# Options for managing the Kaimaumau wetland, Northland, New Zealand

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## ABSTRACT

This report details results of a scoping study made during the 1996/97 summer to identify possible management responses to the major problems affecting the Kaimaumau wetland. The perceived drying out of the wetland is found to be real but is a consequence of a run of lower-than-normal annual rainfalls rather than effects of drainage in and around the wetland. A feature of wetlands on sand country is that seasonally inundated margins surround a permanent wet zone. During a run of dry years, water table rise is less and shorter in duration. Recommendations are made concerning management of water levels in the wetland. Invasion of the wetland system by woody weeds, particularly Sydney golden wattle, is the most serious management problem. Trials for developing methods of replacing wattle with native trees are recommended. Trials are also needed to clarify the relationship between fires and the distribution and abundance of rare plants in the wetland. Systematic monitoring of some populations of these plants is necessary to identify the threats affecting them and thus the remedial actions needed. The difficulty of managing fire-adapted native vegetation against incursions by fire-adapted introduced weeds is discussed. Several recommendations are made for inclusion in a fire contingency plan. Use of large-scale controlled burning as a method of reducing the fuel load and thus the fire hazard is not recommended because of the risks of accelerating the spread of woody weeds and initiating persistent peat fires. Small-scale tightly controlled and carefully timed burns could be used to create habitats for some threatened plants. Suggestions are made for rationalising the boundaries of the Scientific Reserve. Inclusion of Lake Waikaramu within the Scientific Reserve is recommended, as comparable habitats within Lake Ohia have been lost. It is recommended that more opportunities are made for involving the local community in the management of the Kaimaumau wetland.

Keywords: wetlands, sand dunes, scientific reserve, drainage management, fire-adapted weeds, *Acacia longifolia*, threatened plants, fire hazard control, Kaimaumau wetland, Lake Waikaramu, Aupouri Ecological District.



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# 1. Special features of the Kaimaumau wetland

The Kaimaumau wetland stretches some 11 km from the mouth of Rangaunu Harbour near Kaimaumau north-westwards to Motutangi, south of the Houhora Heads. It is flanked along its north-eastern margin by the young dunes of East Beach and rises in altitude from near sea level to 10 m. Its sedge, rush and shrub vegetation is representative of acid low-fertility wetlands that were once more widespread on the sand country of the Aupouri and Karikari Peninsulas. The low-lying wetlands and intervening drier ridges provide habitats for many species of native plants and animals. Up to 11 of these plants have been listed as threatened including a number of orchids. The land is the only remaining freshwater wetland in Northland that exceeds 1000 ha and its outstanding conservation values have been partially protected by designation of 955 ha of the wetland as Scientific Reserve in 1984. An additional area of wetland, as well as young dunes forming its seaward margin, is partially protected as a 2312 ha Conservation Area (Fig. 1).

Seen from the air, the physiographic form of the wetland is elongate and striated: broad peat-covered flats are interspersed with long narrow sandy ridges that run parallel with the shoreline. This pattern of flats and ridges originated as a series of foredunes; the ridges are progressively older with distance from the coast. They formed as sea level dropped gradually from its interglacial maximum to positions seaward of, and below, the present-day coast. Some of the lower ridges are almost completely buried by peat. The silica-rich sands here are of low natural fertility. Soil formation, largely beneath kauri forest, has consolidated and podsolised the sands to produce impermeable hardpans that act as barriers between surface water and the groundwater beneath. The hardpans are likely to be the primary cause of the impeded drainage and resulting peat accumulation within the Kaimaumau wetland.

The wetland is generally thought by local residents to have become drier in recent years but whether this is the case is unclear. If real, it raises the question of whether the change is related to drainage operations in adjacent farmland, modification of drains passing through the wetland, or other reasons.

The vegetation of the wetland has been repeatedly modified by fire and was almost completely destroyed during a very fierce fire in November 1988. Woody and herbaceous weeds have re-colonised the wetland since this fire, sometimes by way of the ancient dune ridges. Some of the most widespread are of Australian origin. The present vegetation remains very susceptible to fire. There are benefits and losses from fires and this raises the question of whether controlled burning could be a practical management tool in this kind of habitat in the future; also, what other options may be practical for weed control and habitat restoration.

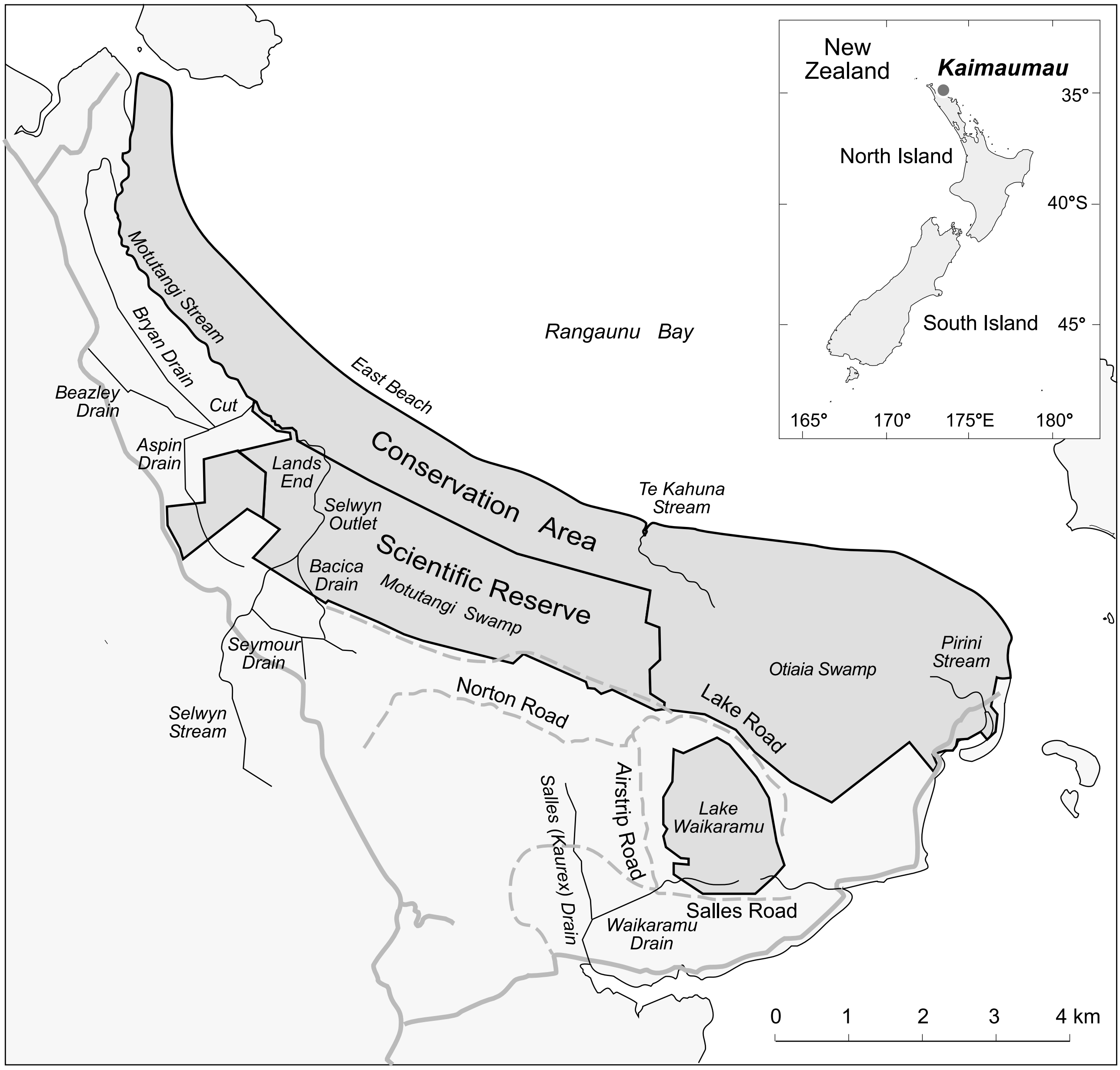


Figure 1. Location map of the Kaimaumau wetland, showing boundaries of public conservation land.

# 2. Site visits and methods

Preliminary discussions with DOC's Northland Conservancy Office in September 1996 indicated that DOC required a scientific overview of unresolved management issues at Kaimaumau. These issues included habitat restoration, weed control, the role of fire, and the impact of drainage. The aim of the overview was to produce management recommendations that were practical and affordable. Meeting this brief entailed close inspection of the wetland, together with evaluation of existing documents about its status and management needs, rather than a detailed survey or ecological research on specific topics.

The authors made an initial reconnaissance visit to Kaimaumau between 21 and 24 October 1996, accompanied by Ray Pierce (Conservation Advisory Scientist, Northland Conservancy), Lisa Forester (Botanist, Northland Conservancy), and Bruce Waddell (Manager, Kaitaia Field Centre). Timing of this visit coincided with late spring levels of the water-table when these were still close to maximum. Issues to be investigated were clarified in the course of the visit as: changes in water-table level, effects of introduced plants and animals, protection of threatened plants, fire control/prescribed burning, and possible rationalisation of the boundaries of the scientific reserve.

Our main period of fieldwork extended from 5 to 14 February 1997 and focused on the first three of the above-listed issues. At this time, water table levels were expected to be representative of summer. Although they had dropped since October, levels had remained fairly high for late summer, a result of heavy cyclonic rains during the previous month. On this occasion we travelled along all access routes into the Scientific Reserve and Conservation Areas, including firebreaks and East Beach. At various points we left these routes to traverse wetland habitats where we examined the linkages between plant community composition, weed invasion, fire history, soils and water levels. A workshop meeting on 7 February included DOC staff with responsibilities for managing the wetland, together with all ERANZ members involved in the study.

One of us (DLH) paid a final visit on 25–26 May 1997, making observations of water levels in late autumn, and taking the opportunity to view two small areas recently damaged by fire.

Although little has been published about Kaimaumau, conflicts of interest between land development, kauri-gum mining and conservation in the 1970s–1980s led to a number of unpublished reports, mainly about the wetland's plants, birds and fishes. These were made available to us by DOC's Northland Conservancy Office. Background information relevant to management of wetland habitats at Kaimaumau is also contained in publications about ecology of the species present, including the environments they live in elsewhere, particularly Australia and South Africa. Literature searches were undertaken by IAEA (indigenous plants and animals), DJC (introduced weeds and pests) and DLH (soils and hydrology).

# 3. Water levels in the wetland

## 3.1 FACTORS AFFECTING WATER LEVELS

At first sight, the Kaimaumau wetland appears to be maintained by a perched water table, held up by a sandstone hardpan beneath the peat, and supplied by springs from a sub-surface groundwater aquifer draining dunesand to the west. On closer examination its hydrology is more complex, with water levels strongly influenced by variation in the wetland's geology and soils.

### 3.1.1 Geology

Maps of the area's geology (Hay 1975, 1981) and landforms (Hicks 1975, 1983) show an ancient high shoreline, cut into stabilised parabolic sand dunes during the last interglacial period some 130 000–80 000 years ago. This forms the wetland's western boundary. The wetland itself is underlain by a belt of old foredunes. These are linear ridges of sand, formed behind beaches as sea level gradually dropped from its interglacial maximum, to positions several kilometres seaward of (and more than 30 metres below) the present coast. The foredunes were dissected by streams that drained to these low-level shorelines, during the last glacial period some 80 000–10 000 years ago. A rapid rise in sea level in the postglacial period, some 10 000–6000 years ago, formed a new shoreline landward of and slightly higher than the present coast. This is the wetland's eastern boundary. Since then, a young foredune belt has built up by sand accumulation as the coast has moved to its present position at East Beach.

The wetland has formed where peat has accumulated on top of the older foredunes. Peat is deepest where they are trenched by former stream valleys; it is of intermediate depth in foredune hollows, shallow over the lowest foredunes, and absent from the highest foredunes which protrude as narrow sand ridges sub-parallel with East Beach. The peat contains much timber, principally kauri, though other species are present. Carbon dates from stumps and logs indicate several cycles of forest growth and death between >50 000 and 30 000 years ago. Hicks (1975) postulated that these cycles continued until post-glacial sea-level rise disrupted drainage, waterlogging the forest and initiating peat accumulation. If so, the wetlands are some 10 000 years old. However, absence of carbon-dated timber from the period 30 000–10 000 years ago suggests that the transition to swamp vegetation could have commenced much earlier. If this is correct, the wetland has been a feature of the Far North's landscape for as long as 30 000 years.

### 3.1.2 Soils

Sutherland et al. (1983) mapped soils of the area as a suite, i.e. a developmental sequence:

- Pinaki sand: slightly weathered sand, with loose to firm subsoil
- Houhora sand: weathered loamy sand, with compact subsoil
- Tangitiki soil: well weathered loamy sand, with leached (A2) and iron pan (B1) horizons
- Te Kopuru podsol: extremely weathered loamy sand, with leached (A2), iron pan (B1), and cemented sandstone hardpan (B2) horizons.

The last-named have extremely low permeability, and in many places are mantled by younger soils, mapped by Sutherland et al. (1983) as:

- Ruakaka loamy peat: deep loamy peat with a massive to fibrous structure, and low sand content
- Ruakaka sandy peat loam: shallow peaty loam with a friable structure and high sand content
- One Tree Point peaty sand: sand stained brown or black with a high content of disseminated organic matter

- Kaikino sand: pale water-sorted sand with a low organic content
- Ohia sand: pale wind-blown sand with a low organic content

Detailed profile descriptions of the various soils are given by Wilson & McDonald (1987).

### 3.1.3 Landforms

Hicks (1975, 1983) undertook a study of landform development on the Aupouri and Karikari Peninsulas. A simplified map of Kaimaumau landforms is shown in Fig. 2. He found that younger parabolic dunes have Pinaki soils with loose subsoil. The next youngest (coastal foredunes) also have Pinaki soils, but with compact subsoil. With increasing age of dunefield (older parabolic unes), Tangitiki soils with iron pans appear in hollows, grading into Houhora soils on dune flanks and crests. On the oldest (inland foredunes), Te Kopuru soils with sandstone hardpans extend under hollows, grading into Tangitiki soils across dune flanks and crests. Younger landforms, such as swamps, lake beds and stream terraces, that cut into the Te Kopuru sandstone hardpans, are veneered with peat or alluvial sand.

An early provisional soil map (Sutherland, C.F. unpubl. 1951) shows soils in the Kaimaumau wetland as either Ruakaka peat (wetter parts) or One Tree Point peaty sand (drier parts), with thin ridges of Tangitiki soil (foredunes) or Kaikino sand (lakeshores) outcropping from the peat. This is somewhat at variance with thick sandstone hardpans encountered in the swamps by gumdiggers (K. Hughes, R. Hay, A. Grbic, B. Hoggard pers. comm.). Landform mapping by Hicks (1975), and subsurface investigations of the peat by Kauri Deposit Surveys (unpubl. Environmental Impact Report 1982) indicate that the surface of the inland foredunes is almost continuous Te Kopuru sandstone hardpan, beneath the soils mapped by Sutherland et al. (1983).

Presence of an impermeable hardpan at the sand-peat contact is very significant for the wetland’s contemporary hydrology. It forms a barrier to water movement between the peat and the sand. Rainwater on the peat must flow sideways through it, until it reaches a place where the hardpan is breached (for instance one of the buried stream valleys) or stops (for instance the landward edge of the coastal foredunes). Only at such places can water drain out of the peat by natural means. Equally, the hardpan is a barrier to upward movement of groundwater into the peat from sand beneath. Natural replenishment of the wetland by groundwater is only possible at places where the pan has been removed by erosion and replaced by younger, permeable sand. If the pan is artificially breached, for instance by drains or bores, exchange of water between peat and sand becomes possible.

Roots and stumps of kauri can be viewed in their growth positions in the hardpan at places where it is sectioned, such as the bed of Lake Waikaramu (when dry), the harbour cliff at Kaimaumau Point, and drains dug by Kaurex (the mining company set up by Kauri Deposit Surveys). Pan formation in podsolised soil around tree roots, followed by waterlogging of topsoil and peat formation around the base of trees, is a possible mechanism for forest death and transition to swamp vegetation, prior to any regional water table rise triggered by sea level fluctuation. This could explain the lack of carbon dates younger than 30 000 years, although younger dates might turn up if more material was tested. An alternative explanation for the hardpan's extreme hardness and great depth may be cementation by organic compounds deposited by water percolating through podsolised soil from the peat above.

One further aspect of the wetland's geomorphology is also significant for an understanding of its hydrology. Lake Waikaramu is clearly recognised by local residents as a seasonally flooded lake and is depicted as such on old survey plans and topographic maps. Hicks (1975) recognised low arcuate ridges in the southern part of the wetland as the shorelines of other seasonal lakes. These are similar to lakes formed in Australia and Africa by water-table fluctuation in semi-arid dunefields (Cooke & Warren 1973). They are evidence of long-term seasonal water-table fluctuation, i.e. above the surface in winter months, below it in summer, over a period of hundreds if not thousands of years.

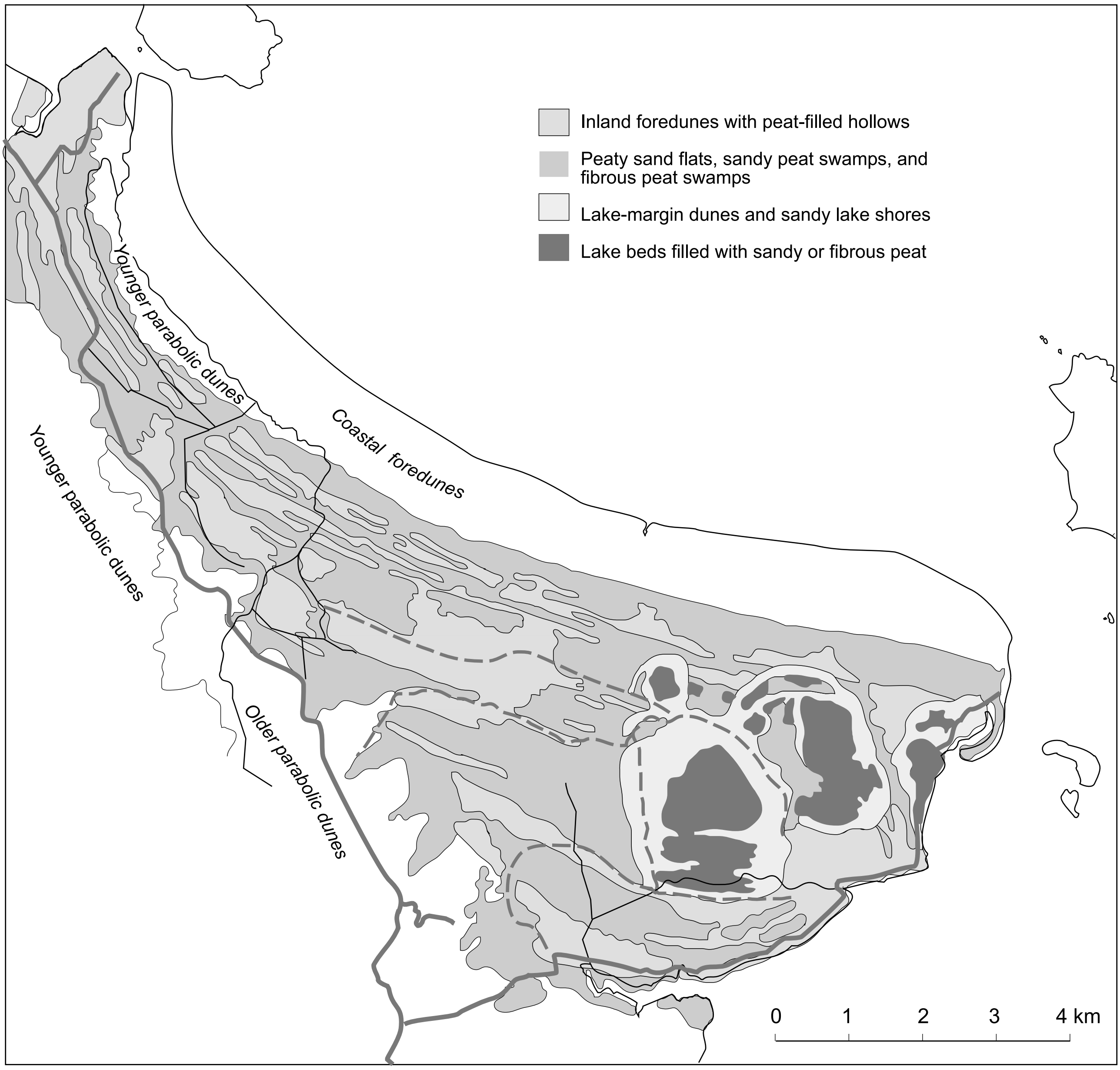


Figure 2. Landforms in the Kaimaumau wetland, based on an aerial photo interpretation by D Hicks from an earlier landform map (Hicks 1975) and field examination 1996/97.

