1. Abstract

A representative set of invertebrates was used to quantify how efficacious the Protected Areas Network of New Zealand (PAN-NZ) is at encompassing invertebrate diversity. The sample localities of 67 species of Pterostichini (Coleoptera: Carabidae) from museum records were modelled against climate, landform and soil variables from Land Environments of New Zealand data (LENZ) using MaxEnt to predict species distributions. The Protected Areas Network of New Zealand (PAN-NZ) were laid over the top using ArcMap to quantify how much of species range was encompassed by PAN-NZ. It was found that Pterostichini are representative of Carabidae and thus these findings can be generalised to make comments on how effectively the PAN-NZ protects invertebrate diversity. Two models were run for each species; models using the full LENZ variables were found to be more accurate than models using just climate variables. Models using just climate data also greatly over-estimated species ranges encompassed by PAN-NZ. Species richness patterns highlight a lack of protection in central and eastern South Island and this is also seen in North Island where areas of species richness lie outside of PAN-NZ. The majority of Pterostichini species are not covered by PAN-NZ, 57 out 67 modelled species had less than 50% of their range covered by PAN-NZ.

Contents

2. Introduction

New Zealand is noted for its highly endemic biota which has evolved in isolation from any other landmass for the last 85 million years (McSaveney & Nathan 2007). Since its separation from Gondwanaland New Zealand has been subject to many geological and climatic changes. About 65 million years ago intense meteor and volcanic activity caused at least half of the fauna and flora to go extinct followed by more than two-thirds of the land lying below sea-level (McSaveney & Nathan 2007). Whilst most of the land was under the sea tectonic plate movement caused the Alpine Fault to form and New Zealand split apart forming North and South Island (McSaveney & Nathan 2007). Volcanic activity and uplift caused the land to rise once again above sea level and the elevation of the Southern Alps, especially along the Alpine Fault, continued along with more volcanic activity and glaciation (McSaveney & Nathan 2007). All of these events have had a huge impact on the fauna and flora of New Zealand causing it to evolve a diverse and distinctive landscape with an equally diverse and distinctive biota. During the last 10,000 years New Zealand's climate and geology has been more stable allowing forest to dominate most of its land surface (Craig *et al* 2000). However the landscape suffered much modification from its natural state with the arrival of humans. New Zealand was one of the last countries in the world to be colonised by people with the arrival of the Maori around 1250-1300 AD and European settlers arriving about 1790 (McSaveney & Nathan 2007). Since this time forest-burning, agricultural land modification, hunting and introduction of exotic species (McGlone 1989) have had a significant impact, causing extinctions of unique species and threatening many more (Ministry for the Environment 1997).

Carabidae are one such set of New Zealand fauna that is listed high on the priorities of conservationists (Larochelle & Lariviere 2001). They are one of the most species rich families of Coleoptera with a global estimate of more than 40,000 species worldwide and are a ubiquitous family of beetle present in most habitats (Erwin 1985). In larger continents such as North America, Europe and Australia species assemblages range from 2,500-3000 species (Larochelle & Lariviere 2001). Carabids are not as prevalent in New Zealand (Lovei 1991) although the species assemblage is by no means poor, with an estimate of at least 600 species (Larochelle & Lariviere 2001). Of the 600 estimated species, 461 species and 15 sub-species are currently described from seven sub-families, 21 tribes and 86 genera (Larochelle & Lariviere 2007). Ninety two per cent of these species are endemic (Larochelle & Lariviere

2001) which is slightly higher than the 80-90% endemicity normally seen in New Zealand species assemblages (McGuinness 2007).

Information on Carabids in New Zealand was, until recently, severely lacking and there is still dispute over the taxonomy of some species with many yet to be described. In comparison to areas such as Europe and North America studies on their ecology are still lacking. This information is needed to be able to devise and deliver effective conservation management. Many species are now recognised as threatened and due to the high endemicity of Carabid species it is even more important to protect these unique species. In addition to the need to conserve endemic species, Carabids provide good subjects and are frequently investigated in ecological studies. Their relatively uniform morphology has enabled studies on their ecophysiology and how they are adapted to cope with environmental (Forsythe 1987; Ribera *et al* 2001). In addition their sensitivity to both abiotic and biotic factors allows us to elucidate their responses to environmental change (Lovei and Sunderland 1996). A more recent use for Carabids is as bioindicators, with studies showing that they can be used to indicate the impact of landscape changes, evaluate environmental health, predict the effect of climate changes, classify habitats for nature protection and characterise soil-nutrients in forestry (Niemela 2000; Rainio and Niemela 2003). There have also been suggestions for future use of Carabids as pest control agents against soil invertebrates and weeds (Kromp 1999) further adding to their potential economic value. The fact that Carabids are fairly large, obvious species also makes them easy to study as they can be trapped using reliable and quantitative methods such as pitfall trapping (Spence and Niemela 1994).

The New Zealand threatened species list recognizes 49 species (10%) of all New Zealand Carabids as threatened (Hitchmough *et al* 2005). However the literature shows there are more rare and threatened species than the ones identified by the threatened species list, but due to the discovery of new species and lack of ecological knowledge about many species they are not included (Johns 2007). Considering most species of Carabid are endemic, the 10% that are officially recognised as threatened are very important. Furthermore, the majority of threatened Carabids are heavily biased to a small number of genera. For example, approximately 44% of *Megadromus* (Harpalinae; Pterostichini) species and 17% of *Holcaspis* (Harpalinae; Pterostichini) species are threatened. Another large proportion of threatened species are from the genus *Mecodema* (Trechinae; Broscini). *Mecodema* and *Megadromus* are considered the most at risk genera of New Zealand Carabids, possibly due to the fact that they are the largest Carabids in New Zealand making them more susceptible to predation, especially by introduced predators such as rats, mice, hedgehogs and mustelids (McGuiness 2007). Another factor influencing their prominent inclusion on the threatened species list may be because they are well known and noticeable due to their size; therefore a decline in their numbers is more likely to be noticed. Most species of Carabidae in New Zealand are adapted to live in damp forest areas and the second most common habitat is tussock grassland (Larochelle & Lariviere 2001). Therefore habitat modification and loss of tussock grassland and forest have also been big contributory factors to the decline of New Zealand Carabidae (McGuiness 2007).

The New Zealand Department for Conservation administers most of the publicly owned land that is legally protected as parks and reserves where native ecosystems are still intact. These areas of land form the Protected Areas Network (PAN-NZ) and many are actively managed through weed control, pest and predator control and ecosystem restoration projects (Department of Conservation 2009). Protected areas administered by the Department for Conservation total more than 8.6 million hectares; approximately one third of New Zealand’s land mass (Statistics New Zealand 2002). Indigenous forest used to cover 85% of New Zealand but this has dropped to a present day value of only 23% (Ewers *et al* 2006). The majority of protected areas are in the South Island lying to the West of the Alpine Fault Line whereas the East side of South Island is afforded little protection (Appendix 8.5). Chatham Island lying to the south of New Zealand is afforded complete protection and patchy areas in North Island are protected (Appendix 8.5). Although about one third of New Zealand is protected there is currently little information describing whether these areas effectively protect invertebrates. Since past studies have suggested that Carabids can be used in ecological studies as a surrogate for other invertebrate species and as indicators of healthy ecosystems (Larochelle & Lariviere 2007) it would make sense to investigate whether the protected areas are of benefit to them. To do this we need to visualise the distribution of New Zealand Carabids and whether their geographic ranges are adequately encompassed by protected land.

Niche modelling has become a powerful tool for conservation purposes, allowing researchers to produce detailed range maps predicting species fundamental distributions based on museum records and known gradients of environmental variables which influence the suitability of the environment for a given species (Guisan and Zimmerman 2000). Such models describes the suitability of the environment in ecological space, however the information can be projected into geographic space allowing us to visualise the predicted distribution of a species (Phillips, Anderson & Schapire 2006). Niche models are often used to help predict how a species range will respond to changes in climatic conditions. They are also very useful when investigating how effectively protected area networks represent species diversity. Gap analysis to identify species not covered by protected area networks helps to improve the efficacy of reserves at protecting threatened species and maintaining biodiversity (Rodrigues *et al* 2004a).

Using the niche modelling programme MaxEnt, geographic ranges of a representative set of New Zealand Carabid species were mapped. These ranges were mapped against the New Zealand Protected Area Network (PAN-NZ) to quantify how efficacious the legally protected areas are for encompassing invertebrate species diversity.

