

**Linkages Between Climate Change and Biodiversity  
in New Zealand**

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## Contents

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Summary .....	5
1. Introduction .....	7
2. Background .....	7
3. Objectives .....	8
4. Recent and Projected Future Climate Change in New Zealand .....	8
4.1 Recent changes.....	8
4.2 Projected change in New Zealand.....	8
5. New Zealand Biodiversity.....	9
5.1 What is biodiversity? .....	9
5.2 Current state of New Zealand biodiversity .....	10
5.3 Factors reducing biodiversity.....	10
5.4 Value of biodiversity.....	11
6. Timescales, Climate Change and Biodiversity.....	11
6.1 Long-term climate change effects on biodiversity.....	12
6.2 Short-term climate change and biodiversity .....	13
Current biotic response to climate change.....	13
7. Predicted Biodiversity Changes in the Short Term .....	14
7.1 Predictive models and empirical relationships.....	14
7.2 Range and distribution changes .....	16
Lowland plants.....	16
Freshwater species .....	16
Alpine zone.....	17
Management implications of range changes.....	18
7.3 Ecosystem functioning changes .....	19
8. Biodiversity Effects of Changing Climate Extremes .....	19
9. Climate Change Interactions with other Factors Affecting Biodiversity .....	21
9.1 Predation by introduced mammals and invertebrates .....	21
9.2 Herbivory .....	22
9.3 Competitive replacement by exotic species.....	22
9.4 Loss of specialised pollinators and dispersers .....	23
9.5 Habitat loss.....	23
9.6 Fire .....	24
9.7 Fragmentation .....	24
9.8 Nutrient changes .....	25
9.9 Toxins and herbicides .....	25
10. Biodiversity and Greenhouse Gas Mitigation Strategies .....	25

11.	Links with International Frameworks and Activities .....	27
12.	Conclusions and Recommendations.....	28
	12.1 Research needs .....	28
	12.2 Policy recommendations .....	29
13.	Acknowledgements .....	30
14.	References .....	30

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## Summary

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The following advice to Government on linkages between biodiversity and climate change was prepared by Landcare Research, Lincoln, for the Ministry for the Environment in June – August 2001.

1. There is a strong possibility that the climate of New Zealand will change substantially over the next 100 years, and this will inevitably impact on indigenous biodiversity and ecosystem functioning through the direct effect of increased atmospheric carbon dioxide concentration, warming, precipitation changes and alteration of the frequency and severity of extreme events.
2. Quantitative prediction of climate change for prescribed greenhouse gas emission scenarios through General Circulation Models at a both global and regional level is imprecise and unlikely to improve in the foreseeable future. Effects of climate change on ecological processes are also only approximately reproduced in current models. Nevertheless, these modelling approaches are crucial to understanding the nature of changing climates, approximate magnitudes of ecological effects, and potential management responses.
3. Anthropogenic climate change impacts are certain to last at least 500 years into the future, and probably the earth has entered a permanent warm state. Consideration of long-term (~120 000 years) as well as medium-term (~500 years) timescales should be incorporated into biodiversity planning.
4. There have been few documented effects on the indigenous biota of the approximately 0.7° C increase of mean annual temperature since the turn of last century, and alterations in the mean atmospheric circulation over New Zealand. However, numerous ecological reactions to extreme climatic events have been observed.
5. Climate change is likely to impact on the indigenous biota and their ecosystems over the next 100 years. Four main classes of change are possible: (i) alteration of latitudinal and altitudinal ranges with movement of species and communities southwards and upwards, accompanied by disruptive transitions; (ii) strong impacts on biota and ecosystems already under stress if extreme weather events become more frequent and severe; (iii) changes to productivity and nutrient cycling within ecosystems due to a combination of climate change and carbon dioxide increases; (iv) disruption of freshwater ecosystems through low flows or drying of stream and rivers and warming of water.
6. Potentially the most serious and pressing problems arise through the interaction of climate change with pre-existing threats to the biota. The most important involve pest and weeds, and the following outcomes are likely: (i) establishment of more invasive and damaging pests and weeds; (ii) further expansion southwards of already present exotic organisms; (iii) climate fluctuations changing the food supply of herbivores and omnivores such as rabbits, rats and mice, with flow-on effects on abundance of

predators of indigenous vertebrates such as cats, stoats, and rats, making extreme difficulties for conservation managers.

7. Climate change will have its greatest impact on small patches of fragmented habitat with low resilience, and freshwater systems in modified landscapes, through increasing exotic weed and pest pressure and disrupting ecosystem processes.
8. As climate change mainly impacts through exacerbating pre-existing ecological and biodiversity problems, steps being taken or planned, by conservation managers in a range of organisations, on the basis of other biodiversity threats to an extent deal with the issue. However, future or present climate change is rarely taken into account when biodiversity issues are discussed and strategy formulated. Little thought has been given to the long-term consequences of climate change (or indeed any other degrading factor) for the evolutionary future of the biota. These issues should be explicitly taken into account in decisions made on priorities for both species and ecosystems.
9. Climate- change predictions are unlikely to improve past provision of generalised forecasts for periods well into the future and they are therefore of little help for those managing the current biodiversity crisis. However, genuine long-term ecological frameworks and strategies that explicitly factor in climate change and global change are badly needed.
10. Facilitation of movement of plants and animals southwards in order to address biodiversity loss in the north through climate change needs more thorough assessment. There is the possibility of unwanted population explosions of northern endemics in the south or genetic dilution or replacement of southern populations.
11. Planting of forests (indigenous, exotic or mixed), encouraging the expansion of indigenous woody systems, and restoring wetlands (which can be strong carbon sinks) to offset New Zealand's contribution through fossil fuel use and agriculture to global warming could, if managed correctly, have large benefits for indigenous biodiversity, largely through expanding the area in large continuous tracts of indigenous vegetation which will permit ecosystem processes to proceed with minimal human intervention.
12. **Priority research topics** in the context of biodiversity and climate change are (i) expansion of long-term monitoring sites for biodiversity and climate; and (ii) modelling of biotic interactions, especially with regard to indigenous/exotic interactions, in a landscape context.
13. **Policy implications.** There is a need for (i) discussion to be initiated on implications for both indigenous and exotic biodiversity over long time and spatial scales in relation to a permanently warmer earth; and (ii) integration of biodiversity issues into carbon sequestration planning.

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## 1. Introduction

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Advice to Government on linkages between biodiversity and climate change was prepared by Landcare Research, Lincoln, for the Ministry for the Environment in June – August 2001.

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## 2. Background

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It has become ever clearer that the global climate changed significantly during last century, warming by  $0.60 \pm 0.06^\circ \text{C}$  between 1900 and 2000, and that the most likely explanation for this change is increasing greenhouse gas concentrations in the atmosphere, in particular carbon dioxide, methane, and nitrous oxide (Houghton et al. 2001). Carbon dioxide concentrations are now higher than at any time for the last million years. Furthermore, depending on the greenhouse gas emission and abatement scenario selected, global warming in the course of this current century may be between 1.4 and  $5.8^\circ \text{C}$ . It is confidently expected that other aspects of global climate will also change, including a shift to higher maximum temperatures, higher minimum temperatures and fewer frost days, reduced diurnal range in temperature, alteration of precipitation patterns through strengthening of the hydrological cycle, and more-intense precipitation events. Changes in the frequency and intensity of ENSO (El Niño-Southern Oscillation) events are possible.

Climate has a strong influence on biological processes and thus exerts direct control on the distribution, abundance, and interactions of the biota. Indirect effects arise from human activity in response to climate change. As a result, the biodiversity status of New Zealand will almost certainly change in response to climate in the course of the present century. However, there is a very low awareness of climate change issues in the biodiversity literature in New Zealand. To give an example: climate change and climate variability are mentioned but once in The New Zealand Biodiversity Strategy (2000), and then only as one in a list of eight research topics. Increased awareness of both the short- and long-term implications of global change is very much needed.

The New Zealand natural environment has undergone great changes in the past, with constant fluctuations at all spatial and temporal scales (McGlone et al. 1996). The conservation ideal is a self-sustaining ecosystem capable of responding to natural change. It is therefore not change in itself that is the issue. However, anthropogenically driven climate change poses new challenges. There are unanswered questions as to how large and how permanent greenhouse climate change will be, how rapidly it will impact, and what will be its interaction with pre-existing biodiversity threats. The main risk from anthropogenic climate change appears to be that both the rate and absolute magnitude of change may not allow ecosystem composition to adapt to the changes by filling new niches. This could lead to a reduction of the diversity of ecosystems that would, in turn, make them less resilient against further changes and reduce their ability to provide services (such as pure water supply, carbon storage, genetic diversity and recreation). Equally important is the issue of to what extent we

should try and preserve present biodiversity in the face of climate change, and the extent to which we should permit or assist the adjustment of indigenous biodiversity to the new situation.