A map showing individual landforms or every soil boundary would be exceedingly complex.  Instead, Fig. 2 depicts areas of the wetland that have similar landforms and soils:

- Sandy foredune ridges alternating with peaty interdune hollows
- Lakeshore ridges with waterlaid sand and marginal windblown dunes
- Seasonal lake beds with sandy peat alternating with truncated foredune ridges
- Peaty sand flats
- Sandy peat swamps
- Deep peat swamps.

These 'landform-soil associations' are of some significance for water levels, and plant and wildlife habitat.

### 3.1.4 Catchment areas and boundaries

The wetland has five catchments, each with a distinct surface outlet:

- Motutangi Swamp, draining to Motutangi Stream
- Waihuahua Swamp, draining to Te Kahuna Stream
- Otiaia Swamp, draining to Pirini Creek
- Swamps south of Norton Road, draining to Okohine Stream
- Seasonal lakes and intervening swamps, with poor natural surface drainage towards the shore of Rangaunu Harbour.

Catchment boundaries (shown in Fig. 3) are indistinct but can be seen in the field and on aerial photographs as bands of slightly higher ground. These are undissected parts of the older foredunes, with a shallow cover of peaty sand over sandstone hardpan. From the higher ground, surface and subsurface water can drain in either direction, but the extent of the higher ground is small compared with the lower-lying central parts of each catchment. These are the former stream valleys, now filled with deep sandy or fibrous peat. Here, drainage is controlled by the peat's surface gradient, sloping in much the same directions as the buried stream valleys underneath, and leading to the present stream outlets.

A contour map prepared for Kauri Deposit Surveys in 1980 (unpubl.) shows exact directions and gradients of the peat. The surface contours have probably been prepared by photogrammetry from aerial photographs, so are likely to be accurate to ± 0.5 m at map scale (1:10 000). They are a useful guide to directions of drainage when water is above the swamp's surface.

There has been a great deal of speculation (by local residents, drainage engineers and scientists alike) whether sub-surface relief of the peat–sand contact may act as a barrier to, or as an outlet for, water moving at depth through the peat. The KDS map has sub-surface contours, but they are little help in resolving this question.  In many places they are interpolated around point observations from boreholes or probes that were too sparse to detect intervening fluctuations in the peat-sand contact.

The pattern of former stream valleys running through dissected foredunes, clearly visible on aerial photographs, is a much better guide to the places where peat is deepest, i.e. where sub-surface water can flow seawards without being

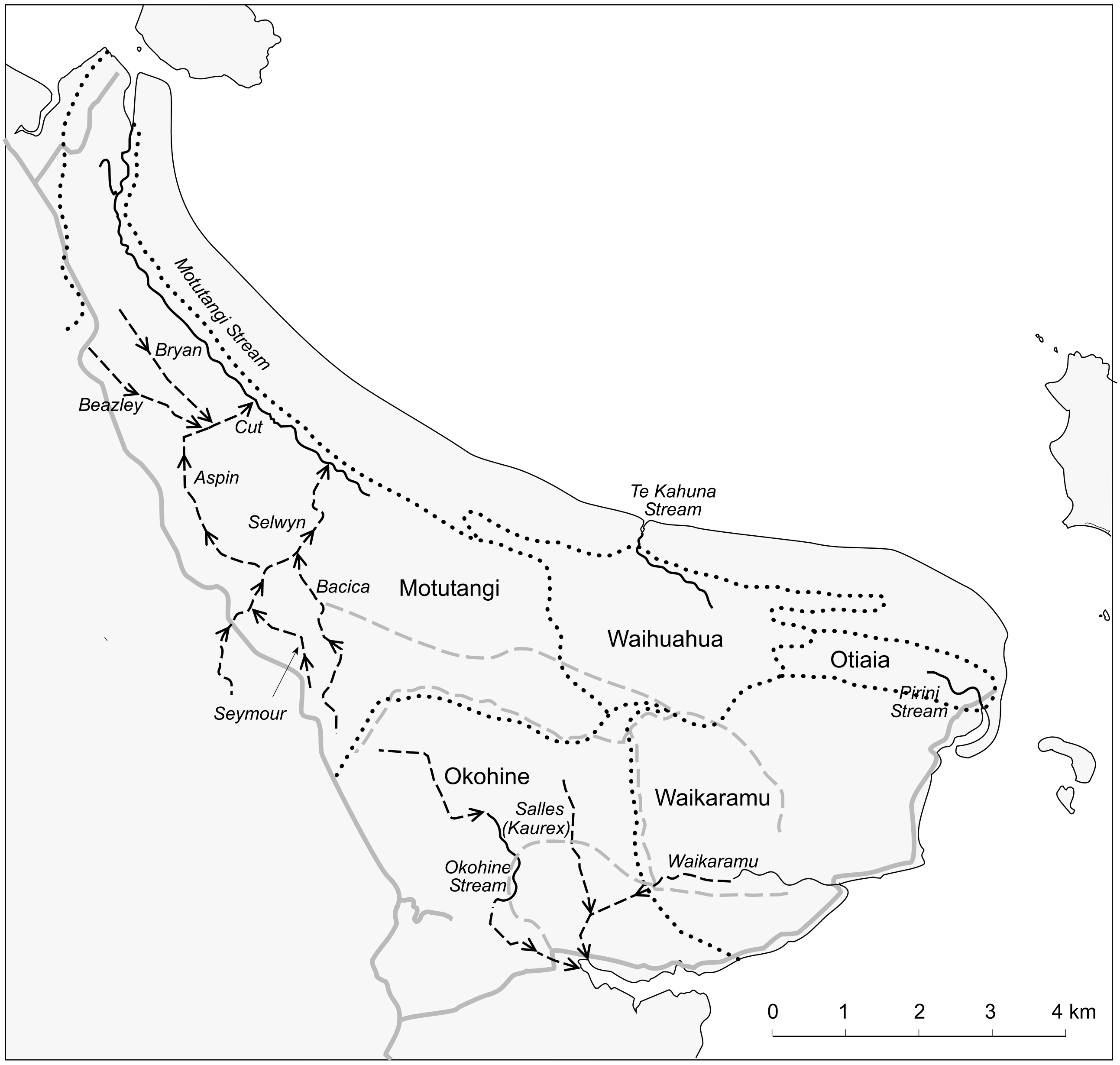


Figure 3. Streams, main drains (dashes) and catchment boundaries (dotted lines) in the Kaimaumau wetland, based on aerial photo interpretation by D Hicks of earlier maps supplemented by field checks of positions and flow directions (arrows) of drains 1996/97.

barred by hardpans on buried sand ridges. The valleys, while diverted by blocks of undissected sand ridge terrain, eventually lead round them towards present stream outlets.

Sub-surface water flow may also be possible through younger foredunes and associated parabolic dunes, on the seaward margin of the Motutangi, Waihuahua and Otiaia catchments. The soils here are Pinaki (i.e. slightly weathered sand with firm subsoil but lacking pans) and are permeable. There is anecdotal evidence lending support to the possibility of freshwater springs in the sea off East Beach. Perennial swamps, present in hollows amongst the landward foredunes but absent from hollows closer to the coast, may be further evidence for water seepage out of the wetland and through the dunes towards East Beach. However, we cannot confirm that it occurs, as no water-tracing experiments have been carried out.

## 3.2 EVIDENCE FOR RECENT CHANGE IN WATER LEVELS

There is a common perception that Kaimaumau is at the very least waterlogged for fewer months of the year than formerly, and at worst is drying out altogether. This perception is shared by local residents (A. Summers, B. Hoggard, pers. comm.), DOC staff (B. Waddell, L. Forester, R. Pierce pers. comm.), and scientists who have visited in recent years (Barkle & Singleton unpubl. report to DOC 1993, K. Thompson pers. comm. 1996). The perceived drops in water level are also postulated as a cause of habitat deterioration for wetland plants and wildlife (J. McRae, A. Penniket, Forest and Bird Society pers. comm. to DOC). Unfortunately, there are no long-term records of water table fluctuation to confirm these perceptions. Nevertheless, some supporting evidence for a drop in recent years is outlined in the next paragraphs.

### 3.2.1 Changes in plant distribution

Over 90% of the wetland was burnt in the 1988 fire, so it is hard to isolate any water-level induced changes in plant distribution from those that are fire-induced or merely due to natural spread of woody weeds. Some inferences can be drawn from a few species that show strong preference for either wet or dry sites, although explanations other than changed water level are possible.

Sydney golden wattle, gorse and kanuka grow readily on dry sandy ridges, such as foredunes and lakeshores protruding through the peat. These sites are now generally covered by dense stands of wattle several metres high. Stands of gorse or kanuka are still present, but small and scattered. The 1988 aerial photographs (pre-fire) show dense wattle along most of the sand ridges, but more extensive residual patches of gorse and kanuka. One author’s recollection (DLH) is that, in 1975, the sand ridges were vegetated by a head-high gorse–kanuka mix; wattle, while present in clumps, was neither extensive nor dense. Cumulatively, these observations confirm that spread of the wattle at the expense of gorse and kanuka is not just a post-fire effect. However, it is not necessarily due to drier conditions on the ridges, as the wattle’s fast growth rate is sufficient for it to overtop and suppress the other species (see Section 4.3).

Sydney golden wattle, while densest on dry sand ridges, also grows on peaty sand flats which are wet for a short period in winter. Since the 1988 fire, many young wattles have been growing vigorously on the peaty sand, amongst a mix of native scrub species (manuka, kumarahou, mingimingi, tangle fern), sedges and exotic weeds (mainly hakea, with oxylobium present at some localities). There has also been dense (though less vigorous) growth of wattles on old gum workings where peat has been drained and stripped leaving a thin mix of dry peat and sand above exposed hardpan. Pre-fire aerial photographs (1988) indicate the occasional wattle on both kinds of site, but cover was not dense. DLH’s recollection of several such sites in 1975 is that they were vegetated by a stunted, knee- to waist-high scrub of manuka, hakea and sedges, with no wattle present. Gorse and kanuka are also present on peaty sand, but plants here are sparse and stunted. We did not see any sites where there was vigorous post-fire regrowth of either gorse or kanuka at the expense of manuka–hakea–sedge. Spread of these species, as well as wattle, might be expected if the peaty sand is becoming drier. Spread of wattle alone on to the peaty sand flats and old gum workings may indicate that these areas are staying dry for longer, but equally could be due to the fire encouraging germination of wattle seed, or just natural germination that might have occurred anyway in the absence of fire.

At lower elevations in the wetland the soil is sandy peat, waterlogged for much of the winter. Here, the hakea and manuka are the dominant plants in association with sedges, and we did not observe any wattle invasion. 1988 photographs show the dark hues typical of this species mix, and DLH's recollection of several sites is that in 1975 they were vegetated by a knee-high mix of sparse hakea and manuka interspersed with sedge, much as they are now. While we cannot preclude the possibility that sandy peat is now waterlogged for less of the year, there is no evidence of the changes in plant composition that might be expected, except perhaps tangle fern. Several people (A. Summers, L. Forester pers. comm.) who know the swamp consider that tangle fern is spreading through the hakea–manuka–sedge. At the sites viewed by DLH in 1975, tangle fern was present but not as abundant as today. However, this cannot be interpreted as definite evidence for drying out, because there are other possible explanations such as post-fire plant succession.

The hakea–manuka–sedge community terminates abruptly on the edge of deep, fibrous peat that has a low sand content. Deep peat is vegetated by sedge (*Schoenus* and *Baumea* spp.), with occasional raupo (*Typha orientalis*) where streams flow into the swamp. When we entered these sites at various dates between October 1996 and May 1997, they were waterlogged. We did not view any sites where we could state with confidence that young manuka or hakea is spreading into areas that were formerly pure sedgeland. The 1988 photographs show standing water on the same sites, and in 1975 DLH was unable to penetrate them, as water levels remained high despite what was an unusually dry summer. These observations do not indicate that plants tolerant of occasional 'drying-out' are establishing on deep peat; on the contrary they suggest that deep peat sites remain permanently waterlogged.

### 3.2.2 Standing water and saturated soil shown on aerial photographs

Comparison of aerial photographs taken in January 1988 and August 1993 shows that areas of deep peat are under standing water at both dates. The water either reflects light (if the camera angle is oblique) or absorbs it (if near-vertical). Areas of sandy peat are very dark where close to photo centres, and remain dark towards the corners of photos. This indicates that water-saturated soil is visible through the sparse hakea–manuka–sedge canopy, rather than standing water (which would reflect light from some angles). Peaty sand, which one might expect to be waterlogged in the winter 1993 photographs, actually appears dry at both dates, as hues on the photographs are dominated by reflected light from plant leaves and stems. The photos do not indicate whether soil is saturated on sand ridges, where light is reflected by the dense canopy of wattle, gorse and kanuka.

### 3.2.3 Field observation of water levels

We have viewed water levels in the wetland on three occasions. At the first, in October 1996, water levels were high following a wet winter and spring. The second time, in February 1997, water levels would normally be low after dry summer weather. They had in fact dropped very little. Areas of sedgeland on fibrous peat, that had standing water in October, still had standing water at much the same level in February. Areas of manuka–hakea–sedge on sandy peat and peaty sand, waterlogged in October, showed drops in water level to 10–80 cm below the surface. Areas of wattle, kanuka and gorse on sand ridges, with moist sand soil above the hardpan in October, had become very dry by February despite frequent, sometimes heavy, summer rain. By May 1997, water levels had risen above the surface of sandy peat at low elevations (but not higher up), while the peaty sand flats remained dry.

Our field observations, though visual and limited in number, suggest that water levels are very responsive to, and fluctuate with, the seasons. This is consistent with features of the wetlands previously discussed: water supply coming primarily from rainfall on to the peat; the hardpan at the peat–sand contact acting as a barrier to downward drainage of water; and landforms that are indicative of regular rises and falls in the water table.

### 3.2.4 Water level records from boreholes

Some firm evidence for regular seasonal water-level fluctuation, above and below the wetland's surface, is given by a series of shallow boreholes that were monitored by Kauri Deposit Surveys for 12 months in 1982–83. Figure 4 depicts examples of how water level fluctuated in each hole. They clearly divide into three groups:

- Water at or a short distance below the surface from April–May to October, falling to >0.5 m from the surface between January and February–March;
- Water a short distance below the surface from June to September, falling to >0.5 m from the surface from January to April–May;
- Water a moderate distance below the surface from June to September, falling to >0.5 m from the surface between December–January and May.

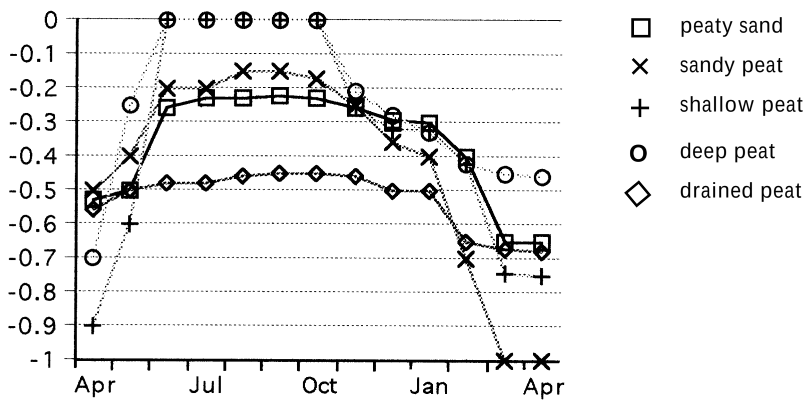


Figure 4. Seasonal fluctuations of water level in boreholes between the Kaurex mine site and Lake Waikaramu, Apr 1985 to Apr 1986. Source: Kauri Deposit Surveys, unpublished environmental impact investigations.

Profile descriptions for the boreholes indicate that the first group are shallow peats, most overlying sandstone hardpan, but including two deep peats. The second group are sandy peats or peaty sands, also overlying sandstone hardpan. The third group are boreholes with shallow peat over sandstone hardpan, close to existing drains.

Several shallow boreholes were installed in the northern end of the Motutangi Swamp during the summer of 1996/97 by Dr K. Thompson of Waikato University. If these have been regularly monitored, they should confirm the magnitude of seasonal fluctuations at this end of the wetland.

The KDS data, while they do not enable any conclusions to be reached about whether the water table has sunk below the surface for longer periods in recent years, do at least confirm our 1996/97 visual observations that water level is seasonally responsive; and our interpretation, i.e. regular oscillation of the water table, above and below the surface, is a natural phenomenon over large parts of the wetland.

## 3.3 REASONS FOR OBSERVED CHANGES

### 3.3.1 Water balance in the wetland

Rainfall on the wetland (P) plus runoff entering it from catchments to the west (I) plus any groundwater inflow (G), equals evapotranspiration (E) plus surface outflow in streams (O) plus leakage to deep groundwater (D) and any lateral leakage (L) to shallow groundwater through coastal dunes to the east. Averaged over many years, inflows balance outflows:

$$P + I + G = E + O + D + L$$

Otherwise, the wetland would either drain, or turn into a lake. In any one year each factor varies, causing changes in the amount of water that is stored in the surface water table (dS):

$$dS = (P + I + G) - (E + O + D + L)$$

As storage changes, the wetland’s water level goes up and down. Storage can also be altered artificially, by digging drains to accelerate runoff or damming streams to retard it. Factors that have contributed to recent water level fluctuations are reviewed in the following paragraphs.