3. Methods

3.1 Crosby regions

Crosby *et al*. (1976) defined 29 geographic regions within New Zealand of approximately equal size, each with a two letter code; in 1998 eight smaller islands were added to the Crosby Regions (Crosby *et al* 1998). These regions are frequently used as analogous to biogeographic realms within New Zealand. The species richness of all New Zealand Carabidae within the Crosby Regions were compared to the species richness patterns modelled in this study to check if the results adequately matched the expected diversity patterns for Carabids. Additionally, in each region the total numbers of Carabid species minus the Pterostichini species were correlated with the total number of Pterostichini species for that area. Data correlation was done between Pterostichini diversity and Carabidae diversity to see if they significantly followed the same pattern, and therefore, if Pterostichini could be considered as representative of Carabidae in general.

3.2 Study taxa

There are seven subfamilies of Carabidae in New Zealand; one of these is the subfamily Harpalinae within which is the tribe Pterostichini. Pterostichini is the most species rich tribe of New Zealand Carabidae comprising 19 % of the family. Just over one third of Carabid species named on the New Zealand threatened species list belong to the Pterostichini (Hitchmough *et al* 2005). The tribe includes the genus *Megadromus*, with all species in New Zealand being endemic to the country although other species of the genus are found in Australia (Larochelle & Lariviere 2001). Other genera in the Pterostichini, such as *Holcaspis* (*S*=35 species), *Neoferonia* (*S*=9), *Plocamostethus* (*S*=2) and *Zeopoecilus* (*S*=3) are entirely endemic to New Zealand (Larochelle & Lariviere 2001). Of the genera in this study, few species are synanthropic, namely *Megadromus antarcticus* (Larochelle & Lariviere 2001).

The geographic locations of sites where beetles have been observed by pitfall trapping were obtained from museum records. Due to few species occurring in the west of South Island there were no samples from this area despite trapping having been carried out. The distributions of five out of the 11 Pterostichini genera were modelled, encompassing 74 % of the species within the tribe (*S* = 67). Sixty three of the species used are recognised in the catalogue compiled by Larochelle & Lariviere (2007). The remaining 4; *Megadromus nsp A*, *Megdaromus nsp B*, *Megadromus nsp C* and *Megadromus crassalis* are new species (Johns, pers. comm.). Several species from the *Holcaspis* and *Megadromus* genera were not included in the models due to the lack of information making it not possible to map their distributions. Additionally *Gourlayia regia* which is an endemic genus and species to Three Kings Islands (north-west of North Island) and *Onawea pantomelas* which is confined to the Banks Peninsula (South Island) were not included. Both of these species are confined to a very confined geographic area so including them in the models would not have provided any more information on their areas of presence or absence. Two genera (*Prosopogmus* (S=1 species) and *Rhytisternus* (S=2 species) were not modelled as they comprise only introduced species and are therefore considered to have no conservation importance. There are two more genera that were not included in the study due to lack of records and information; *Aulacopodus* (S=4 species) and *Psegmatopterus* (S=1 species). Removing the two introduced genera and including *Gourlayia* and *Onawea* means that 79% (S=69) endemic species of this tribe were incorporated in the study. The sample localities from museum records, of 67 species out of 89 species of Pterostichini were converted into New Zealand Map Grid co-ordinates.

3.3 Niche modelling software

MaxEnt is a niche modelling programme which predicts maximum entropy. It can be used with presence only data whereas many other programmes require presence and absence data which can be difficult to collect (Phillips *et al.*, 2006). Spatial predictor variables can be either continuous or categorical and the output is continuous which allows detailed distribution maps to be produced and analysed in other programmes, such as ArcMap. A comparative analysis of niche model performance by Elith *et al.* (2006) concluded that MaxEnt is one of the best performing nichel models in use, providing a consistently accurate output. However, it is important to temper the conclusions from niche models with the fact that there are several conditions which it cannot account for and which could affect the predicted ranges of species. These include dispersal barriers, biotic conditions (such as inter-specific competition) or anthropogenically induced conditions which may make an area unsuitable for the species to survive in (Hutchinson 1958; Phillips *et al.* 2006). When extrapolating from MaxEnt output these conditions must be considered before making statements about suitability of areas for a species.

The sample localities from museum records were put into MaxEnt along with Land Environments of New Zealand (LENZ) climate, landform and soil data from Leathwick *et al.* (2003). LENZ data adequately represents the range of terrestrial ecosystems present in New Zealand; it is based on 16 abiotic variables, modelled at 100 square metre resolutions, which are likely to influence the distribution of a species and is useful for conservation planning (Leathwick *et al* 2003).

Table 1. Environmental variables used in models

Number	Environmental variable	Range
1	Acid-soluble phosphorus (mg/100g)	five classes: 0-7, 7-15, 15-30, 30-60, 60+
2	Age since last major rejuvenation (years)	three classes: <2000, 2000-postglacial (approximately 30,000), preglacial
3	Altitude	-
4	Exchangeable calcium (mg/100gm)	four classes: 0-1, 1-10, 10-40, 40+
5	Chemical limitations to plant growth	three classes: nil-low limitations (1), saline soils (2), ultramafic soils (3)
6	Annual rainfall deficit (mm)	0.0 – 412
7	Drainage	very poor, poor, imperfect, moderate, good
8	Induration	five classes: none, very weakly, weakly, strongly, very strongly
9	June solar radiation (Mj/m²/day)	3.3 – 7.5
10	Mean annual solar radiation (MJ/m²/day)	11.7 – 15.4
11	Mean annual temperature (Cº)	-5.1 – 16.3
12	Particle size (mm)	five classes: clay/ silt (<0.06), sand (0.06-2), gravel (2-60), coarse gravel (60-200), boulders-massive (>200)
13	Average monthly ratio of rainfall to potential evaporation (ratio)	0.5 – 30.6
14	Slope (degrees)	flat (0-3), undulating (4-7), rolling (8-15), strongly rolling (16-21), moderately steep (21-25), steep (26-35), very steep (>35)
15	Mean July minimum temperature (Cº)	-8.4 – 9.8
16	Mean October vapour pressure deficit at 0900 hours (kPa)	0.0 – 0.64

From Leathwick *et al.* (2003), except Altitude which is from NZDEM (2009)

Two models were run for each species in MaxEnt; the first mapped the species against just climate variables and the second mapped the species against climate, landform and soil variables (Table 1). This gave outputs with two different degrees of detail, one set of maps based on a species range in response to climate and one set of map based on a species range in response to the full complement of environmental layers. Each cell of the maps is assigned a probability of presence ranging from 0-1. For each species, a threshold was applied to convert the probability map to a binary presence-absence map, where a species was considered present in a cell if the probability of presence was greater than 0.5. Probabilities less than 0.5 were deemed unsuitable for that species to occur in accordance with guidelines set out by Phillips *et al* (n.d.) for the interpretation of MaxEnt results. The binary output of the full model maps and climate only maps were combined to compare the distributions mapped from the two sets of variables. The separate binary maps for all species were combined to make a map so species richness based on climate variables and a map of species richness based on climate, landform and soil variables.

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Both the climate model and the full LENZ data model were used in analysis because the reality of a species distribution will fall somewhere between the ranges predicted by both models as the climate dataset overestimates range size and the full dataset underestimates range size. MaxEnt output gives AUC scores to indicate how accurate the distributions are in accordance with the training data and these scores and the differences of range size given by both models were compared.

Using the sample data points where the species were originally observed, the values of each climate, landform and soil variable were extracted at those points. A test for correlation was done on the variables to identify which were highly correlated and how significantly they were correlated. By calculating which variables are correlated identification can made of where variables may interact and their impact on a species distribution.

3.4 Gap analysis

Species distribution maps were overlaid on a map of the Protected Areas Network (PAN-NZ) to investigate the degree of overlap between the individual species and protected areas. The proportion of species that were encompassed in protected areas was calculated from each species distribution map. Rodrigues *et al* (2004b) advised that species with a range of less than 100,000 hectares should have 100% of their range in a protected area to consider them at all protected by the network. Whereas species with large ranges over 25,000,000 hectares should have at least 10% of their range in a protected area to be considered covered by the network. However, Rodrigues's work did not include any terrestrial invertebrate species, which can maintain viable populations in much smaller areas. Therefore it was decided that if more than 50% of a species range was in the PAN-NZ then they could be considered a covered species. Each climate map and full LENZ data map were extracted using the PAN-

NZ map as a mask so that only distributions in the protected areas were left. The total numbers of cells of a species range in the extracted maps was subtracted from the total number of cells of a species range before the extraction to calculate the area of range that is protected. Species with over 50% of their range in a protected area were deemed to be adequately represented by the PAN-NZ.