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### **3. Objectives**

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- To report on policy implications of scientific linkages between biodiversity and climate change in New Zealand.
- To discuss changes in vegetation cover and freshwater ecosystems.
- To highlight potential synergies and areas of conflict for current national policies, particularly with regard to links with international frameworks and activities.
- To recommend key areas for future research and priorities for policy development.

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### **4. Recent and Projected Future Climate Change in New Zealand**

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#### **4.1 Recent changes**

Mean temperatures have increased in New Zealand by 0.7° C between 1900 and the 1990s (Folland & Salinger 1995). The trend is dominated by warming since the 1940s. Precipitation trends have been much more variable, and fluctuations in the strength of atmospheric circulation over New Zealand, with long periods in one circulation phase or another, have led to strongly regionalised changes (Mullan et al. in press). From a biological perspective, seasonal changes and changes in extremes are more important drivers of change than annual means. In general, warming has been more marked in winter than summer, and at night rather than during the day, and there has been a pronounced decline in the diurnal temperature range (Salinger et al. 1996). Consequently, frost days have decreased in most areas, most notably in the southeast South Island and central North Island by up to 15 days (Mullan et al. in press). An overall trend towards less precipitation has occurred in most districts, except in the west and south of the South Island (Salinger et al. 1996). Much of the precipitation trend has been the result of more frequent ENSO events since 1975. However, it has to be borne in mind that much of New Zealand's natural biodiversity occurs at relatively high altitudes and in wetter sites where coverage by climate stations is poor.

#### **4.2 Projected change in New Zealand**

General Circulation Models (GCMs) of the atmosphere are run at coarse spatial scales for the entire globe. Raw results provided by the GCMs for various greenhouse gas emission scenarios are statistically "downscaled" to permit local-scale climate changes to be inferred for the New Zealand region (Mullan et al. in press). Currently seven GCM downscaled patterns are available. All differ, and sometimes quite markedly, in their predictions for the New Zealand region. Major differences arise between equilibrium simulations that show a maximum warming at the poles, and transient simulations that predict much slower warming of the Southern Hemisphere high latitudes.

In the New Zealand region the latitudinal gradient strengthens relative to the present in the transient simulations, increasing the westerly wind flow. This has major implications for



rainfall patterns, leading to increased rainfall in western districts and drier conditions in the east. Changes in precipitation patterns are likely to be around 10% for each degree of global warming, and will serve to steepen the current gradients. Under the transient scenarios New Zealand is likely to lag average global warming considerably because of the slow thermal response of the large southern ocean.

In general terms, New Zealand is likely to warm by about 0.7° C for every degree of global warming from 1990 to 2100. This results in estimates of New Zealand warming for the turn of next century of about 1 to 4° C. Major changes in frosts in the South Island are predicted, with 30 fewer frost days by 2100, or half the number of existing frosts. Warm days (above 25° C maximum) increase greatly in the north and east of the North Island, by as much as 30–50% in the Northland region, but much less to the south, with no significant changes in Southland and Otago.

Some caveats have to be noted. GCM climate modelling is not an exact science and a number of factors come into play. First, all GCMs are dependent on the greenhouse gas emission scenario chosen. Second, the sensitivity of the GCMs to an external forcing is of the order of  $\pm 50\%$ ; has been that way for close to 20 years despite theoretical advances, enormous progress in computing power, much finer spatial scales and more accurate parameterisation; and is unlikely to get much better (North 2001). Scaling down to the New Zealand level inevitably involves further compromises because of the complex orography of the country. And finally, climatic extremes, all-important from a biological viewpoint, have to be generated on the basis of statistical comparisons with the current climate regime rather than independently through the GCM. As the GCMs do not yet have adequate representation of cyclical climate patterns such as ENSO and the Pacific Decadal Oscillation, an important source of information about extreme weather patterns is also missing.

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## **5. New Zealand Biodiversity**

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### **5.1 What is biodiversity?**

Biodiversity is a shortened form of the term “biological diversity” and is defined as “...the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems” (UNEP 1994). Expressed in this way, biodiversity cannot be exactly quantified, as the various components are not commensurable.

Ecosystems are not readily quantified, as they are scale and context dependent; often they are entities defined to facilitate study, conservation or other human uses. In biological terms, an ecosystem is a community of organisms and their physical environment interacting as an ecological unit. In practice, quantification of biodiversity often comes down to enumerating species – as the most stable, easily documented and basic element – and their abundance, and variation in number and type between locations. However, species themselves differ greatly in their genetic distinctiveness, trophic position, importance to ecological processes, replaceability etc., and as basic units they are not strictly comparable.

## 5.2 Current state of New Zealand biodiversity

A total of c. 30 000 indigenous multicellular organisms have been documented, and it is estimated that perhaps as many as 80 000 would be recorded if a complete enumeration was possible (Taylor & Smith 1997). While this is not a large number of species compared with the number occurring in similar-sized regions in tropical and subtropical areas, New Zealand is still recognised as a megadiverse location, and as one of the 25 global biodiversity hotspots (Myers et al. 2000). This recognition comes from four different aspects of New Zealand indigenous diversity: a high degree of specific endemism; concentration of species belonging to ancient or unique groups; adaptation to an isolated continental island, in particular the evolution of plants and animals in a mammal-free, bird-dominated environment; and finally, the threat from exotic invasive species. New Zealand also has a large range of distinctive communities and ecosystems packed into a small area, a consequence of a broad latitudinal range, steep precipitation gradients and a diverse topography.

Endemism is high at the species level in most broad groupings of organisms (herbs, trees, beetles, birds etc.), ranging between 80 and 100% for most; the only exceptions being highly motile groups, which are either flighted or small enough to drift airborne, or those with light, easily dispersed propagules, such as most unicellular organisms and certain plant groups such as ferns and orchids. Endemism is not nearly as prevalent amongst genera (the next taxonomic level up) as New Zealand's isolation by ocean, although lasting for some 70 million years, has not been complete and there have been regular interchanges of organisms, in particular with Australia, over that time.

Polynesian settlement in the 12th century AD and European settlement in the 19th collectively induced a biodiversity decline. In terms of documented species extinctions c. 80 species have been lost, or a 0.1% decline in estimated diversity. However, this figure conceals three other results of settlement: first, the asymmetrical impact on larger and more distinctive New Zealand species; second, the widespread decline of many populations; and third, the disproportionate destruction of warm, dry lowland indigenous ecosystems, and lowland wetlands.

Certain biotic groups have been more prone to loss than others. Large ground-dwelling birds and reptiles have been decimated. Vertebrates make up two-thirds of the total loss, with land birds suffering a 32% decline and frogs a 43% decline. Restriction in species ranges through predation and habitat loss has been as severe in its impact at the ecosystem level; no area within New Zealand – aside from a handful of offshore islands – retains anything approaching the prehuman biomass of birds, reptiles, and amphibians. In comparison, documented losses among invertebrates and plants have been small (0.02% and 0.5% respectively; Taylor & Smith 1997) although lack of a fossil record of equivalent quality to that of the vertebrate fauna probably means that actual losses have been underestimated. It is likely that a significant number of plant and invertebrate species became extinct during the widespread habitat modification of the human era. Predation by rats, mice and pigs has been the major cause of invertebrate loss, the larger, ground-dwelling species being more vulnerable. Many large molluscs, wētū and beetles therefore have highly restricted ranges, and are often confined to offshore islands. The size asymmetry in extinction does not apply to plants, as trees appear to be no more vulnerable to extinction pressure than smaller plants.

## 5.3 Factors reducing biodiversity

Threats to indigenous biodiversity come from several different sources: predation (including hunting, food gathering and collectors); habitat loss; herbivory; fragmentation; competition

from exotic species; loss of specialist pollinators and dispersers; fire; ambient nutrient changes; and toxic chemicals. However, these are not independent and, in most cases of species decline or extinction, more than one of these factors are likely to have been operating.

#### **5.4 Value of biodiversity**

In considering climate change impacts on human activities the nature of the impact (positive or negative), the severity or cost of the impact, time that will elapse before the impact is experienced, and the probability of it happening at all, will be taken into account. It is therefore possible to gain some idea of what is an appropriate expenditure to avert or ameliorate a possible negative impact or to take advantage of a possible benefit. It is clear that biodiversity cannot be treated in the same manner.

