

THE POLYNESIAN SETTLEMENT OF NEW ZEALAND IN RELATION TO ENVIRONMENTAL AND BIOTIC CHANGES

Summary: Polynesian settlement of New Zealand (*c.* 1000 yr B.P.) led directly to the extinction or reduction of much of the vertebrate fauna, destruction of half of the lowland and montane forests, and widespread soil erosion. The climate and natural vegetation changed over the same time but had negligible effects on the fauna compared with the impact of settlement. The most severe modification occurred between 750 and 500 years ago, when a rapidly increasing human population, over-exploited animal populations and used fire to clear the land.

Human predation, and destruction of forest habitat eliminated the moa and other large ground birds. Moa appear to have been more abundant in drier conifer-broadleaved forest on fertile lowland sites, than in wetter areas and in cool upland forests. Most forests remaining today are wet mountain land communities, and may never have experienced severe browsing pressure until Europeans introduced browsing mammals. The moderate amount of browsing pressure exerted in them by moa may have been insufficient for the plants to develop browsing adaptations capable of coping with the impact of mammals. Knowledge of these climatic, physical and cultural forces which shaped the biota of present day New Zealand are important for understanding how to manage the remaining estate.

Keywords: Conifer-broadleaved forest; climatic change; vegetation change; erosion; moa; fire; deforestation; Polynesian; settlement; prehistory; birds; predation; extinction.

Introduction

Human impact on the environment and biota of New Zealand was both late and severe. Not only did Polynesians burn the forests and reduce the avifauna in variety and numbers, but their introduction of the rat and heavy exploitation of the larger birds virtually eliminated the only indigenous browsing vertebrates. Thus, even that vegetation which survived unscathed is likely to have differed from its pre-human condition. These islands are therefore still in a ferment of biological change that began with Polynesian settlement shortly before 1000 yr B.P. However, anthropogenic modification is just one of many environmental factors: large-scale erosion, earthquakes, volcanic eruptions, fire, extreme climatic events and long-term climatic trends are all part of the natural background of change. It is difficult to distinguish the effects of these natural changes from those caused by humans.

Nevertheless, the question of what is natural or original is central to many environmental issues and has implications beyond scientific curiosity. As the sensitivities and perceptions of the settler, hunter, horticulturalist, farmer, miner and developer give way to, or come into conflict with, those of the urban dweller, recreationalist, naturalist and conservationist, questions as to the status and ecology of the present biota in relation to that of the past assume greater importance. Decisions on appropriate land use - although largely dominated by short-term economic

factors - are also influenced by the extent to which a given area or biotic community reflects its natural condition.

Management of areas set aside to preserve natural values must be based on an understanding of their history and likely future. Even when they are protected, there will inevitably be changes in biotic composition and structure. Thus some judgement must be made as to whether or not the changes are due to, or a reaction to, previous human influences, or if they are part of the natural background of change.

We are potentially well-placed in New Zealand to answer these questions. Human impact began within the lifespan of some of our longer lived trees, and many of the forests existed before human influences began to dominate. The short timespan of human occupancy ensures that much evidence is contained within abundant, accessible, surficial deposits. We also know to a degree not possible in many other places what sort of people were the first settlers, their origins, their technological capabilities and their historical traditions. Prehistory was 'caught alive' in New Zealand (Golson, 1959).

Before much progress can be made in establishing the effects of Polynesian settlement, a 'baseline' must be set for 'New Zealand without humans' even though it is difficult to be sure exactly what the date should be. Dated archaeological sites indicate that settlement occurred at around 1000 yr B.P. (Davidson, 1984).

However, if the founding population was small and grew slowly it is possible that settlement occurred more than a century or two earlier.

Fire was the primary agent transforming the landscape during Polynesian settlement throughout the Pacific (Kirch, 1982), and was used from the beginning in New Zealand. There is no secure way to distinguish anthropogenic fire from natural fire which was significant long before settlement. Major deforestation had occurred in some areas at least 1500 years before the first records of Polynesian settlement; and at about 1800 yr B.P. one of the largest eruptions recorded in New Zealand (Taupo Pumice) devastated the central North Island. It is therefore expedient to set the baseline for 'New Zealand without humans' back to 3000 yr B.P. to avoid the complications associated with these large-scale disruptions of the biota and the uncertainty over the date of first settlement.

New Zealand Vegetation at 3000 yr B.P.

Our knowledge of New Zealand vegetation at 3000 yr B.P. is based on extant remnants of forest, charcoal in soils and alluvial deposits, pollen from lakes and bogs, macrofossil remains, subfossil logs, and soil surface forest dimples. Figure 1 is a very generalized depiction of the vegetation at 3000 yr B.P. based on these sources.

85-90% of New Zealand was covered with forest. Only 15% of the South Island and 1.5% of the North Island lay above the timberline. Grassland or shrubland occurred, as it does now, on river terraces subject to regular flooding, frost-prone valley floors, steep cliffs, active sand dunes, leached shallow soils, ultramafic soils, and recently disturbed areas that were normally in forest. Wetlands with sedge, rush or shrub land cover were common, but forested wetlands may have been as abundant. But outside these limited areas the forest cover was unbroken.

In nearly all lowland forested areas, the major type was tall conifer-broadleaved forest (Nicholls, 1983). Conifer-broadleaved forests are complex and defy simple classification. However, a distinction can be drawn between those on drier sites (600-1000 mm rainfall *per annum*) and those in wetter areas.

Only scattered remnants are left of the drier forests, but at 3000 yr B.P. they stretched from Southland to East Cape along the eastern side of both islands. Matai (*Prumnopitys taxifolia*), totara (*Podocarpus totara*) and kahikatea (*Dacrycarpus dacrydioides*) were the dominant tall podocarps and on fertile soils formed dense stands (Holloway, 1954;

Moar, 1971; McGlone, 1978; McGlone and Bathgate, 1983). On stony, light soils under dry climates (600-800 mm rainfall *per annum*) kanuka (*Leptospermum ericoides*) scrub was dominant on the Canterbury Plains (Cox and Mead, 1963). Pollen analyses from low rainfall regions of the Canterbury Plains with heavier, deeper soils suggest forests dominated by matai, kahikatea and totara, but with numerous shrubby clearings of *Coprosma*, kanuka, manuka (*Leptospermum scoparium*), *Muehlenbeckia*, etc. (Moar, 1971; McGlone and Moar, unpublished information). In south Canterbury/north Otago, *Plagianthus regius* may have formed an important component of the forest.

In the very driest districts, and in the valleys and inter-montane basins of inland mid-Canterbury close to the high central portion of the Southern Alps mountain chain, there was diverse but distinctive inland conifer-broadleaved forest type. Toatoa (*Phyllocladus alpinus*), mountain totara (*Podocarpus hallii*) and a number of small hardwood trees such as broadleaf (*Griselinia littoralis*), kowhai (*Sophora microphylla*), kanuka and *Myrsine australis*, formed a low forest in such situations. On especially harsh sites, bog pine (*Halocarpus bidwillii*) was one of the few woody plants able to stand the climatic extremes of dry and cold. It is impossible to draw definite boundaries for this dry inland conifer-broadleaved forest, as it graded into and inter fingered with lowland conifer-broadleaved forest and, in wetter upland sites, graded into subalpine scrub and mountain cedar (*Libocedrus bidwillii*) communities.

Conifer-broadleaved forests in wetter districts, predominantly on the western side of both islands, tended to have fewer scrub-dominated clearings and were much richer in tree ferns. Rimu (*Dacrydium cupressinum*) was the dominant in many of these forests, although nearly all the tall podocarp trees were represented throughout. Recent alluvial soils tended to carry stands of matai, totara and kahikatea, but have been largely cleared. Broadleaved trees were abundant in these forests.