3.5 Analysis

Maps were visualised, formatted and examined in ArcMap. All data was analysed and all graphs were produced using the statistical software program R, except Fig.4 "Ranges (ha) included in PAN-NZ for each species from the full LENZ models and the climate models", which was produced using Excel. Statistical significance was decided at P=<0.05 and means were presented as ± standard deviation (SD). Pterostichini diversity was plotted against Carabid diversity to determine if there was any correlation. Paired t-test was used to check for differences between range sizes from the full LENZ model and climate model. Correlations between environmental variables were identified using the cor function, categorical variables were ordered so it was possible to check for correlations between categorical and continuous variables. The significance of these correlations was calculated using cor.test and specifying spearmans rank to account for continuous and categorical variables.

4. Results

4.1 Pterostichini representativeness

Pterostichini species richness was strongly and positively correlated with Carabidae species richness across the Crosby Regions (Fig. 1; correlation; $R^2=0.25$, $P=0.005$).

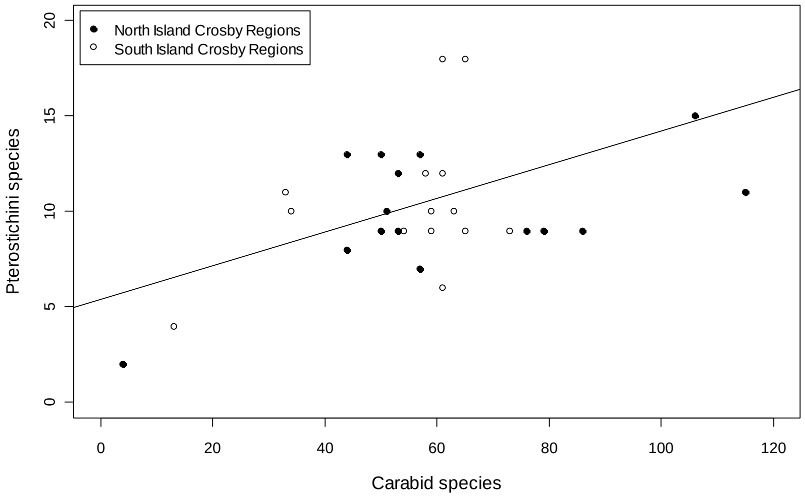

Fig. 1. Carabid species numbers plotted against Pterostichini species numbers for each Crosby Region

This result confirms that Pterostichini follow the same pattern of diversity as the Carabid population in both North and South Island and are a good representative of the family.

4.2 Models

Two models were fitted to each of the 67 species of Pterostichini (median number of museum records per species = 12, full range of records = 2 – 233). One model used the full LENZ data and the other model used only the climate data The full LENZ data models gave consistently higher AUC scores than the climate models (full LENZ model; mean±SD = 0.99±0.01, climate model; mean±SD = 0.97±0.04). Although the scores for both only slightly differ, and are very high values with very little deviation showing the accuracy of MaxEnt for mapping species distribution.

Patterns of diversity on the species richness maps show highest number of species occurring in central and eastern South Island. The climate map (Fig. 2b) shows a slightly bigger distribution of species rich areas in comparison with the full model map (Fig. 2a) and the ranges predicted by the two models differ significantly (paired t-test; *P*=<0.001). In South Island the maps follow the same geographical pattern of species richness occurrence, however, in the North Island there are evident differences in patterns between the maps. The full LENZ map identifies high species numbers around the Turangi and Palmerston North areas where the climate map does not. Overall in South Island the maps concur with the general pattern of Carabid diversity in New Zealand identified by Crosby *et al* (1998). However just as the maps from the models show discordance in the North Island they also follow the Crosby Regions less closely.

Very low species numbers occur in areas of protected land on either North or South Island seen by the mostly blue areas within the protected areas (Figs 2c and 2d). Concurrently there are high species numbers in the unprotected areas indicated by the red areas (Figs 2e and 2f). Despite the full model being likely to slightly underestimate species distributions it is more accurate to use the full model maps when making statements about distributions and diversity patterns.

The correlation tests between variables revealed high correlations between climate variables and the response of climate to a change in landform were correlated (Appendix 8.4). For example as altitude increases the mean annual temperature decreases (cor = -0.91, *P* =<0.001). However, these correlations do not highlight any unusual circumstances regarding the distributions of Carabids.

4.3 Protected Areas Network

Just ten out of 67 modelled species (15% of species) using only climate variables had more than 50% of their range covered by protected land. Nine of these species were covered to the same extent when modelled using the full LENZ data of climate, landform and soil variables.

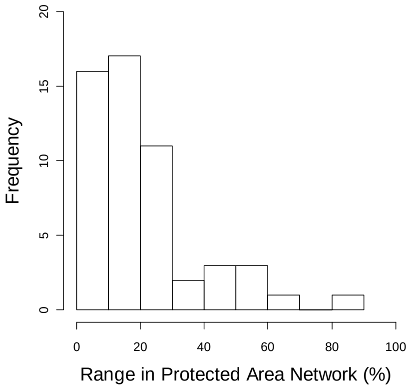

Fig. 3. Frequency of the percentage of ranges in Protected Area Network, using values from the full LENZ model

Just as the range sizes predicted by the climate and full LENZ models differ significantly in size, it also appears that they predict very different range sizes included in PAN-NZ for each species (Fig. 4). The climate models predict a far greater range included in PAN-NZ, for example in the case of *Holcaspis dentifera* there are millions of hectares difference.