Indigenous biodiversity does have a value, but it is difficult to put it in strict monetary terms. While income from the harvesting of terrestrial and freshwater biodiversity is significant, ecosystem services provided by indigenous land biodiversity is considered to be the major source of value, estimated at half the current national GNP (New Zealand Biodiversity Strategy 2000). Preservation of indigenous biodiversity in the form of unmodified ecosystems therefore helps maintain this value. However, it is clear that economic value of biodiversity – no matter how it is calculated – is only a minor factor behind the promotion of the conservation ethic in New Zealand (Craig et al. 2000) and elsewhere (Ehrlich 2001). Threatened species and ecosystems make up an insignificant part of the total New Zealand biomass, but it is these to which most attention is now paid by conservation agencies and public alike. For individual species, attractiveness to humans (in itself a multi-dimensional concept), size, distinctiveness, and ecological role are the most important factors; for ecosystems, role in recreation, historical nature, and aesthetic wilderness and landscape values predominate. In the long-term, these are likely to be the biodiversity values of most significance to future New Zealanders; passage of time does not diminish the sense of loss and impoverishment that comes with extinction or destruction of native habitats.

The value of biodiversity, in the sense of how much the nation is prepared to forego in order to preserve it, is therefore focussed on a relatively small group of species attractive to humans and at high risk of extinction, and on the preservation of areas of unmanaged pristine environment. Concern for intergenerational equity with regard to the environment is one of the major drivers for action, and this is likely to increase with an aging population concerned about its legacy. Open-ended commitment to species preservation is a strong political force in New Zealand, is likely to become stronger rather than weaker and, in the context of ongoing climate change, poses a myriad of complex and often contradictory management issues to be resolved.

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## **6. Timescales, Climate Change and Biodiversity**

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In considering climate change, two timescales have to be taken into account. First, a short-term scale (c. 500 or so years), that fits well within the lifespan of the longer-lived elements of biotic communities, and thus can be regarded as an ecological processes scale. The second, the long timescale (~120 000 years), is the average length of a glacial-interglacial cycle. Major landscape and climate cycles operate at these timescales, and it is the

appropriate length of time over which to consider significant evolutionary processes (McGlone 2000). In the next two sections, the implications of climate change for both these timescales are considered, but with more detailed analysis of the possible outcomes in the near future in the context of the short timescale.

### **6.1 Long-term climate change effects on biodiversity**

The possibility that climate change currently being experienced will continue into the remote future is rarely considered in a policy context, but increasingly it must be if adequate strategies to protect biodiversity are to be developed. Stabilisation of the concentration of atmospheric carbon dioxide at levels higher than present (e.g., 450 or 650 ppm) is predicted to lead to rising temperatures for hundreds of years due to the slow response time of the oceans (Houghton et al. 1996). Recent modelling of the interaction of greenhouse gas concentrations, the solar radiation cycle and the Northern Hemisphere ice sheets has indicated that the current warm earth condition (interglacial) is likely to persist for at least 50 000 years (Loutre & Berger 2000), about four times as long as previous interglacials.

New Zealand is in the middle of an evolutionary explosive phase that was triggered by emergence of the axial mountain ranges during the Pliocene and Pleistocene, and climate change initiated by cooling during the Plio-Pleistocene era (Trewick et al. 2000; McGlone et al. 2001). While New Zealand has relatively few genera and families for a landmass of its size, a disproportionately large number of species occur in a few genera that have undergone spectacular radiation. Of particular interest are radiations in the alpine regions of the southern mountains and the drier eastern areas, but many genera have also radiated in moist lowland forest environments. Many plants and animals also have highly distinctive local populations and morphs. A few have formed clines across the landscape, in which there is step-wise replacement or changes in morphology or ecological character of a species from area to area.

The majority of New Zealand plants and animals are therefore adapted to cooler average conditions than prevail now, the result of the 2.5-million-year-long Pleistocene period during which climates were only for brief intervals warmer (c. 1–2° C) than present, but for long periods 2–6° C cooler. The indigenous biota will therefore have to adjust to conditions that may be permanently warmer than the long-term average by 3.5 to 8° C. There will be several consequences.

First, certain habitats will be lost or permanently transformed. Eventual loss of much of the current alpine areas of New Zealand and severe reduction of cold-winter habitat seems inevitable under even moderate scenarios for rising greenhouse gas concentrations. A large part of the lowland North Island will effectively enter a subtropical climatic zone with mean annual temperatures between 1 and 4° C warmer than the warmest experienced over the last 3 million years. Outside of these northern lowlands, it is possible that novel climate regimes will prevail.

Second, there are long-term consequences for soil development. Over the last few million years, the intense erosion and windblown loessic dust of the long glacial periods have regularly rejuvenated New Zealand soils. While erosion in mountain areas and redistribution of its products in the form of silts and gravels to the lowland has maintained this rejuvenation in many catchments, large areas of low-lying and rolling country will slowly, but surely, lose mineral nutrients through leaching of the upper soil layers.

The third consequence is the disruption of the semi-regular cycles of expansion and contraction of cool- and warm-climate-adapted species. A permanently warm climate regime, with only moderate fluctuations from the mean, will strand the cold-adapted section of the biota in a small, and probably shrinking, climatic space.

The final consequence, which follows from the previous three, is disruption of evolutionary trajectories. Perhaps, in the long term, the most important aspect of anthropogenic climate change will be the radical alteration of these evolutionary trajectories (Myers & Knoll 2001). Current conservation effort is clearly and appropriately devoted towards the retention of current biodiversity in the face of predators, weeds and habitat destruction. However, these activities should take place in the context of a broader strategy that seeks to maintain evolutionary processes over the longer term.

There is a biological case for a strategy that values species according to their ability to contribute to further evolutionary development in the changed New Zealand context. Such a strategy would stress those elements of the biota that are capable of coexisting with human-disturbed or -managed landscapes, and those capable of responding to a warmer and more variable climate. Maintenance of a substantial indigenous presence throughout the range of managed and disturbed landscapes would help ensure this evolutionary potential. Such an evolutionary development strategy would also value the protection or re-establishment of large, extensive, connected areas of habitat in which the full range of ecological processes can take place.

## 6.2 Short-term climate change and biodiversity

### Current biotic response to climate change

Evidence of indigenous biological responses to climate change over the last century has been examined in a few studies. Tree limits were investigated in 1989/90, and some evidence presented of an “advance zone” of seedlings and saplings of several species (Wardle & Coleman 1992). However, in most cases altitudinal extensions of less than 7 m were mapped, while 100 m might have been expected on the basis of climatic warming to that date. While the advance zone might be a delayed response to warming, it may merely represent temporary populations of saplings that will not grow to maturity. More recent unpublished work has failed to record treeline movement at other locations. Given the much slower warming rate for summer and daytime temperatures – those that are most significant at treeline – there also has to be some doubt as to whether a response should be expected.

In the introduced flora there has been evidence for southwards movement of population of exotic *Paspalum* grasses during warm periods (Field & Forde 1990). No similar climate-related movement has been documented for indigenous plant species, but in the lowlands most are constrained by discontinuous populations separated by extensive human modified habitats. Anecdotal evidence suggests that some northern plants are expanding in areas to which they have been transplanted south of their natural range – for instance pūhutukawa (*Metrosideros excelsa*) and karaka (*Corynocarpus laevigatus*) in the Wellington district. Fluctuations in the range of the Indian myna (*Acridotheres tristis*) may possibly be climate related, as this species, first introduced in the 1870s, appears to be restricted by cool summer temperatures (Clout & Lowe 2000) and disappeared from the South Island and North Island south of 40°S in the late 19th century, a period of cooling climates, while flourishing north of that latitude (Heather & Robertson 1996).

There have been observations on fruiting and flowering or outbreaks of populations of some invertebrate species that are linked directly or indirectly to climate. Studies on mast-seeding plant species, of which New Zealand has a number (including the beech species, snowgrasses and a number of conifers) reveal climate links (Webb & Kelly 1993). Mast species may react to warmer than normal summers preceding floral initiation, and the following year exhibit mass seeding. A 22-year data series on snowgrass species has shown that cycles of seeding are related to ENSO events and warmer than normal summers (McKone et al. 1998).

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## 7. Predicted Biodiversity Changes in the Short Term

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### 7.1 Predictive models and empirical relationships

The problems and uncertainties of reliably predicting future climate states feed through to the biodiversity models that are driven off them. As climate predictions have a sensitivity of c. 50%, reliable modelling of future biodiversity states from greenhouse gas emission scenarios is not possible. Nevertheless, scenario biodiversity modelling has great value in suggesting the magnitude of the biological alterations that could result from climate change, and exploring the responses to different environmental base states.

John Leathwick (Landcare Research, Hamilton; pers comm. 2001) has produced the first national-scale assessment of indigenous forest changes possible with a doubling of atmospheric carbon dioxide. His technique utilises a forest tree-abundance model based on climate and soil factors (Leathwick et al. 1996, 1998) and compares computed present tree-species abundances under the current climate regime with estimated future forest species abundance under a warming of 1.4° C and precipitation changes of 10%. The results indicated highly significant changes (> 30%) forests in many lowland and northern sites, and in eastern lowland sites where rainfall changes were predicted to be most significant. In contrast, changes were relatively minor in forests growing in cool, wet, nutrient-limited sites.