In Northland, and as far south as the Waikato Basin, kauri (*Agathis australis*) was abundant. It grew both in dense stands and as small groups or scattered emergents in conifer-broadleaved forest (Ecroyd, 1982).

A feature of the lowland landscape was extensive swamps and bogs. Often, and very commonly in the North Island, such wetlands had dense tall conifer-broadleaved forest cover. Kahikatea, rimu, silver pine (*Lagarostrobos colensoi*), kauri, tanekaha

(*Phyllocladus trichomanoides*), kaikawaka (*Libocedrus plumosa*) and swamp maire (*Syzygium maire*) were common dominants especially on waterlogged soils and shallow mire margins. Shrubby bogs were abundant throughout, especially in southern and montane regions: manuka, bog pine, and small-leaved coprosmas formed dense to sparse overstoreys or thick, fringing marginal scrub.

By 3000 yrs B.P. the axial ranges of both the North and South Islands were predominantly covered with beech (*Nothofagus*) or beech-conifer-broadleaved forests. Mountain beech (*Nothofagus solandri* var. *cliffortioides*) and silver beech (*Nothofagus menziesii*) formed the timberline nearly everywhere, the major exception being the central portion of the Southern Alps. In beech-free upland areas, montane conifer-broadleaved forests passed upwards to subalpine shrublands at timberline.

At 3000 yr B.P. the general trend in pollen profiles from lowland beech-free areas was towards a greater representation of matai, *Nestegis*, *Quintinia*, and tanekaha at the expense of rimu, rata (*Metrosideros robusta*), *Ascarina lucida* and tree ferns (McGlone and Moar, 1977; McGlone, 1983a, McGlone *et al.*, 1984).

The broad outline of beech dominance had been established by 3000 yr B.P., but at many places beech population growth continued. In Fiordland-western Southland, beech was widespread but not dominant at 3000 yr B.P. The big increases in beech, and silver beech in particular, in Fiordland-western Southland started about 2500 yr B.P. or later (Harris, 1963; Johnson, 1978; Burrows and Greenland, 1979). Beech continued to expand primarily at the expense of upland conifer-broadleaved forest and subalpine shrublands.

In montane-subalpine areas which have remained free of beech - mainly central Southern Alps, the southern Ruahines, northern Tararuas and isolated peaks in the northern North Island - there is pollen evidence that mountain cedar increased sharply at or shortly after 3000 yr B.P. (McGlone, *et al.*, 1988).

Climatic change since 3000 yr B.P.

The vegetation changes summarized above, point to continuing alteration of broad climatic conditions. Interpreted very generally, the changes in lowland forest composition suggest that a once mild, equable climate with occasional disturbance to forest structure, was giving way to one in which drought, frost and disturbance was common (McGlone and Moar, 1977; McGlone *et al.*, 1984). This trend has been continuous

since 7-6000 years ago, but intensifying towards the present. Spread or increase of beech and mountain cedar in the uplands may reflect a more continental climate and cooler average temperatures.

Physical evidence supports the concept of a general decline in average temperatures over the past 3000 years. In the last 5000 years there have been a series of ice advances and retreats which followed an interval of limited glacial activity (Burrows, 1979). Moraines in the Southern Alps indicate that glaciers expanded at 3500-3000, 2700-2200, 1800-1700, 1500, 1100, 900, 700-600, and 400-100 yr B.P. (Gellatly, *et al.*, 1985). It is difficult to interpret these glacial records in terms of temperature because of variations in the extent and timing of advances in different valley systems. Burrows (1982) suggests that mean temperature from 1000 AD till 1900 AD has not varied by more than 0.5°C. Before 1000 AD temperature fluctuations may have been greater because some glaciers advanced even more than later (Burrows, 1979).

Decreasing annual temperatures and a more continental climate may have been caused by a general strengthening of atmospheric circulation. This seems to have begun at around 7000 yr B.P., but must have accelerated significantly at or after 3000 yr B.P. (McGlone and Bathgate, 1983). Strengthening of the zonal westerly flow brings droughty conditions to the east of the North and South Islands, while stronger meridional southerly flow cools the entire country, but tends to increase rainfall in the east and south and diminish it in the north and west (Salinger, 1984.)

Burrows and Greenland (1979) discuss the influence of slow-moving anticyclones on these weather patterns. When there are more relatively low-latitude anticyclones over Australia and the Tasman Sea, there tends to be an increased westerly wind flow over New Zealand. However, if slow-moving anticyclones with centres at relatively high latitudes persist either to the east or west, there is an increased southwesterly to northeasterly flow accompanied by cool cloudy weather. If these anticyclones are centred east of New Zealand, the west side of the South Island may experience dry spells while precipitation is consistent in the east. When they are centred to the west, over eastern Australia and the South Tasman Sea, the eastern side of both islands is drier, and the main divide of the Southern Alps cooler and stormier.

The increased variability in the climate since 3000 yr B.P., as deduced from vegetation records and glacier moraines, can thus be partly explained by alterations of circulation patterns which have been