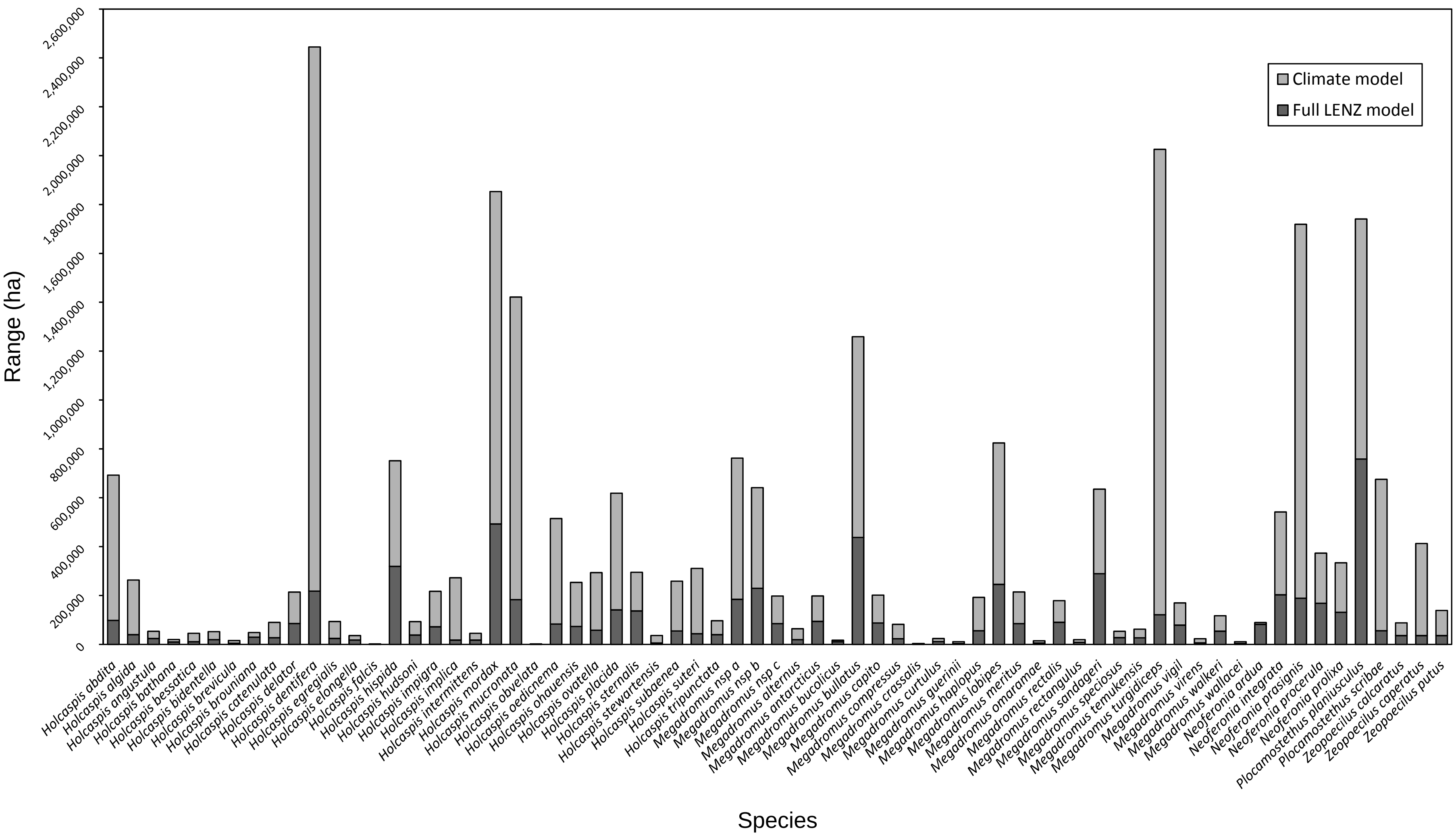

Fig. 4. Ranges (ha) included in PAN-NZ for each species from the full LENZ models and the climate models

Extra species data not used in the models should also be considered. *Onawea pantomelas* is confined to the Banks Peninsula on South Island which has very little protected land. However, most samples were collected from Ahuriri Scenic Reserve (Johns, 2007) and due to its continued survival the few reserves there may be adequate but this cannot be quantified by this study. *Gourlayia regia* which is endemic to Three Kings Islands is protected and the inclusion of this species makes the figures reach 11 and ten out of 68 species with more than 50% of their range in protected areas. These results show that the majority of Pterostichini species are either not protected or protected only to a small extent.

Ten of the species with less than 50 % of their range inside protected areas are listed on the threatened species lists (Appendix 8.7). However due to lack of taxonomic information some species on the list are not given Latin names, meaning described species which were used in the models may be some of the unnamed species which are on the list, and the figure could actually be up to 19 species. This means that there are up to 57 species from the study set that have less than 50% of their range covered by protected areas and are not on the threatened species list. However there were several more species that could not be included in this study. With the addition of these species the potential figure is 75 species of Pterostichini without 50% of their range in a protected area.

5. Discussion

Analysis of the Crosby Regions shows that we are justified in using Pterostichini as a representative of Carabidae as their patterns of diversity closely follow the patterns of New Zealand Carabid diversity. Considering the majority of Carabidae have similar ecological requirements it is fairly justified to generalise these findings from Pterostichini to other tribes.

Pterostichini are a good representative of Carabidae in both North and South Island; however there are apparent differences in the full model and climate maps of North Island. These differences are also seen when comparing the maps with the Crosby Regions. This could be due to the fact that there was less sampling effort there. However MaxEnt is designed to work with presence only data and should have been able to compensate for this. *Aulacopodus* was not included in the models due to lack of information and sample localities, however the Crosby Regions show that 3 out of 4 species from this genus occur in the North Island (Crosby et al 1998). If these species had been included in the models this would perhaps have given a clearer picture of Pterostichini distributions in the North Island. Additionally the Crosby Regions show *Psegmatopterus politissimus* occurs in both North and South Island and may have helped to sharpen the picture in North Island.

Most areas of high species richness lie outside of PAN-NZ. For this particular tribe the majority of these areas lie along central and eastern South Island which has very little protected land in comparison with the west, on the other side of the Alpine fault. There are also several smaller areas of high species richness in North Island occurring in central and southern areas. Very few of the species are anthropophilic (S=5) and yet their highest concentrations are central and east coast of South Island where the highest human populations occur. When people first settled in New Zealand land was extensively cleared to make it more suitable for farming. Lowland areas were the worst hit and the remaining forest cover is in upland mountainous regions (McGlone 1989). Current protected areas include places where indigenous vegetation has been left, however this means that protected areas are in mountainous regions which are clearly unsuitable for Pterostichini species. Rodrigues *et al* (2004a) recognized that many protected area networks were in places of less economic value leaving other ecosystems without enough protection and this appears to be the case in New Zealand. Only a few species are adequately encompassed by PAN-NZ according to guidelines decided by Rodrigues et al (2004b); species with a range of less than 100,000 hectares should have 100% of their range in protected areas. The only species which came close to fulfilling this requirement was *Plocamostethus scribae* which has 98% of its range in PAN-NZ. However taking into consideration that invertebrates can have viable populations in much smaller areas than vertebrates the guidelines set out by this study are at least 50% in PAN-NZ, so other protected species with ranges less than 100,000 hectares are *Neoferonia ardua*, *Holcaspis stewartensis* and *Megadromus speciosus*. However most species have ranges over 100,000 hectares and this leaves the majority of Pterostichini species unprotected as little of their range is in PAN-NZ (Appendix 8.6).

A study by Walker *et al* (2006) identified areas of New Zealand where indigenous cover has recently been lost and is under threat of continued loss. Areas classed as chronically and acutely threatened correspond with the areas of highest Pterostichini species richness shown by the models. New Zealand Carabidae are predominantly silvicolous and evolved to live in the forest environment which thrived before the arrival of people. Vegetation cover before human settlement (Appendix 8.8) shows that many of the areas high in Pterostichini diversity were covered with indigenous forest. The Banks Peninsula used to be densely covered in forest which is where many species of Carabid are found despite the fact that it is now heavily populated by humans and has little remaining forest cover. A map of present day loss of indigenous vegetation shows the areas of high species richness appear to be the worst hit (Appendix 8.9). Many areas of tall-tussock grassland, the second most common Carabid habitat (Larochelle & Lariviere 2001), are classed as ‘critically under-protected’ and ‘under-protected’ (Walker *et al* 2006). Historically a forest-grassland cycle occurred every 1-2 thousand years where large areas of scrub and forest were burnt off by natural causes, afterwards tussock grassland colonised these areas and natural succession meant the forest grew back (Ashdown & Lucas 1987). With the advent of human settlers this cycle was disrupted; human fires allowed tussock grassland to colonise many more areas and forest was never allowed to grow back (Ashdown & Lucas 1987). These areas that were formerly forest are now predominantly tussock grassland (Molloy *et al* 1962) and an important habitat for Carabids.

It appears that the west coast would be an ideal place for Carabids to colonise with its large areas of protected forest and limited human disturbance. Carabids in New Zealand are generally flightless causing limited dispersal capabilities (Larochelle & Lariviere 2007) which could be why they have not yet colonised the west of South Island which appears, in terms of habitat, to be suitable. Another barrier to their dispersal may be the Alpine Fault which divides the east and west of South Island. However, both the climate and the full model showed that the conditions were not right for species to survive in the west of South Island. Thus it is not habitat alone which makes an area suitable for Pterostichini species and their occurrence in human populated areas could be due to an intolerance of the climatic conditions, so they cannot migrate to the other side of the island. If the climate did become suitable it is possible that the mountain range may not pose a barrier over time as erosion causing mountain passes to form has allowed other species to migrate across this mountain range (Craw *et al* 2008).

Modelling of species distribution is often done using only climate variables, known as climate envelope models (Hijmans and Graham 2006; Pearson and Dawson 2003). However comparing the results of the two models we can see that using climate alone is not enough to accurately predict a species distribution. Beale et al (2008, 2009) found that climate envelope models were unlikely to reliably predict the distribution of a species in response to climate. The results of this study show contradict this as the climate model tends to follow the same pattern as the full LENZ model but just over-estimates range size. However this significant difference between the range sizes the models predicted gives further credence to the finding that climate alone is not enough to rely upon. The great difference in species range sizes included in PAN-NZ also highlights an important issue regarding conservation planning. Just using climate models does not provide a detailed enough picture to adequately determine which areas are suitable for species survival and so should not be used in conservation planning. A more detailed picture of climate, landform and soil features needs to be used for use in this sort of analysis. The development of LENZ, the first collection of ecosystem information based on climate, landform and soil data layers for New Zealand makes it the best source of information to map species distributions. It is the most comprehensive information available to date regarding what influences a species distribution. Despite this, it is questionable as to how applicable LENZ is to invertebrate species. Walker *et al* (2006) note that using LENZ may not distinguish between small-scale ecosystems which can support very high numbers of indigenous species. Therefore the information, although it is the best there is at this time, can be considered to be of relatively coarse scale as specific microclimates are often needed to provide species with their required habitat.