Predictions of changes in distribution of individual tree species have also been made from time to time for various climate change scenarios. The interaction of precipitation, temperature and soil factors makes prediction of future distributions on the basis of a generalised understanding of the species ecology difficult and, while the models possibly do not get the spatial details right, they give a robust sense of how broad-scale climate effects might work. Bioclim models – based on statistical correlations between current distributions and various climate factors – have been applied to a restricted set of indigenous forest species, e.g., tawa (*Beilschmiedia tawa*) in the central North Island (Hollinger 1990; Leathwick et al. 1996), and kauri (*Agathis australis*) and several hardwood species in the northern North Island (Mitchell & Williams 1996). Sometimes the results are counter-intuitive, as in the surprising result that northern broadleaves and kauri might become more restricted under climate warming of 4° C because declining populations over the current range are not offset by gains to the south (Mitchell & Williams 1996).

A different modelling technique, called the forest-gap approach, relies on simulating forest dynamics on small plots with prescribed climate and soils, which can be scaled up to landscape or even national dimensions. This approach has been used to predict the effect of climate on forest composition (Hall & McGlone in press), and to predict migration rates and

effects of land use. It predicts large changes in New Zealand forest composition with climate change.

With the vast majority of the biota, generalisations will have to be based on ecological insights regarding distribution in relation to climate. One of best-established correlations in ecological literature is that between latitude, altitude and biological diversity. In general, sites and regions at lower latitude and altitude are richer in most forms of life, and there are strong correlations with measures of available energy such as evapotranspiration. However, although the correlations are well founded, the causal mechanisms remain obscure, although many have been proposed (Gaston 2000). At present, there is no way in which the energy/species-diversity observation could be used quantitatively to predict the potential species number in a given area. Furthermore, such observations only predict species number, not species functional types. Plant attributes (e.g., physiology, dispersal ability, resource requirements) and contingent factors (e.g., landscape and evolutionary history) seem as strong in predicting which species might or might not occupy a given region.

There are a variety of diversity patterns within New Zealand. Forest species show strong positive relationships between diversity and decreasing latitude and altitude (e.g., Druitt et al. 1990; Bellingham et al. 1999). Plants capable of tolerating cool, open and frost- and drought-stressed habitats are much more common at high altitudes and in south-eastern districts. Imposed on this pattern are geographic areas that have been hot spots of speciation within New Zealand. Northland, south-west Nelson, Marlborough, and Fiordland show high diversity over a range of taxa such as alpine plants, insects, and molluscs (McGlone et al. 2001). Birds do not show patterning of either of these types, in that they are neither more species-rich at high latitudes, nor show biodiversity hot spots. It is possible that the latitudinal/species-diversity gradient could be used to predict future change, but as we know little of the processes driving it, this would be only an empirically based correlation. The biodiversity hot spots in New Zealand appear to be structured more by geography and history, and it seems unlikely that changing climate patterns can be used to predict future changes in these regions.

Scientists are therefore not sure if the species number in any particular area reflect environmental constraints, including climate, or if they are largely historically controlled. If the former, we might expect that there is some upper limit to diversity and that some areas might be either saturated with species or, alternatively, underpopulated and open to invasion. If the latter, the only control on species number would be the availability of species with the right attributes to colonise a given site. A careful study of mollusc diversity in species-rich sites in New Zealand found that even the most species-rich sites (59 species), equal to the richest in the world, were probably still unsaturated with regard to the overall available species pool (Barker & Mayhill 1999). Wisser et al. (1998) showed that an exotic herb, *Hieracium lepidulum*, preferentially invaded species-rich plots in beech forest, suggesting that saturation is not a general state of affairs. A comparative study of different continents has demonstrated that invasion and naturalisation of exotics has occurred at a much faster rate in warmer, lower-temperate latitudes rich in indigenous species, than in cooler, higher-temperate latitudes where indigenous species are few (Sax 2001).

We are probably therefore safe to assume that if a species has the right attributes to exist in a given environment, there will be no necessary barrier to it invading. As there is a strong gradient of increasing species-richness towards the equator in both hemispheres, each degree of temperature increase widens the zone from which invasive species can be selected.

## 7.2 Range and distribution changes

### Lowland plants

Many species have range boundaries that can be correlated either with a macro-environmental variable such as soil or climate, or are clearly linked with a certain habitat type. For instance, Northland has a rich biota of plants and animals that are not found further south. Some, if not most, of the northern biota have attributes that are clearly suited to warm rather than cool climates, such as higher photosynthesis rates under warm conditions (kauri) or lack of cold tolerance (pōhori *Vitex lucens*, mangrove *Avicennia resinifera*). It seems reasonable to assume that many such species will find, under a warming regime, suitable habitats opening up further south beyond their current geographic range. Models for warming-induced range changes, which include also precipitation-related factors, have suggested that for some species this will indeed be so (e.g., tawa; Leathwick et al. 1996); for others, it appears that other environmental factors such as soils and day length will counteract this tendency (e.g., kauri; Mitchell & Williams 1996).

However, we should bear in mind that this is a complex issue. Potential range limits assessed on current species distributions invariably assume a stable equilibrium between the species abundance and some critical environmental factor or competition. As these are usually assessed on the basis of current species distribution, the ecological concept of “fundamental niche” versus “realised niche” is important. A fundamental niche is the total range of habitats that a species is capable of surviving in. The realised niche is the smaller range of habitats that a species (limited perhaps by predators, parasitism, dispersal, rare events, or opportunity) actually currently occupies. It is therefore the realised niche that forms the basis for our current models and predictions. It is an everyday observation that both animals and plants can exist, and in many cases successfully reproduce in the wild, outside their realised niche. Mitchell & Williams (1996) illustrate this with the case of *Eucalyptus regnans*, which, on the basis of production forestry in New Zealand, has a much larger fundamental niche in Australia than its realised niche. A further case is that of New Zealand species which have extended their range overseas: for instance, karaka is an aggressive weed in parts of Hawai'i, exceeding its current mean annual New Zealand temperature range by at least 10°C.

### Freshwater species

New Zealand freshwater ecosystems are relatively simple. There are just 36 indigenous species of fish and 16 exotic species. None of the invertebrate groups are particularly rich in species (Winterbourn 1987). Food chains are generally short. In the case of freshwater systems, little is known as to the temperature tolerances of aquatic invertebrates (but see Quinn et al. 1994), and there are few data on fishes (McDowall 1992). Many species in the indigenous freshwater fish fauna may be little affected by temperature change. Most species are found widely from north to south and at high and low elevations and appear to be highly flexible in habitat and genetically diverse (Glova 1990). New Zealand field records show that only two species of native freshwater fish have a significant relationship between density and water temperature, and native species are able to thrive within a wide temperature range (Richardson et al. 1994). However, there is a subset of the fish and invertebrate fauna adapted to cool waters (peak temperatures < 16–18°C. These organisms will be affected strongly if average highs exceed this range, as is likely in streams that have lost tall shading vegetation along their banks, and if water flows drop through drier conditions and greater abstraction of water for agriculture (B. Biggs pers. comm. 2001). While there may be movement within catchments and between habitats in response to temperature change, southwards movement seems unlikely for many because many freshwater species are trapped in east-west flowing



river systems or lakes because they do not have a marine phase in their life-cycle. Modelling of exotic fish populations suggests that there could be a generalised shift southwards for brown trout and rainbow trout (Glova 1990), with possible benefits for indigenous fish they compete with and prey on in the North Island. Direct impacts are likely to be slight on indigenous fish (McDowall 1992).

Estuarine systems are likely to be subject to heavier impacts because they are currently under a great deal of stress through their catchments being a focus for human settlement and the ultimate repository of the sediment created by land use changes in the waterways that feed them. They will be affected by warmer sea-surface temperatures, and by rising sea levels.

Warming could extend the range of mangroves but negatively affect the *Zostera* biotically rich seagrass meadows, which are possibly sensitive to low salinities at high temperatures (Burns et al. 1990)

The most important consequence of global climate change for coastal systems will be sea level rise. Along coastlines in a more or less natural state, new areas of marshland habitat will be created by sea level rise, replacing that inundated. However, along most New Zealand coastlines, intensive development of the land close to marshes and estuaries means it is unlikely that people will allow new areas of marshland or estuary to form. Prevention of sea-level changes through barriers, drainage and the like seems the most probable outcome. Rising sea levels in these areas of intensive development may remove large areas of the rich biological habitat represented by coastal marshlands (Burns et al. 1990). However, it is important to realise that rising sea levels will be a minor contributor to the ecological problems faced by coastal systems. Sedimentation, eutrophication and pollution by waste resulting from human activities and development are far more important.

