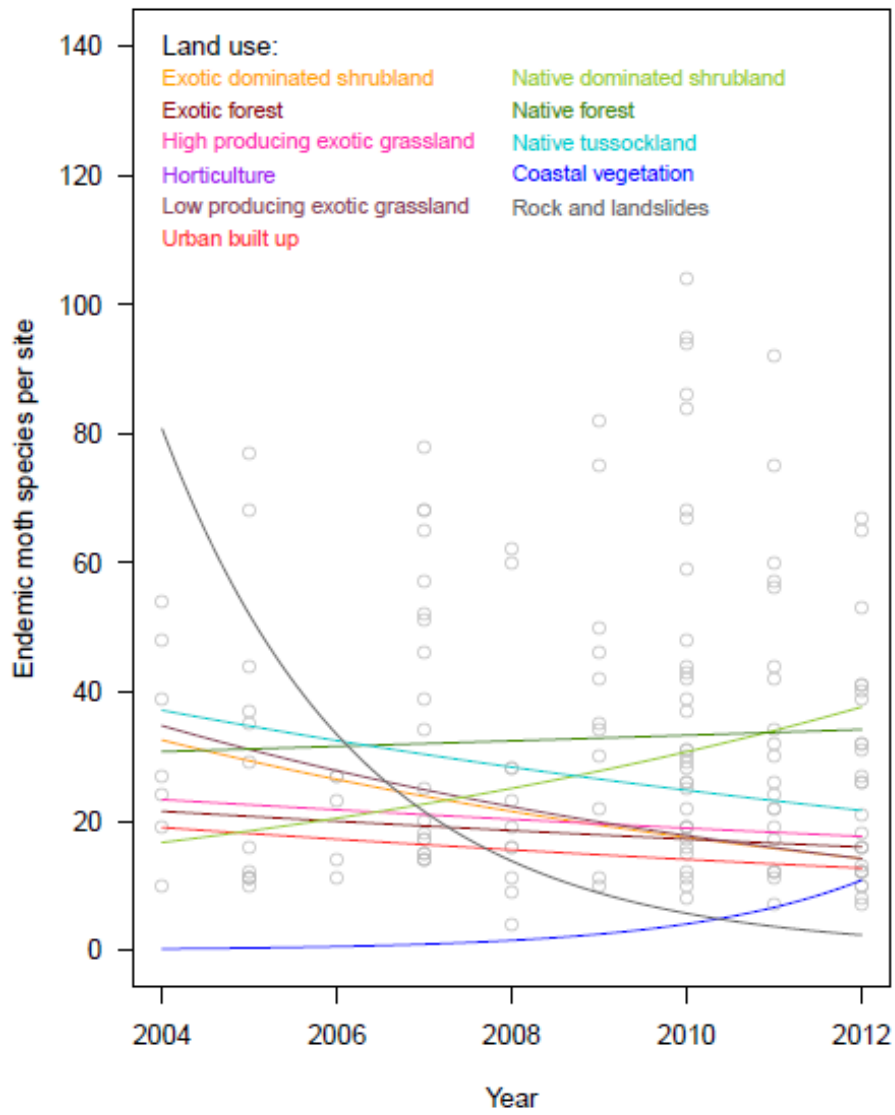


Figure 4.3 Endemic moth species richness and land use over time. Fitted lines are the model predictions at the mean elevation, mean latitude and mid-summer.