### 3.3.2 Gains from rainfall

The closest Meteorological Service gauge, at Waiharara a short distance west, has recorded annual rainfalls averaging 1176 mm between 1956 and 1994. Other sources of rainfall information have been located, mainly unofficial gauges kept by local farmers, but some may be unreliable due to less-than-daily readings, intermittent gaps in record, or gauge siting problems. One good record is a gauge kept at Kaimaumau by Mrs Barbara Hoggard and her late husband, which recorded annual rainfall averaging 963 mm between 1976 and 1996. Figure 5 shows annual rainfalls for Kaimaumau superimposed on the Waiharara record for 1976–96.

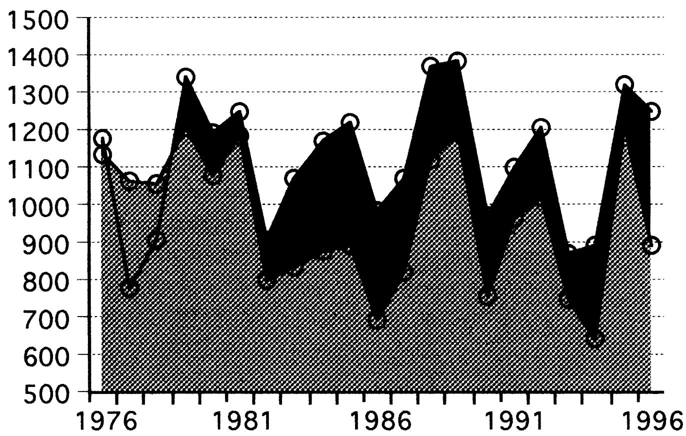


Figure 5. Fluctuations in annual rainfall between 1975 and 1997 at Waiharara (black) and Kaimaumau (shaded).

- Both sites show the same pattern of year-to-year fluctuation,
- Rainfall in the eastern part of the wetland (Kaimaumau) is generally more variable than in the west (Waiharara).

Long-term analyses of rainfall for the Waiharara gauge (Northland Regional Council 1991, 1996) show annual rainfalls well below average between 1990 and 1994 (Table 1). Rainfall was high in 1995, and close to average in 1996.

TABLE 1. ANNUAL RAINFALL 1990–96 (mm), AND ANNUAL AND SEASONAL RAINFALL (AS A PERCENTAGE OF THE AVERAGE VALUES FOR 1956–94).

| YEAR | ANNUAL (mm) | ANNUAL (% of ave.) | SUMMER (JAN–MAR) | AUTUMN (APR–JUN) | WINTER (JUL–SEP) | SPRING (OCT–DEC) |
|---|---|---|---|---|---|---|
| 1990 | 974 | 83 | 61 | 87 | 94 | 81 |
| 1991 | 1103 | 94 | 57 | 106 | 119 | 72 |
| 1992 | 1208 | 103 | 80 | 77 | 162 | 81 |
| 1993 | 871 | 74 | 60 | 81 | 68 | 113 |
| 1994 | 891 | 76 | 58 | 72 | 98 | 107 |
| 1995 | 1321 | 112 | 179 | 88 | 105 | 194 |
| 1996 | 1249 | 106 | 127 | 92 | 138 | 125 |

The drops in dry years can be expected to have a substantial impact on the Kaimaumau water table. Most of the decline has occurred in summer, and to a lesser extent in autumn and spring.

Between 1990 and 1994, water-level drops induced by lack of rain would have become noticeable from spring onwards, and bottomed out in autumn. Only in winter, when the water table was restored by winter rain, would water levels have appeared ‘normal’. In 1995 and 1996, spring–summer rainfalls would have kept water levels reasonably high until autumn.

The Waiharara record has been smoothed by plotting five-year running means, so that any trends become visible. Figure 6 shows several periods when conditions become successively drier, interspersed with periods when conditions become successively wetter.

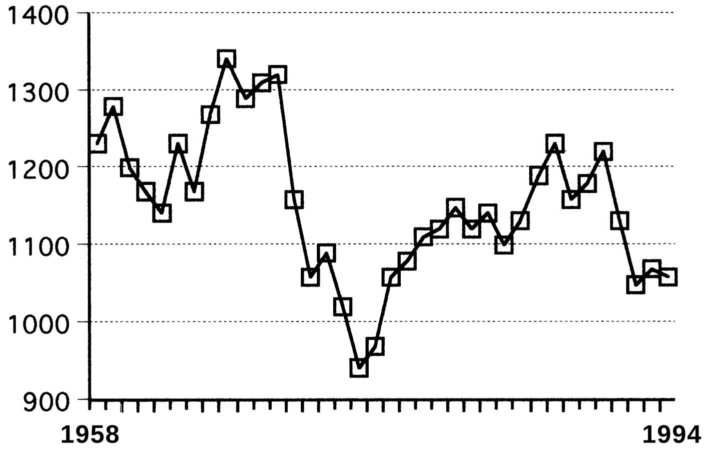


Figure 6. Long-term rainfall trends at Waiharara, 1957–96 (five-year running means).

The high rainfall of 1995 may be just a temporary fluctuation upwards, as 1996 rainfall is back close to average values. Nevertheless, Fig. 6 clearly shows that a series of wet years can be expected, sooner or later, to follow the current series of dry years. In fact, more recent years have been wetter.

### 3.3.3 Gains from surface water

Surface runoff enters the Motutangi Swamp via a number of small streams and drains from stable sand country (vegetated parabolic dunefields) to the west. Streamflow has been intermittently recorded on the largest of these, Selwyn Drain, by the former Ministry of Works & Development (1965–74) and Northland Regional Council (1986–96). Annual specific discharge averages 0.9 litre/sec/km$^2$. This equates to 28 mm of surface runoff each year from catchments draining into the Motutangi—a small quantity compared with an average 1180 mm of rain falling directly on the wetland surface. Much of the 28 mm passes as low flow through drains dug below swamp level, until it reaches the Motutangi Stream at the wetland's outlet. During floods, when the drains overtop their banks, some of the floodwater ponds on low-lying peat basins, notably upstream of the Cut (on drained farmland) and east of the Motutangi Stream's hairpin bend at Land's End.

Surface runoff from the west cannot enter any other wetland catchments, because it is intercepted by the Okohine Stream and flows down the Okohine until it reaches Rangaunu Harbour south of Kaimaumau.

### 3.3.4 Gains from groundwater

An investigation of groundwater resources (Northland Regional Council 1991) has demonstrated the existence of a confined water table (artesian aquifer) deep beneath the Aupouri Peninsula (Fig. 7). It is recharged by rainfall on a now-stabilised transverse dunefield beneath Aupouri Forest. Pressure heads in boreholes indicate outflows at depth to both the west and east coasts. Towards the east coast, the aquifer is confined by buried hardpans, similar to the surficial hardpan on the older foredunes but much older, and deeply buried by successive accumulations of sand.

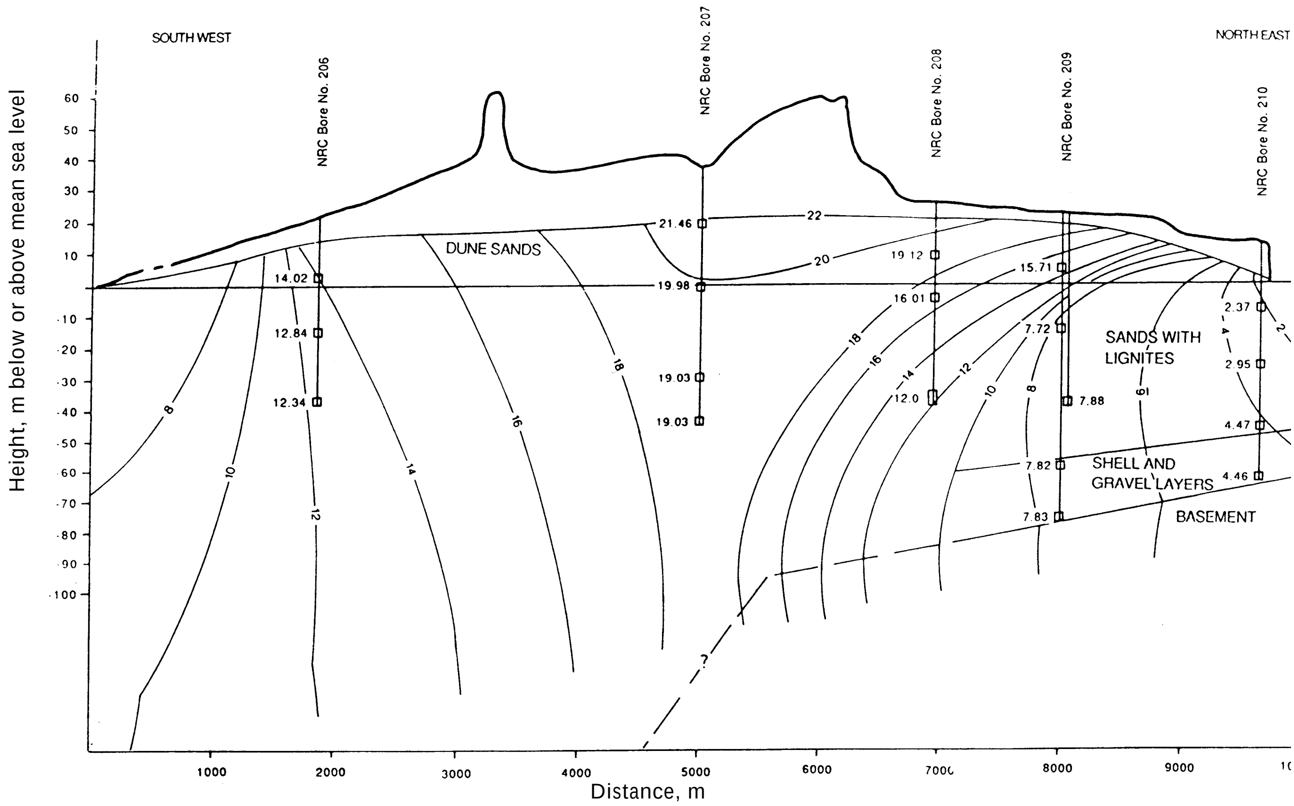

Figure 7. Groundwater potential underneath the Aupouri Peninsula, Northland. Numbers next to bores are the heights (m asl) to which water would rise, from intake screens at the positions shown. Kaimaumau wetland lies just south of the cross-section between bores 208 and 210, but is lower, between 10 and 3 m a.s.l. (GCNZ data analysed by Northland Regional Council 1991.)

Pressure head in the confined water table is 2–5 m a.s.l. at the east coast. Artesian recharge of the wetland from this source is physically possible if water finds a way up through weak points in successive buried hardpans between the aquifer (60 m down) and the surface, but currently there is no evidence that deep groundwater upwells to the surface. Springs and seepages pointed out by local residents are all at locations where geological formations lead back to another shallow and unconfined water table.

Groundwater springs in the Motutangi Swamp are located where its western edge intercepts an unconfined water table, perched at shallow depth on the hardpans of Type 1 parabolic dunes buried beneath Type 3 dunes (Hicks 1983). Recharge of this perched water table is by rainfall infiltrating permeable Pinaki soils on the Type 3 dunes.

Seepages of groundwater through sand in the bottoms of drains, in farmed parts of the Motutangi, are associated with former stream valleys cut through the older foredunes, and now buried by peat (Hicks 1983). Here, the peat is underlain by a layer of unconsolidated alluvial sand. Where buried stream valleys extend back into the Type 1 dunefield, the alluvial sand acts as an extension of the unconfined aquifer perched on its hardpans. The sand conducts shallow groundwater out into the swamp until it seeps into peat (or into drains) at lower elevations.

### 3.3.5 Losses to evapotranspiration

Losses of water from the wetland are possible by direct evaporation (E) from open water surfaces and evapotranspiration (ET) from the leaves of plants.

No measurements of evaporation have been made at Waiharara, which is the only official Meteorological Service site close to Kaimaumau. Pan evaporation has been recorded at the Kaitaia meteorological site since 1986 (Fig. 8) and fluctuates around the 1986–96 average of 1249 mm, without displaying any clear trend. Evaporation from open water is usually 0.6–0.8 of the rate of pan evaporation (Linsley et al. 1975), so about 750–1000 mm may evaporate from standing water at Kaimaumau in a typical year.

Evapotranspiration by plants is exceedingly difficult to measure, and its measurement is normally attempted only in the course of research projects. This has not occurred at Kaimaumau; indeed, direct measurements of evapotranspiration from wetlands are not known to have been made anywhere in New Zealand. ET is usually estimated from meteorological data or water balance calculations instead.

Estimates of evapotranspiration from short-grass vegetation have been made at the Kaitaia Airfield meteorological site, from meteorological data collected 1969–80 (Fig. 9). Average annual ET was 1027 mm, peaking in January at 170 mm and falling to 19 mm in June. However, ET from wetland vegetation is thought to be considerably less than from pasture.

Estimates of ET, from micrometeorological studies or water balances in several gauged wetland catchments (Campbell & Williamson 1997, D.I. Campbell pers. comm.) indicate that it is typically one-third to one-half of open-water evaporation rates. Campbell's estimates for the Kopuatai peat dome, where vegetation is dominated by *Empodisma* and *Sporadanthus*, but also contains significant *Schoenus*, *Baumea* and *Gleichenia*, are towards the upper end of the range. This suggests ET at Kaimaumau may be in the order of 375–500 mm annually. An estimate of the impact of ET on the wetland is gained by subtracting these figures from rainfall in a wet year, an average year, and a dry year (Table 2).

In the absence of comparative data on ET rates for individual swamp plant species, we do not know the effect of a fire on evapotranspiration from the

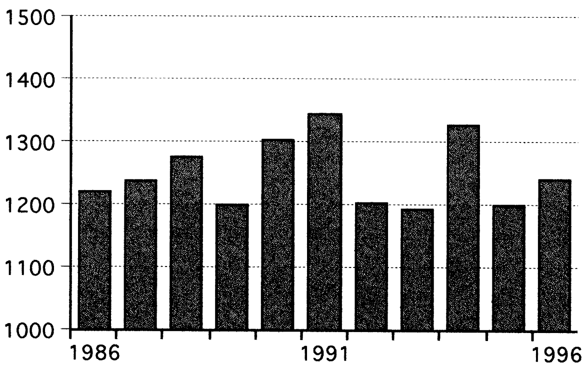


Figure 8. Pan evaporation at Kaitaia. (NZ Meteorological Service.)

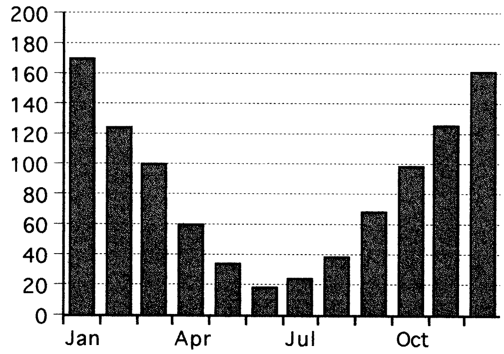


Figure 9. Estimates of evapotranspiration from short grass at Kaitaia Airfield, 1969–80. (NZ Meteorological Service data, cited by Northland Regional Council 1991.)

TABLE 2. ESTIMATES OF WATER AVAILABLE TO REPLENISH THE WETLAND IN WET AND DRY YEARS.

| | RAINFALL (mm) | BALANCE AVAILABLE (mm) TO REPLENISH WETLAND ET=375 mm | ET=500 mm |
|---|---|---|---|
| Wet year | 1300 | 925 | 800 |
| Average year | 1180 | 805 | 680 |
| Dry year | 900 | 525 | 400 |

wetland. The 1988 fire could have reduced evapotranspiration for several years afterwards, until biomass of the swamp vegetation recovered. On the other hand, greater open-surface evaporation could have occurred for several years after the fire. Post-fire spread of the fast-growing Sydney golden wattle may even have increased evapotranspiration, relative to the gorse-kanuka and hakea-manuka-sedge plant communities it replaced.

In short, there is insufficient information to say whether greater evapotranspiration has contributed to longer seasonal drying out of the peaty sand flats. However, we conclude that the interaction between ET and rainfall becomes significant for Kaimaumau's water balance in years when rainfall is below average.

### 3.3.6 Losses to streams

Runoff in streams flowing out of the wetland has not been gauged. The only estimates of surface outflow are design capacities for various drainage schemes (Ministry of Works unpubl. 1953, Department of Lands & Survey unpubl. 1978, Kauri Deposit Surveys unpubl. 1980). These are estimates of 20-year flood peaks (which the drains are generally designed to carry), and cannot be used to show whether annual runoff from the wetland has gone up or down.

In either case, volumetric outflows in streams are a response to water levels in the various swamp catchments, rising if rainfall increases the head of water, and falling if the head drops in the absence of rain. As annual rainfalls have decreased in 1990–96, stream outflows are also likely to have declined, so cannot be invoked to explain drying-out. They are a symptom, not a cause.

### 3.3.7 Losses to groundwater

Leakage to deep groundwater is unlikely for two reasons already discussed in Section 3.1. First, impermeable hardpans at the peat-sand contact, and other buried hardpans beneath, are barriers to downward movement of surface water. Second, borelog data (Northland Regional Council 1991, see Fig. 7) indicate that if any weak points are present in the hardpans, head in the confined aquifer is sufficient to force groundwater upwards. This would recharge the swamp, not drain it.

Leakage to shallow groundwater is likely along the wetland's eastern margin, for other reasons also discussed in Section 3.1. This margin is bounded by younger foredunes which have permeable soils and do not constitute a barrier to lateral seepage of water where peat has built up against their landward edge. Rates of outflow would increase if head increased in the unconfined groundwater table underneath the coastal dunes. For this to happen, either water level would have to rise in the swamp catchments, or sea level would have to drop. As neither has happened, greater leakage to shallow groundwater cannot be invoked as a possible cause of declining water levels in the wetland.

### 3.3.8 Drainage

Artificial drainage reduces water storage within the peat by creating a greater number of surface outflows with lower outlets and steeper gradients than natural channels in the swamps. Figure 3 shows location of drains in and around Kaimaumau.

Kaimaumau has a long history of drainage by gumdiggers, mainly in the period 1910–40. Most of the gumdiggers' drains have fallen into disuse since the 1940s, silting up with a mixture of peat and sand, so that gum diggings which pock the swamps are once again flooded. Figure 3 does not show these old drains, except where they have been re-opened in recent years. Most of the functioning drains lie outside public conservation land, and are either on farmland (maintained by the Motutangi and Waiharara Drainage Committees) or scrubland in private ownership (the Vuksich block, which contains drains excavated by KDS/Kaurex in the 1980s). There are four exceptions:

- A Kaurex drain extends into the bed of Lake Waikaramu (public conservation land), which was used by Kaurex for water supply. This drain was never cut through the Airstrip Road. Water was apparently piped underneath, and the pipe was removed when Kaurex closed. Airstrip Road effectively dams the drain and maintains lake level. An old gumdiggers' drain from the south-east corner of the lake to Kaimaumau, open in the mid-1970s, now also appears to be blocked.
- The Aspin Drain was excavated in the 1930s by the Motutangi Drainage Committee to straighten a natural stream channel linking the Selwyn and Motutangi Streams. It cuts through Block 5, which at the time of excavation was unoccupied Crown land, but was purchased by DOC in 1988 and is now a designated Conservation Area.
- In 1978, the Selwyn Stream was diverted from the Aspin Drain down a new outlet, known as the Selwyn Outlet Drain, to the hairpin bend of the Motutangi at Land's End. At the time, this was also unoccupied Crown land, but is now within the area passed to DOC and gazetted as Scientific Reserve in 1984.
- The Selwyn Outlet Drain intercepted another long-established farm drain, the Bacica, which formerly flowed into the Aspin. The lower end of the Bacica is also within the Scientific Reserve.