### **Alpine zone**

In the case of alpine organisms, which may suffer range contraction under warming climates and rising treelines, there is an interplay between temperature regime; temperature-related phenomena such as freeze-thaw cycles, frost and snow-cover; and physical habitat, such as bare rocky sites, bogs and scree slopes. As commented on above, treeline has not moved on the New Zealand mainland despite the warming of last century, and marked retreat of glaciers over that time (Chinn 1995). However, there has been little seasonal trend in snow storage since 1930 (Fitzharris & Garr 1996), and therefore features of the alpine environment besides annual temperature may have changed little.

Not all organisms found in the alpine zone belong to obligate alpine species. For instance, about 40% of the plant species regularly occurring in the alpine zone are also found below treeline, and a significant number occupy similar open habitats at sea level (Mark & Adams 1995). The true cold-specialised alpine species tend to occur in the higher, more extensive alpine areas where, even with considerable warming, open habitat is likely to remain. In contrast, many restricted alpine endemics tend to be found in isolated upland sites and, while potentially threatened by increased woody growth, often are confined to certain habitats such as bogs, shingle slides, bluffs and outcrops, which may persist even under an upward moving tree or shrub line. Therefore it is by no means clear that warming has directly affected the distribution of alpine plants or that continued warming necessarily must. Little work has been done on alpine animals from this point of view. A study of alpine grasshoppers (White & Sedcole 1991) demonstrates how complex the effect of warming could be on an organism with variable-length lifecycles, and different morphological stages. Their conclusion was

that warming would lead to populations shrinking and being displaced to higher altitudes and marginal habitats. A recent study of microhabitats of an alpine cockroach has shown that decreased snow cover led to increased thaw-freeze cycles in the alpine zone and thus, paradoxically, warmer winters with less snow resulted in a much more stressful climate (Sinclair 2001). Overall, there is no basis for simplistic assumptions about the results of warming on alpine organisms, and counter-intuitive outcomes are possible.

### **Management implications of range changes**

Potential range change of indigenous species is a complex issue, both scientifically and philosophically. The size of the problem that might already exist is demonstrated by the claim that at least 80% of New Zealand plants are already not distributed as widely as their ecological tolerances would permit (Wardle 1991), suggesting major biotic interchanges within New Zealand are possible even without warming.

As discussed above, some projections based on climate change scenarios have northern species becoming rare or absent, while habitats open for them further south. In northern temperate regions the concept of corridors for species to move north in response to warming is repeatedly raised. While this is an appropriate response for glaciated Northern hemisphere areas with a long Pleistocene history of retreat and advance of biota (Currie 2001; Shafer et al. 2001), it is not as clear that it is for New Zealand. Major retreat and advance of plant populations does not seem to have occurred in the recent past in response to climate change: instead, populations tended to have sufficient habitat breadth or genetic diversity to contract or expand within regions (McGlone et al. 2001). Much of the diversity of the New Zealand biota is therefore held within highly variable populations scattered over a large range and showing unique adaptation to given sites (Harris & Beaver 2000).

One consequence of continuing natural and human-mediated dispersal within New Zealand is that indigenous plants and animals are now occurring well outside their natural ranges. For instance, in the Wellington district the strictly northern trees *Corynocarpus laevigatus*, *Metrosideros excelsa* and *Pittosporum crassifolium* have all become established in local coastal forests (Simpson 1997). With continuing warming, it is highly likely that such “naturalisations” will accelerate, and some thought has to be given to what might be their affect on the local fauna and flora. It is, for instance, possible that such indigenous introductions might out-compete local elements to the detriment of local biodiversity. Introduction of indigenous plant species from outside their current range to enrich depleted reserves is therefore not regarded with favour at present. Such plants can rapidly become aggressive “weeds” displacing local species or genetically intermixing with local varieties (Molloy 1995: 315).

More thought needs to be given to the consequences of changing distributions of indigenous biota, both that which is occurring through various processes at present, and that which might be driven by future climate change. Over the very long term (thousands of years), adjustment of the biota to the new climate regime might be inevitable. However, in the shorter term (hundreds of years) the gains made in preserving northern diversity through transplantation south might be accompanied by losses in southern communities. The issue of prevention of human-mediated expansion of indigenous species outside of their natural range, and of transplantations of biota in order to permit indigenous species to remain within their preferred climatic tolerances, while not particularly pressing at the moment is likely to become of greater significance as global climate change continues. Eventually decisions will have to be made as to what attitudes will be appropriate.

### 7.3 Ecosystem functioning changes

Carbon dioxide is necessary for the growth of all green plants, and temperature affects the metabolic processes of all organisms. Warming and rising carbon dioxide concentrations acting together are likely to cause some changes in ecosystem productivity.

Experiments with raised carbon dioxide levels have demonstrated an early increase in carbon uptake in pines, but acclimatisation to the raised levels occurred within 2 years (Griffen et al. 2000). A model of annual carbon uptake in New Zealand indigenous forests showed that carbon uptake was most sensitive to the physiological parameter of maximum carboxylation, which at a stand level depends on the relative proportion of conifer and broadleaved trees and nitrogen availability, and secondarily to temperature (Whitehead et al. 2001). Current carbon uptake was predicted to be highest in the central North Island and north-western areas of the South Island, and low in the south-eastern corner and isolated sites in the eastern South Island. However, a recent assessment of carbon stocks in indigenous ecosystems found that they cannot be accurately predicted from climate and edaphic factors as there was no relationship between biomass and site variables for both shrubland and forest. Poor predictive ability was suggested to result from differing site disturbance histories (Coomes et al. 2001). As stochastic disturbance (e.g., blow down of forest, slipping etc.) will continue, and possibly increase in the near future, prediction of future carbon stocks in relation to climate change will be difficult.

Overall, carbon uptake by New Zealand vegetation is low by international standards probably because of the low nitrogen status of many soils. On average, there seems little possibility that there will be significant increases in productivity on typical nutrient-poor New Zealand soils. Even on nutrient-rich soils that can support increased productivity, it is highly likely that the carbon to nitrogen ratio would become greater, with decreases in rate of tissue breakdown in the soil and thus a slowing of nutrient cycling. Foliage and fine roots would also be of less value per unit of mass to primary consumers, possibly leading to higher consumption. Overseas experiments under raised carbon dioxide have reported increased seeding in pines and other changes in carbon allocation pattern (LaDeau & Clark 2001). Such changes could markedly alter vegetation dynamics.

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## 8. Biodiversity Effects of Changing Climate Extremes

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Climate warming, especially if it is associated with increased cloudiness or overall precipitation increases (which could buffer the system) will lead to decreased cold-related phenomena – such as low altitude snow fall, frost, freeze–thaw cycles and out-of-season frosts. Although cold-related biological phenomena such as deciduousness, diapause in invertebrates, hibernation, and chilling requirements for germination are not as widespread as in other temperate zones, they are important factors in the biology of the species concerned (Dumbleton 1967; Morris 1989; Wardle 1991).

Growing seasons should increase in length, all other factors being equal. Shorter, milder winters and less extreme cold events will combine to give a longer growing or reproducing season. Summer and daytime temperatures are a major influence on photosynthesis, and therefore have a strong effect on the overall productivity of an ecosystem when nutrient status permits. Climate change to date has affected overnight temperatures and winter temperatures

far more than daytime temperatures and summer temperatures (Salinger et al. 1996) and so has acted primarily to extend the growing season. Major impacts should therefore be experienced in the lowlands where winter cold and overnight lows are a key factor in preventing southwards extension of many plant and invertebrate species, especially those introduced from warmer regions of the world. However, it is likely that New Zealand – at least during the transition to a warmer world – will experience unusual combinations that will stress the adaptive capacities of organisms and ecosystems, and I give two examples.

It has been argued that in mountain beech (*Nothofagus solandri* var. *cliffortioides*) and k-mahi (*Weinmannia racemosa*) forest warm temperatures and drought promote excessive honeydew production, which in turn promotes damaging outbreaks of *Platypus* beetle damage leading to die back of mature trees, which can ultimately determine the forest structure (Wardle 1984). The 2-week-long period of record below-freezing temperatures in Southland and Otago in July 1996 came during the warmest decade on record, but gave rise to severe cold-related damage and death among a wide range of indigenous and exotic trees, shrubs and herbs (P. Bannister pers. comm. 2001). In both these cases, neither of these occurrences could have been easily predicted and they show that unpredictable consequences of changing climates are highly likely.