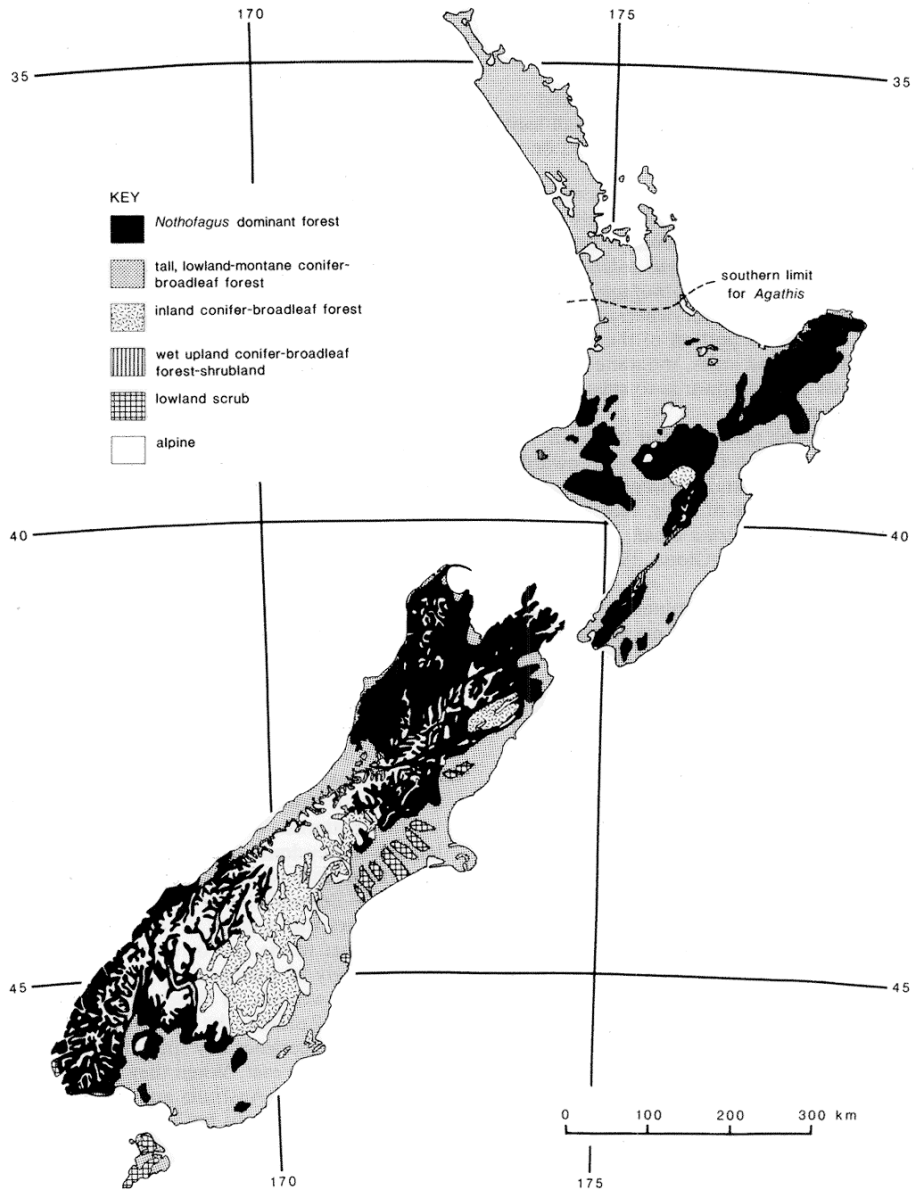


Figure 1: New Zealand vegetation c. 3000 yr B.P.

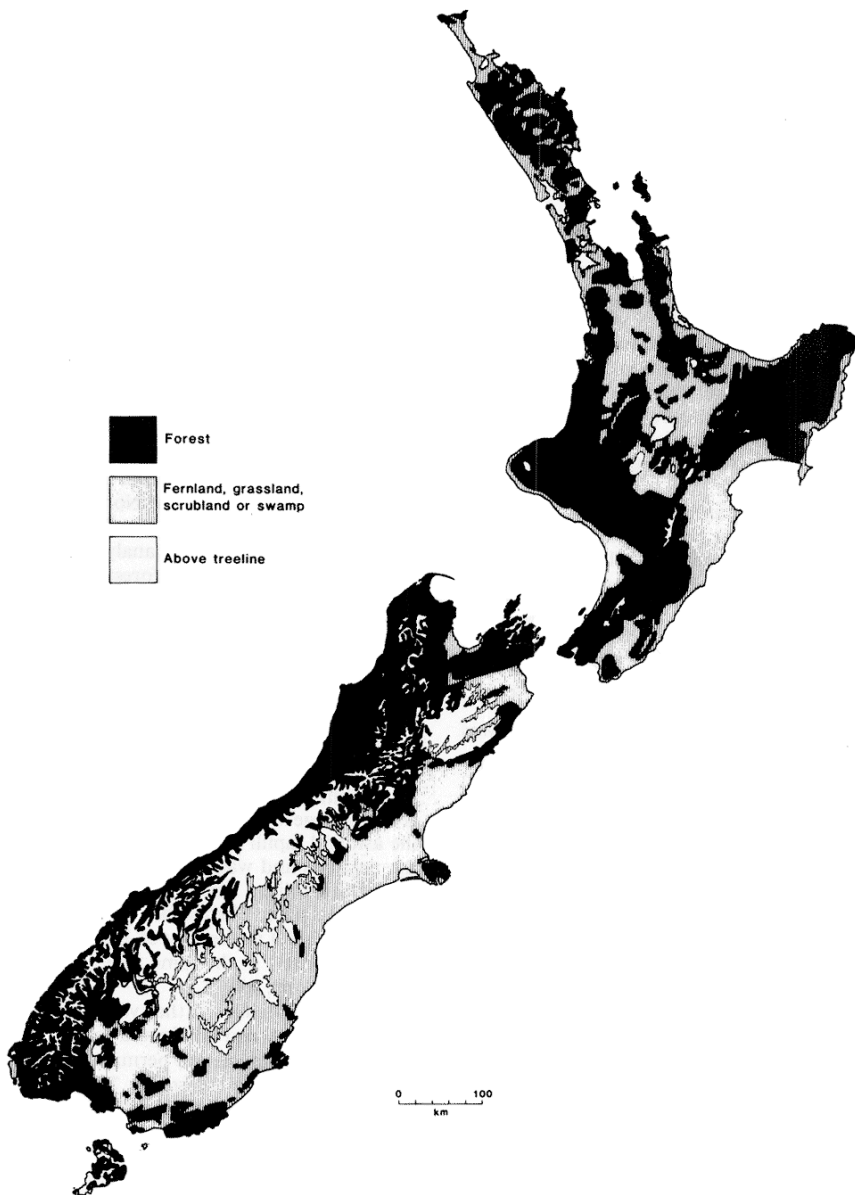


Figure 2: Extent of forest at time of first European surveys, 1840-1860 AD. (From: McGlone, 1983b).

observed since instrumental recording of weather began in New Zealand (Burrows and Greenland, 1979). Fluctuations of meridional versus zonal wind flow and positions of anticyclones lead to variable precipitation, while a strengthening wind flow may bring prolonged outbreaks of cold weather and increased disturbance to forest.

Natural Fire

Natural fire cannot be distinguished with any certainty from human fire. If 1000 yr B.P. is accepted for the approximate date of human settlement, any fires before then were of natural origin. Lightning strikes are the only likely sources of fire in most parts of the country as fire from volcanic eruptions will affect only limited areas. Widespread soil charcoal indicates that natural fire has been a recurring feature of the environment. In the South Island, there were at least six outbreaks between 2000 and 6500 yr B.P. (Molloy, 1977).

By itself, charcoal can indicate only that some of the forest was destroyed but pollen analysis will show whether or not an area was permanently deforested. Several pollen sites in central Otago indicate that deforestation by fire began by at least 2500 yr B.P., and that some regions were nearly totally deforested by 1700 yr B.P. (McGlone, 1973 and unpubl.). It seems that these fires did not result in permanent deforestation outside the inland Otago/south Canterbury regions. Even there, forest destruction was probably patchy and predominantly confined to the drier valley bottoms and lower slopes (Anderson, 1984). Although these areas cannot be delineated accurately, there can be no doubt that the first Polynesians to penetrate inland southeastern South Island discovered a landscape already partly in low scrub and grassland.

This natural deforestation supports the concept of more variation in precipitation as wind flow increased. Stronger westerlies would lead to dry, droughty conditions in central Otago, and thus increase the probability of devastating fires.

Volcanism

Since 3000 yr B.P. there have been numerous local eruptions from andesitic cones such as Egmont (Taranaki), Ruapehu, Tongariro, Ngauruhoe, and the basaltic cones of the Waitemata isthmus. Although much vegetation was destroyed close to the cones, especially after pyroclastic flow eruptions, the effect did not reach more than a few km beyond, except for

light showering with ash. Vegetation studies and pollen profiles from sites on the flanks of the Taranaki volcanoes show that forest was only partly destroyed, even after major andesitic eruptions, and that it recovered rapidly (Druce, 1966; McGlone *et al.*, 1988).