The full data models predicted distributions that were very scattered; some were just single cells one hectare in size with no adjacent suitable land, rather than the large tracts of land as predicted by the climate models. The New Zealand Ministry for the Environment advises that successful habitat conservation for invertebrates, due to their small size, can mean conserving as little one hectare of native forest, scrub or tussock. This strategy should be approached with caution as small isolated populations are susceptible to stochastic events which could severely damage their viability. Many of the species used in this study are not only endemic but are confined to particular areas. For example *Holcaspis brevicula* is a little known and threatened species, found in only one area of fragmented forest in the Canterbury Plains (Brockerhoff *et al* 2005). The case of *H. brevicula* shows that in some cases a small area of protected land dedicated to the species is better than nothing at all. The one hectare areas identified by the models as suitable for Carabid species should not be dismissed as being too small or isolated from other suitable areas. On the other hand, although an area may be environmentally suitable and provide a habitat protected from human disturbance there are other issues which need to be taken into consideration and cannot be accounted for in these models. Predation and inter-specific competition can make such an area unsuitable for a species to maintain its population and to make more accurate predictions of species ranges we need to incorporate these biotic interactions (Guisan et al 2006). Therefore species distribution models can provide the basis for deciding on suitable areas for PAN-NZ but more work needs to be done to address the other issues affection conservation of species.

Due to the representativeness of Pterostichini it is evident that areas of high Carabid diversity are not well represented by PAN-NZ. Protected areas of land are not chosen using factors that influence Carabid distributions and do not work for the conservation of Carabid species and the protection of their habitat. Although the total land area of New Zealand cannot be designated as protected land the findings of this study help to identify gaps and show areas which should be given more consideration for protection.

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8. Appendices

8.1 Crosby regions and species numbers used to calculate Pterostichini diversity

Crosby Region	Island	Carabid Species	Pterostichini Species
Auckland (AK)	North	86	9
Bay of Plenty (BP)	North	73	9
Buller (BR)	South	79	9
Central Otago (CO)	South	65	18
Coromandel (CL)	North	57	7
Dunedin (DN)	South	61	18
Fjordland (FD)	South	50	9
Gisborne (GB)	North	54	9
Hawke's Bay (HB)	North	57	13
Kaikoura (KA)	South	34	10
Mackenzie (MK)	South	44	8
Marlborough (MB)	South	65	9
Marlborough Sounds (SD)	South	53	9
Mid Canterbury (MC)	South	94	23
Nelson (NN)	South	115	11
North Canterbury (NC)	South	59	10
Northland (ND)	North	76	9
Otago Lakes (OL)	South	63	10
Rangitikei (RI)	North	44	13
South Canterbury (SC)	South	33	11
Southland (SL)	South	50	13
Stewart Island (SI)	South	13	4
Taranaki (TK)	North	53	12
Taupo (TO)	North	59	9
Three Kings Islands	North	4	2
Waikato (WO)	North	61	12
Wairarapa (WA)	North	51	10
Wanganui (WI)	North	58	12
Wellington (WN)	North	106	15
Westland (WD)	South	61	6

8.2 Full list of Pterostichini species

Species	Status	Included in models
Aulacopodus brouni (Csiki, 1930)	Endemic	N
Aulacopodus calathoides (Broun, 1886)	Endemic	N
Aulacopodus maorinus (Bates, 1874)	Endemic	N
Aulacopodus sharpianus (Broun, 1893)	Endemic	N
Gourlayia regia Britton, 1964	Endemic	N
Holcaspis abdita Johns, 2003	Endemic	Y
Holcaspis algida Britton, 1940	Endemic	Y
Holcaspis angustula (Chaudoir, 1865)	Endemic	Y
Holcaspis bathana Butcher, 1984	Endemic	Y
Holcaspis bessatica Johns, 2003	Endemic	Y
Holcaspis bidentella Johns, 2003	Endemic	Y
Holcaspis brevicula Butcher, 1984	Endemic	Y
Holcaspis brouniana (Sharp, 1886)	Endemic	Y
Holcaspis catenulata Broun, 1882	Endemic	Y
Holcaspis delator (Broun, 1893)	Endemic	Y
Holcaspis dentifera (Broun, 1880)	Endemic	Y
Holcaspis egregialis (Broun, 1917)	Endemic	Y
Holcaspis elongella (White, 1846)	Endemic	Y
Holcaspis falcis Butcher, 1984	Endemic	Y
Holcaspis hispida (Broun, 1877)	Endemic	Y
Holcaspis hudsoni Britton, 1940	Endemic	Y
Holcaspis impigra Broun, 1886	Endemic	Y
Holcaspis implica Butcher, 1984	Endemic	Y
Holcaspis intermittens (Chaudoir, 1865)	Endemic	Y
Holcaspis mordax Broun, 1886	Endemic	Y
Holcaspis mucronata Broun, 1886	Endemic	Y
Holcaspis obvelata Johns, 2003	Endemic	Y
Holcaspis odontella (Broun, 1908)	Endemic	N
Holcaspis oedicnema Bates, 1874	Endemic	Y
Holcaspis ohauensis Butcher, 1984	Endemic	Y
Holcaspis ovatella (Chaudoir, 1865)	Endemic	Y
Holcaspis placida Broun, 1881	Endemic	Y
Holcaspis sinuiventris (Broun, 1908)	Endemic	N
Holcaspis sternalis Broun, 1881	Endemic	Y
Holcaspis stewartensis Butcher, 1884	Endemic	Y
Holcaspis subaenea (Guérin-Méneville, 1841)	Endemic	Y
Holcaspis suteri (Broun, 1893)	Endemic	Y
Holcaspis tripunctata Butcher, 1984	Endemic	Y
Holcaspis vagepunctata (White, 1846)	Endemic	N
Holcaspis vexata (Broun, 1908)	Endemic	N
Megadromus nsp A (Johns, pers. comm.)	Endemic	Y
Megadromus nsp B (Johns, pers. comm.)	Endemic	Y
Megadromus nsp C (Johns, pers. comm.)	Endemic	Y
Megadromus alternus (Broun, 1886)	Endemic	Y
Megadromus antarcticus (Chaudoir, 1865)	Endemic	Y
Megadromus asperatus (Broun, 1886)	Endemic	N

Megadromus bucolicus (Broun, 1903)	Endemic	Y
Megadromus bullatus (Broun, 1915)	Endemic	Y
Megadromus capito (White, 1846)	Endemic	Y
Megadromus compressus (Sharp, 1886)	Endemic	Y
Megadromus crassalis (Johns, pers. comm.)	Endemic	Y
Megadromus curtulus (Broun, 1884)	Endemic	Y
Megadromus enysi (Broun, 1882)	Endemic	N
Megadromus fultoni (Broun, 1882)	Endemic	N
Megadromus guerinii (Chaudoir, 1865)	Endemic	Y
Megadromus haplopus (Broun, 1893)	Endemic	Y
Megadromus lobipes (Bates, 1878)	Endemic	Y
Megadromus memes (Broun, 1903)	Endemic	N
Megadromus meritus (Broun, 1884)	Endemic	Y
Megadromus omaramae Johns, 2007	Endemic	Y
Megadromus rectalis (Broun, 1881)	Endemic	Y
Megadromus rectangulus (Chaudoir, 1865)	Endemic	Y
Megadromus sandageri (Broun, 1893)	Endemic	Y
Megadromus speciosus Johns, 2007	Endemic	Y
Megadromus temukensis (Bates, 1878)	Endemic	Y
Megadromus turgidiceps (Broun, 1908)	Endemic	Y
Megadromus vigil (White, 1846)	Endemic	Y
Megadromus virens (Broun, 1886)	Endemic	Y
Megadromus walkeri (Broun, 1903)	Endemic	Y
Megadromus wallacei (Broun, 1912)	Endemic	Y
Neoferonia ardua (Broun, 1893)	Endemic	Y
Neoferonia edax (Chaudoir, 1878)	Endemic	N
Neoferonia fossalis (Broun, 1914)	Endemic	N
Neoferonia integrata (Bates, 1878)	Endemic	Y
Neoferonia prasignis (Broun, 1903)	Endemic	Y
Neoferonia procerula (Broun, 1886)	Endemic	Y
Neoferonia prolixa (Broun, 1880)	Endemic	Y
Neoferonia straneoi Britton, 1940	Endemic	N
Neoferonia truncatula (Broun, 1923)	Endemic	N
Onawea pantomelas (Blanchard, 1843)	Endemic	N
Plocamostethus planiusculus (White, 1846)	Endemic	Y
Plocamostethus scribae Johns, 2007	Endemic	Y
Prosopogmus oodiformis (Macleay, 1871)	Introduced	N
Psegmatopterus politissimus (White, 1846)	Endemic	N
Rhytisternus liopleurus (Chaudoir, 1865)	Introduced	N
Rhytisternus miser (Chaudoir, 1865)	Introduced	N
Zeopoecilus calcaratus (Sharp, 1886)	Endemic	Y
Zeopoecilus caperatus Johns, 2007	Endemic	Y
Zeopoecilus putus (Broun, 1882)	Endemic	Y