Table 4.4 Model output of endemic moth species richness by landscape variables

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-101.27	121.2124	-0.84	0.4034
Seasons	0.5957	0.0648	9.19	0
northing	0	0	3.61	0.0003
Year	0.0507	0.0603	0.84	0.4005
simple_land_useCoastal vegetation	-1192.39	740.4177	-1.61	0.1073
simple_land_useExotic dominated shrubland	1.052	136.2045	0.01	0.9938
simple_land_useExotic forest	-132.405	139.8526	-0.95	0.3438
simple_land_useHigh producing exotic grassland	-136.763	122.5045	-1.12	0.2643
simple_land_useHorticulture	-1.4126	0.3815	-3.7	0.0002
simple_land_useLow producing exotic grassland	17.6098	118.6624	0.15	0.882
simple_land_useNative dominated shrubland	-411.183	145.3804	-2.83	0.0047
simple_land_useNative forest	-233.066	118.4886	-1.97	0.0492
simple_land_useNative tussockland	-71.1424	112.4995	-0.63	0.5271
simple_land_useRock and landslides	679.1101	221.7245	3.06	0.0022
simple_land_useUrban built up	-106.433	311.9401	-0.34	0.733
Altitude_all	0.9903	0.1209	8.19	0
I((Altitude_all)^2)	-0.0008	0.0001	-9.36	0
Year:simple_land_useCoastal vegetation	0.5925	0.3681	1.61	0.1075
Year:simple_land_useExotic dominated shrubland	-0.0005	0.0678	-0.01	0.9937
Year:simple_land_useExotic forest	0.0659	0.0696	0.95	0.3442
Year:simple_land_useHigh producing exotic grassland	0.0681	0.061	1.12	0.2642
Year:simple_land_useLow producing exotic grassland	-0.0088	0.0591	-0.15	0.882
Year:simple_land_useNative dominated shrubland	0.2048	0.0723	2.83	0.0046
Year:simple_land_useNative forest	0.1163	0.059	1.97	0.0486
Year:simple_land_useNative tussockland	0.0356	0.056	0.64	0.5253
Year:simple_land_useRock and landslides	-0.3384	0.1104	-3.07	0.0022
Year:simple_land_useUrban built up	0.0528	0.1551	0.34	0.7335
Year:Altitude_all	-0.0005	0.0001	-8.19	0
Year:I((Altitude_all)^2)	0	0	9.36	0

Table 4.5 Drop 1 table of model output of endemic moth species richness by landscape variables

	Df	Deviance	AIC	LRT	Pr(>Chi)
<none>		877.46	1427.81		
Seasons	1	971.08	1519.44	93.63	0
northing	1	889.9	1438.25	12.45	0.0004
Year:simple_land_use	10	935.84	1466.19	58.38	0
Year:Altitude_all	1	945.89	1494.24	68.43	0
Year:I((Altitude_all)^2)	1	972.92	1521.27	95.46	0

Table 4.6 Model output of exotic moth species richness by landscape variables

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-1141.44	1654.607	-0.69	0.4903
Seasons	0.032	0.224	0.14	0.8863
northing	0	0	4.25	0
Year	0.5639	0.8226	0.69	0.493
simple_land_useCoastal vegetation	-0.7832	1.3881	-0.56	0.5726
simple_land_useExotic dominated shrubland	1099.574	1695.666	0.65	0.5167
simple_land_useExotic forest	453.7242	1704.598	0.27	0.7901
simple_land_useHigh producing exotic grassland	1170.059	1673.959	0.7	0.4846
simple_land_useHorticulture	2.4376	1.6779	1.45	0.1463
simple_land_useLow producing exotic grassland	1000.994	1662.232	0.6	0.547
simple_land_useNative dominated shrubland	598.978	1771.483	0.34	0.7353
simple_land_useNative forest	1155.686	1712.097	0.68	0.4997
simple_land_useNative tussockland	2.178	0.9031	2.41	0.0159
simple_land_useRock and landslides	-0.7913	2.403	-0.33	0.7419
simple_land_useUrban built up	613.7757	2256.951	0.27	0.7857
Altitude_all	0.3914	0.3483	1.12	0.2612
I((Altitude_all)^2)	0	0	0.77	0.4394
Year:simple_land_useExotic dominated shrubland	-0.5462	0.843	-0.65	0.5171
Year:simple_land_useExotic forest	-0.225	0.8475	-0.27	0.7907
Year:simple_land_useHigh producing exotic grassland	-0.5817	0.8322	-0.7	0.4846
Year:simple_land_useLow producing exotic grassland	-0.4975	0.8264	-0.6	0.5472
Year:simple_land_useNative dominated shrubland	-0.2971	0.8808	-0.34	0.7359
Year:simple_land_useNative forest	-0.5743	0.8512	-0.67	0.4999
Year:simple_land_useUrban built up	-0.3054	1.1222	-0.27	0.7855
Year:Altitude_all	-0.0002	0.0002	-1.13	0.2592

Table 4.7 Drop 1 table on model output of endemic moth species richness by landscape variables

	Df	Deviance	AIC	LRT	Pr(>Chi)
<none>		31.65	235.75		
Seasons	1	31.67	233.77	0.02	0.8861
northing	1	51.07	253.17	19.42	0
I((Altitude_all)^2)	1	32.23	234.34	0.58	0.4453
Year:simple_land_use	7	41.19	231.29	9.54	0.2161
Year:Altitude_all	1	32.99	235.09	1.34	0.2473