Rhyolitic eruptions are vastly greater in volume and many times more destructive than andesitic or basaltic eruptions. There have been several rhyolitic eruptions since 3000 yr B.P. which have destroyed forests over a wide area but the Taupo pumice eruption and the Kaharoa Ash eruption have been the most important for vegetation. The Taupo Pumice eruptions (*c.* 1800 yr B.P.) from a vent near the northeastern shore of Lake Taupo, destroyed forests over a radius of 80 km through a combination of pyroclastic ground flows and airfall tephra (Froggat, 1981). However, beech stands within a few km of the vent suggest that forest was not totally destroyed. It has often been claimed that the large tracts of treeless scrub and fern in the central North Island were related to the effects of the Taupo Pumice eruption (e.g. Green 1975). Recent pollen analysis of a site close to eruption centre shows that forest recovered quickly and that there was no long period of treeless vegetation (Clarkson, *et al.*, 1986). It may be that the eruption favoured podocarps over beech because it provided deep, coarse, ash beds in valley bottoms. Pollen analyses from more distant sites in the Waikato Basin, Bay of Plenty, and Hawkes Bay, show that their forests were also disturbed and burnt after the fall of the Taupo Pumice (McGlone, 1981). As the pumice must have been cold when it fell in these areas, foliage was most probably destroyed either by the ash and lapilli fall, or by acids absorbed onto the ash particles and washed out of the eruption cloud by rain. Dead foliage and trees created ideal conditions for fires to start. The much smaller Kaharoa eruption (*c.* 700 yr B.P.) in the Bay of Plenty probably destroyed forest in the same way, albeit on a smaller scale (McGlone, 1981).

Despite speculation that volcanic eruptions destroyed forest and eliminated fauna, there is no evidence that they caused permanent deforestation except very close to the crater. Their primary influence has been to renew soils with ash and coarse alluvium.

Anthropogenic Fire

It is difficult to be sure when anthropogenic burning began as there is no distinctive human signature to the fires, nor have any of the crops introduced by

Polynesians provided an independent pollen record of settlement. Nearly all sites show some charcoal influx throughout the Holocene; these traces - presumably caused by occasional and restricted natural fires - cannot be distinguished from those of the first fires lit by humans

The most probable indicators of anthropogenic burning are a continuous influx of abundant microscopic charcoal to sites, together with decline of forest and spread of bracken and grassland. Using these criteria, substantial deforestation can be detected throughout New Zealand (leaving aside the naturally burnt central Otago/South Canterbury region) beginning at around 800 to 400 yr B.P. depending on the locality (McGlone, 1983b). Anthropogenic fires may have also occurred on a smaller scale before this because there was a minor increase of charcoal and bracken spores at 1000-800 yr B.P. at some sites (McGlone, 1983b). Drier, fertile, lowland coastal sites were the first to be burnt extensively and little of the wet hill country was deforested. The pollen evidence suggest that, at anyone site, deforestation proceeded rapidly once it had begun, and only rarely is there any evidence of regression back to forest. Major burning seemed to begin at roughly the same time throughout the country, with only sporadic and limited clearance before 750 yr B.P. and then rapid, extensive deforestation. By the time of widespread European settlement in the 1840s and 1850s, close to one half of the original forest cover had been destroyed (Masters, *et al.*, 1957) (Fig. 2). It is important to note that because these fires had greater impact in drier regions, some forest types, especially dry inland conifer-broadleaved, were nearly eliminated and others, such as lowland matai-totara forests, were greatly reduced. Consequently, remaining forests are not at all representative of the pre-human situation.

Deforestation and Erosion

The degree to which deforestation triggered landform instability and erosion is controversial. Both Grant (1985) and McFadgen (1985) favour cycles of climatic change over the last 2000 years as the primary cause of both inland and coastal erosion and instability. In essence, they claim that certain periods are characterised by high frequencies of intense cyclonic rainstorms which induce slipping over very wide areas.

McGlone (1983b) suggested that Polynesian burning may have initiated subsequent erosive episodes. Grant (1985) rejects this suggestion: 'There is no unquestionable evidence in New Zealand that damage to vegetation by fires has been, and is at

present, a primary cause of increased erosion and sedimentation on a major scale.' (p. 109). If by 'erosion and sedimentation' Grant means the large-scale erosive processes active in the axial greywacke ranges, and which build large river terraces, he is undoubtedly correct, as a number of recent studies have concluded (O'Loughlin and Pearce, 1982). However, there is abundant circumstantial evidence for localized soil movement after burning in the form of tree charcoal preserved in hollows buried by downslope movement of soil and debris (Molloy, 1977). Sediment profiles from lakes or swamps often show an influx of alluvium at the same time that pollen and charcoal frequencies indicate deforestation of the catchment. O'Loughlin, *et al.*, (1982) have shown that removing forest can lead to slope erosion, and Pearce (1982) documents recent mass movement on a large-scale after deforestation in the eastern Raukumara Peninsula. It seems, therefore, that Polynesian forest fires did initiate erosion at all scales, but large-scale mass-movement occurred only in areas of soft, weaker rocks. In terms of vegetation however, localized soil erosion after fire is important, because leached or unweathered substrates are exposed and nutrients are lost with the topsoil.

The greatest consequences of burning of vegetation would be expected on unstable substrates. It is therefore surprising that McFadgen (1985) does not 'attribute any instability in coastal sequences to human occupation. He suggests that late Holocene dune sand and coastal alluvium accumulated during three major depositional episodes, each consisting of an unstable (accumulation) phase followed by a stable (soil-forming) phase. The first episode (Tamatean) began more than 1800 years ago; the second (Ohuan) 450 years ago; and the third (Hoatan) about 150 years ago, and its unstable phase continues. McFadgen rules out forest clearance, earthquakes, volcanic eruptions or sea level changes as explanations for the unstable phases in favour of increased frequencies of tropical and extratropical cyclones.

To accept McFadgen's climatic cycle hypothesis means also accepting that: the stable soil-forming phases were synchronous; the climatic changes he suggests would probably have the effects he claimed; and human interference with dune systems did not lead to their disturbance.

Given the short time over which these coastal sequences have accumulated, and the very recent dates suggested for the Ohuan and Hoatan phases, it is impossible to establish synchrony from site to site on the basis of radiocarbon dating because of the large

errors involved. European and Maori artifacts can be used to date some soils roughly, but not all. The phases can be dated with these methods only if there is an assumption that they are synchronous. In this regard, the position of the sea-borne Loiseles Pumice (c. 650 yr B.P.) in the coastal sequences is important as it provides a well-dated and distinctive time horizon not subject to the same degree of uncertainty. The Loiseles Pumice occurs in a variety of contexts: sandy layers; occupation horizons; within, and immediately above and below soil layers (McFadgen, 1985, fig. 16). Thus, although the Loiseles Pumice is placed towards the end of the Tamatean unstable phase, it is clear that a variety of coastal processes and events were occurring at the time of its deposition, and not all of them are compatible with instability. The stratigraphic and chronological evidence of McFadgen (1985) appears to better fit an hypothesis in which coastal sequences were disturbed at various times by a variety of events, some of the most important of which were Polynesians and then Europeans using the fragile dune systems.

McFadgen (1985) links episodes of sand movement and deposition at the coast with high rates of aggradation in the major river systems. Rivers are said to aggrade faster when there are more cyclonic storms of tropical or extra-tropical origin producing more erosion in upland catchments. When there are fewer such storms, and hence less erosion, dune systems stabilize and soils form. Under the associated moister, calmer conditions vegetation increases on exposed dunes. However, despite the claim that coastal depositional episodes are linked with the alluvial sedimentation periods of Grant (1985), there is no compelling evidence of a match. Grant has 7 stable soil-forming episodes to McFadgen's 2, and thus there is a high possibility of a fortuitous match, given the uncertainty of radiocarbon dates in this time range. Furthermore, dune instability and sand deposition inland does not necessarily follow from increased sand supply to the coast. If sand increases on the coast, dunes commonly prograde and may or may not migrate inland.