Extrapolation from the generalised predictions for global climate change indicates that average temperature change within 100 years will probably larger than current year-to-year variability. Future extremes of rainfall and temperature will almost certainly lie outside the current range and predictions are that rainfall will become more variable than now (Mullan et al. in press). Although claims are often made for increasing severity of storm events worldwide, there is little evidence in New Zealand of such changes (Salinger et al. 1996) and GCM model results differ on whether more should be expected as a consequence of greenhouse warming (Houghton et al. 1996). Disturbance is seen as a major determinant of forest structure, and more frequent and intense storm events have the potential to drastically shorten the turnover period for trees and thus alter forest composition (Bellingham et al. 1999). Heavy rainfall and storm events resulting in slips and erosion have long-lasting effects on waterways where they change the sediment regime. At the other extreme, prolonged drought has been implicated in changes in indigenous forest structure, paradoxically often in high altitude areas with abundant rainfall (Jane & Green 1983; Grant 1984).

New Zealand is strongly buffered by the vast oceans in which it sits and is predicted largely for that reason to have a slower response than the global average to warming (Mullan et al. in press). Ecosystems appear to have a substantial amount of buffering within them, as they tend to tolerate large year-to-year changes in both mean conditions and extremes with little outward sign of major change. New Zealand ecosystems tend to be dominated by long-lived perennial species, which give little scope for major ecosystem alteration within the seasonal to few year's duration of major departures from the long-term mean. Unless exceptional climatic events occur, and there is no way at the present of predicting these, the expectation should be of slow progressive change overall of ecosystems in response to climate change, although more rapid change will occur in localised areas. However, New Zealand ecosystems are under extreme pressure from various sources (Atkinson & Cameron 1993; Craig et al. 2000). The most damaging impact of climate change is therefore likely to come from its interaction with ongoing ecosystem stressors.

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## 9. Climate Change Interactions with other Factors Affecting Biodiversity

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### 9.1 Predation by introduced mammals and invertebrates

Predation has been the major factor in driving numerous birds, reptiles, amphibians and invertebrate populations to extinction or severely restricting their ranges (Clout & Lowe 2001). Fast-breeding predatory mammals, in particular rats, stoats, ferrets, possums and cats, have been the primary agents, although pigs, dogs, wasps and some birds, such as the thrush, have had effects on some populations at various times. While hunting and food gathering was a major influence on extinction during the early Māori era, and collecting for feathers and skins may have hastened the demise of the huia, it appears not to be a serious threat currently. The primary predators in New Zealand are mammalian and therefore little affected directly by temperature in comparison to food supply; hence the wide distribution of the most serious predators (rats, possums, stoats). However, warmer, drier winters are thought to extend the breeding seasons of rodents, goats, pigs and possums, and while this alone would not necessarily increase their population sizes in the absence of increased food, it would permit them to recover more quickly from control operations (Hay 1990).

Mast, or exaggerated interannual cycles of fruiting in plants, is common in New Zealand, and it is possible that it is a pervasive influence on mammalian predator cycles. Climate cycles leading to fluctuation in food abundance can spark off serious predator outbreaks. For example, mast beech seeding results in high numbers of mice, rats and invertebrates. Rats have a direct effect on native vertebrates, and the availability of rats and mice as prey in turn increases populations of stoats, which feed on native birds (Choquenot & Ruscoe 2000; Fitzgerald & Gibb, 2001). It is not a straightforwardly negative effect, however, as breeding and chick survival of indigenous birds can be assisted by the presence of abundant food. The management implications are therefore complex. Masting cycles, although predictable to a certain extent as heavy flowering can give a warning of potentially heavy seed yield, can be extraordinarily difficult to handle. For example, the recent elimination of yellow head (*Mohua ochrocephala*) from Mount Stokes came about as a result of a complex interaction between milder weather, mast seeding of beech, a trapping campaign to control stoats, and a range extension of rats (DOC internal report: Mohua, 2001).

Warmer than average summer days – a precondition for much masting behaviour – are predicted to increase with global warming, but ENSO and other cyclical climate events are still not reflected well in the GCM models. However, there is some indication of stronger and more intense ENSO events accompanying the recent warming, and major changes in atmospheric circulation patterns from 1976 onwards have seen more frequent west to south-west airflow over New Zealand (Mullan et al. 2001). A combination of warmer days and more intense ENSO and other climatic cycles could result in more masting, and more variable seed production. If this eventuates, a more complex situation for management of bird/predator cycles is also likely.

In contrast to mammals, invertebrate predators are highly climate sensitive. The major introduced invertebrate predators in New Zealand are the social and paper wasps. Wasps are implicated in reduction of indigenous invertebrate abundance through direct predation, and in reducing bird populations through competition for nectar, honeydew and invertebrates and

attacks on nestlings (Beggs 2001; Clout & Lowe 2001). Wasps are highly responsive to climate conditions. Wet winters characterised by flooding do not favour nest survival and can lower populations, while warm, dry conditions are ideal for explosive population growth (Beggs 2001). There are numerous other temperature-sensitive invertebrates already in the warmer parts of the country including big-headed ant (*Pheidole megacephla*) and Argentine ant (*Linepithema humile*), which are regarded as among the worst invasive species in the world, with a capacity to wreak havoc on the arthropod fauna (Lowe et al. 2000). Overall, it appears that warmer conditions cannot but increase the range and pressure exerted by invertebrate pests.

## 9.2 Herbivory

Herbivory, mainly from introduced deer, possums, goats, and hares, and in modified areas cattle, sheep and rabbits, has been responsible for reducing palatable plant species and encouraging the proliferation of browse-resistant species, both exotic and native. Although browsing pressure has yet to drive any known plant to extinction, certainly extreme range reduction has occurred and modification of ecosystem functioning is underway (Nugent et al. 2001) although not in any straightforwardly predictable way (Wardle et al. 2001).

While climate and carbon dioxide changes are likely to alter the relative abundance and foliage palatability of plants (Tateno & Chapin 1997), we are far from understanding how that will affect introduced herbivores. Over 50 years of study of the major mammalian herbivores – deer, possums and rabbits – has come up with few generalisations as to herbivore influence on the vegetation, as impact is variable from year to year and place to place. Herbivore impact is modified by soil fertility, and other influences on vegetation cover. Impact is therefore often patchy, with major destruction of palatable species in some areas and little in others (Wardle 1991; Payton 2000). Moreover, there is little information suggesting one way or another that average climate is a significant controlling factor by itself on population size, although long, cold, wet winters tend to lead to increased mortality among most mammalian species (King 1990). Mean changes in climate probably will not have as marked an effect as preferred food abundance.

## 9.3 Competitive replacement by exotic species

Leaving aside direct predation or herbivory, exotic species can fundamentally alter ecosystem structure through monopolising resources. Climate effects that increase the aggressiveness of exotics or, conversely, decrease the abundance or resistance of indigenous species, may therefore be significant.

Competitive displacement is of importance for vascular plants. A number of aggressive exotic weeds have displaced native species, in particular, but not always, in modified habitats. *Elodea canadensis* (waterways), broom (*Cytisus scoparius*, in river beds), marram grass (*Amophila arenaria*, sand dunes), hawkweed (*Hieracium* spp., inland and alpine areas), wild ginger (*Hedychium gardnerianum*, northern forest fragments), tradescantia (*Tradescantia fluminescens*, ground floors in forest fragments throughout) are examples. Over the relatively short duration since introduction (< 150 years) the effect has been major population reduction but not extinction of indigenous species, but the potential is there for this to happen, especially in fragments.

A number of tropical and subtropical islands elsewhere have been invaded by ecosystem transforming elements such as strawberry guava (*Psidium cattleianum* – worst woody weed in Hawai'i) and miconia (*Miconia calvescens* – tree weed on Tahiti and Hawai'i), and the

threat is that parts of New Zealand will become as badly affected with global warming, unless extreme vigilance is maintained. For instance, wild ginger has the potential to severely limit forest regeneration by virtually excluding all understorey competitors in bush reserves in the north of the North Island. It is presently limited to warmer districts, but is possibly expanding its range southwards (McFadgen 1999). Evidence that the warmer north is perhaps more vulnerable to invasion by exotic weeds comes from studies of offshore islands: the northern islands have, on average, four times as many problem weeds as those of the south (Atkinson 1997).

With a few exceptions, native birds have been comprehensively displaced from modified habitats by introduced birds, but there is little evidence that in unmodified natural areas introduced birds adversely impact on indigenous bird species. Being warm-blooded, they are also far less likely to be directly affected by climate change, although the Indian myna is an exception in this regard because its nesting behaviour results in lethal egg cooling in cold districts (Clout & Lowe 2000). Wasps, which are climate responsive, have greatly reduced food resources for some indigenous birds, particularly in beech honeydew areas (Beggs 2001).

Certain exotic invertebrates (e.g., Argentine ant *Linepithema humile*) are capable of dominating the biomass of a given area to the exclusion of competing indigenous species. Because invertebrates are highly sensitive to climate, and vastly more diverse in warmer climates, warming New Zealand climates pose a high risk of invasion and spread. The Argentine ant, for example, is currently restricted in its range to Northland and warmer coastal districts of the North Island, but has the potential to spread south with warming climates (J. Beggs pers. comm. 2001).