(Larochelle and Lariviere 2007)

8.3 AUC scores from MaxEnt output for each species

Species	Full LENZ data models	Climate data models
Holcaspis abdita	0.998	0.969
Holcaspis algida	0.996	0.984
Holcaspis angustula	0.988	0.978
Holcaspis bathana	1	0.998
Holcaspis bessatica	0.998	0.965
Holcaspis bidentella	0.997	0.962
Holcaspis brevicula	0.998	0.983
Holcaspis brouniana	0.998	0.972
Holcaspis catenulata	0.994	0.976
Holcaspis delator	0.987	0.965
Holcaspis dentifera	0.992	0.846
Holcaspis egregialis	0.998	0.976
Holcaspis elongella	0.998	0.992
Holcaspis falcis	1	0.999
Holcaspis hispida	0.986	0.858
Holcaspis hudsoni	0.988	0.981
Holcaspis impigra	0.991	0.974
Holcaspis implica	0.996	0.945
Holcaspis intermittens	0.998	0.991
Holcaspis mordax	0.975	0.845
Holcaspis mucronata	0.971	0.858
Holcaspis obvelata	1	0.999
Holcaspis oedicnema	1	0.99
Holcaspis ohauensis	0.999	0.974
Holcaspis ovatella	0.994	0.944
Holcaspis placida	0.994	0.964
Holcaspis sternalis	0.971	0.954
Holcaspis stewartensis	1	0.999
Holcaspis subaenea	0.992	0.955
Holcaspis suteri	1	0.984
Holcaspis tripunctata	1	0.981
Megadromus nsp A	0.991	0.952
Megadromus nsp B	0.995	0.984
Megadromus nsp C	0.979	0.955
Megadromus alternus	0.997	0.995
Megadromus antarcticus	0.989	0.985
Megadromus bucolicus	1	1
Megadromus bullatus	0.967	0.938
Megadromus capito	0.96	0.942
Megadromus compressus	0.999	0.932
Megadromus crassalis	1	0.999
Megadromus curtulus	1	1

Megadromus guerinii	1	0.998
Megadromus haplopus	0.996	0.967
Megadromus lobipes	0.993	0.977
Megadromus Meritus	0.99	0.981
Megadromus omaramae	1	0.996
Megadromus rectalis	0.988	0.987
Megadromus rectangulus	0.998	0.987
Megadromus sandageri	0.988	0.98
Megadromus speciosus	1	1
Megadromus temukensis	0.999	0.995
Megadromus turgidiceps	0.994	0.92
Megadromus vigil	0.993	0.986
Megadromus virens	0.999	0.978
Megadromus walkeri	0.997	0.994
Megadromus wallacei	0.999	0.996
Neoferonia ardua	1	0.998
Neoferonia integrata	0.992	0.987
Neoferonia prasignis	0.999	0.948
Neoferonia procerula	0.975	0.96
Neoferonia prolixa	1	0.966
Plocamostethus planiusculus	0.95	0.94
Plocamostethus scribae	0.999	0.983
Zeopoecilus calcaratus	0.998	0.991
Zeopoecilus caperatus	1	0.987
Zeopoecilus putus	0.997	0.993

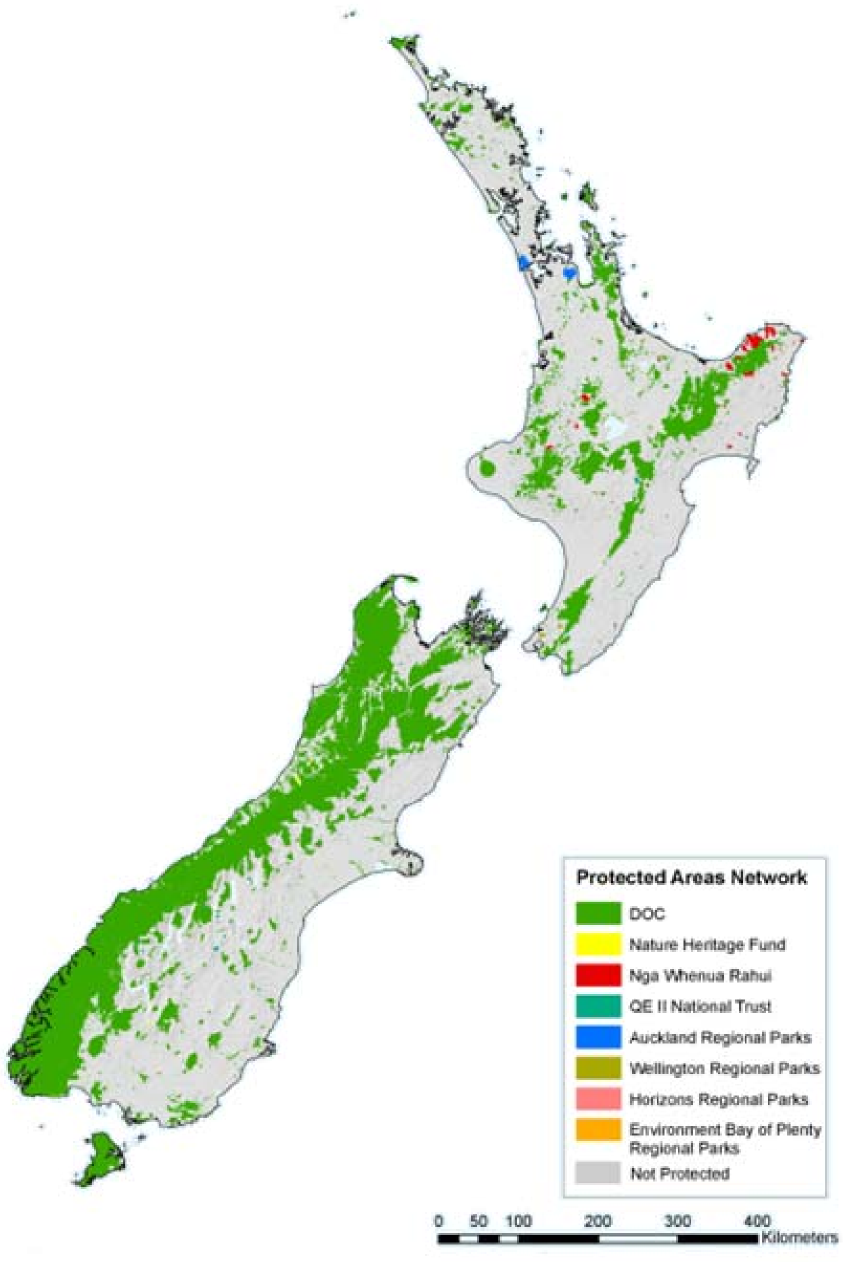
8.4 Correlation values for each environmental variable