The relation of the coast to the primary sites of erosive activity must be carefully considered before any conclusions are reached about linkages between them. Eroded material is held in basins and reworked gradually by normal bank erosion. Pearce and Watson (1986) have shown that it may take hundreds of years for the products of inland erosion to reach the coast. Grant (1985) points out that the dominant process on sandy coasts during the present episode of alluvial

sedimentation is erosion, not accumulation. A close match between erosive episodes and coastal response should not therefore be expected where basins intervene between sources of sediment and the coast.

Undoubtedly alluvial deposits have increased periodically in river catchments, most probably as a consequence of greater storminess; and particular coastal sites have had several episodes of such instability. However, these observations extend over only 2000 years and rely heavily on radiocarbon dating. It seems that the only reasonable conclusion is that alluviation in inland catchments and coastal instability have varied episodically since 1800 yr B. P. It is premature to erect a New Zealand-wide stratigraphy for these phenomena, although regional stratigraphies seem better supported. Human influence on rock erosion rates cannot be ruled out, and probably did affect areas of soft rock or unstable substrates. Deforestation caused by humans has led to soil erosion and is highly likely to have affected coastal dunes.

Climatic Change, Anthropogenic Impact, and the Extinction of Avian Biota

It is well established that a major extinction episode began around 1000 yr B.P. and continues to the present. During it, approximately 30 species and subspecies of birds have been eliminated on the New Zealand mainland (Cassels, 1984). Many others have become rare or uncommon. Unfortunately, the bird fossil record before the Holocene is poor, and it is impossible to compare this extinction episode with previous ones. Nevertheless, it seems that the extinction event after 1000 B.P. was relatively abrupt, and not part of a long decline in populations of species (Cassels, 1984).

A number of factors may have contributed to the decline and extinction of so many bird species: (i) deteriorating climates may have directly eliminated some species; (ii) natural changes in vegetation composition may have made some regions less productive; (iii) destruction of habitat by natural or human fire; (iv) predation on some birds by kiore (*Rattus exulans*), and dogs introduced by the Polynesians; (v) direct predation by humans. I will deal with each of these in turn.

(i) Climatic deterioration

Deterioration of the climate has been one of the most persistent theories to explain the extinction and decline

of bird species within New Zealand, but it alone is highly unlikely to have caused any extinctions. Endemic terrestrial birds which survived the bleak, cool conditions of the glacial maximum would hardly succumb to the relatively minor climatic changes of the last millenium. Burrows (1982) concluded that recent changes in climate were not great enough to have led to major environmental change. As discussed above, climatic deterioration began several millenia before bird extinction began, and no large climatic changes have occurred since 1000 yr B.P. The only direct effect that could be expected from recent climatic change is localised retreat of some bird populations from upland or exposed sites.

(ii) *Changes in vegetation*

The conifer-broadleaved forests have seen numerous changes in the last 3000 years, none of which are likely to have reduced their attractiveness to birds. However, when conifer-broadleaved or beech-conifer-broad leaved forests were replaced by beech forests there would have been a marked reduction in suitable habitat for a wide range of birds. Beech forest is, overall, a poorer habitat for present day birds (Wardle, 1984) because it does not have the abundant fruit, nectar and edible foliage resources which are of particular importance to the larger birds. There is little diversity in the understorey shrub and ground layers, and seed production is erratic because of the mast-fruiting of beech. Beech forest was probably poor habitat for the moa as well. In central Otago, no moa-hunting sites are known from closed beech forest (Anderson, 1982). Over the last 7000 years what we infer as prime moa habitat in upland and southern areas (that is conifer-broadleaved forest or tall scrubland) was replaced by beech, but most of this happened well before human settlement. The small amount of conifer-broadleaved communities which was replaced by beech during the Polynesian era was predominantly in Fiordland-western Southland, and there was very little replacement elsewhere. This would have reduced the attractiveness of those areas for most birds, but for moa in particular.

(iii) *Anthropogenic fire*

The role of deforestation in the elimination of birds should not be overlooked. Drier, fertile, lowland sites were the earliest to be burnt and the most completely deforested, and these were probably the most productive areas for bird life. Deforestation may have been particularly devastating to moa. A reasonable assumption from the distribution of kill sites is that the moa were concentrated in lowland areas of low to

moderate rainfall and covered predominantly with conifer-broadleaved forest. Most, and largest, moa kill sites are in the east of the South Island, mostly at or near the coastline, although lowland central Otago was also rich in sites (Trotter and McCulloch, 1984; Anderson, 1984). In the North Island the major hunting sites were almost all at or near the coast, with few or insignificant kill sites in the mountainous, wet, central districts (Davidson, 1984). New Zealand lowland alluvial soils under a moderate to low rainfall are generally fertile, and are the most productive of fast-growing shrubs and small trees in canopy gaps and forest ecotones. Current evidence suggests that these seral communities provided the best moa browse (Greenwood and Atkinson, 1977; Burrows, 1980; Burrows, *et al.*, 1981; Anderson 1982). Thus, tall undisturbed forest may have been rather unattractive, especially in wet areas, while open, drier forests with much seral vegetation would have provided abundant moa browse. When most of these optimum moa habitats were destroyed between 1000 and 500 yrs B.P., the greater part of the moa population may have been eliminated also.

(iv) *Predation by dog and rat*

Cassels (1984) believes that the dog which Maoris used in hunting would have helped eliminate large ground-dwelling birds. He did not consider it an effective feral predator although Anderson (1981), on the contrary, thought it important. The kiore (*Rattus exulans*) undoubtedly played a role in the elimination of smaller birds, but cannot have directly affected birds larger than chickens, or preyed on the large, strong-walled eggs of the larger birds (Fleming, 1969).

(v) *Predation by humans*

The consensus among archaeologists is that moa and other large ground-dwelling birds became extinct mainly because they were hunted by humans (Anderson, 1984; Trotter and McCulloch, 1984; Davidson, 1984). This view is strongly supported by the fact that no moas became extinct during the Holocene before humans arrived; that birds became extinct in areas which were not burnt and were unlikely to have been severely affected by climate and vegetation change; and that kill sites were abundant and widespread. Further evidence comes from the presumed nature of the extinct birds when compared with their surviving relatives (Cassels, 1984). Many were flightless, large, often diurnal, characteristic of forest ecotones, built nests on the ground, and laid small clutches of large eggs. All of these features made them vulnerable to humans and terrestrial

predators in general. In contrast, surviving birds are mainly flighted, and those that are flightless are mostly nocturnal.

A major objection to the hunting hypothesis is that there are large areas of sparsely settled, rugged, bush-clad country from which these birds also vanished. Although it was also inhabited by nearly all of the extinct birds very few moa-hunting sites have been located there (Davidson, 1984). From what little we know of their biology and food preferences, the larger, extinct ground-dwelling birds were probably concentrated in favoured habitats, such as alluvial scrub-covered sites, forest-shrub ecotones and patches of regenerating forest. If this was so, snares or systematic hunting with dogs may have been sufficient to reduce the larger, ground-dwelling diurnal birds to below replacement levels in these smaller areas. It may not have been necessary to hunt the entire forest tract to eliminate vulnerable birds whose replacement rate was so low. Such a small number of birds would have been taken at anyone site that middens would have been inconspicuous.

Hunting by humans was almost certainly the major cause of the extinction of the larger avifauna.

Deforestation directly destroyed habitat and may have caused both local extinctions - for instance kiwis, kakapo and takahe in the east of the South Island - or may have reduced and concentrated populations thus making them more vulnerable to hunting.