In recent years the Motutangi Drainage Committee has maintained the Aspin, Selwyn and Bacica drains with bucket excavators, and there are strong differences of opinion amongst local farmers about whether the maintenance constitutes routine cleaning, or deepening and widening.

### Effect of drainage on water level

Regardless of what it is called, excavation and maintenance of the Aspin, Bacica and Selwyn Outlet Drains has lowered the water table immediately adjacent. During our inspection in February 1997, deterioration of the peat, and weed invasion, were obvious along their banks. However, the water table was back at the surface about a hundred metres in from the drain edge, where peat was saturated and well-structured. A similar edge effect has followed scrub conversion to pasture (accompanied by shallow drainage through paddocks) at several places where farms adjoin the reserve's northern boundary.

While the present impact of four drains is slight, if the existing network were extended by digging extra drains into or through public conservation land, they could certainly lower the wetland's water table, currently perched in peat above the hardpan. By how much, would depend on the gradient and density of drains, far more than their width or depth.

The above observations apply to public conservation land. On farmed parts of the Motutangi in private ownership, including Mr Alan Summers' property, structural breakdown of peat followed by pasture deterioration is widespread. Here, the deepening of main drains may have increased gradients down an already dense network of shallow feeder drains through farm paddocks, and thus lowered water tables (in peat above the hardpan) more extensively. The drains here may have also tapped shallow groundwater which used to seep through the peat and alluvial sand from Type 3 Parabolic Dunes (with no hardpans and high permeability) along the swamp's western boundary.

### Effect of drainage on water quality

Concerns have been expressed from time to time, by DOC staff and environmental groups, about whether water from farm drains could have detrimental effects on plants or wildlife in the wetland. Because the wetland's sandy soils are infertile and its peat soils are oligotrophic, an artificial increase in their fertility might alter plant successions or stimulate growth of weeds. Suspended sediment, and herbicide or pesticide residues, are other contaminants that might promote plant growth or aquatic life. Nitrogen has been a particular concern, not just on account of farm drainage, but because nitrogenous fertilisers are applied to pine forest growing on the Aupouri Peninsula's groundwater recharge zone. Fears have also been expressed that Sydney golden wattle (a nitrogen-fixing species) may raise nitrogen levels within the wetland's soil and water.

Of the wetland's five catchments, three contain areas of farmland: the Motutangi, the Okohine, and areas draining to Rangaunu Harbour. The latter two catchments lie outside DOC stewardship and are not part of this investigation. Almost the entire western half of the Motutangi is farmed, and the surface runoff from its drains enters the Scientific Reserve through the Bacica, Selwyn and Aspin Drains on its way to the Motutangi Stream. Raupo and occasional flax, growing in pockets of undrained swamp adjacent to the drains and stream, indicate that some nutrient enrichment is occurring here. Raupo is also present within the lowest-lying parts of the Scientific Reserve, east of the Motutangi Stream at Land's End. Here, the Motutangi backwaters, when in flood, divert runoff from the drains into what would otherwise be oligotrophic peatland. To put this in perspective, hydrological investigations on the Selwyn Stream (Section 3.3.3) indicate that drains contribute an average 28 mm of surface runoff out of the 1180 mm of rainfall falling on farmland in the western catchment.

Groundwater is another pathway by which pollutants could reach the wetland. As described in Section 3.3.4, groundwater from the farmland and forest resurges into the Motutangi. Groundwater resurges from a shallow water table perched at the Type 1–Type 3 dune contact, at restricted locations, i.e. buried stream valleys infilled with permeable alluvial sand, that lead out from the Type 1 and Type 3 dunefields. The alluvial sands, where topped by undrained peat, are the sites where raupo and flax grow. Elsewhere in the Motutangi, and in the other catchments, groundwater fed by rainfall on the farmland and forest moves eastwards at depth in a confined aquifer. Water quality tests on borewater between Houhora and Paparore (Northland Regional Council 1991) indicate that the deep groundwater has low concentrations of nitrate (range 0.01–3.5 g/$m^3$) and most other dissolved nutrients, the only high-level dissolved chemicals being bicarbonate (11–221 g/$m^3$) and iron (0.1–4.1 g/$m^3$). Likely reasons for the low nutrient levels are removal by chemical processes and/or filtration, as soil water in the aquifer's recharge zone percolates downwards through some 50–100 m of sand (Northland Regional Council 1991). In any case, resurgence of groundwater from the deep aquifer is precluded by several buried hardpans within the sand formations, the highest of which holds up a near-surface water table in the wetland peat (Sections 3.3.2 and 3.3.4). The near-surface water-table is largely rain-fed (Section 3.2.3), so any contamination is likely to be associated with wind-borne salt, aerial application of fertiliser, or chemical spray drift. Water quality analyses of peat water by Kaurex (Kauri Deposit Surveys unpubl. Environmental Impact Report 1982) did not indicate abnormal levels of any contaminant, though it should be noted that these came from a fairly restricted number of sites around the proposed mine workings, and were sampled for a limited range of chemicals. In the absence of thorough field sampling followed by adequate laboratory analysis, no firm conclusion can be made that water in the wetland is either pure or contaminated.

Nitrogen release from Sydney golden wattle is unlikely so long as the nitrogen-fixing bacteria in its root nodules remain symbiotically bound with healthy growing plants. Some loss of nitrogen from the plant is likely as a result of normal mortality of nodules. However, there is a risk that nitrogen will be released into the sands and peaty sands, where the wattle grows, if plants become diseased, stressed in other ways, or are killed by fire. At present, no botanical effects have been detected; whatever effects there may be are therefore probably localised. This risk could be quantified by monitoring peat water and vegetation at a site where wattle is either intentionally or fortuitously killed off.

## 3.4 IMPLICATIONS FOR VIABILITY OF THE WETLAND

Local residents, DOC staff, and environmental groups have expressed fears that the entire wetland will gradually dry out if recent drops in water level continue. Sections 3.1–3.3 have presented evidence that on public conservation land:

- Current drying out is attributable to a natural reduction in the wetland's principal water source—rainfall falling directly on the wetland catchments—and can be expected to reverse once a series of wet years arrives.
- The drop in water levels has been sufficient to affect one kind of wetland habitat definitely—the peaty sand flats—and another possibly—the sandy peat swamps. Water levels in other habitats—dry sand ridges, and fibrous peat swamps—remain much the same.
- The wetland's landforms indicate that water table fluctuation has been a feature of this environment for a very long time. The magnitude of seasonal fluctuations has changed many times, in keeping with climatic changes over the past 10 000 years. The wetland's plant and animal communities would have adjusted to this pattern of seasonal and long-term fluctuation.

On areas of privately owned scrub and farmland within the wetland's catchments the magnitude of drying out, its causes, and its impacts, seem different. The privately owned areas have generally been subject to greater vegetation clearance, soil disturbance, and drainage.

Until a series of wet years arrives to raise water levels again, the uneven nature of the drying out does have implications for viability of some wetland habitats on public conservation land. These are:

- Little change in plant habitat on dry sand ridges—as these were already dry year-round.
- Little or no waterlogging of plant roots on peaty sand flats, cf. waterlogging for several weeks in winter during wet years.
- Reduced duration of waterlogging in sandy peat swamps—but possibly not to the stage where plants are affected, as they still remain waterlogged for several months each year.
- Little change in plant habitat in deep swamps on fibrous peat—as these still remain wet year-round.

## 3.5 MANAGING WATER LEVELS WITHIN THE WETLAND

This section of our report discusses what, if anything, needs to be done to maintain water levels within the wetland. It is not a detailed analysis of engineering options; rather, it is an examination of what the options are, whether they are feasible, and whether any of them are needed enough to warrant commissioning design work.

### 3.5.1 Weirs in streams

Weirs are a possibility in the Motutangi, Waihuahua and Otiaia catchments, all of which have natural stream outlets. The gradients of streams are very low, for instance the Motutangi has a 1 in 4000 gradient (P. Cook pers. comm.). So a 0.4 m high weir could back up water for about 1.6 km. Surface contours on the Kauri Deposit Surveys 1980 map (unpubl.) suggest that this would flood fibrous peat swamps in the deepest parts of the Motutangi catchment which are permanently waterlogged anyway. The weir would alter the water table gradient underneath the sandy peat swamps sufficiently to maintain water close to or above their surface year-round. It would raise the water table somewhat in the peaty sand flats, without necessarily bringing water to the surface. A weir on the Waihuahua outlet (Little River) or the Otiaia outlet (Pirini Creek) would have similar impacts on the various swamp environments in those catchments.

Possible disadvantages of weir construction are:

- Cost. It is not just a matter of plugging the channel. Bed and banks would need to be excavated and back-filled to create an impermeable seal, so that water does not seep under or round the structure. Quantities of impermeable clay, together with gravel for concrete, would have to be trucked on-site. Other costs are in consultation, getting formal Resource Consents, and in Hearings of objections.
- Possible ineffectiveness. All three outlet channels flow close to the swamps' eastern margin, bounded by the younger foredunes which have permeable Pinaki soil. The so-called 'pans' in dune hollows on Pinaki soil are merely compact sand with pore spaces partly blocked by organic detritus. While less permeable than the loose sand above, they still pass water. So there is a risk that, as water ponds up-channel behind a weir, it will merely start seeping sideways through the younger foredunes towards East Beach.

### 3.5.2 Weirs in drains

The Aspin, Bacica and Selwyn Drains have gradients of about 1 in 2000, still very low, so a 0.4 m weir in any of these would back up water for about 0.8 km. The effect on water level in the Motutangi Swamp would be similar to that described for a weir on the Motutangi stream. The cost of construction would be relatively low, as the drains are bounded by impermeable sandstone hardpan, and a fairly small timber or concrete structure would suffice.

A possible disadvantage of constructing weirs in drains is that the backwater effect would extend well upstream. Depending on weir position, it could flood drains on private farmland and raise water tables beneath adjacent paddocks.

### 3.5.3 Bunds between sand ridges

Mr Alan Summers has suggested that water levels in interdune hollows could be maintained in the Motutangi by constructing low barriers to surface-water drainage (about 0.3 m high). These bunds could be built between dune ridges which cross his boundary, and could be formed with compacted sand, not totally impermeable, but sufficient to impede water seepage. There is some merit in this proposal as it is likely to work, is relatively low-cost, and could be done on the farm with implements attached to a tractor.

### 3.5.4 Stopbanks along drain edges

Mr Summers has suggested 1.5 m stopbanks along the upper part of the Selwyn Outlet Drain (between the Aspin confluence and the first dune ridge downstream), to ensure that floodwater from the Selwyn Stream passes down the Selwyn Drain instead of overflowing down the Aspin. This would not permanently raise water levels in the conservation part of the Motutangi Swamp, as floodwater would still drain away through the Selwyn Outlet–Motutangi confluence at Land's End. It would send floodwater into DOC land, but this already happens whenever the Selwyn Outlet Drain overflows. The stopbank proposal is probably not a cause for concern if restricted to the Aspin confluence, but would be if it is expanded along the Selwyn Outlet's entire length with a flood control weir at Land's End. While undoubtedly an expanded structure would raise water levels in the eastern half of the Motutangi swamp, it could also induce unwanted habitat modifications if the flood control weir were too high. During floods, it would back up floodwater from the DOC land on to private farmland upstream to a much greater extent than a weir contained within the drain.

### 3.5.5 Diverting drains

One means of protecting conservation land would be for present and future drains to be diverted around the edge of the Scientific Reserve and Conservation Area. The Motutangi Drainage Committee's draft management plan actually discusses the possibility of closing the Selwyn Outlet, and diverting the Bacica and Selwyn down the Aspin. This is vigorously opposed by Mr Alan Summers, whose farm at the bottom end of the Aspin already floods when water passes from the Selwyn into the Aspin. Given the Selwyn Outlet's limited impact on the Scientific Reserve, and in fairness to Mr Summers, DOC could consider keeping the status quo until such time as an alternative means of discharging the Selwyn's floodwater, satisfactory to downstream as well as upstream farmers, could be negotiated.

### 3.5.6 Regulating water levels

Maintaining water at set levels, at different times of year, has occasionally been suggested as a means to attain specific management objectives at Kaimaumau, e.g. to enhance orchid habitat, or to suppress weeds by waterlogging their roots. It could be attempted using any of the engineered structures for water control previously outlined, as long as adjustable weirs and floodgates are installed.

Problems with the concept of regulating water levels are:

- Nobody knows exactly how much inundation the different plants and animals at Kaimaumau require, or can tolerate. Appropriate water levels would have to be established by trial and error, and unforeseen damage to the wetland ecosystem might occur in the process.
- Seasonal drying out is part of the natural swamp habitat, as is year-to-year variation in the extent of the dried-out areas. Artificially maintaining waterlogged ground, in areas that dry out due to weather conditions, seems to run counter to the aim of restoring a near-natural habitat.

### 3.5.7 Minimum management

Engineering solutions such as weirs, stopbanks and bunds are expensive ways to remedy a situation that (on conservation land) is a natural phenomenon. The alternative is to wait for the situation to reverse itself naturally when a series of wet years arrives, and accept the habitat changes meanwhile.

Some recommendations about how DOC could handle drainage issues in each swamp catchment follow. The tenor of our recommendations is ‘minimum management’, i.e. measures which entail as little alteration as possible to natural fluctuation in water levels.

## 3.6 WATER LEVEL MANAGEMENT IN SPECIFIC AREAS

### 3.6.1 Motutangi

Much of the Motutangi Swamp is outside conservation land and has been extensively drained for farming. What used to be wet, sandy or fibrous peat has been converted to a well drained mix of sand and powdery, oxidised organic matter. Regardless of whether the main drains have been over-deepened—a subject of some controversy amongst local farmers—they certainly contribute to peat deterioration, by increasing gradients through an extensive network of feeder drains that run back into pasture and de-water the land between.

Similar effects on conservation land are fortunately restricted to banks of the Aspin, Bacica and Selwyn Outlet drains, and farm boundaries. To ensure that deterioration does not increase, DOC needs to prevent extension of new drains into conservation land. Improved drainage of adjacent farms, where needed, should be carried along the reserve boundary, and DOC need not object to new drains located in this position. To prevent ‘edge effects’ from boundary drains, bunds between dune ridges on the reserve side of drains, as proposed by Mr Alan Summers, could be considered, to rectify drying out of the peat and maintain plant habitat.

As discussed above, there is some evidence that vegetation in flooded parts of the Motutangi is being affected by nutrient-enriched water from existing farmland. There appears to be little that DOC can do to prevent this, as no matter what route farm runoff takes, surface floodwater will continue to pond in the vicinity of Land’s End, and shallow groundwater will continue to resurge in alluvial sand wherever streams pass through the older foredunes.

Current farm development is restricted to the Motutangi’s south-east corner, which lies within the privately owned Vuksich block. Much is already being developed for farming, apart from an area bounded by Lake and Norton Roads. Runoff from the areas being developed passes down a network of shallow drains, and through the Bacica Drain into the Scientific Reserve. Sediment, dissolved fertiliser, and herbicide residues are present in the water. Their impact should be seen in perspective against a contribution of similar pollutants from a much larger area in the western half of the Motutangi’s catchment that is already developed farmland.

### 3.6.2 Waihuahua and Otiaia

These catchments are the heart of the wetland, almost unmodified by artificial drainage. There are old gumdiggers' drains here and there, but they are blocked by sand and peat accumulation. Re-opening old drains or digging new ones should be avoided, so that water levels, and the associated variety of plant and animal habitats, remain little-disturbed. The adjacent Vuksich and Radojkovich development blocks could be drained by opening deep drains through the Lake Road ridge into the two swamp catchments. However, it would be more economic for these farmers to excavate shorter, shallower drains leading south into existing drains on farmland near the Okohine Stream (central part of Vuksich block), the Kaurex drain network leading to Rangaunu Harbour (eastern part of Vuksich block), and existing drains on farmland at Kaimaumau (the Radojkovich block).

There are several low points in the Lake Road ridge where water can pass between the Waihuahua and the Vuksich block. These appear to be old gumdiggers' drains, partly filled by sand. It would be a good insurance to block them with impermeable material, e.g. excavate, backfill with sand from the ridge, and grout with cement. Provided that this is done, the hardpan beneath Lake Road ridge will continue to keep the Waihuahua hydrologically isolated, and DOC then need have no concern about any boundary drains dug by the Vuksich family on the south side of the boundary.

The Otiaia where bounded by Lake Road may not be hydrologically isolated, as the formation here is lake-deposited Kaikino sand, which is quite permeable and two or more metres above the underlying sandstone hardpan. However, it is about two metres higher than the main part of the Otiaia swamp, so it is unlikely that any drains dug by the Radojkovich family south of their Lake Road boundary would have a de-watering effect on the Otiaia.

### 3.6.3 Areas draining to Okohine Stream

Currently there is no conservation land in this catchment. Areas of swamp remain within the Vuksich development block, but cannot be hydrologically isolated from drains on the rest of the Vuksich property, unless DOC constructs bunds across several low points along the Norton Road ridge, and also across the sandy peat swamp that divides the Norton and Lake Road sand ridges.

In the event that mining of kauri gum, peat wax or peat oil recommences in the Okohine, under mining licenses currently held by Resin and Wax Ltd, the Kaurex drain network could be reactivated. At present this flows south to Kaimaumau Harbour, and discharge from mined areas would not pose any threat to conservation land. If there is any future proposal to drain mined areas northwards through the Lake Road ridge, that would be inconsistent with maintaining water quality and wetland habitat in the Waihuahua and Otiaia catchments.

Sediment, nutrients and herbicide residues from land development in the Okohine are unlikely to affect plants or wildlife in present areas of the Scientific Reserve or Conservation Area. If remnant swamps within the Okohine were to be added, construction of bunds would probably be needed to isolate them from other parts that are scheduled for future farm developments.

### 3.6.4 Areas draining to Rangaunu Harbour

The only conservation areas here are the shoreline reserve round Lake Waikaramu, unoccupied Crown land in the lakebed, and a triangle of land bounded by the Otiaia swamp boundary (defined by a sand ridge), the Radojkovich development block, and privately owned land between Kaimaumau and Kuaka Points.

The Kaurex drain extension into the bed of Lake Waikaramu, blocked some time after 1989 by removal of the pipe across Airstrip Road, should not be re-opened, nor should the old now-blocked gumdiggers' drain at the Lake's south-east corner.

Any attempt to mine Waikaramu for gum or peat, or use it as a reservoir for mine operations, would be detrimental to the Lake's geological significance and value as wildlife habitat. The existing water right has lapsed, so a new application could be opposed. The mining permit is still valid, so DOC would have to ask its current holder (Resin and Wax Ltd) to exclude the lake bed if mining recommences.

The triangle of land east of Waikaramu does not have any drains, other than marginal ones along parts of the boundary with private farmland. The underlying formations are old lakebeds, now completely infilled with peat, and lakeshore sand deposits. Both formations are fairly permeable and extend across property boundaries. Drainage of neighbouring farmland is unlikely to affect the sand deposits (already dry), but could have an 'edge effect' on peat in the former lakebeds. This effect could possibly be minimised by constructing low-permeability bunds of compacted sand, similar to those proposed for a farmland/swamp boundary at the north end of the Motutangi.