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.00	0.15	0.01	0.25	0.18	0.15	0.23	0.09	-0.04	-0.12	-0.06	0.02	-0.20	-0.08	-0.13	0.25
2	0.15	1.00	0.16	0.05	0.43	-0.15	0.19	0.36	-0.04	-0.02	-0.14	0.34	-0.03	0.28	-0.08	-0.11
3	0.01	0.16	1.00	-0.12	0.04	-0.44	0.14	0.32	-0.05	-0.02	**-0.91**	0.33	0.39	0.42	**-0.78**	-0.48
4	0.25	0.05	-0.12	1.00	0.18	0.19	-0.12	-0.09	-0.05	-0.03	0.09	-0.21	-0.17	-0.19	0.11	0.10
5	0.18	0.43	0.04	0.18	1.00	-0.06	0.37	0.25	-0.03	0.01	-0.04	0.22	-0.01	0.05	-0.02	-0.10
6	0.15	-0.15	-0.44	0.19	-0.06	1.00	-0.14	-0.20	0.14	0.16	0.43	-0.32	-0.55	-0.29	0.26	0.57
7	0.23	0.19	0.14	-0.12	0.37	-0.14	1.00	0.29	0.17	0.17	-0.06	0.29	0.04	0.24	-0.09	0.02
8	0.09	0.36	0.32	-0.09	0.25	-0.20	0.29	1.00	-0.11	-0.03	-0.33	**0.82**	0.12	0.45	-0.25	-0.18
9	-0.04	-0.04	-0.05	-0.05	-0.03	0.14	0.17	-0.11	1.00	**0.83**	0.42	-0.07	-0.18	0.07	0.30	0.39
10	-0.12	-0.02	-0.02	-0.03	0.01	0.16	0.17	-0.03	**0.83**	1.00	0.36	0.02	-0.16	0.12	0.20	0.39
11	-0.06	-0.14	**-0.91**	0.09	-0.04	0.43	-0.06	-0.33	0.42	0.36	1.00	-0.32	-0.39	-0.33	**0.86**	0.54
12	0.02	0.34	0.33	-0.21	0.22	-0.32	0.29	**0.82**	-0.07	0.02	-0.32	1.00	0.22	0.46	-0.25	-0.21
13	-0.20	-0.03	0.39	-0.17	-0.01	-0.55	0.04	0.12	-0.18	-0.16	-0.39	0.22	1.00	0.25	-0.19	**-0.69**
14	-0.08	0.28	0.42	-0.19	0.05	-0.29	0.24	0.45	0.07	0.12	-0.33	0.46	0.25	1.00	-0.17	-0.25
15	-0.13	-0.08	**-0.78**	0.11	-0.02	0.26	-0.09	-0.25	0.30	0.20	**0.86**	-0.25	-0.19	-0.17	1.00	0.24
16	0.25	-0.11	-0.48	0.10	-0.10	0.57	0.02	-0.18	0.39	0.39	0.54	-0.21	**-0.69**	-0.25	0.24	1.00

1 = Acid soluble phosphate
2 = Age
3 = Altitude
4 = Exchangeable calcium
5 = Chemical limitations to plant growth
6 = Annual rainfall deficit
7 = Drainage
8 = Induration

9 = June solar radiation
10 = Mean annual solar radiation
11 = Mean annual temperature
12 = Particle size
13 = Ratio of rainfall to potential evaporation
14 = Slope
15 = July minimum temperature
16 = Vapour pressure deficit

8.5 Protected areas of New Zealand (PAN-NZ)



(Rutledge *et al* 2007)

8.6 Species ranges predicted by models

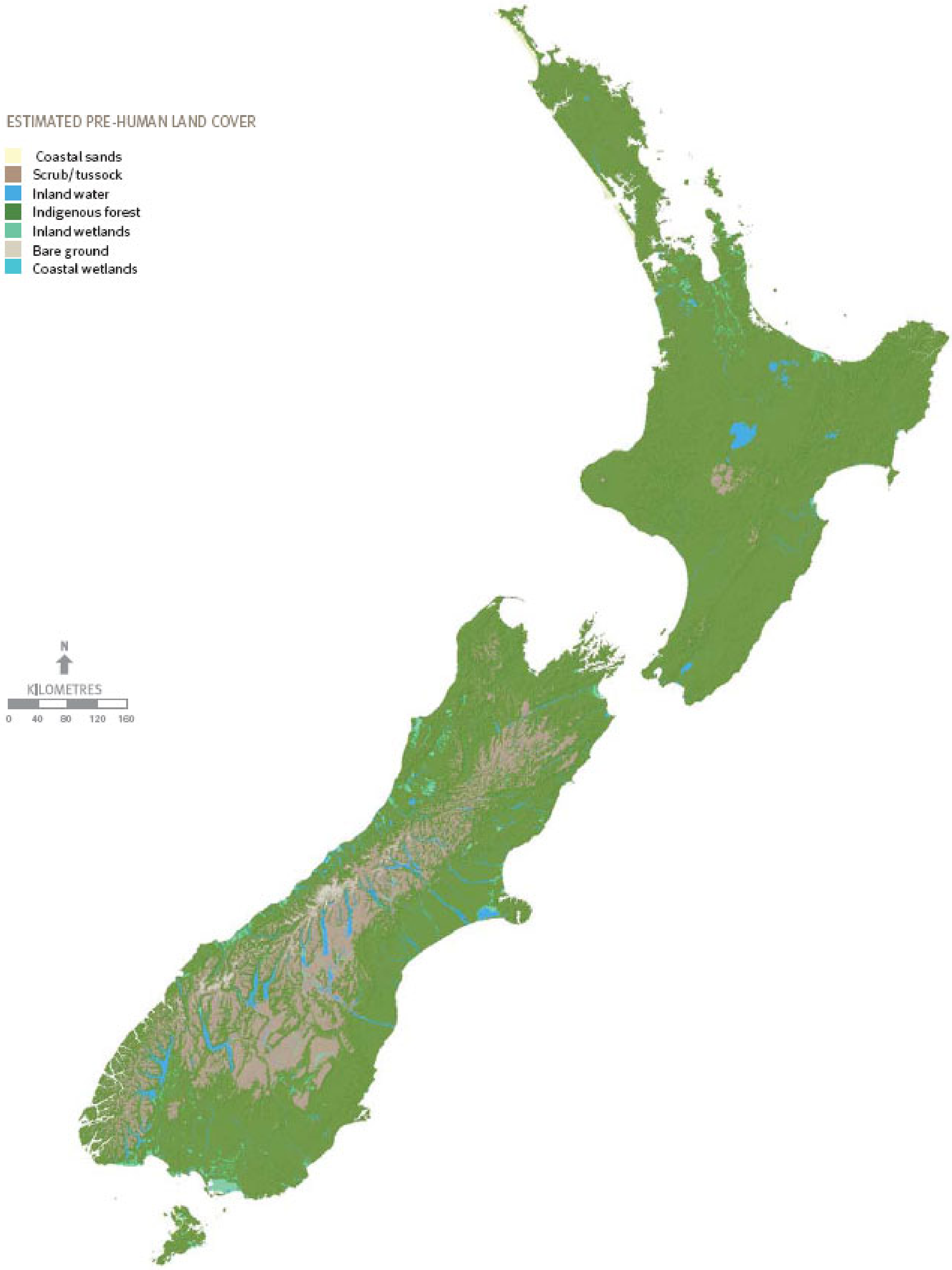
	Full LENZ models			Climate models		
Species	Range predicted by models (ha)	Range included in protected areas (ha)	Range included in protected areas (%)	Range predicted by models (ha)	Range included in protected areas (ha)	Range included in protected areas (%)
Holcaspis abdita	323,944	98,060	30	2,337,984	594,355	25
Holcaspis algida	318,766	39,569	12	867,232	223,438	26
Holcaspis angustula	649,621	23,780	4	888,262	29,481	3
Holcaspis bathana	66,446	9,825	15	130,327	9,880	8
Holcaspis bessatica	305,113	10,310	3	1,045,636	34,726	3
Holcaspis bidentella	497,170	19,387	4	1,334,058	32,539	2
Holcaspis brevicula	497,170	4,650	1	469,542	11,054	2
Holcaspis brouniana	356,324	29,594	8	525,897	18,959	4
Holcaspis catenulata	367,058	27,288	7	971,930	62,378	6
Holcaspis delator	405,617	85,349	21	745,728	128,390	17
Holcaspis dentifera	747,728	218,192	29	6,105,214	2,226,847	36
Holcaspis egregialis	156,236	24,543	16	794,638	68,936	9
Holcaspis elongella	303,576	18,061	6	226,114	18,027	8
Holcaspis falcis	44,677	740	2	41,095	1,191	3
Holcaspis hispida	1,852,440	318,822	17	4,657,206	432,538	9
Holcaspis hudsoni	417,903	38,071	9	713,021	54,848	8
Holcaspis impigra	326,885	71,767	22	731,869	145,393	20
Holcaspis implica	375,778	17,355	5	2,407,595	255,147	11
Holcaspis intermittens	353,831	17,355	5	629,539	27,893	4
Holcaspis mordax	2,109,132	492,866	23	5,854,288	1,359,956	23
Holcaspis mucronata	1,370,128	182,818	13	6,806,935	1,238,608	18
Holcaspis obvelata	70,794	1,147	2	33,571	583	2
Holcaspis oedicnema	123,714	83,478	67	597,675	431,281	72
Holcaspis ohauensis	480,664	73,238	15	1,453,727	180,358	12
Holcaspis ovatella	358,639	58,007	16	1,533,518	235,768	15
Holcaspis placida	870,696	140,807	16	2,451,480	477,868	19
Holcaspis sternalis	937,229	137,062	15	1,296,034	157,902	12
Holcaspis stewartensis	10,070	5,677	56	47,472	30,774	65
Holcaspis subaenea	595,296	54,794	9	2,531,330	203,733	8
Holcaspis suteri	184,708	43,216	23	796,241	267,656	34
Holcaspis tripunctata	307,622	39,343	13	715,974	57,308	8
Megadromus nsp a	456,008	184,560	40	1,559,125	577,565	37
Megadromus nsp b	560,970	229,599	41	875,565	411,774	47
Megadromus nsp c	706,936	84,873	12	1,286,299	113,028	9
Megadromus alternus	282,582	19,420	7	551,622	44,406	8
Megadromus antarcticus	693,926	94,065	14	775,921	104,058	13
Megadromus bucolicus	38,135	10,298	27	32,452	6,739	21
Megadromus bullatus	1,013,151	437,329	43	1,721,217	821,619	48