The Polynesian Revolution

Fig. 3 gives an outline of cultural and environmental change during the Polynesian era. It is clear that the years between 750 and 500 yr B.P. were ones of radical change. Prior to 750 yr B.P. middens contained abundant bird and marine mammal bone; moa were extensively hunted; and deforestation was limited. After 450 yr B.P. middens contained mainly shellfish and fish remains; moa were no longer a significant prey item and some species may have become extinct; and by 400 yr B.P. the pattern of forested versus non-forested open country had become established. Cultural changes included a replacement of the archaic toolkit with that of the classic Maori, and widespread building of pa (fortified villages) in the North Island. How are these changes connected? One of our major clues is the dramatic change in diet as revealed by middens.

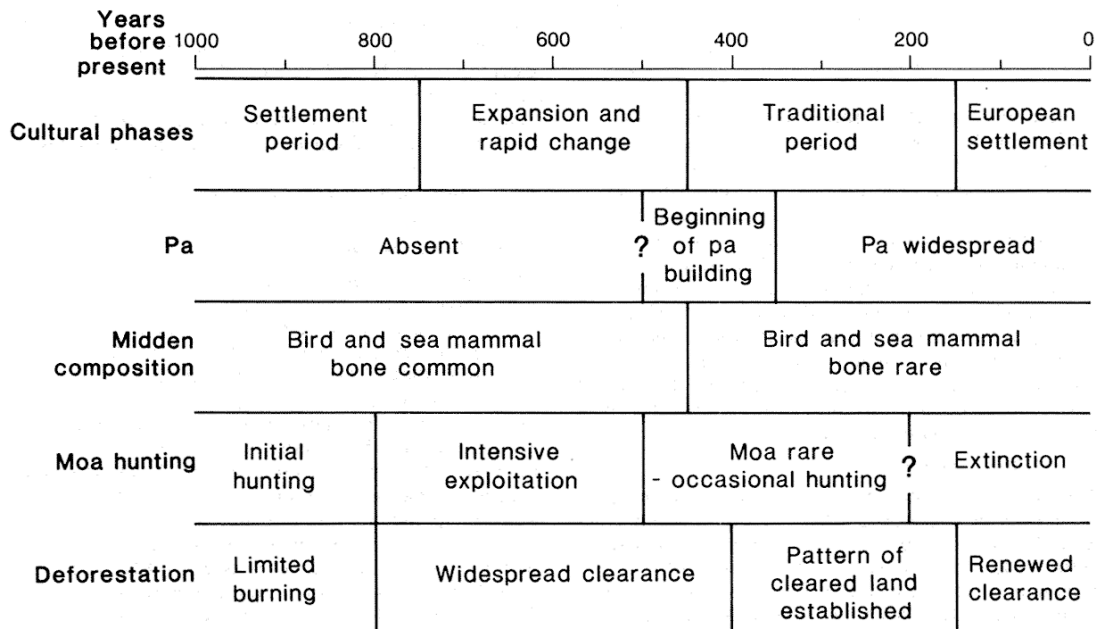


Figure 3: Cultural and environmental change, 1000 yr B.P. to present. Cultural phases after Davidson (1984).

Birds, other than moa, which were exploited in the settlement phase and represented in middens, include a wide range of both sea and forest birds (Davidson, 1984; Cassels, 1984). Shags are found in the largest number of sites, but parakeets, penguins, pigeons, petrels, ducks, rails, kiwi, kaka and tui were also commonly taken. Fur seals were the most exploited mammals but the diet also included elephant seals, sea lions, leopard seals and dolphins. Colonial sea birds and seals were clearly more widely distributed before the arrival of humans: some marine mammals extended further to the north; and colonial sea birds were more abundant on the mainland and at inland sites (Cassels, 1984).

Forest bird and moa populations were so depleted that they were rare in middens after about 450 yrs B.P. This can be linked plausibly to deforestation, but other explanations must be sought for the decline of colonial sea birds and sea mammals. Both Anderson (1984), Trotter and McCulloch (1984) stress the rapidity with which the moa were eliminated from any one area, and suggest a brief, intensive over-exploitation phase. The same model can be applied to colonial sea birds and sea mammals. In the case of the moa, populations declined sharply before deforestation and this strengthens the case for exploitation rather than habitat destruction (Anderson, 1984).

We may never know just how great the bird and mammal populations were before over-exploitation, but the evidence from middens suggests that they may have been very large. Bird and mammal remains are scarce in recent prehistoric middens. Nevertheless, there is good ethnographic evidence that exploitation of birds and mammals continued on a regular basis (Davidson, 1984). It is possible that there 'were changes in the way in which prey items were prepared or disposed of which affected their chances of being preserved in middens. Changes in domestic practices, such as whether dogs were kept tethered or not, could have altered the representation of bone (Davidson, 1984). Even making these allowances it is hard to avoid the conclusion that birds and mammals were a much bigger part of the diet in the settlement phase than in the traditional phase. This in turn suggests an enormous resource of easily exploited birds and mammals available during the settlement phase. Inevitably, the most vulnerable and accessible portions of the bird and mammal stock - the roosting or breeding colonies - were seriously depleted, and the survivors may have become very shy. Thereafter, items which could be obtained more reliably and were

not as sensitive to over-exploitation, such as fish, shellfish, and bracken root became dominant in the diet.

The perception of the economic worth of forests may have changed radically when bird stocks in them declined. On one hand, they were less valuable when the most easily exploited bird populations had gone; on the other, once they were cleared by fire, other food sources became available. Starch-rich bracken and ti (*Cordyline australis* or cabbage tree) became abundant in regenerating fern and shrublands; kumara and other crops could be grown on areas of superior soils; and forested, oligotrophic wetlands became productive swamps stocked with eels and fish, and attractive to waterfowl. If the phase of over-exploitation of birds and mammals suggested by Anderson (1984) and Trotter and McCulloch (1984) occurred, then it is reasonable to propose that the subsequent deforestation phase was part of a deliberate strategy to increase the productivity of the landscape in other ways.

An important consequence of the easily exploited stocks of protein-rich food during the early settlement phase, was high growth rates in the human population. An exponential population growth model, such as that of Groube (1970), suggests a sharp increase during which the New Zealand population doubled many times in the course of only a few centuries. This point was probably reached between 750 and 500 B.P. when bird and mammal stocks had been depleted, large-scale deforestation had begun, and fortified pa were built. The rapidly growing human population outstripped the initial stock of easily gathered resources and began to use the landscape more intensively, mostly by clearing forest, cultivating crops, and encouraging higher yielding seral and swamp vegetation. At the same time, the spread of fortifications may indicate that shortages of resources had become chronic, leading to conflict.

Conclusions and Discussion

Over the last 1000 yrs human impact on the New Zealand biota and landscape has eclipsed anything brought about by natural processes over the past 3 millennia. It is seen in the destruction of vast amounts of forest; the near elimination of certain forest types; and the extinction of around 30 bird species and a unknown number of other vertebrates and invertebrates through hunting, predation, introduction of predators, and destruction of habitat. Although there were climatic changes over this period which affected land stability and plant cover, they were not

large enough to influence the course of these events. Over limited areas, climatic change, volcanism, vegetation change and natural fires may have influenced the composition of the fauna. The sizes of animal populations would have been affected but probably quite locally and within the range of variation experienced throughout the entire Holocene period. Without humans, New Zealand would still be a largely forested country with its full complement of animal life.

Extensive human impact on the environment appears to have been sudden, and concentrated over a short period between 750 to 500 yr B.P. This period coincides with dietary and cultural changes in the Polynesian society and the beginning of widespread pa construction.