Lots 18 and 19 of the Radojkovich block adjoin the eastern and northern shorelines of Lake Waikaramu, though they are separated from the lake edge by a narrow esplanade strip of conservation land. Lot 18 is already being developed for farming, though Lot 19 remains in scrub for the time being. Land development on these blocks is unlikely either to drain the lake or contribute pollutants in surface runoff, because there are no streams or drains leading in either direction. Drainage appears to be subsurface through the permeable Kaikino sand which underlies these blocks and forms a ring of elevated ground around the lakeshore. The possibility of dissolved fertiliser or herbicide residue reaching the lake by shallow groundwater seepage cannot be discounted, although the quantities are unlikely to be great, due to the sand's filtering effect on pollutants.

The Lake's western margin is also separated by a narrow esplanade reserve from slightly elevated Kaikino sand deposits located in the eastern end of Lot 20 on the Vuksich Block. Future land development there could also have a minor impact on the Lake's water quality, through groundwater seepage.

The southern margin of the lake is bounded by an esplanade reserve, backed in some places by developed farmland (Hilton and Bilcich properties) and in others by scrubland in private ownership (Lot 16). Drainage appears to be partly sub-surface, and partly via a network of shallow gumdiggers' drains (some of which have been resuscitated to serve as farm drains), away from the lake towards Rangaunu Harbour.

In all these blocks it would be wise to ensure that drains excavated or extended in the course of land development stop at the esplanade reserve boundary. While acquiring any of the blocks would provide a wider buffer zone of scrub around the Lake, their acquisition is not essential for the purpose of avoiding lake drainage or maintaining water quality.

## 3.7 LEGAL ASPECTS

Under the Land Drainage Act 1908, landowners are entitled to carry out drainage works on downstream land in order to improve drainage on their own properties. The Resource Management Act 1991 may require them to obtain a consent from regional councils for new drainage work, as opposed to maintaining existing drains, which they can do as of right. However, the interpretation that resource consents are required for new work seems to be disputed, and some drainage authorities have proceeded with new work without consents. Environment Court cases are pending which may resolve this question. DOC may also wish to seek legal advice as to whether the Land Drainage Act provisions override protection afforded Scientific Reserves and Conservation Areas by the Conservation Act 1987.

## 3.8 LIAISON WITH NEIGHBOURING LANDOWNERS

Landowners need to be able to drain their land effectively, in ways that do not affect the Scientific Reserve and Conservation Area. Conversely, DOC needs to maintain Kaimaumau's water levels for habitat protection and restoration in ways that do not impede drainage or farming on neighbouring land.

Liaison with local drainage committees (constituted from local landowners), and also with individual landowners undertaking drainage independently of the committees, is essential, particularly in view of DOC's obligations towards neighbouring landowners under the Land Drainage Act.

Greater exchange of information about plans for drainage (landowners) and plans for maintaining water levels (DOC) could bring issues of concern out into the open at an early stage. This should improve the chance that they can be resolved to everybody's satisfaction (see Section 12).

# 4. Weed problems

## 4.1 GENERAL REMARKS

Weeds may alter the balance of species in ecosystems, cause the disappearance of certain species, or alter the vulnerability of communities to fire and other damage (Williams & Timmins 1990). Problem weeds are defined as those that 'permanently alter the structure, successional processes, and organisms present in native communities' (Timmins & Williams 1987). Once an invader has gained a foothold, even in relatively undisturbed vegetation, the invasion is likely to be expanded during subsequent disturbance.

### *Relationships of the flora of the Kaimaumau wetland*

There is a strong relationship between the present introduced and indigenous flora of the wetland and that of parts of eastern Australia. For example, many of the orchid species in the wetland have apparently originated from Australia by wind dispersal. Many of the sedges present are shared with Australia, e.g. *Baumea articulata, B. rubiginosa, B. juncea*, *B. arthrophylla*, *B. teretifolia*, *Eleocharis sphacelata*, *Isolepis inundata* and *Schoenus brevifolius*; so also are *Polygonum salicifolium, Schoenoplectus validus, Triglochin striatum, Typha orientalis*, and the fern *Gleichenia dicarpa*.

Some of the most problematic weeds now dominating large areas of gumland, including the Kaimaumau wetland, are also of Australian origin. These include Sydney golden wattle (*Acacia longifolia*), two species of hakea (*Hakea sericea*, *H. gibbosa*), and stiff bottlebrush (*Callistemon rigidus*). These are all fire-adapted species and their range in Australia includes coastal wetland habitats similar to Kaimaumau, where they often grow with species (such as those listed above) that are indigenous to both countries.

## 4.2 PROBLEM WEEDS IN KAIMAUMAU WETLAND

Major weeds are listed in approximate order of the threat they pose, based on current distribution and perceived difficulty of control.

**Group 1 weeds** are widely established within the wetland and cannot readily be controlled by conventional means, although there may be opportunities to limit further spread. These weeds are: prickly hakea (*Hakea sericea*), Sydney golden wattle (*Acacia longifolia*) and gorse (*Ulex europaeus*).

**Group 2 weeds** have the potential to spread greatly from their present restricted locations.

These include bottlebrush (*Callistemon rigidum*), broom (*Cytisus scoparius*), downy hakea (*Hakea gibbosa*), heather (*Calluna vulgaris*), prickly Moses (*Acacia verticillata*), watsonia (*Watsonia bulbillifera*), oxylobium (*Oxylobium lanceolatum*), radiata pine (*Pinus radiata*), and two species of gum (*Eucalyptus robusta, E. botryoides*). Maritime pine (*Pinus pinaster*) is at present only found in the recent foredunes.

**Group 3 weeds** have a restricted distribution in the wetland, but their further spread appears to be controlled either by habitat conditions or by their use for firewood (as in the case of black wattle). These species include brush wattle (*Paraserianthes lophantha*), black wattle (*Acacia mearnsii*), pampas (*Cortaderia selloana*) and Mexican devil (*Ageratina adenophora*).

**Group 4 weeds** are potential threats to Kaimaumau although not recorded from the wetland. They are mainly Australian species that grow in similar habitats in eastern Australia and are adapted to grow in fire-prone areas on nutrient-poor soils that are seasonally wet. Many of these species are listed in van Kraayenoord & Hathaway (1986) as suitable for erosion control and are already in the country. Examples are: *Banksia integrifolia*, *Melaleuca ericoides*, *Grevillea* spp., *Leptospermum laevigatum*, *Callistemon citrinus*, and *Acacia longifolia* var. *sophorae*.

There are other weeds found in the general vicinity of the wetland which, although they could become problems in the foredune conservation area, appear less of a threat to the wetland because conditions there are unsuitable, e.g. low fertility. These include: boneseed (*Chrysanthemoides monilifera*), Spanish heath (*Erica lusitanica*), Madeira vine (*Anredera cordifolia*), sweet pea shrub (*Polygala myrtifolia*), and woolly nightshade (*Solanum mauritianum*).

## 4.3 GROUP 1 WEEDS: SPECIES WIDESPREAD IN THE WETLAND

### 4.3.1 Prickly hakea (*Hakea sericea*)

This shrub originates from eastern Australia (the type locality is probably Botany Bay). It is adapted to grow on nutrient-poor soils and survive frequent fires (Cheeseman 1906). It was introduced to New Zealand last century and often used for hedges in the Auckland district. By 1940 it was dominating large areas of gumland (Allan 1940).

#### *Distribution in the wetland*

Prickly hakea is found in all seasonally wet parts of the Kaimaumau wetland, but growth is stunted and plants are chlorotic and unthrifty in sites where the water table remains high for longer periods. Establishment and survival in the seasonally wet sites probably depends on the micro-topography, and how long seedlings are totally immersed when they are small. Prickly hakea does not grow in permanently wet sites. Prickly hakea has been replaced by the taller Sydney golden wattle in better drained locations such as the shores of Lake Waikaramu.

#### *Reproduction and dispersal*

A heavily lignified follicle protects a pair of winged seeds from fire; in South Africa the follicle opens only when the plant dies (Richardson et al. 1987), whereas at Kaimaumau at least some seed is released from living plants. Follicles accumulate over the lifetime of the plant with no decline in viability, and a large seed bank is retained on the plant, ready to be released by fire (Richardson et al. 1987). After a fire the follicles dehisce and all release their seed in the course of a few days (Kluge & Neser 1991). The seeds are thin-coated and germinate readily after release; no viable seed bank persists in the soil (Richardson et al. 1987). In Golden Bay, *Hakea sericea* plants with stems 10–15 cm diameter have c. 600 follicles per plant or c. 260/$m^2$ (Williams 1992). Seed banks of up to 75 000 seeds/$m^2$ [sic.] have been reported from a 15-year old stand (Neser & Kluge 1986). Prickly hakea does not propagate vegetatively, and frequent fires encourage its spread.

### *Population dynamics*

Prickly hakea requires high light levels and is short-lived. On drier sites in the absence of fire it is replaced by taller natives such as kanuka, but because it tolerates seasonally wet areas on poor soils it competes with low-stature manuka, and can remain a permanent part of this type of scrub. Early seedling growth is more rapid than manuka, and seedlings probably grow to a metre after 3–4 years, plants mature after 4–5 years, and adults reach 3–4 m after 10 years (Timmins & Mackenzie 1995). Prickly hakea produces prominent axillary rays and annual rings are not formed, so rates of spread and the age structure of populations cannot be determined from stem sections.

### *Weed status elsewhere*

Prickly hakea is listed as a weed of protected natural areas in northern and central New Zealand; it is also a weed in north-west Nelson and on some offshore islands (Williams & Timmins 1990, Williams 1992, Atkinson 1997). In South Africa, the species has become a major weed in fynbos shrublands and occupies an estimated 480 000 ha (Kluge (1983) in Kluge & Neser 1991). It competes with indigenous vegetation including the South African proteas, forming impenetrable thickets of up to 8900 plants/ha (Richardson et al. l987, van Wilgen & Richardson 1985). The most important trait that separates this species from other Australian hakeas in South Africa is its ability to produce a very large seed bank in the absence of seed predators (Richardson et al. 1987).

### *Options for control*

At Kaimaumau prickly hakea is too widespread for hand control methods, such as cutting adults and/or pulling seedlings, to be practicable. Nor is the intensive treatment of applying weed killer to cut stems (20% ‘Roundup’, Timmins & Mackenzie 1995) an option except for isolated plants.

Herbicides have been used in South Africa but played only a minor role as they are expensive, difficult to apply, and non-selective: tebuthiuron remains the only product registered against prickly hakea there (Kluge & Neser 1991). Control of mature plants by cutting, and burning the heaps once the seed has germinated, thus removing the numerous seeds and germinated seedlings, has been successful but extremely costly (Breytenbach 1989, Kluge & Neser 1991). This method also increased the intensity of fires because of greater fuel loads and had negative environmental impacts. During the search for alternative methods of control, the biology of *H. sericea* was investigated in South Africa and Australia. In South Africa, where specialised seed predators were absent, approximately ten times more seed was produced than in Australia (Pieterse & Cairns 1988a), so a weevil (*Erytenna consputa*) that destroys developing fruits, and a seed-eating moth (*Carposina autologa*), were introduced from Australia.

Another weevil (*Cydmaea binotata*) was released to destroy seedlings. It also attacks *Grevillea robusta, Hakea suaveolens* and *H. gibbosa*. In addition, a fungus (*Colleotrichum gloeosporioides*), thought to be indigenous to South Africa, was found to kill *H. sericea* plants (Neser & Kluge 1986). Since the introduction of the seed predators, seed production and the number of accumulated fruits of *H. sericea* has dropped to c. 20% of pre-release levels (Neser & Kluge 1986, Kluge & Neser 1991). *Erytenna consputa* has now become one of the major causes of destruction of developing prickly hakea fruits in South Africa.

#### *Probability of re-establishment from nearby land following control*

Prickly hakea is widely distributed on nearby land. Seeds are winged and dispersed by wind. Distances that seeds can travel and rates of spread are not known, but *H. sericea* 'has the potential for dispersal over a considerable distance' (Richardson et al. 1987). Persistent strong winds, such as those experienced in Northland, encourage the spread of the species. Manual removal of prickly hakea from the reserve would simply result in seed re-dispersing into the reserve from adjacent land.

#### *Recommendation*

This weed appears to be a serious problem throughout its New Zealand range. The costs of controlling it should be investigated to determine whether introducing a biological control agent(s) is justified. Such agents, especially the seed predators introduced into South Africa, may prove to be the most effective long-term control.

### 4.3.2 Sydney golden wattle (*Acacia longifolia*)

As the name suggests, Sydney golden wattle came from eastern Australia. It is adapted to grow on nutrient-poor soils and survive frequent fires. It was reported from the North Cape area by Cheeseman in 1897 but not listed as a naturalised plant in his 1906 flora (Cheeseman 1906, Allan 1940). It is now established in Northland, Auckland City, Hamilton and Wellington (Webb et al. 1988). The plant is not eaten by farm stock, presumably because its leaves contain cyanogens (Everist 1974).

#### *Distribution in the wetland*

This wattle replaces prickly hakea in better-drained locations such as the shores of Lake Waikaramu. It is found on the sand ridges where drainage is better, and extends into the lower, seasonally wet areas but is not found in permanently wet sites. Some of the seasonally wet sites appear to have been colonised by wattle recently, but this cannot be confirmed easily because the plants do not produce annual growth rings.

#### *Reproduction and dispersal*

Sydney golden wattle seeds have a hard, water-resistant testa; as seeds remain in the soil for many years before germination a considerable seed bank builds up. In South Africa, before biological control agents were introduced, seed densities in the soil seed bank reached 34 000 seeds/$m^2$ (Pieterse (1986) in

Neser & Kluge 1986). Seeds are enclosed between two valves of a pod, and as the valves curve or twist to release the seed, the pod becomes lighter and more prone to wind dispersal. Although most seed would fall close to the parent tree, dehisced pods with a residual seed could be carried by the wind for longer distances.

### *Population dynamics*

Sydney golden wattle requires high light levels and is short-lived; in Australia it is one of several rapidly growing shrubs that exploit open conditions created by fires. It depends on high densities of seed in the soil seed bank and rapid growth rates to outcompete other species that rely on fire-induced opportunities. The population dynamics of the species differs greatly according to fire frequency (Pieterse & Cairns 1988b). In the absence of fire, few seedlings establish beneath the parent plants, but large quantities of seed are added to the soil bank annually. Seeds are produced on trees that are only a few years old, and mature trees produce large numbers of seeds. An 11 mm diameter twig collected from Kaimaumau had 83 pods containing 630 seeds. A lack of annual rings prevents measurement of its rates of spread and the age structure of populations. Litter and topsoil samples were gathered by the authors from several sites dominated by wattle. These produced seedlings of wattle and gorse, indicating that disturbance of wattle stands could result in either of these species re-colonising the site. This wattle, which like gorse can fix nitrogen, generally represses gorse from vegetation when both species establish together.

### *Weed status elsewhere*

In New Zealand, Sydney golden wattle is not listed as a weed of protected natural areas by Williams & Timmins (1990) or Timmins & Mackenzie (1995), but is listed by Clunie ( unpubl. report to DOC 1995) as an established weed of medium control priority.

In South Africa, the species is a serious weed of the south-west Cape fynbos (Milton 1980). There the success of Australian acacias has been attributed to their rapid establishment after fire, aided by nitrogen fixation and possibly allelopathy, and to the recent deterioration of soil nutrient status beyond the tolerance of the indigenous vegetation (Milton 1980). Moreover acacias have fewer natural enemies than in their place of origin and produce large crops of dormant seed. *Acacia longifolia* trees in South Africa produce approximately ten times more seed/$m^2$ than in Australia because of the absence of specialised seed predators (Pieterse & Cairns 1986). Litter production in an established wattle thicket is c. 700 g/m/yr dry weight, about three times that of heathland (Milton 1980). The litter does not readily break down and it smothers ground vegetation and seedlings of competing species, and creates a fuel load that encourages fires.

### *Options for control*

Sydney golden wattle is too widespread in the wetland for it to be eliminated by cutting adults and/or pulling seedlings by hand. Furthermore, untreated stumps will re-sprout (E. Cairns pers. comm.). In South Africa, before biological control agents were introduced, large numbers of seeds were added to the soil seed bank annually. In the absence of fire, 89% of the seeds were removed from the soil surface by predators including rodents, birds and ants, but still more than 2400 seeds/m$^2$ were added to the soil seed bank annually (Pieterse & Cairns 1988b). Not all of these seeds remain in the soil seed bank, as some germinate and die and others are destroyed by fungi or seed predators. A fire which kills adult trees and stimulates germination may reduce the soil seed bank by c. 90% (Pieterse 1986), but still 80 juvenile plants/m$^2$ can establish and a further 166 viable seeds/m$^2$ remain in the seed bank (Pieterse & Cairns 1988b). Losses and gains pertaining to the annual seed crop have not been determined for New Zealand conditions so these South African figures are a guide only. Control methods involving the removal of older plants by cutting, ringbarking, spraying and controlled burning have been tried in South Africa, but unless the numerous seedlings that germinate are destroyed, the resultant seed crop simply increases the density of plants. Any control option that does not include fire, must be able to eliminate the substantial soil seed bank, or 'control' will only succeed in eradicating the existing mature plants, and the very large seed bank will be relatively unchanged (Pieterse & Cairns 1988b). A cut-and-burn treatment can eradicate dense stands of wattle if the large numbers of seedlings that develop after the fire are controlled chemically or by chemical and mechanical follow-up work (Pieterse & Cairns 1988b). Methods that involve burning increase the loss of organic material from the soil and have a negative environmental impact. Satisfactory control has been achieved in South Africa with herbicides, but they have played only a minor role, as they are expensive and non-selective. Chemical control is achieved by spraying foliage of seedlings or juveniles with either glyphosate (2.4% v/v) or triclopyr (0.6% v/v); concentrations vary depending on the age of the plants (Pieterse 1994).

In South Africa, Milton & Hall (1981) concluded that biological control was the only economically feasible solution for long-term management. Since the bud-galling wasp (*Trichilogaster acacaelongifoliae*) was introduced to South Africa in 1982–83 a reduction in seed production of 89–95% has been achieved on galled branches when more than 50% of branches are affected. Galling also encourages the abscission of unaffected inflorescences and suppresses vegetative growth (Dennill & Donnelly 1991). A second seed-destroying insect, the snout beetle (*Melanterius ventralis)* was released in 1985. The beetle feeds on developing seeds and is efficient at finding the few pods left after attack by gall wasps. Between them the wasp and beetle can achieve close to 100% reduction in seed production (Dennill & Donnelly 1991). Both these insects were chosen as biological control agents as they are specific to Sydney golden wattle. Tests undertaken in South Africa could form the basis of preliminary trials for specificity in New Zealand and reduce the time and expense of testing any biological control programme here.

At Kaimaumau, even with biological control under optimum conditions, Sydney golden wattle will remain part of the vegetation of the dry sand ridges until taller vegetation replaces it. Even if biological control agents reduce the vigour of plants and seed output, ongoing removal of wattle trees may be necessary.