#### **9.4 Loss of specialised pollinators and dispersers**

Severe reduction in bird fruit dispersers (e.g., kererū *Hemiphaga novaeseelandiae*) and brush-tongued honey eaters (e.g., bellbird *Anthornis melanura* and tūwharuro *Prosthemadera novaeseelandiae*) have impacted on forest processes and may be contributing to reduction in extent and regenerative capacity of some plant populations (Robertson et al. 1999). The genera in the current woody flora are largely fleshy-fruited (c. 60%) and trees in particular (72%) (Wardle 1991; Burrows 1994). It is likely that loss of pollinators and dispersers will interact with climate change mostly through reducing the ability of bird-pollinated and -dispersed trees and shrubs to keep up with changes in their preferred climate space.

#### **9.5 Habitat loss**

Habitat loss ranks second only to predation as a major cause of biodiversity loss within New Zealand. Like predation, habitat loss has been asymmetrical, in that it has been most widespread and most intense on relatively fertile, dry, warm sites that predominate in the lowlands and which are most suitable for agriculture and urban uses. It has been least intense in infertile, wet and high-altitude terrain, which provides the largest proportion of our protected natural areas (Craig et al. 2000).

Clearance of land covered with indigenous vegetation for settlement and agriculture has all but ceased in New Zealand, and is effectively illegal under current legislation. Warming climates could conceivably make some areas attractive for intensive human use that were previously not, but it is highly unlikely that there would be any change in the regulatory regime to allow this. Transformation of deep, cool-water rivers and streams to shallow, fluctuating overheated waterways, either directly through lower precipitation or through

consequent extraction of water for intensive agriculture, is the most likely way in which habitat for native freshwater species will be lost.

Climate change will also affect the chances of restoration in the rainshadow, eastern districts of the main islands, where forest destruction was greatest, and stresses through lower average precipitation and extreme drought in the future are likely to be highest (Mullan et al. in press). Some of these areas could become too dry to support indigenous forest and thus effectively prevent any chance of reversing the tide of habitat loss.

## **9.6 Fire**

Fire is a major risk to native ecosystems because they evolved for an environment of low fire frequency, and few plants have specific adaptations to resist or tolerate fire (Ogden et al. 1998). The fire-adaptations and fire-tolerance of many exotic species is a potent factor in reducing biodiversity in drier districts. Between 1987 and 1998, more than 28 000 ha of conservation-managed land was burnt by 2000 separate wild fires (McFadgen 1999).

Regional fire risk is affected by the frequency and severity of various synoptic climatic features that lead to highly elevated fire risk (Heydenrych et al. 2001). Climate predictors include the Southern Oscillation Index, sea surface temperatures and zonal and meridional indices. Both positive (La Niña) and negative (El Niño) extremes of the Southern Oscillation Index, and anomalous zonal and meridional pressure gradients are associated with increased fire severity, but in different areas of the country. Predicted intensification of the westerly wind flow over New Zealand will therefore result in more severe fire episodes in the east and, if ENSO fluctuations intensify, extreme fire seasons may become more common. The major effect of this change will be to the scrub grassland and regenerating forest communities in drier districts close to roads and settlements, which are the major risk factors for ignition. Among the results could be retreat of beech forest east of the main divide, loss of native species in grassland/shrubland, and proliferation of annual exotic grasses.

## **9.7 Fragmentation**

Formerly extensive areas of vegetation have been broken up by intensive land use and fire into fragments orders of magnitude smaller. Fragments of habitat, often unrepresentative to begin with, lose species at a rate much greater than intact vegetation, and are more open to weed and pest invasion through a variety of mechanisms (Timmins & Williams 1991). This process is particularly acute in lowland forest and wetland communities fragmented due to clearance and draining of the lowlands, giving rise to patches of lightly modified native ecosystems surrounded by very large extensive areas of fertilised agricultural countryside, saturated with predators, herbivores, weeds and pests, and regularly sprayed with herbicides and toxins. Under such circumstances there is accelerated species loss from the fragments due to stochastic fluctuations in recruitment of the resident biota; unusual events such as extreme drought, frost, storm damage, flooding etc.; and increased openness to weed and pest invasion.

Climate change is likely to intensify most of the negative effects, especially if variability increases. Extreme climatic events (which are buffered by the variety of habitats present in large, unbroken areas of native ecosystems) can be devastating in smaller patches of habitat without this variety, that are also remote from possible sources of recruitment.



### **9.8 Nutrient changes**

The New Zealand biota is by and large adapted to much lower levels of soil nutrients than those that prevail in other temperate areas, in particular nitrogen and phosphorus, due to the low initial nutrient status of many widespread rock types. Extensive use of phosphatic and nitrogenous fertilisers has changed soil nutrient levels and affected waterways, lakes and swamps. Their main influence has been to encourage rank growth of introduced plants to the exclusion of indigenous plants, mainly on agricultural land. Weather patterns have an under-appreciated influence on nutrient supply through deposition of ocean-source nutrients in coastal districts. Precipitation changes could affect leaching, oceanic-deposition distribution and soil decomposition. Nevertheless, climate change is unlikely to affect nutrient processes to such an extent that ecosystem changes would affect biodiversity in a major way. However, warmer climates in the presence of nutrient-enhanced soils are likely to increase rates of invasion by fast-growing weed species pre-adapted for these conditions.

### **9.9 Toxins and herbicides**

Unrestricted use of DDT and other agrochemicals in past years has conceivably left a legacy among animal populations, and bird reproductive failure and diminution of some invertebrate populations has been reported (Salmon 1991). Use of toxins/herbicides remains both an ecological management and political issue in the battle against pests and weeds. Climate change should have little interaction with use of toxins and herbicides, other than indirectly if it promotes the unacceptable explosive spread of certain weeds and pests that can only be controlled in this way. Unpalatable choices with delicate political and public relation implications could thus be forced on ecological managers. Examples would be intensive herbicide campaigns to prevent southwards spread of ecosystem-disrupting weeds such as wild ginger, or major aerial spraying of insecticide against an invasive insect, as happened in the 1997 Auckland campaign against spotted tussock moth.

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## **10. Biodiversity and Greenhouse Gas Mitigation Strategies**

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One of the strategies for reducing New Zealand's contribution to atmospheric greenhouse gas concentrations is to encourage regeneration of indigenous forest in areas that are currently in scrub or pasture, or planting exotic or indigenous forests that will either act as a temporary carbon store in the medium term, thus buying time for an adjustment to a low fossil-fuel-use economy, or directly replace fossil fuel for some uses. Both have consequences, largely positive, for biodiversity.

Increasing the amount of land in regenerating native forest, especially in lowland and in particular on fertile arable land, will be important in maintaining biodiversity. In the first place, it should increase connectivity between currently isolated forest patches. There is abundant evidence that small fragments of forest suffer exaggerated losses of biodiversity through stochastic effects, increased predation, higher levels of weed invasion and reduced genetic diversity and interchange compared with continuous tracts (Timmins & Williams 1991). Of particular importance, therefore, is the maintenance of contiguous but varied habitats and processes. To give an example: limiting reserved forest to hill slopes, while continuing to farm alluvial valleys and floodplains, is to preserve only one fragment of the original continuum with very large consequences for the overall biodiversity and ecological

processes, especially for larger mobile organisms with varied habitat requirements. While larger areas of forest are only likely to delay, rather than prevent, loss of indigenous vertebrates and large invertebrate diversity through predation, the consequences for the evolutionary prospects of other groups are likely to be very good. More and larger populations increase the potential for an evolutionary future for the species involved (Woodruff 2001).

Under the current land-use regime, and the current status of international negotiations regarding the Kyoto Protocol, the prospect of re-establishing indigenous forest as part of a strategy to mitigate greenhouse gases is uncertain. Moreover, there is some concern that carbon storage gains might not be as large as often predicted (Schlesinger & Lichter 2001). The areas most likely to be of use for natural low-cost re-establishment are already in some form of low woody cover, and it is not clear that these represent a changed land use. Furthermore, warm, moderate-rainfall, fertile sites in lowlands of most use to restoring biodiversity are at the same time the most valuable to agriculture, and the least likely to have adjacent to them unmodified indigenous forest to act as a source of propagules and nuclei. If international agreements permit greenhouse credits for non-plantation reforestation, it is likely that it will take place mainly on infertile, cool, wet sites close to existing tracts of upland forest. There are numerous private and local body initiatives focussed on forest restoration. In total, these are likely to be small contributors in area, but their impact at the local ecosystem level could be considerable, as they tend to restore forest and wetland to areas where they are largely missing. However, unless planned in a total landscape context with due respect to interconnectivity and genetic sources, their contribution to indigenous biodiversity might not be great.