In the pre-settlement era, populations of browsing birds were at their densest in the drier, more open forests of the fertile lowlands, largely in the east. They were thus vulnerable to both hunting and loss of habitat by fire. The complete extirpation of many browsing birds from wetter, upland, often beech-dominated forests is to be expected because their populations were small and concentrated in scattered sites. Even low hunting pressure in these regions would have eliminated the most vulnerable birds. An important corollary of this hypothesis is that browsing pressure was never high in the beech forests and in the denser, wetter, upland conifer-broadleaved forests.

In recent times it has been argued that browsing birds, and in particular the moa, had a considerable influence on the flora and vegetation (Greenwood and Atkinson, 1977; Caughley, 1983). Greenwood and Atkinson proposed that the divaricating plant form evolved in response to moa browsing. This is disputed but the conclusion that browsing birds must have modified the vegetation where they were abundant is not (McGlone and Webb, 1981). However, extant forests in New Zealand are predominantly beech, or upland and southern conifer-broadleaved associations growing under wet, cool climates. The browsing pressure in them was probably only weak and highly localized at the time of human settlement. The repeated observation that introduced mammals cause very great changes to the vegetation, and nearly eliminate some components of local floras, is sometimes interpreted as representing a return to a state of affairs akin to that which prevailed before human settlement. But if in fact these forests had never faced severe browsing pressure it does not come as a surprise that they are uniquely vulnerable to it now, and that their present condition is indeed

without parallel.

There has been belated recognition of the dominant influence that human settlement has had in New Zealand - at least on the lowland environment. In part, this lag has been because it is very difficult to distinguish anthropogenic change from natural environmental variability. But there has also been a marked reluctance to accept that the settlement of New Zealand by Polynesians brought many environmental changes. To a degree this reluctance derives from the proposition that the pre-industrial hunter-gathers and neolithic agriculturalists lived in harmony with their environment, practising a conservation ethic and avoiding short-sighted and exploitative destruction typical of later industrial societies (Diamond, 1986). Traditional Maori society did practice resource conservation, but only within the context of a landscape they had already depleted and where food shortages were an unpleasantly common fact of life. We make a mistake if we project these attitudes back to a time when the population was small (but expanding) and the animal food resources both large and vulnerable.

Perhaps more important has been the effect of a very influential paper which argued that climatic change over the last 1000 years had played a dominant role in determining the structure and distribution of New Zealand forests (Holloway, 1954). For nearly 3 decades palaeo-environmental research and discussion was strongly influenced by his idea that climatic changes was the key to understanding much of the environmental and cultural changes which had taken place since human settlement. Only over the past few years has opinion veered sharply away from the view that recent environmental changes can be explained by long-term climatic trends. Consequently, more emphasis has been placed on understanding normal geological processes and climatic variability, and their effects on the vegetation (Veblen and Stewart, 1982; Ogden, 1985).

Our knowledge of the impact of human settlement on the environment is still impressionistic and general, rather than quantitative and particular. What is now needed are regional studies which integrate the work of many disciplines in answering questions on the timing, rate and sequence of environmental change. The timing, pattern, and impact of settlement was different in various parts of the country and one generalized model cannot encompass the range of variation.

We must also move beyond simple advocacy in addressing the possible role which browsing birds

played in the pre-settlement vegetation of New Zealand, and the changes which followed their extinction. At present the arguments amount to little more than a strongly held belief that a large number of browsing birds must have had a substantial impact on the vegetation. This is clearly a very reasonable assumption, but no testable hypotheses have flowed from it.

Once a coherent picture has been proposed of the distribution and composition of pre-settlement vegetation, testing can take place in two different ways: palaeo-ecological information can be tested against the proposal; and experiments can be done on the present vegetation. For instance, pollen analysis can distinguish between pollen types from browse-resistant plants (e.g. *Pseudowintera*) and browse-sensitive plants (e.g. *Griselinia*, *Schefflera*). Detailed analysis across the extinction time-horizon may detect changes in the abundance of these pollen types. In some circumstances, well-preserved leaf floras are found which could be analysed for signs of browsing or in which the ratio of browse-sensitive to browse-resistant plants could be measured. Studies on present vegetation could include simulating moa browsing experimentally, and analysing the information from browsing mammal exclosure plots. If there are plants in the New Zealand flora which are strongly adapted to a browsing regime, then their adaptations may well have incurred some resource costs. When browsing pressure is lowered they should therefore be at a demonstrable disadvantage in relation to those not browse adapted.

In the present economic climate there would inevitably be questions as to whether such research is necessary or desirable. I believe that we should attempt to understand the forces which shaped the history of vegetation and landscape so as to understand those fragments which are left in something like their original condition. Such research may direct attention to habitats and landscapes of greatest importance and give valuable information on how to manage them most appropriately. Without a historical perspective, or a longer view, the end to which reserved areas are being managed will be vague, and the ability to anticipate and accommodate inevitable changes will remain weak.

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References

- Anderson, A.J. 1981. Pre-European hunting dogs in South Island, New Zealand. *New Zealand Journal of Archaeology* 3: 15-20.
- Anderson, A.J. 1982. Habitat preferences of moa in central Otago, A.D. 1000-1500, according to palaeobotanical and archaeological evidence. *Journal of the Royal Society of New Zealand* 12: 321-336.
- Anderson, A. 1984. The extinction of moa in southern New Zealand. In: Martin, P.S.; Klein, R.G. (Editors). *Quaternary Extinctions*. pp. 728-740. The University of Arizona Press, Tucson.
- Burrows, C.J. 1979. A chronology for cool-climate episodes in southern Hemisphere 12000-1000 B.P. *Palaeogeography, Palaeoclimatology, Palaeoecology* 27: 287-347.
- Burrows, C.J. 1980. Diet of the New Zealand Dinorthisiformes. *Naturwissenschaften* 67: 151.
- Burrows, C.J. 1982. On New Zealand climate within the last 1000 years. *New Zealand Journal of Archaeology* 4: 157-167.
- Burrows, C.J.; Greenland, D.E. 1979. An analysis of the evidence for climatic change in New Zealand in the last thousand years: evidence from diverse natural phenomena and from instrumental records. *Journal of the Royal Society of New Zealand* 9: 321-373.
- Burrows, C.J.; McCulloch, B.; Trotter, M.M. 1981. The diet of moas, based on gizzard contents samples from Pyramid Valley, North Canterbury, and Scaifes Lagoon, Lake Wanaka, Otago. *Records of the Canterbury Museum* 9: 309-336.
- Caughley, G. 1983. *The deer wars*. Heinemann, Auckland.
- Cassels, R. 1984. The role of prehistoric man in the faunal extinctions of New Zealand and other Pacific Islands. In: Martin, P.S.; Klein, R.G. (Editors). *Quaternary Extinctions*. pp. 741-767. The University of Arizona Press, Tucson.
- Clarkson, B.D.; Clarkson, B.R.; McGlone, M.S. 1986. Vegetation history of some west Taupo mires. In: Veale, B; Innes, J. (Editors). *Ecological research in the central North Island*. pp. 34-37. New Zealand Forest Service, Rotorua.
- Cox, J.E.; Mead, C.B. 1963. Soil evidence relating to post-glacial climate on the Canterbury Plains. *Proceedings of the New Zealand Ecological Society* 10: 28-38.
- Davidson, J. 1984. *The prehistory of New Zealand*. Longman Paul, Auckland.