#### *Probability of re-establishment from nearby land following control*

The distance seeds can travel and the rate of spread are not known, but in Northland the persistent wind encourages the spread of the species. This wattle is widespread on land adjacent to the Scientific Reserve. Of particular concern is its presence on the young dunes behind East Beach, although some of these might be *Acacia sophorae*. We made no survey of these dunes, but it is apparent that there are at least scattered individuals of wattle between the mouth of the Te Kahuna Stream and the rear of these dunes near the Selwyn Outlet. Judged by its presence on sand along the eastern Australian seaboard, Sydney golden wattle could become as dominant on the young dunes as it has done on the old dune ridges in and around the wetland. If this should happen, it will become extremely difficult to exclude it from remaining vulnerable sites within the wetland itself.

#### *Recommendation*

The costs and benefits of controlling this species throughout its New Zealand range should be investigated to determine whether biological control is a viable option. Use of biological control agents, especially the seed predators that have been successfully introduced into South Africa, may be the most effective way of controlling this weed in the long term. Before biological control is attempted, however, the exact biotype and its Australian origin need to be determined to ensure that biological control agents are properly matched. Non-matching delayed biological control in South Africa (Kluge & Neser 1991).

There is likely to be some public opposition to any proposal to introduce a biological control agent, most probably from landowners who use other wattle species for timber, shelter or ornamental reasons. The main biological control agent used against Sydney golden wattle in South Africa is reported to be specific to *A. longifolia* (Kluge & Neser 1991), so is unlikely to pose a threat.

### 4.3.3 Gorse (*Ulex europaeus*)

This weed originates from Europe and has been in Northland (Bay of Islands) since the 1830s (Darwin 1845).

#### *Distribution in the wetland*

Gorse is scattered in drier parts of the sand ridges and in the younger foredunes between the wetland and East Beach. Observations by one of us (DLH) show that gorse was previously dominant on some of the better-drained sites (such as the airstrip and the western shores of Lake Waikaramu), now occupied by closed stands of wattle.

#### *Reproduction and dispersal*

Seed is shed from the pod by explosive action and usually falls close to the parent plant. Dispersal for greater distances is by transport on vehicles, mud, or hooves. Viable seed can germinate from the soil seed bank for several decades after the last parent plant has been removed, making the total elimination of gorse very difficult. Germination trials of litter and soil from beneath wattle stands revealed that viable seed of both species is present in the seed bank.

#### *Population dynamics*

Although gorse is a nitrogen-fixer it is unable to compete with Sydney golden wattle on the drier sites in the wetland, and wattle stands have largely replaced gorse. If the wattle were to be controlled, soil disturbance would result in another crop of gorse and wattle seedlings. Biological control of wattle could re-establish gorse as part of the succession. Gorse lives for 20–30 years (Williams 1983), and during that time a very large soil seed bank is formed. Elsewhere in the country gorse is often seen as a nurse crop that precedes the establishment of native vegetation, but work in Otago suggests that mature gorse stands can be followed by further gorse (Lee et al. 1986).

### *Weed status elsewhere*

Gorse is a serious weed in many parts of New Zealand hill country, partly because of the fire cycles that are associated with the young stands. The dense regrowth of gorse after a fire, with self-thinning of the over-stocked stands and resultant high fuel loads, creates a fire hazard that often results in further burning and more gorse. These fire cycles result in high densities of seed in the soil seed bank, and the gradual reduction in numbers of native species, and thus the removal of seed sources of natives. Similar cycles are associated with the wattle stands in the wetland.

### *Options for control*

In the wetland the control of gorse by cutting or spraying is not practical as the species is widely distributed. Cutting and stump spraying is slow and expensive, and plants can re-establish from viable seed in the seed bank for many years following soil disturbances. Gorse spider mite (*Tetranychus linearius*) was seen on Lake Road near Lake Waikaramu and at the Motutangi end of the wetland. The gorse plants infested with the mite were very unthrifty and would have been unable to compete with either native plants or other weeds.

### *Probability of re-establishment from nearby land following control*

Although gorse is found in the foredunes and is present on farmland, and could easily be re-introduced to the wetland, viable seed in the soil is a greater threat to its continued presence in the wetland.

### *Recommendation*

Any small outlying patches of gorse that may be recent arrivals should be eliminated quickly before seeds begin to accumulate in the soil. Biological control of gorse can be facilitated by collecting the spider mite from sites where it has established and spreading it to other parts of the wetland. Elsewhere in New Zealand, gorse seed weevil (*Apion ulicus*) is playing a significant part in reducing the soil seed bank (Williams 1983). The seed weevil should be introduced to the wetland if it is not already there, or spread more widely if it is present.

## 4.4 GROUP 2 WEEDS: SPECIES WITH POTENTIAL FOR FURTHER SPREAD

### 4.4.1 Stiff bottlebrush (*Callistemon rigidus*)

This shrub comes from near Sydney and along the coast of New South Wales to the Victoria border where it is widespread in damp heaths and shrublands. It is one of several bottlebrushes that are adapted to thrive in nutrient-poor, seasonally wet sites that are periodically burnt.

#### *Distribution in the wetland*

Bottlebrush is found only in the eastern end of the wetland. It is on both sides of the track to Little River, south of Lake Road near the Little River track, and east to the track that runs from Lake Waikaramu into the Waihuahua catchment. A further large patch is present south of the Otiaia wetland.

#### *Reproduction and dispersal*

Stiff bottlebrush is a member of the Myrtaceae and, in common with most other members of the group, has woody capsules and small seed. An above-ground seed bank forms in the plant crown, where the capsules remain tightly closed until the parent plant dies or is killed by fire. The seed, as in prickly hakea, retains its viability on the plant for many years but, once released, germinates or dies and thus does not form a seed bank in the soil. When seed is released it requires full light to germinate and establish. The seed is small, and is easily spread by wind, vehicles or animals.

#### *Population dynamics*

Stiff bottlebrush is adapted to survive fires and re-sprout from the rootstock. In common with several others in the genus, it forms a lignotuber that survives a fire, and later re-sprouts. Plants collected from the wetland had thick fire-resistant papery bark at the base. It was apparent that plants had re-sprouted from the base after the 1988 fire even though the remainder of the plant had been killed. Fire stimulates the release of seed and a new generation of seedlings. Plants less than 30 cm tall and growing along the vehicle tracks have lignotubers; the woody shoot that arises from the tuber is easily detached, leaving both lignotuber and rootstock capable of resprouting.

#### *Weed status elsewhere*

Stiff bottlebrush is naturalised on the Karikari Peninsula on the eastern side of Rangaunu Inlet and in Auckland City.

#### *Options for control*

Unless control is immediate and complete, bottlebrush could become one of the most widespread and difficult weeds to control in the wetland. It is adapted to grow on poor soils in moist to seasonally inundated sites that are periodically burnt.

Bottlebrush is difficult to see except when plants have grown taller than surrounding vegetation and are in flower. Small plants are able to establish and survive to maturity before they become obvious. If the wetland is burnt before they are removed, fire releases the seed.

### *Probability of re-establishment from nearby land following control*

Bottlebrush is grown in nearby gardens and is present along the road to the Kaimaumau township. It is likely to be spread with garden refuse into illegal dump sites bordering the wetland and, as the seed is very small, it is likely to be carried back into the wetland by vehicles, birds or wind.

### *Recommendations*

Bottlebrush can be controlled only if both rootbase and lignotuber are killed, either by removing them or by cutting the stems and treating the crown with weedkiller. Particular care must be taken to ensure that seed capsules are destroyed, either by putting cut shrubs beneath closed vegetation, or by leaving the cut material in heaps and spraying seedlings that arise. We noticed small fragments of stem with seed capsules along the road between the bottlebrush sites in the wetland and the DOC dump site for the cut shrubs. If bottlebrush is to be shifted from where it was growing, any vehicle tray or trailer should have a netting cage to ensure that fragments are not dispersed more widely.

## 4.4.2 Broom (*Cytisus scoparius*)

This shrub originates from Mediterranean Europe, Asia Minor, and Russia. In New Zealand it is found throughout the North and South Islands, where it is a serious weed, and it is present in Stewart Island and the Chathams.

### *Distribution in the wetland*

Broom is scattered on the drier ridges and is present along the roadway south of Lake Waikaramu.

### *Reproduction and dispersal*

Broom flowers for two periods each year: from September to November, and from December to February (Williams 1981). Abundant seed is produced if seed predators are absent. Broom bushes at Lincoln produced almost 13 million seeds over the life of the plant (Williams 1981). Plants will resprout if damage is not too severe.

### *Population dynamics*

In favourable sites broom grows to 2.5 m in two years. It fixes atmospheric nitrogen and will tolerate strongly acid soils and those with very low levels of phosphorus. Broom lives to 10–15 years and is usually replaced by taller-growing native vegetation. Growth rings are produced, and ages of plants and rates of spread can be determined. Browsing animals, including hares, eat broom plants and can keep young plants hedged.

### *Weed status elsewhere*

Broom occupies many thousands of hectares of land in the South Island and central North Island. Unless growing on pastoral or agricultural land, broom is usually soon replaced by native vegetation because of its short life span. In sites where taller vegetation is inhibited by substrate or climate, broom can assume a more permanent role in the vegetation. Although it usually forms only a temporary part of the vegetation succession and is replaced by taller native trees, any disturbance of the vegetation, such as fire, will result in a vigorously growing crop of seedlings from the substantial seed bank that develops under parent plants. Seeds in the soil are long-lived and can respond to disturbance decades after the broom has apparently disappeared.

#### *Options for control*

Isolated individuals can be dug out, but locations need to be recorded to ensure that seedlings are removed. Chemical control is detailed by Timmins & Mackenzie (1995). Biological control agents for broom are being considered by the Ministry of Agriculture and Forestry.

#### *Probability of re-establishment from nearby land following control*

Because broom seeds are very long-lived they can be transported on vehicles or earthmoving machinery from sites where broom is not an obvious part of the vegetation. Particular care should be taken to check sites in the wetland where earthmoving machinery has operated. This will reduce the chances of broom, and other species with hard-coated seeds, being further dispersed from sources inside or outside the wetland.

#### *Recommendation*

A more precise survey of broom distribution is required before the cost required to control this species can be determined. The survey, which should also include the foredunes, should be made between October and December when mature plants are flowering and very obvious.

### 4.4.3 Downy hakea (*Hakea gibbosa*)

This shrub originates from New South Wales (Webb et al. 1988) and was introduced to Northland as a hedge plant. It is now naturalised in several sites as far south as Opotiki (Allan 1940, Webb et al. 1988).

#### *Distribution in the wetland*

Downy hakea is currently known from only a few sites in the wetland, on Lake Road and the track south of the Otiaia wetland. This distribution may be a result of dispersal by vehicles or it may reflect ease of access along those tracks during weed surveys.

#### *Reproduction and dispersal*

Downy hakea seed is adapted to germinate in full light following fires (Richardson et al. 1987). The follicles are heavily wooded and are adapted to survive hotter fires than other hakeas naturalised in New Zealand. Seeds remain for years in follicles of hakea crowns and show no decline in viability (Richardson et al. 1987).

### *Population dynamics*

Downy hakea is adapted to grow in shrubland that is periodically burnt, on nutrient-poor soils. Seed production is only one-third that of *H. sericea* (Richardson et al. 1987).

### *Weed status elsewhere*

Downy hakea is a serious weed in South Africa where it has invaded fynbos vegetation.

### *Options for control*

These are discussed by Timmins & Mackenzie (1995).

### *Probability of re-establishment from nearby land following control*

Downy hakea was not seen outside the wetland so that the chances of reinfestation following control appear to be low.

### *Recommendation*

A detailed search for downy hakea is needed, especially in areas surrounding the localities where it has been found. As it has been found on Lake Road, a careful search on either side of the roadway, and along this road, should establish whether it has seeded into the wetland or has been taken there by vehicles.

## 4.4.4 Heather (*Calluna vulgaris*)

This low-growing shrub originates from Europe and is widespread in the central North Island, in parts of Taranaki, and in a few localities in southern South Island.

### *Distribution in the wetland*

A small patch of heather, numbering about 10 plants, is present at the western end of the Motutangi catchment within the Scientific Reserve (NZMS 260: 270 028).

### *Reproduction and dispersal*

Plants can flower and set seed within two years of establishing as seedlings. A robust plant can produce 160 000 seeds per year. Dispersal is by gravity and wind, with distances of up to 250 m reached in winds of 30–40 m/s (Timmins & Mackenzie 1995).

### *Population dynamics*

A cycle of ‘pioneer’, ‘building’, ‘mature’ and ‘degenerate’ stages have been described in Europe. The cycle may be completed within 12–20 years in New Zealand but ‘degenerate’ stands are replaced by more juvenile heather. Spread can be achieved through adventitious growth (particularly rooting from older branches) as well as seeding.

### *Weed status elsewhere*

Heather was introduced to Tongariro National Park in the early years of the 20th century. It is now the major weed problem of the Park and has spread into many other areas of conservation value on and around the volcanic plateau.

### *Options for control*

Small plants can be dug out provided that the root crown is completely removed. Plants can be killed by spraying with Roundup (1%) or Escort (0.05%) after cutting the plant at the base and spraying the stump (H. Keys in Timmins & Mackenzie 1995).

### *Probability of re-establishment from nearby land following control*

Heather at Kaimaumau appears to be confined to a single patch within the Reserve with apparently little risk of re-infestation from nearby land.

### *Recommendation*

It is imperative that the small patch of heather should be dug out or sprayed and a thorough search made to ensure that no other patches of heather have been overlooked.

## 4.4.5 Prickly Moses (*Acacia verticillata*)

This tree grows in south-east South Australia and across Victoria to the extreme south-east of New South Wales and Tasmania, where it is found in woodlands and heaths, often on sandy soils and damp areas (Webb et al. 1988).

### *Distribution in the wetland*

Prickly Moses is scattered in sites around the margins of the wetland, but at present is not found within the current boundaries of the scientific reserve. It grows along the north-west margin of Block 5 and near the mouth of the Selwyn drain at the Motutangi end of the wetland, on farmland to the south of the scientific reserve (e.g. Vuksich property), on Terrible Ridge, and along the main road to Kaimaumau township. The largest patch seen was in Block 5.

### *Reproduction and dispersal*

Prickly Moses produces pods, each containing several durable seeds that contribute to the soil seed bank. Although most seed falls close to the parent tree, wind could carry pods that have lost all but the last seeds.

### *Population dynamics*

Prickly Moses is an acacia that depends on rapid germination and growth from buried seed stimulated by fire or other site disturbance. The seed bank builds up during the life of the parent trees, which are relatively short-lived. An ability to fix nitrogen may give this wattle a competitive advantage over other species growing on nutrient-poor substrates.

### *Weed status elsewhere*

Prickly Moses is recorded as a weed from the Bay of Plenty, northern Waikato, northern Taranaki, and the Manawatu (Webb et al. 1988).

### Options for control

This plant could be controlled by cutting adults and spraying seedlings, but the seed is likely to endure in the soil for decades and seedlings are likely to re-appear after disturbance.

### Probability of re-establishment from nearby land following control

Care is needed to ensure that seed is not carried to other sites after work in areas that contain Prickly Moses.

### Recommendation

With cooperation from adjacent landowners it would be possible to destroy all adult plants and this would greatly reduce the chances of this tree spreading. Regular monitoring for and destruction of any seedlings that appear would then be necessary as follow-up work.

## 4.4.6 Watsonia (*Watsonia bulbillifera*)

This member of the iris family is native to South Africa. It is a garden escape naturalised in Northland and Auckland, Gisborne, near Wellington, and in Nelson province.

### Distribution in the wetland

Watsonia is found in a few scattered locations on Lake Road near Lake Waikaramu, and westwards to near the junction of Lake Road and Norton Road. It has also been found (and sprayed) in the wetland itself near the track to Little River.

### Reproduction and dispersal

The plant produces seasonal growth from persistent corms. The flower heads grow to more than a metre tall in most places where watsonia grows, and the tall flower spike projects above surrounding vegetation. *W. bulbillifera* reproduces freely from vegetative cormils. It can be dispersed on spoil on roading equipment and the wheels of vehicles traversing muddy roads.

### Population dynamics

Watsonia clumps expand by vegetative growth; dispersal over longer distances is usually by cormils. Once established, the clumps can exclude other plants but cannot tolerate shading by taller shrubs.

### Weed status elsewhere

The plant is commonly seen along roadsides in the district.

### Options for control

The current programme of spraying in use by DOC appears to be effective. Small clumps of the plant can be dug out.

### *Probability of re-establishment from nearby land following control*

The plant is likely to have spread into the wetland from roadside tips where people have dumped unwanted watsonia clumps from their gardens.

### *Recommendation*

Eliminate, as far as possible, any roadside tipping in the vicinity of the wetland. Continue with the present spraying programme.

## 4.4.7 Oxylobium (*Oxylobium lanceolatum*)

This tall shrub is the only oxylobium naturalised in New Zealand and has been in the country since at least 1935 (Allan 1940). It originates from Western Australia, where some species in the genus contain sodium fluoroacetate (1080).

### *Distribution in the wetland*

Most oxylobium is found at the Waihuahua end of the wetland on well-drained ridges between major tracks and the main road. However, the plant is scattered between there and the Motutangi end of the wetland, and the full extent of its distribution is not known.

### *Reproduction and dispersal*

This plant can flower when only one metre in height. Each flower head has about 4–8 flowers; the pods split at the vertex and seeds are retained until the pods are shaken by wind. The branches are slender, and as the flower heads (and later pods) are at the tips of the branches, seed is scattered as branches wave in the wind. We have no information about longevity of seed, the distance seed is scattered naturally, whether a soil seed bank develops, longevity of individual plants, and growth rates.

### *Population dynamics*

In the Kaimaumau wetland, oxylobium grows as a multi-stemmed shrub from a permanent woody rootstock. This growth form may be partly a result of regrowth from a rootstock following fires. Roots are nodulated, suggesting that the plant is able to fix atmospheric nitrogen. In some localities nearer Auckland and Tom Bowling Bay it has formed dense stands within scrub.

### *Weed status elsewhere*

Oxylobium is not listed as a weed in protected natural areas by Williams & Timmins (1990) or Timmins & Mackenzie (1995), but is listed by Clunie (unpubl. report to DOC 1995) as a weed that should be prevented from establishing in the Auckland Conservancy.

### *Options for control*

This weed is best controlled in spring or early summer, before the seed pods mature.

#### *Probability of re-establishment from nearby land following control*

The distance that seed can travel or how it is spread is not known.

#### *Recommendation*

There is a need to promote a study of the basic biology of this species.

### 4.4.8 Radiata pine (*Pinus radiata*)

Radiata pine was introduced to New Zealand from California for use as a timber tree. It is widely grown and has naturalised freely (Webb et al. 1988).

#### *Distribution in the wetland*

Radiata pine is being spread by wind, from small plantations at the Motutangi end of the wetland, into seasonally wet manuka–hakea communities. Many of the young pines are chlorotic and appear intolerant of seasonal waterlogging.

#### *Reproduction and dispersal*

The mature pines provide a continuing source of seed that can be blown into the swamp during hot windy weather.

#### *Options for control*

Felling of trees and pulling of seedlings is a practical method of removing this weed.