Increased plantings of exotic, indigenous or mixed forests specifically for greenhouse gas mitigation credits are less problematical under the Kyoto agreement, as they involve a clear change in land use. Plantations are known to contain substantial amounts of indigenous diversity including birds, invertebrates and vascular plants (Dyck 1997). In fact, some plantation forests contain significantly more indigenous plant diversity after 30 years than many natural indigenous forests (Allen et al. 1995; Ogden et al. 1997). Isolated forest plantations, with no provision for linkages with larger areas of indigenous forest, will nevertheless achieve only limited diversity and have but a limited future as they are too small and uniform to ensure the full range of biodiversity-supporting biological processes.

Extensive well-planned exotic or exotic-indigenous plantations perhaps present the most practical opportunities for meeting biodiversity and greenhouse gas mitigation targets. Highly selected, fast-growing (and perhaps sterile) production trees planted on the most productive sites may underwrite establishment costs; the bulk of the forest would gain greenhouse carbon credits for the nation, underpinning costs of biodiversity management. In the short-term, such forests could buy time for fossil fuel adjustments, and yield returns in excess of the value of the timber produced (Solberg 1997). In the medium term, the forest tract, be it indigenous or mixed indigenous-exotic, is likely to have high biodiversity values, combined in some instances with continuing prospects for selected high-value commercial production. If planted adjacent to existing tracts of indigenous forest, the long-term value after several generations of tree growth might be a permanent addition to the self-sustaining natural environment, with all that implies for continuing evolutionary trajectories and ecosystem services. Given the amount of opposition that the controversial logging of high-value timber from indigenous forest has created, such an approach offers a way forward.

Wetlands offer another source of biodiversity amelioration and greenhouse credits. Lowland wetlands are major potential sinks for carbon absorption (perhaps up to 2 tonnes/ha: L. Schipper pers. comm. 2001), and also one of the most disrupted ecosystems in New Zealand. Before the deforestation of the Māori era, and logging and swamp drainage of the European phase, treed or scrub-covered wetlands were ubiquitous throughout the lowlands. Re-establishment of woody, tall herb or mixed wetlands has major potential for biodiversity enhancement, as the fire-affected successor swamp ecosystems generally have low diversity, and are open to environmentally degrading influences such as eutrophication, and spread of exotic weeds. A major advantage of wetland carbon sequestration is that, unlike forest, the carbon stored is far less likely to be re-emitted in the future.

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## 11. Links with International Frameworks and Activities

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The international framework for climate change and biodiversity is provided by the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations Environment Programme Convention on Biological Diversity (CBD). The need for the rate of climate change to be reduced is recognised by the UNFCCC, as is the possibility that that conservation and sustainable management of ecosystems can contribute to both framework conventions. In particular, the CBD has called for strengthened collaboration between them on the impact of climate change on biological diversity and the integration of biodiversity into the implementation of UNFCCC and its Kyoto Protocol.

As a signatory to the CBD convention, New Zealand has taken on responsibilities to undertake actions to protect biodiversity in both protected and non-protected areas, to restore and rehabilitate degraded ecosystems, promote recovery of threatened species, and control alien species that threaten biodiversity values, while acknowledging the expectation of a broad range of environmental, economic and social benefits from investments in biodiversity.

At present, the most significant synergy developing between the conventions is that centred on Land Use, Land-Use Change and Forestry (LULUCF). As discussed above, there is considerable scope for New Zealand to achieve its commitments under both conventions by reforestation and wetland restoration programmes, which act as both carbon sinks and reducers of greenhouse gas emissions, while sustaining biodiversity at the species and ecosystem levels. It also offers the potential to involve local communities and produce economic and social benefits.

The Convention on Wetlands of International Importance especially as Water Fowl Habitat (Ramsar Convention) is of importance through the potential of restored wetlands to act as significant carbon sinks. However, it is important to note that the wetlands most significant for species biodiversity and, in particular, for endangered or rare species biodiversity are not lowland lagoon and lake herbaceous dominated systems – most suitable for water fowl and bird life in general – but the more complex, peat-forming wetlands or small tarn system in upland and inland situations.

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## 12. Conclusions and Recommendations

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### 12.1 Research needs

Biodiversity climate-change issues are largely inseparable from the other major biodiversity issues that centre on accelerated species loss and ecosystem degradation through predation, habitat loss and invasion by exotic weeds and pests. As discussed above, the most serious immediate threats to biodiversity through climate change are almost exclusively through impacts on these ongoing processes, and research into these issues is being currently funded through a range of agencies. Any long-term strategy for the protection of biodiversity should encompass climate and environmental change as part of its core research programme. Of particular relevance is the impact of extreme climate events in controlling species distribution and abundance. Other research issues worthy of priority consideration in the climate change context are:

- (i) **Expansion of long-term observation systems.** Long-term data sets of climate and biota have been invaluable in determining the interaction between climate and seed production and rat and stoat outbreaks, and widespread networks of plant plot records have permitted modelling of plants in the context of current climate and disturbance regimes. It has long been known that common and introduced biota are collected and observed far less often than uncommon and indigenous species. As many of the interactions that will determine the fate of the indigenous biodiversity will come from these sources, this data deficiency has to be rectified. It is important that these observation systems are set up in a sustainable manner and based around ongoing scientific investigations.
- (ii) **Modelling of species distributions and ecosystem processes in a climate change context.** While models will always have severe limitations, they are unrivalled for making assumptions explicit and exploring options. The highest priority in this field is modelling potential outcomes of indigenous and exotic species interactions and field verification of the processes involved. As dynamic processes of dispersal and invasion are key to future changes, such modelling should be spatially explicit.
- (iii) **Implications for diversity and evolutionary trajectories of intermixing indigenous biota.** While interactions between exotic and indigenous biota are routinely studied within a conservation management context, little attention has been paid to the long-term results and implications of mixing previously separate species.
- (iv) **Exploration of the potential of carbon sequestration projects to deliver biodiversity benefits.** Restored or planted forests and wetlands offer good opportunities to become carbon sinks, to reduce methane and nitrous oxide emissions and enhance biodiversity. However, more research is needed to quantify the benefits and to establish the best way forward to maximise all aspects.

## 12.2 Policy recommendations

The most severe and immediate biodiversity problems within New Zealand are not climate-related and, although climate change will exacerbate some of them, it is likely to be a minor contributor, at least in the short term.

Several issues to do with large spatial and temporal scales, over which climate change effects will be marked in the intermediate- and long-term, have been highlighted in this review but have had little serious discussion to date in New Zealand, largely because attention has been focussed on short-term biodiversity maintenance. The first is the future of long-term evolutionary processes in a warming, human-dominated world; the second, possibilities of restoration of indigenous ecosystem properties across large areas of landscape; and third, the long-term outcome of indigenous–exotic interactions. As choices made in the near-future will strongly influence the distant-future, it is appropriate that these issues be debated. Without their resolution, the framework for future New Zealand biodiversity will remain weak. Specific points relating to biodiversity and global climate change that should be addressed through further discussion and policy development are:

- (i) **Indigenous biota range expansions within New Zealand**  
Continuing global climate change will most likely intensify the expansion (both natural and anthropogenic) of indigenous species outside their natural ranges with consequences for the resident biota. It is not clear how these are to be regarded, although there is a precedent in reserves for such introductions to be treated as weeds. The probable consequences of such changes and conservation attitudes towards them need to be discussed.
- (ii) **Conservation of climatically threatened species**  
Planning for long time scales and radically altered climate states necessitates serious consideration of the value or even possibility of conserving certain species whose previous climatic space is likely to vanish.
- (iii) **Ecosystem processes and evolutionary change**  
Changing climates give extra impetus to efforts to ensure that ecosystem-level processes continue that will lead to evolutionary adjustment of the biota to the new state. However, little is known in the New Zealand context about how well catered for these processes are, and what might need to be done to ensure the long-term evolutionary future.
- (iv) **The role/status of exotic species**  
It is accepted that there are a large number of exotic species within New Zealand that are unlikely ever to be eliminated. A substantial minority of these are already adapted to warmer climates and biotic pressure from these can be expected to increase. Moreover, nearly all, wild exotic species are undergoing genetic change due to evolutionary pressures in the New Zealand environment, and many can be presumed to be already distinct from their ancestral populations. The status and role of the exotic biota within indigenous New Zealand ecosystems needs to be discussed
- (v) **Integration of biodiversity issues into Kyoto-related mitigation strategies**  
The potential gain for indigenous biodiversity from carbon sequestration initiatives to offset greenhouse gas emissions is large, in particular for wetlands. However, there has to be more certainty around the long-term benefits for biodiversity, the trade-offs

necessary to gain both carbon credits and biodiversity benefits, and the ultimate outcome for indigenous ecosystem processes. This is therefore both a research and policy development initiative.

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