Megadromus capito	1,306,216	87,666	7	1,557,048	113,805	7
Megadromus compressus	178,749	22,770	13	936,176	59,203	6
Megadromus crassalis	91,034	2,348	3	65,525	1,074	2
Megadromus curtulus	50,362	11,331	22	73,109	12,329	17
Megadromus guerinii	99,395	3,555	4	106,596	7,570	7
Megadromus haplopus	312,151	55,523	18	1,632,512	136,565	8
Megadromus lobipes	406,849	245,467	60	899,130	578,933	64
Megadromus meritus	318,846	84,576	27	455,263	129,538	28
Megadromus omaramae	82,569	5,522	7	200,708	8,952	4
Megadromus rectalis	584,104	90,275	15	581,317	88,532	15
Megadromus rectangulus	232,265	8,119	3	517,879	11,262	2
Megadromus sandageri	692,660	289,116	42	860,835	346,167	40
Megadromus speciosus	55,129	27,511	50	47,202	25,687	54
Megadromus temukensis	231,021	26,825	12	470,356	35,513	8
Megadromus turgidiceps	465,661	121,144	26	6,577,498	1,904,867	29
Megadromus vigil	368,888	78,877	21	446,472	90,930	20
Megadromus virens	180,854	5,762	3	765,988	17,017	2
Megadromus walkeri	261,964	54,054	21	294,031	62,875	21
Megadromus wallacei	64,747	3,942	6	126,485	6,992	6
Neoferonia ardua	99,612	82,149	82	121,630	6,992	6
Neoferonia integrata	344,887	202,577	59	601,492	339,043	56
Neoferonia prasignis	495,122	189,058	38	3,038,349	1,530,055	50
Neoferonia procerula	832,346	168,405	20	1,288,532	205,024	16
Neoferonia prolixa	157,245	131,479	84	221,416	202,266	91
Plocamostethus planiusculus	1,376,728	758,166	55	1,564,443	982,773	63
Plocamostethus scribae	56,767	55,666	98	625,970	619,883	99
Zeopoecilus calcaratus	132,758	35,801	27	206,180	52,142	25
Zeopoecilus caperatus	374,744	35,801	10	726,248	376,614	52
Zeopoecilus putus	214,711	35,801	17	309,343	102,805	33

8.7 Pterostichini on the Threatened Species Lists (Hitchmough et al 2005)

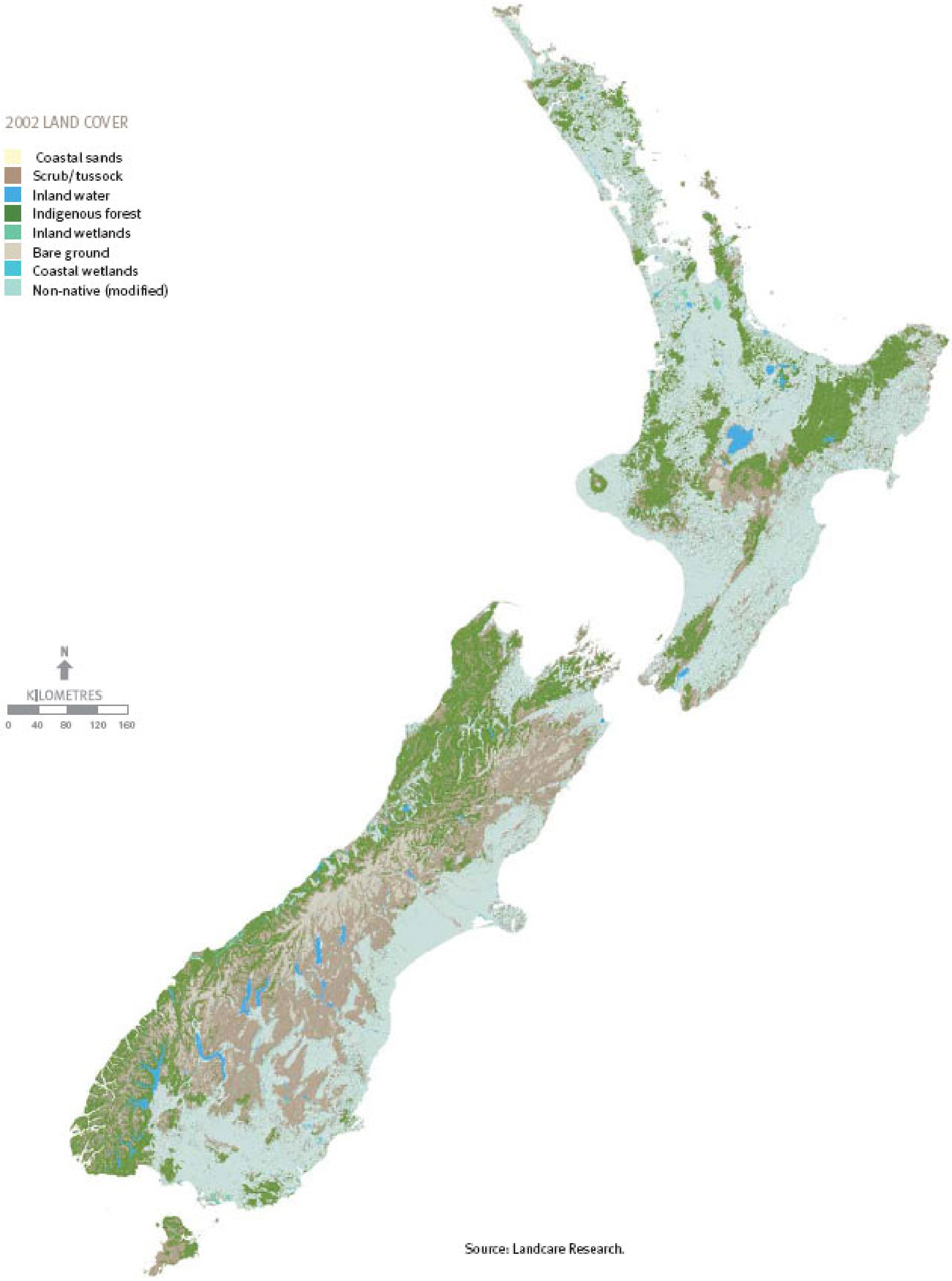
Species	Included in study
Holcaspis abdita	Y
Holcaspis bathana	Y
Holcaspis bidentella	Y
Holcaspis brevicula	Y
Holcaspis falcis	Y
Holcaspis new species	N
Megadromus antarcticus	Y
Megadromus bucolicus	Y
Megadromus compressus	Y
Megadromus fultoni	N
Megadromus haplopus	Y
Megadromus nsp	N
Megadromus nsp	N
Megadromus nsp	N
Megadromus nsp	N
Megadromus nsp	N
Megadromus omaramae	Y
Zeopoecilus species	N
Zeopoecilus species	N
Zeopoecilus species	N

8.8 Estimated pre-human land cover



(Landcare research, Accessed August 2009)

8.9 Present day land cover (from year 2002)



Source: Landcare Research.

(Landcare research, Accessed August 2009)