#### *Probability of re-establishment from nearby land following control*

Because pine seed can be blown at least 4 km (Campbell 1984), the presence of pine plantations on adjacent farmland will always allow re-invasion of the wetland by pine seedlings. Agreement with adjacent landowners to minimise the planting of pines near the reserve boundaries will reduce the chances of re-invasion and make it possible to replace the pines with less invasive shelter species.

#### *Recommendations*

Mature trees that are currently seeding should be removed immediately and this should take precedence over the removal of juveniles. The juvenile pines mature at 8–10 years and are obvious before this age, making control relatively easy when the mature trees have been removed. Progressive elimination of seed sources can be scheduled in relation to other weed control. As pines have a very distinctive colour, changing the entire appearance of the landscape, their removal should be a high priority.

### 4.4.9 Gums (*Eucalyptus botryoides* and *E. robusta*)

*Eucalyptus botryoides* (called southern mahogany or bangalay in Australia) comes from the southern half of coastal New South Wales, and coastal Victoria, where it often grows in beach dunes near the sea. It grows abundantly on poor sandy soils of coastal locations (Boland et al. 1984) as well as on swampy estuarine soils (Halliday & Watton 1989).

*Eucalyptus robusta* (known as swamp mahogany in Australia) grows in coastal sites from the tropic of Capricorn in Queensland and extends south to almost the Victorian border (Brooker & Kleinig 1996). *E. robusta* can grow in wetter sites than the related *E. botryoides*. It is found in coastal swamps and lagoons where soils are subject to flooding (Halliday & Watton 1989) as well as on clay soils.

#### *Distribution of gums in the wetland*

Both species are growing in the immediate vicinity of the wetland. *E. botryoides* is on the side of the road near the Kaurex site and juveniles have established downwind. *E. robusta* is present on private land at the south-east corner of Lake Waikaramu, where the presence of small size classes suggests that the species is naturalising.

#### *Weed status elsewhere*

*E. botryoides* is naturalised in North Auckland in scattered localities as far north as the Karikari Peninsula. *E. robusta* has not previously been reported as naturalised.

#### *Options for control*

Gums are easy to locate and can be treated similarly to radiata pine.

#### *Probability of re-establishment from nearby land following control*

These species have been used for timber or shelterbelts on nearby farms, and if they are planted near the reserve boundaries there is a strong possibility of their establishment in the wetland from wind-blown seed. Both species are adapted to thrive in the seasonally wet soils of the wetland and therefore have the potential to greatly expand their range into the wetland.

#### *Recommendation*

Seek the cooperation of neighbouring landowners to remove all gums likely to be a risk to the wetland.

### 4.4.10 Maritime pine (*Pinus pinaster*)

Maritime pine originates from the Mediterranean region

#### *Distribution near the wetland*

Maritime pine is found in the foredunes, but does not appear to have established on the dry ridges within the wetland. There appears to be no reason why it could not establish on the dry ridges and peaty sand flats of the wetland.

#### *Weed status elsewhere*

Maritime pine is a widespread weed in the fynbos of South Africa. It is found in many parts of Northland and has naturalised widely in New Zealand (Webb et al. 1988) especially on the coast, including coastal dunes.

### *Options for control*

This pine can be controlled by removal of seeding adults and by preventing seedlings from maturing.

### *Probability of re-establishment from nearby land following control*

Re-invasion of maritime pine from wind-blown seed is likely, but the risk can be reduced by ensuring that mature trees are removed from the boundaries of the wetland. This may require liaison with adjacent landowners if maritime pine is on contiguous properties.

## 4.5 GROUP 3 WEEDS: SPECIES WITH A RESTRICTED DISTRIBUTION IN THE WETLAND

**Pampas** is scattered in the foredunes, and is found scattered along dry ridges in the wetland. As it is one of the worst invaders of the west coast of Northland, it should be removed where practicable.

Neither **brush wattle** nor **black wattle** appears to be posing a threat to the wetland at present.

## 4.6 GROUP 4 WEEDS: SPECIES POSING POTENTIAL THREATS THOUGH NOT YET PRESENT

The *Plant Materials Handbook for Soil Conservation* (van Kraayenoord & Hathaway 1986) recommends several species for stabilising dunes, but these, if planted in the foredunes or wetland, are likely to become serious weeds. These species include:

- Coast banksia (*Banksia integrifolia*), which grows naturally in Eastern Australia south from latitude c. 25° in Queensland to the Victorian border. This species can grow on sand dunes just inland from the beach.
- Lilly pilly (*Acmena smithii*), which is widespread in the Northland region and will grow on a wide range of soils including sandy soils with some enrichment of humus. It can establish in low light conditions and compete with later-successsional stages of native vegetation.
- Coast tea tree (*Leptospermum laevigatum*). Coast tea tree is a problem weed in South Africa yet has been used in New Zealand to stabilise erosion sites. It is listed as naturalised in several localities in New Zealand and is widely naturalised in Western Australia (Wrigley & Fagg 1993). Other Australian leptospermums, such as *L. arachnoides* and *L. epacridoideum*, probably have the potential to invade the wetland if grown in gardens in New Zealand.
- Swamp she-oak (*Casuarina glauca*) is found in Eastern Australia in coastal locations south from southern Queensland to the Victoria border, where it grows mainly on drier soils with a high organic content that border swamps (Borland et al. 1984). It has been found naturalised in three locations in New Zealand.

- *Acacia sophorae*, sometimes regarded as a variety of *A. longifolia*, has been used by the Forest Research Institute in several coastal locations since 1992 for trials of nitrogen-fixing species as replacements for lupin. These trials include a site at Waipapakauri on the other side of the Aupouri Peninsula from the wetland. The plants in the Aupouri trial were removed in 1995 and 1996 (Dr C.T. Smith pers. comm). Trials of *A. sophorae* have also been made at several Bay of Plenty beaches but are now being removed by Environment Waikato. It is a major weed on the Wanganui–Manawatu coast, where it has been used for many years, and is being eradicated from Whitiau Scientific Reserve.
- Brush cherry (*Syzygium australe*) is a widespread species in Northland and is bird-dispersed. It may have a tendency to invade drier parts of the wetland.

Many Australian species are grown in gardens in Northland, including Houhora on the Aupouri Peninsula, just north of the wetland. Some have the potential to invade the wetland if they were given a foothold. These include: silky oak (*Grevillea robusta*), *Kunzea* spp., bottlebrushes including *Callistemon citrinus*, *C. linearis* and *C. linearifolius*, *Beaufortia* spp., and paperbarks (*Melaleuca*). *Melaleuca quinquinervia* is found naturally in wetland habitats in Australia that are very similar to Kaimaumau and has also become a serious weed in Florida (Wrigley & Fagg 1993).

## 4.7 GENERAL RECOMMENDATIONS: WEEDS

It is essential that coordination is established between the Department of Conservation and land-controlling authorities to ensure that potential weeds are not spread by one organisation, later to be controlled by another. In particular, there needs to be regular liaison between DOC and other agencies such as the Forest Research Institute and the Northland Regional Council about the weed potential of species undergoing trials for revegetation work in the Far North. Regional councils are responsible for both erosion control using introduced species, and for the control of weeds. There are no fewer than 24 species listed by Clunie (unpubl. report to DOC 1995) as ‘significant environmental weeds’ in the Auckland Conservancy that are also listed in *Plant Materials Handbook for Soil Conservation* (van Kraayenoord & Hathaway 1986). The same handbook also lists brush wattle, black wattle, Sydney golden wattle, prickly Moses, maritime pine and pampas as suitable plants for soil conservation work; a few of these are suitable for revegetation of eroded farmland, but all are invasive and so should not be used in proximity to conservation reserves.

### 4.7.1 Public access and the spread of weeds

Species with small seeds such as bottlebrush, gums, leptospermums, kunzeas, or species with hard seeds such as broom, gorse, Sydney golden wattle, or other wattles, can easily be re-introduced to the wetland on vehicles, earthmoving machinery or rotary scrub cutters. Care must be taken to ensure that weeds are not spread in this way. Small patches of weeds that are not widely distributed should not be left near tracks where they are likely to be further carried by vehicles. During our survey we located three plants, growing close together, of *Sarracenia flava,* a pitcher plant native to south-eastern USA. From the location of these plants in the wetland, it seems likely that they had been deliberately introduced.

### 4.7.2 Re-locating sites in the wetland

The 1993 colour aerial photographs of the wetland and its surrounds could be enlarged at least five times without undue loss of definition. This would provide a satisfactory base map for recording the positions of weed infestations and thus increase the effectiveness of follow-up spraying or seedling removal. Although weed infestations can be pinpointed by bearings taken from several higher points along Lake Road or other prominent positions, the use of GPS technology should be investigated. The open vegetation of Kaimaumau would make location by GPS relatively easy to use.

# 5. Threatened plants

## 5.1 SPECIES THAT ARE THREATENED

At least 12 species of uncommon plants have been recorded from the Kaimaumau district, and some of these are threatened. They include two lycopods or club mosses, three species of ferns, eight species of orchid, and a small herb. The taxonomic status of several of these plants is not resolved. Whatever their taxonomic rank may be, it seems wise to take all practical means to safeguard their Kaimaumau populations in the interests of maintaining genetic diversity. In the following discussion of each species, taxonomic status and criteria used for assessing degree of threat follow those of de Lange et al. (1999).

***Phylloglossum drummondii***

Endangered. This tiny plant has been recorded by McRae, D.P. (unpubl. 1987) within wattle forest at Kaimaumau. It is doubtful how long it could persist in such a habitat given that it is usually found in recently burnt or other bared areas, in very short turf, or in open manuka shrubland. Wilson & Given (1989) comment that the colony of this plant at Lake Ohia, on the Karikari Peninsula, had ‘recently suffered severe browsing by insects or snails’.

***Lycopodiella serpentina* (= *Lycopodium serpentinum*)**

Vulnerable, i.e. ‘believed likely to move into the endangered category in the near future if the causal factors continue operating’ (de Lange et al. 1999). It was found at Kaimaumau by Elliott et al. (1983) in bog vegetation associated with ‘very wet, flat areas’ located ‘between the foredunes and the second sandstone ridge’. It is also mentioned by Wardle & Clunie (unpubl. 1982) although apparently not seen by them.

### *Cyclosorus interruptus*

Declining. We found this species locally abundant in the western part of the wetland and it is apparently not threatened at Kaimaumau at present (cf. Clunie 1988).

### *Thelypteris confluens*

Vulnerable. As with the previous species, it is locally abundant in the western part of the wetland and is apparently not threatened at Kaimaumau at present (cf. Clunie 1988).

### *Todea barbara*

Vulnerable. This fern occurs sporadically in the northern part of Northland, sometimes in gullies, but more usually in open habitats. Bartlett (1980) records 'a single depauperate plant...on the roadside east of the airstrip near Lake Waikaramu'. We found three *T. barbara* plants, two of them (with crown diameters of 0.5 and 1 m) growing together close to a track in the eastern part of the Waihuahua catchment. The surrounding vegetation was bracken and *Schoenus brevifolius,* one metre in height and clearly post-1988 in age. The third plant, in similar post-1988 vegetation, was at least 100 m further along the same track if travelling towards East Beach.

### *Calochilus* aff. *herbaceus* (CHR 65825; Kaimaumau)

Taxonomically indeterminate but considered to be critically endangered. This taxon was discovered by H.B. Matthews in 1924 and rediscovered by J. and M. Perry in the 'orchid block' in 1986 (McRae, D.P. unpubl. 1987). He records that 'only 7 plants were found' at that time. No information is available concerning its ecological requirements.

### *Corybas carsei*

Critically endangered. This species was recorded by Bartlett (1980) (as *C. unguiculatus*) from the Ahipara gumfield plateau. He states that this species was originally recorded 'from peaty swamps bordering Lake Tongonge near Kaitaia, an area long since drained'. Wilson & Given (1989) state that 'it is presently known from a few sites between Kaimaumau and Warkworth. It was found by McRae, D.P. (unpubl. 1987) in the 'orchid block' but he gave no details of its particular habitat. Elsewhere it is recorded from 'peaty swamps' as well as secondary forest and scrub.

### *Cryptostylis subulata*

Range restricted; not considered under any immediate threat in New Zealand or in its source country, Australia. This orchid was encountered in tall *Schoenus brevifolius* sedgeland of sites with high water table, in small damp openings of manuka–*S. brevifolius* shrubland, and in drier parts of the wetland such as along track margins. It is also present in the manuka scrub owned by Mrs B. Hoggard at Kaimaumau settlement. She remarked that 'it has increased greatly in the last two years' (pers. comm. 11 Feb 97). In the Kaimaumau area its numbers have reached a level such that it cannot be regarded as threatened.

### *Thelymitra malvina*

Range restricted. It is not considered threatened outside New Zealand (de Lange et al. 1999). Typically it grows on old kauri stumps where it may use mycorrhizal fungi to break down organic matter. If this is the only kind of micro-site where this orchid grows, it may be necessary to augment the number of kauri logs currently available in the Kaimaumau area. Searches are needed to establish the particular kinds of micro-site where *T. malvina* grows, especially a search of the kauri stumps on the bed of Lake Waikaramu.

### *Thelymitra* sp.

This is an 'undescribed' species recorded from Kaimaumau by McRae (1987) as a pers. comm. from Dr B.P.J. Molloy. We have no information on either its taxonomic status or ecological requirements.

### *Thelymitra* (a) (WELT 79140; Ahipara)

Taxonomically indeterminate but regarded as endangered. Although recorded from Kaimaumau, the exact locality is not known (L. Forester, pers. comm.) and no further information is available.

### *Spiranthes* aff. *novae-zelandiae* (CHR 518297; Motutangi)

An insufficiently known and taxonomically indeterminate form. The writers saw it growing with *C. subulata* in high water table *Schoenus brevifolius* sedgeland in the Motutangi catchment within the Scientific Reserve. We estimated that more than 30 individuals were present and some were in flower (7 Feb 97). It has also been found beside Lake Road and in Block 5 near 'Land's End'.

### *Pterostylis tasmanica*

Declining. This taxon has also been referred to as *P. plumosa* and *P. barbata.* It was recorded in the 'orchid block' by McRae, D.P. (unpubl. 1987) and was seen in the recently burnt Otiaia Swamp in 1983 (C. Ogle, pers. comm.).

### *Utricularia delicatula*

Although this is an endemic taxon (Webb & Sykes 1997) its conservation status is unclear. It was found at Kaimaumau by Elliott et al. (unpubl. 1983) in 'wet bog' areas similar to the conditions in which they found *L. serpentina*. They suggested that this population might be the largest remaining in the country.

## 5.2 DISCUSSION

Our observations of these plants were limited by the fact that our main field trips were at the wrong time of the year for finding many species of orchid as well as *Phylloglossum drumondii.* So little is known about the ecological requirements of many of the taxa listed above that it is difficult to identify factors that may affect their survival. Most of them are associated with habitats that are disturbed periodically, particularly by fire. Some are associated with the poor aeration and low fertility of wetland environments. Neither fire *per se* nor flooding can be considered as threats to populations of these plants even though individual plants will be destroyed by particular fires or prolonged rises in watertable. Prior to the 1988 fire, Mrs B. Hoggard's stand of open manuka scrub was considered a good habitat for orchids, and nine years after the fire, it was apparent that its value as an orchid habitat was still very high.

Reducing the frequency of fires may result in less favourable habitat for some orchid species and, in the long term, constitute a threat to their survival. However, when fires promote the further spread of woody weeds such as Sydney golden wattle, habitat conditions become so altered that recovery of small plants such as orchids may no longer be possible.

The privately owned 'orchid block' (Lot 16, S.O. 64251) described by McRae (1987) was clearly rich in orchids at the time of his visits. This was at least 14 years ago, before the 1988 fire, and it is possible that subsequent increases in wattle have reduced the value of this area as an orchid habitat. The deep litter formed under Sydney golden wattle excludes almost all plants; it is not known how long orchid corms can survive in such an environment. Systematic searches at the appropriate time of the year would be necessary to establish the current distribution and abundance of orchid species now present.

Long-term monitoring of systematic trials is essential if the effect of fires on the distribution and abundance of threatened species in wetlands is to be clarified. We recommend that the Department identify three matched (as similar as possible) pairs of sites that include scrub, shrubland or open habitats known to be important as habitats for threatened species. 'Importance' can be measured in terms of either the number of orchid species present or the number of individuals of any one threatened plant species. After monitoring all sites for three years, one site of each pair can be burnt and monitoring continued on all sites for a further three years. It should be borne in mind that successional changes may make any of the selected sites less favourable for orchids in the future. Each site can be plotted on a large-scale aerial photograph or map and located by GPS for ease of refinding.

Without regular monitoring of individual marked plants we cannot identify factors that are threatening them and thus identify appropriate remedial actions. For example, the browsing effects of rabbits or hares on small plants such as orchids and *Phylloglossum* are unknown because a single browse event can completely remove the plant, leaving no evidence of what happened. Trials on one or two of these sites, comparing the fate of caged with uncaged groups of orchids, would help to determine whether rabbits or hares are having significant adverse effects on orchids at Kaimaumau.

The taxa most in need of monitoring are *Phylloglossum drummondii, Lycopodiella serpentina,* the three *Thelymitra* taxa, and remaining taxa of *Calochilus, Corybas, Spiranthes, Pterostylis,* and *Utricularia. Todea barbara* has an erratic distribution throughout its New Zealand range and there may therefore be less to learn from a concentrated monitoring of the individuals present at Kaimaumau.

Once the essential habitat characteristics for each of these threatened plants have been identified, it will be possible to relate these habitats to the prevailing long-term trends in succession (Section 6). Particular actions, such as localised controlled burning, may be needed to maintain, and if possible increase, the population sizes of these threatened species into the future (see Section 10.1).

The future of Lake Ohia as a habitat for threatened plant species is a least partly dependent on restoring seasonal water levels (by means of the weir). However, when this is done, it should not be seen as a reason for not maintaining similar habitats in suitable parts of Kaimaumau, particularly the margins of Lake Waikaramu.

# 6. Long-term changes in the vegetation

McQueen & Forester (2000) recorded successional trends in peat bog vegetation of Kaimaumau for ten years following the 1988 fire. They used step-point analysis to record plant cover in each of seven plots. No soil information is provided but the vegetation sampled (up to 4 m tall) indicates that four plots were on deep peats, two were on sandy peats or peaty sands, and one was on a dune site (cf. Section 3.1.3 of this study). They found that the peat bog vegetation (on deep peats) recovered quickly and had reached pre-fire composition within ten years. *Schoenus brevifolius*, bracken and *Gleichenia dicarpa* all recovered quickly from rhizomes. Prickly hakea also established quickly from 'vast quantities' of seed released by the fire. Manuka established more slowly from seed. Sydney golden wattle and gorse established quickly where they were present before the fire. If not present originally on a site, these species were slower to establish. Wherever they established, wattle and gorse became dominant, replacing the succession towards manuka or kanuka scrub. They concluded that wattle and prickly hakea had expanded their ranges following the fire and that these species would re-establish if burnt again.