Table 4.8 Model output of nonendemic moth species richness by landscape variables with interactions terms

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	52.1611	1452.139	0.04	0.9713
Seasons	0.376	0.4912	0.77	0.444
northing	0	0	2.64	0.0083
Year	-0.031	0.7215	-0.04	0.9657
simple_land_useCoastal vegetation	-2062.29	2849.517	-0.72	0.4692
simple_land_useExotic dominated shrubland	108.8503	1471.138	0.07	0.941
simple_land_useExotic forest	-746.087	1556.392	-0.48	0.6317
simple_land_useHigh producing exotic grassland	-54.9162	1445.939	-0.04	0.9697
simple_land_useHorticulture	-2.2693	1.5189	-1.49	0.1352
simple_land_useLow producing exotic grassland	-31.8955	1462.294	-0.02	0.9826
simple_land_useNative dominated shrubland	-505.955	1589.441	-0.32	0.7502
simple_land_useNative forest	-394.346	1562.281	-0.25	0.8007
simple_land_useNative tussockland	-669.581	1564.613	-0.43	0.6687
simple_land_useRock and landslides	-175.731	1907.741	-0.09	0.9266
simple_land_useUrban built up	-1.74	1.2819	-1.36	0.1747
Altitude_all	0.3786	0.3873	0.98	0.3283
I((Altitude_all)^2)	0	0	0.65	0.5167
Year:simple_land_useCoastal vegetation	1.0243	1.4168	0.72	0.4697
Year:simple_land_useExotic dominated shrubland	-0.0546	0.7318	-0.07	0.9406
Year:simple_land_useExotic forest	0.3698	0.7743	0.48	0.6329
Year:simple_land_useHigh producing exotic grassland	0.0265	0.7193	0.04	0.9707
Year:simple_land_useLow producing exotic grassland	0.0152	0.7274	0.02	0.9833
Year:simple_land_useNative dominated shrubland	0.2516	0.7907	0.32	0.7504
Year:simple_land_useNative forest	0.1961	0.7772	0.25	0.8008
Year:simple_land_useNative tussockland	0.3334	0.7783	0.43	0.6684
Year:simple_land_useRock and landslides	0.087	0.9495	0.09	0.927
Year:Altitude_all	-0.0002	0.0002	-0.98	0.3254

Table 4.9 Drop 1 table for model output of nonendemic moth species richness by landscape variables

	Df	Deviance	AIC	LRT	Pr(>Chi)
<none>		19.91	224.32		
Seasons	1	20.5	222.91	0.59	0.4441
northing	1	26.92	229.33	7.01	0.0081
I((Altitude_all)^2)	1	20.32	222.74	0.41	0.5214
Year:simple_land_use	9	24.1	210.51	4.19	0.8987
Year:Altitude_all	1	20.88	223.29	0.97	0.3253

Chapter 5

Discussion

5.1 Preliminary Results

Analysis of trends on 10 years' worth of species data is already showing remarkably similar trends to those found in overseas studies. The increase in species over latitude and altitude both indicate that temperature may be a driver in structuring the communities of Lepidoptera at sites. Given that landscape change tends to occur below 400 m, higher numbers of species at higher elevations also provides evidence that some lowland sites are no longer favoured habitats for many New Zealand Lepidoptera. The seasonality effect on species numbers also suggests a sensitivity to climate that does not bode well for biodiversity projections in the face of climate change. All of these trends were consistent with expectations (Leingärtner, Krauss & Steffan-Dewenter, 2014).

The decline in species at low altitudes and the increase in endemic species at higher altitudes over time provides evidence for species shifts from lower to higher elevation. This may well be due to land use change, as trends were different for modified lowland landscapes than for sites with natural vegetation. Comparison of the different land use types are worth noting. The decline of moth and butterfly species in human modified landscapes over time was expected and consistent with trends in the pervasive literature on this subject (Blair & Launer, 1997; Thomas & Abery, 1995). Of the broad differentiation that was made between human-modified landscapes and natural landscapes, native habitats all showed slight increases in the number of endemic species present at sites over time, however tussock grasslands showed declines in endemic species over time. This will certainly be worth exploring further if the trend persists after the addition of earlier data. The Graeme White Tussock Grassland Moths database and the database of this study could be pooled to confirm such a trend. Like overseas studies, New Zealand Lepidoptera show potential to be indicators of ecosystem health (Brereton, Middlebrook, Botham & Warren, 2011).