- Diamond, J.M. 1986. The environmentalist myth. *Nature* 324: 19-20.
- Druce, A.P. 1966. Tree-ring dating of recent volcanic ash and lapilli, Mt Egmont. *New Zealand Journal of Botany* 4: 3-21.
- Ecroyd, C.E. 1982. Biological flora of New Zealand 8. *Agathis australis* (D. Don) Lindl. (Araucariaceae) Kauri. *New Zealand Journal of Botany* 20: 17-36.
- Fleming, C.A. 1969. Rats and moa extinction. *Notornis* 16: 210-211.
- Froggat, P. C. 1981. Stratigraphy and nature of Taupo Pumice Formation. *New Zealand Journal of Geology and Geophysics* 24: 231-248.
- Gellatly, A.F.; Rothlisberger, F.; Geyh, M.A. 1985. Holocene glacier variations in New Zealand (South Island). *Zeitschrift für Gletscherkunde und Glazialgeologie* 21: 265-273.
- Golson, J. 1959. Culture change in prehistoric New Zealand. In: Freeman, J.D.; Geddes, W.R. (Editors). *Anthropology in the South Seas*. p. 29-74. Avery, New Plymouth.
- Grant, P.J. 1985. Major periods of erosion and alluvial sedimentation in New Zealand during the late Holocene. *Journal of the Royal Society* 15: 67-121.
- Green, R.C. 1975. Adaptation and change in Maori culture. In: Kuschel, G. (Editor). *Biogeography and Ecology in New Zealand*. pp. 591-641. Junk, The Hague.
- Greenwood, R.M.; Atkinson, I.A.E. 1977. Evolution of divaricating plants in New Zealand in relation to moa browsing. *Proceedings of the New Zealand Ecological Society* 24: 21-33.
- Groube, L.M. 1970. The origin and development of earthwork fortifications in the Pacific. In: Green, R.C., Kelly, M. (Editors) *Studies in Oceanic Culture History*, Vol. 1. *Pacific Anthropological Records* 11: 133-164.
- Harris, W.F. 1963. Palaeo-ecological evidence from pollen and spores. *Proceedings of the New Zealand Ecological Society* 10: 38-44.
- Holloway, J.T. 1954. Forests and climates in the South Island of New Zealand. *Transactions of the Royal Society of New Zealand* 82: 329-410.
- Johnson, P.N. 1978. Holocene plant remains from the shores of Lake Manapouri, New Zealand. *New Zealand Journal of Botany* 16: 141-5.
- Kirch, P.V. 1982. Ecology and the adaptation of Polynesian agricultural systems. *Archaeology in Oceania* 17: 1-6.
- Masters, S.E.; Holloway, J.T.; McKelvey, P.J. 1957. *The National Forest Survey of New Zealand 1955. Vol. 1. The indigenous forest resources of New Zealand*. Wellington, Government Printer.
- McFadgen, B.G. 1985. Late Holocene stratigraphy of coastal deposits between Auckland and Dunedin, New Zealand. *Journal of the Royal Society of New Zealand* 15: 27-65.
- McGlone, M.S. 1973. Pollen analysis In: Leslie, D.M. Relic periglacial landforms at Clark's Junction, Otago. *New Zealand Journal of Geology and Geophysics* 16: 575-578.
- McGlone, M.S. 1978. Forest destruction by early Polynesians, Lake Poukawa, Hawkes Bay, New Zealand. *Journal of the Royal Society of New Zealand* 8: 275-81.
- McGlone, M.S. 1981. Forest fire following Holocene tephra fall. In: Howarth, R.; Froggat, P.; Vucetich, C.G.; Collen, J.D. (Editors). *Proceedings of tephra workshop, June 30th-July 1st 1980*. pp. 80-86. Victoria University of Wellington, Wellington.
- McGlone, M.S. 1983a. The history of New Zealand lowland forest since the last glaciation. In: Thompson, K.; Hodder, A.P.H.; Edmonds, A.S. (Editors). *Lowlands forests in New Zealand*. pp. 1-17. University of Waikato, Hamilton.
- McGlone, M.S. 1983b. Polynesian deforestation of New Zealand: a preliminary synthesis. *Archaeology in Oceania* 18: 11-25.
- McGlone, M.S.; Bathgate, J.L. 1983. Vegetation and climate history of the Longwood Range, South Island, New Zealand, 12000 B.P. to the present. *New Zealand Journal of Botany* 21: 293-315.
- McGlone, M.S.; Moar, N.T. 1977. The *Ascarina* decline and post-glacial climatic change in New Zealand. *New Zealand Journal of Botany* 15: 485-489.
- McGlone, M.S.; Neall, V.E.; Clarkson, B.D. 1988. The effect of recent volcanic events and climatic changes on the vegetation of Mt Egmont (Mt Taranaki), New Zealand. *New Zealand Journal of Botany* 26: 123-144.
- McGlone, M.S.; Nelson, C.S.; Todd, A.J. 1984. Vegetation history and environmental significance of pre-peat and surficial peat deposits at Ohinewai, Lower Waikato lowland. *Journal of the Royal Society of New Zealand* 14: 233-244.
- McGlone, M.S.; Webb, C.J. 1981. Selective forces influencing the evolution of divaricating plants. *New Zealand Journal of Ecology* 4: 20-28.

- Moar, N.T. 1971. Contributions to the Quaternary history of the New Zealand flora 6. Pollen diagrams from Canterbury, Nelson and north Westland, South Island. *New Zealand Journal of Botany* 9: 80-145.
- Molloy, B.P.J. 1977: The fire history. In: Burrows, C.J. (Editor). *CaSSo History and science in the Cass district, Canterbury, New Zealand*. pp. 157-170. Department of Botany, University of Canterbury, Christchurch.
- Nicholls, J.L. 1983. The extent and variability of the native lowland forest. In: Thompson, K.; Hodder, A.P.H.; Edmonds, A.S. (Editors) *Lowland Forests in New Zealand*. Pp. 79-92. University of Waikato, Hamilton.
- Ogden, J. 1985. An introduction to plant demography with special reference to New Zealand trees. *New Zealand Journal of Botany* 23: 751-772.
- O'Loughlin, C.L.; Pearce, A.J. 1982. Erosion processes in the mountains. In: Soons, J.M.; Selby, M.T. (Editors). *Landforms of New Zealand*. pp. 67-79. Longman Paul, Auckland.
- O'Loughlin, C.L.; Rowe, L.K.; Pearce, A.T. 1982. Exceptional storm influences on slope erosion and sediment yield in small forest catchments, North Westland, New Zealand. *The First National Symposium on Forest Hydrology*, The Institution of Engineers, Australia, Melbourne.
- Pearce, A.J. 1982. Complex mass-movement terrain in the eastern Raukumara Peninsula, New Zealand: lithologic and structural-tectonic influences and the effects of recent deforestation and reforestation. *Landslides and mudflows*. Reports on Alma-Ata International Seminar, Centre of International Projects, GKNT, UNESCO/UNEP, Moscow. pp. 235-249.
- Pearce, A.J.; Watson, A.J. 1986. Earthquake induced landslide. *Geology* 14: 52-55.
- Salinger, M.J. 1984: New Zealand Climate: the last 5 million years. In Vogel, J.C. (Editor) *Late Cainozoic palaeoclimates of the Southern Hemisphere*. Pp 131-150 Balkema, Rotterdam.
- Trotter, M.M., McCulloch, B. 1984: Moa, men and middens. In: Martin, P.S.; Klein, R.G. (Editors) *Quaternary Extinctions*. pp. 708-727. The University of Arizona Press, Tucson.
- Veblen, T.T.; Stewart, J.J. 1982. On the conifer regeneration gap in New Zealand: the dynamics of *Libocedrus bidwillii* stands on South Island. *Journal of Ecology* 70: 413-436.
- Wardle, J.A. 1984: *The New Zealand Beeches*. New Zealand Forest Service, Christchurch.