5.2 Experimental design

Good science typically calls for a randomised sampling design (Anderson, 2001), and it is clear that Brian's original collection methods do not conform to this. There is probably an over-representation of sites that are naturally abundant in Lepidoptera, and the sites that were visited most were naturally dependent on where Brian was living at the time. The distribution of sites visited by Brian expands of from the regional to the national over three decades (Figure 3.4) as Brian's professional

career increasingly took him further afield, so not all sites have the same level of replication. However there is some standardisation to be gained from all observations being undertaken by the same person and often revisiting the same sites, an upside that is not reflected in many overseas studies (Groenendijk & Ellis, 2011).

The dependency of counts of species used in analysis on the correct species identification may also have impacted results. Accuracy of species identification by Brian might be expected to increase over time, so earlier results may not be as reliable. However Brian regularly consults his field notebooks and maintains an extensive collection of moths so that species identifications can be clarified at later dates (B. Patrick, pers. comm. 2014). There are still some species nomenclature issues to resolve in the database which may have altered species abundance counts, however, so more time spent polishing the database is needed.

5.3 The future of biodiversity conservation

Criticism has been raised as to the ability of scientific studies that are not hypothesis driven and experimental in nature to answer ecological questions (Lindenmayer & Likens, 2010). A concern for 'passive' and curiosity-driven monitoring studies is the difficulty of resolving drivers of change when there are no treatments, and it is true that most of the literature on the drivers of decline are correlational (Fox, 2013; Hardy, Sparks & Dennis, 2014). However the argument against curiosity-driven studies does not appear to consider the practical and social aspects of science, and the fact that research is largely limited by funding. Observations need to be made first before hypotheses can be formed and experimental studies designed (Keeling, 1998), and often before research will be funded. This dataset, for example, was instrumental in obtaining funding from the Brian Mason Scientific and Technical Trust to complete digitation of the data and make it publicly available. Thus, 'Cinderella' science, though unglamorous (Nisbit, 2007) is still a very necessary part of conservation science. Further, a great deal of the long-term data sets used in studies of Lepidoptera decline overseas were due to the large concerted effort of volunteers and enthusiasts from overseas, and it is the massive scale of such studies that appears to make the temporal ecological modelling worthwhile (Dennis & Sparks, 2007; Kozlov et al., 2010; Salama et al., 2007). Therefore, unpaid research has the potential to contribute a great deal to knowledge of Lepidoptera species. Indeed, the work presented here would suggest that, with the lack of research on New Zealand pollinators in general - experimental or otherwise - we cannot afford to ignore any ecological data that might help us fill the gap in knowledge of temporal trends in Lepidoptera abundance and diversity. From this perspective, community-driven research is key to the future of New Zealand biodiversity conservation (Patrick, 2004).

5.4 Next steps

Increasing the number of sites and observations in the database is needed to strengthen the trends documented here. Based on the close match of the preliminary results to overseas studies, it is expected that additional observations will only enhance the current results. As with spatial studies, however, it is always possible that temporal data misses important changes if terminated too early (Keeling, 1998) or if gathered too infrequently; it was only due to occupancy modelling, for example, that the temporal declines in declines in *A. caji* were noticed after ineffective temporal studies (Conrad et al., 2002). Completing entry of Brian's earlier sites is therefore important for capturing as much temporal variation as possible (Van Strein et al., 1997). A variety of assumptions also went into databasing and analyses which will need adjusting and clarifying with Brian before the tests are truly robust representations of wider trends.

Further analyses will also be worthwhile carrying out in order to bring the knowledge of New Zealand Lepidoptera closer to that of the global literature. Ordination of changes in species composition of sites could be expected to shed light on the features of sites that are hosting different levels of abundance and richness and which species are most sensitive to ongoing landscape and climate changes. Similarly, from a species perspective, quantifying life-history traits which may indicate risk of decline may aid conservation initiatives (Blake, Woodcock, Westbury, Sutton & Potts, 2011). It would also be interesting to focus on changes in abundance of a few rare and a few common New Zealand species: *Lycaena* and *Zizina* species would both be worthwhile, since species from this genus are also found in Britain where they have been well monitored (Léon-Cortés et al., 1999). Given Britain so far has documented greatest declines, such a comparison may indicate where our country stands in the high stakes of Lepidoptera biodiversity (New, 2004).

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