Prior to invasion by woody weeds, stands of mixed kanuka and manuka probably grew on the better drained ridges. Although at present there is no evidence of kauri more recent than 30 000 years B.P., kanuka/manuka stands in the past, if not burnt, would have changed to forest probably containing kauri, tanekaha and native hardwood species. Since the arrival of humans, continued clearing of forest in the surrounding countryside has gradually increased the distances to seed sources of native trees. Seeds of kanuka and manuka are readily dispersed by wind, and this may be one reason why they have persisted at Kaimaumau. Kanuka is longer-lived than manuka but sheds its seeds seasonally when the capsules mature. Manuka retains some capsules on the plant that open to release seed when the stand is burnt. Thus repeated burning usually reduces the proportion of kanuka relative to that of manuka.

The frequency of fires at Kaimaumau is almost certainly now greater than that of prehuman times when lightning was the only cause. Fire frequency would have increased after arrival of Maori and then increased still further with European settlement. There is, however, no reason to think that fires changed the botanical composition of the Kaimaumau sedgelands and rushlands in any fundamental way until after the arrival of woody weeds.

Since woody weeds first invaded the wetland, fire-adapted alien trees and shrubs, usually with greater seed outputs than natives, have become dominant over large parts of Kaimaumau. Each successive fire has enabled gorse, hakea, wattles and other weeds to increase at the expense of native species. Prickly hakea, gorse and broom are likely to have been present in the area by the latter part of the nineteenth century (cf. Allan 1940). The most significant of the more recent invaders, both in and around the wetland, is Sydney golden wattle. There was apparently no wattle in the vicinity of Kaimaumau in 1940, but it has spread widely through the area during the last 20 to 30 years (B. Hoggard, pers. comm. 11 Feb 1997). Reliable information is lacking for bottlebrush, downy hakea, prickly Moses, oxylobium, black wattle and brush wattle but they are likely to have spread during the same period. Although none of these species has spread to the same extent as Sydney golden wattle, all should be closely monitored to determine the level of control that is needed.

Sydney golden wattle has spread extensively along the fossil dune ridges that traverse the length of the wetland, establishing with and then overtopping bracken, gorse, and manuka- and kanuka-dominated communities. The very dense stands of wattle are found where there were scattered plants prior to the 1988 fire, and vegetation that now contains few wattle plants appears to have been invaded by wattle shortly after the 1988 fire. Whether this invading wattle originated entirely from seed already present prior to the fire, or whether seed from post-fire wattles has contributed to this invasion is unclear. If the former, it implies that preventing fires will have a very major effect in reducing further spread of wattle.

The present vegetation of the ridges is now a mosaic of communities, some still without wattle and others showing all stages of replacement by wattle. This replacement usually culminates in dense stands of wattle 10–15 metres high (rarely up to 20 m) with litter layers 5–10 cm in depth. There is almost no regeneration of native or alien species, including the wattle, in these stands.

Two exceptions to this general trend were noted. Along roads traversing the fossil dune ridges there are patches of soil beside the road where a shallow A horizon of loamy fine sand, 0–8 cm in depth, overlies the cemented sandstone hardpan. Such soils, possibly the result of bulldozing, support small stands of stunted kanuka, 3–4.5 m tall, and wattle is absent. Some of these stands originated before the 1988 fire and include several native species such as *Cladonia* lichens and *Leucopogon fasciculatus.* Apparently the wattle cannot establish where the hardpan is at or close to the surface.

A second exception can be found on the north-east side of Lake Waikaramu where there are stands of closed-canopy kanuka 8–10 m high. These trees established well before the 1988 fire with a mixture of prickly hakea and gorse, suppressed individuals of which still remain. Several large trees of black wattle (40–50 cm dbh × 10–11 m high) apparently established with the kanuka. There are no black wattle seedlings to be found anywhere within this stand or its vicinity. More significantly, even though numerous seedlings of Sydney golden wattle are present on and beside the roads passing through the kanuka stand, not a single wattle seedling could be found within it. Similar though smaller stands are present on the western shore of Lake Waikaramu and also scattered around the shores of seasonal lakes to the east.

# 7. Wattle control

## 7.1 OPTIONS AVAILABLE

If nothing is done to curtail the spread of Sydney golden wattle, it is likely to dominate most, if not all, of the old foredune and lakeside ridges (where the soils are sands and peaty sands). To what extent this tree will spread into the wetter sandy peat soils of the wetland itself is still unclear. In any case, the ‘do-nothing’ option will not help the Kaimaumau reserve. Several options remain: cutting, ringbarking, controlled burning, spraying, or some form of biological control. As pointed out by Macdonald et al. (1989), the first four of these options, when applied as single operations to a tree such as wattle, can create light gaps that are quickly filled by seedlings germinating from the vast store of viable seed in the soil (see wattle biology, Section 4.3.2). However, these methods could be applied in combination. Cutting or burning, together with chemical control of seedlings, can reduce the stock of seed in the seedbank, and enable follow-up spraying to control wattle over limited areas (Pieterse & Cairns 1986).

An important general principle in attempting the control of a problem weed is to remove outlier or satellite infestations before tackling the larger stands (Moodie & Mack 1988). At Kaimaumau there are many seed sources of Sydney golden wattle outside the wetland, and these have resulted in an increasing number of outliers within the wetland. We suggest that trials are made to determine whether cost-effective methods can be found for removing these outliers, as well as dense stands of wattle, and replacing them with native trees. We further suggest that some of these trials are developed in association with new firebreaks and waterholes (see fire contingency plan, Sections 10.3, 10.4). All trials should be accurately costed so that comparisons can be made with the cost of developing a method for biological control of wattle. The two approaches should not be seen as mutually exclusive: most biological controls are only partly successful so that there will probably always be a need to use them in conjunction with other methods.

## 7.2 WATTLE CONTROL TRIALS

### *Wattle outliers on sandy peat flats*

Outliers of Sydney golden wattle are present throughout the wetland and on the foredunes behind East Beach. The aim of this trial is to find a feasible method of limiting further spread of Sydney golden wattle. A suitable site can probably be found at the Motutangi end of the Norton Road–Lake Road link track. Scattered wattles appear to be invading prickly hakea–manuka shrubland in this part of the wetland. They are also invading the foredunes between East Beach and the wetland.

The trial should involve: (1) cutting the wattles (paint with herbicide if resprouting proves to be a problem); (2) plotting the locations of the treated trees (using GPS where necessary); (3) checking treated areas annually and recording newly established seedlings of all tree species; (4) weeding out any wattle or other alien tree species among the seedlings; and (5) recording the total time taken for the operation to facilitate later budgeting.

### *Wattle at low density*

These stands are in scrub or forest (not less than 3 m in height) of mixed composition. They may include kanuka, manuka and any exotic species. This trial is designed to identify conditions where wattle at low density can be replaced by native trees without felling the wattle and making large light gaps.

The trial should involve: (1) selecting individual wattle trees that are either showing signs of loss of vigour (thinning or partial collapse of the crown) or, when killed, will not leave a large light gap; (2) ring-barking and painting the tree; (3) recording newly established seedlings of all tree species; (4) weeding out any wattle or other alien tree species; and (5) recording the time taken. We suggest two treatments: (a) removing all wattle seedlings annually, and (b) planting with well-grown (>1 m) native trees (kanuka, kauri and tanekaha) and removing wattle seedlings annually. As the plantings will require watering during the first two summers, this treatment should be located near waterholes of where it can be sprayed with fire hoses.

### *Wattle at high density*

These trials will need to be undertaken on conservation land. The most efficient approach would be to create a new firebreak that passes through a dense stand of wattle. A suitable strip (Kaikino sands on lake-margin dunes) lies between 332999 and 335990 (Map 004, NZMS 260). This area is suggested as suitable for a firebreak because it is aligned approximately north-south and could therefore prevent fires from travelling from the wetland to Kaimaumau settlement, or vice versa, as well as providing access to the Otiaia wetland. This trial should be conducted in two phases:

Phase 1. Removal of wattle seed from the seed bank. The aim in this part of the trial is to find out how many years are needed to remove nearly all wattle seed from the soil bank. The firebreak itself should be at least 100 m wide and would necessitate bulldozing and crushing all wattle and other vegetation. The trial would require a widening of the firebreak to at least 200 m for a distance of 200 m, thus providing a cleared area of approximately two hectares on one side of the firebreak. In South Africa, burning has been shown to kill 90% of the seed in the seed bank (Section 4.3.2). To reduce fire risk, all trees and litter would be pushed into heaps and left for c. 12 months until the fine material has broken down and the heaps are safe to burn in suitable weather. If burning the heaps is still not feasible, seedlings in the heaps would have to be killed by spraying: the seedling crop may well include gorse and other weeds. In a zone at least 100 m beyond the margin of the trial area, any seeding wattle should be cut down and left to rot so that seed from external sources is not added to the soil seed bank in the trial area.

In year one the entire trial area would be disked to scarify the soil and encourage germination. In the second year the trial would be divided in two, with half the area again being disked to kill seedlings and bring more seed to the soil surface, while seed in the other half of the trial would be left in situ and seedlings treated with chemical herbicide or desiccant. If there were danger of a herbicide reaching the water table to cause problems for plants or wildlife, possible alternatives are steam treatment of seedlings or use of a knapsack flamethrower. In year three (and four?), the activities for year two would be repeated. It is essential that the vegetation of the trial area is sampled annually to record the decline in wattle seedlings.

Phase 2. This part of the trial is aimed at testing methods of establishing native vegetation on bare ground. This phase would not be initiated until the numbers of wattle seedlings had dropped to a level at which those remaining could be removed by hand-pulling or spot spraying. Then the area would be seeded with manuka slash, kanuka, kumarahou and other native species suitable for the sandy soil. Any residual wattle seedlings that established would require spot spraying or hand pulling.

### *Glasshouse experiment to test inhibiting effect of litter*

This experiment would be used to test whether pine or kauri litter has an inhibiting effect on the growth of Sydney golden wattle seedlings in (a) full light and (b) partial shade conditions. Positive responses from this experiment would justify a field trial.

A trial would involve: (1) spreading pine litter beneath mature or ring-barked wattle trees to prevent a second cycle of wattle from developing, and (2) a long-term programme of planting (and in the early years managing) kauri in mature wattle. Pine litter and/or bark would be added to part of the trial to determine whether kauri, through its production of acid litter, could replace the wattle.

Trial work, and more extensive restoration planting, is labour-intensive. Thus it would be essential to ensure that the treated areas were protected by adequate fire-breaks to reduce the risk of burning a trial plot.

If any way can be found of creating conditions in which native trees can compete effectively with Sydney golden wattle, it would itself be a form of biological control. If, in addition, the competitive ability of the wattle can be weakened through introduction of a species-specific biological control agent, as in South Africa, there is the prospect of one day reducing the influence of this alien at Kaimaumau.

# 8. Introduced mammals

Cattle, pigs, goats, red deer (escapes from a nearby farm), possums, rabbits, hares, hedgehogs, Norway and ship rats, house mice, cats, stoats, weasels and ferrets have all been recorded from the immediate vicinity of the Kaimaumau wetland if not the wetland itself. No attempt was made in this study to assess their numbers or measure their impact, but some points can be made.

Cattle were grazed in the wetland in the past. Pigs have been found in the wetland in a few places at the Motutangi end and in the foredunes, and they have been reported from the vicinity of Lake Waikaramu.

Goats, deer and possums have apparently had no impact on the wetland; high water tables, the lack of high-quality food and, in the case of possums, the lack of denning sites, are all factors tending to make Kaimaumau unsuitable for these animals.

The browsing effects of rabbits, hares and rats on plants in the wetland are unknown but they could be significant for some orchids (see Section 5).

Predation by rats, stoats, weasels, ferrets, and possibly hedgehogs, are together likely to be having some effect on the breeding success of wetland birds such as fernbird, bittern, banded rail, spotless crake, and brown quail.

# 9. Animals of conservation value

The invertebrate fauna of Kaimaumau is apparently quite unstudied. Among the vertebrates, the black mudfish, Northland green gecko, bittern and fernbird have particular conservation value.

The black mudfish (*Neochanna diversus*) is regarded as a Category C threatened species (Molloy & Davis 1994). They are difficult to detect in the seasonally wet habitats where they live, even with electric fishing equipment. Any permanent rise in water levels within the wetland would probably impact adversely on mudfish unless new seasonally wet habitats were created by the rise in water level.

Eight other species of fish were recorded at Kaimaumau by BioResearches (unpubl. report to Kauri Deposits Surveys 1982). These included the giant bully (*Gobiomorphus gobioides*) and the introduced mosquito fish (*Gambusia affinis*). There has been concern about a possible negative interaction between mosquito fish and mudfish.

In an unpublished MSc study of mudfish in the Waikato region, R. Barrier found that the seasonally wet habitat of the mudfish separated it ecologically from the permanently inundated habitat of the mosquito fish. Assuming this separation operates at Kaimaumau, any permanent rise in water level would increase habitat for mosquito fish at the expense of mudfish.

The Northland green gecko (*Naultinus grayii*) is an endemic gecko restricted to northern Northland. Its ‘stronghold’ is considered to be the Kaimaumau wetland.

Of the birds recorded from the wetland, those of significant conservation value are the Australasian bittern (*Botaurus poiciloptilus*) and the fernbird (*Bowdleria punctata vealeae*). Both species appear to have re-colonised the wetland successfully following the 1988 fire.

However, little is known about either the effects of repeated burning of the wetland or the invasion of alien plants on native wildlife.

# 10. Fire hazard and access for fire control

We do not know the pre-human frequency of fires, or of fires subsequent to Maori settlement. Older residents recollect that fires were an annual event during the main period of gum-digging between 1910 and 1940 (Evans l969, Wagener l989). Since 1940, fires have been less frequent, whether accidentally spread from scrub burns on adjacent farms, or deliberately lit to 'improve' access. Mrs B. Hoggard, whose family has farmed at Kaimaumau since 1940, recalls four fires that burnt through most of the wetland: the first in the 1940s (exact date uncertain), a second in 1959, a third about 1978, and the fourth in 1988. The apparent contradiction of a fire-susceptible wetland is explained by seasonal water table fluctuations where parts of the wetland dry out during summer months (Section 3).

Most native plants of the Kaimaumau wetland are adapted to fire and many rely on periodic fires for their regeneration (Section 6). Since the 1940s, however, several fire-resistant weeds have spread through the wetland, and with each successive fire their spread is accelerated. Until the seed output of these weeds is substantially reduced, ***all measures should be taken to prevent uncontrolled fires***.

Each fire has been followed by dense regrowth of scrub; the germination of both native and exotic species being promoted by fire. This regrowth creates a stock of fuel (plant litter as well as standing wood) for the next fire. If controlled burning of scrub is practical, it could reduce the overall fuel load. Practised in different parts of the wetland in different years, this would decrease the risk of a major conflagration spreading throughout. If such action was feasible, it might break the fire cycle, but the question remains of whether controlled burning could be carried out without increasing the rate of spread of woody weeds such as wattle, gorse, hakea, oxylobium and bottlebrush.

Since the 1988 fire, which burned over 90% of the wetland, DOC's Kaitaia Field Centre has maintained firebreaks by mechanically slashing annual regrowth, and has dug several waterholes alongside tracks so that water can be pumped into hosepipes or scooped up with monsoon buckets. A small stock of fire-retardant chemical is held at the Field Centre. Prompt responses to several fire outbreaks (the most recent being March l997 adjacent to the Kaimaumau Road and May 1997 in a rubbish dump) have prevented their spread.

Although these efforts have been effective, the fuel load at Kaimaumau has continued to increase, thus making another major fire more likely. Exact needs, costs and contingency procedures for fire-fighting do not appear to have been consolidated in a single document. This makes it difficult for Field Centre staff to obtain resources for fire control when faced with Conservancy constraints. In this section we discuss different approaches to fire control in terms of their advantages and disadvantages for breaking the fire cycle, as much as for extinguishing fires as they occur.

## 10.1 CONTROLLED BURNING

Reasons that can be advanced for use of controlled burning are: (i) to break the cycle of repeated widespread fires (see above), (ii) as a method of woody weed control, and (iii) to maintain native communities (or particular plant species within those communities) that depend on periodic fires for their survival.

Controlled burning is an accepted practice for fire hazard reduction in acacia shrublands in Australia. But that is in an environment where native invertebrate predators of acacia and hakea seed are present. At least three fire-adapted woody weed species are now widespread at Kaimaumau and all the evidence shows that their spread is accelerated by fires. These weeds, through their dense regrowth after a fire, have displaced native species on the dry sand ridges and seasonally dry peaty sands. There is the additional problem that unless burns coincide with times of year when water levels are high, fires will spread downward from vegetation into underlying peat or sandy peat. Once in the peat, fires are liable to smoulder for weeks, with risk of repeated outbreaks. In 1975 one of the authors (DLH) witnessed what was intended as a controlled burn, for land development in the Tangonge Swamp, turn into a subsurface peat fire that lasted for seven weeks. On balance, the case for using controlled burning as a method of breaking the fire cycle at Kaimaumau is not realistic.

Pieterse & Cairns (1986), working with *Acacia longifolia* in South Africa, where this species is also a weed, showed that an intense fire could reduce the number of viable wattle seeds in the seed bank to 8% of the original number. Remaining viable seeds, however, were still sufficient to produce dense even-aged stands of wattle seedlings (Pieterse & Cairns 1988b).

Use of herbicide to eliminate post-fire seedlings can control wattle in limited areas (see Section 4.3.2) but herbicides are expensive and non-selective. In any case, the burning of wattle stands to control this species at Kaimaumau would be rendered ineffective by the proximity of a significant seed source in the remaining unburnt wattle stands. As pointed out earlier (Section 4.3), biological control appears to be the best hope for effective control of weeds such as Sydney golden wattle.

The study of McQueen & Forester (2000) confirms that many native wetland plant communities at Kaimaumau are fire-adapted; recovery from rhizomes or seed that survive the fire is relatively rapid, and occasional fires are probably needed to maintain the character of these communities. Examples are manuka shrubland on dry sand ridges, and stunted scrub and sedgeland dominated by manuka, *Leucopogon, Baumea* or *Schoenus* on seasonally dry peaty sand. Other wetland communities, such as *Baumea–Schoenus* sedgeland on sandy peat and *Baumea–Schoenus–Typha* sedgeland on deep peat, are fire-adapted in the sense that fires can burn through exposed sedges but recovery is effected quickly by sprouting from below water level.

There is evidence that some orchid species are most likely to establish on recently burnt sites on sandy peat soils (e.g. McRae 1987). Controlled burns may therefore be a useful method of maintaining habitats for some orchid species or other endangered plants such as *Phylloglossum drummondii*, provided that woody weeds are excluded.

Thus, although the use of fire for either reducing fire hazard or controlling weeds appears to be impractical at Kaimaumau, a case can be made for tightly controlled burning of small areas of particular wetland communities, especially if such action provides additional habitats for endangered species. Its success would depend on selecting sites distant from dense concentrations of woody weeds, burning when water tables were relatively high, and then weeding the burnt areas for seedlings of problem weeds.

## 10.2 EASE OF ACCESS

All-weather vehicle tracks, including alternative exits, are essential for safe entry and rapid evacuation of firefighters. A good network of vehicle tracks also facilitates laying out hoses, carting pumps to water sources, and servicing helicopters. The more tracks, the greater the chance that a fire can be reached and brought under control before it spreads.

Vehicle tracks increase public access and thus the risk of accidental or intentional fires starting inside conservation land. This must be traded off against the greater ease with which firefighters can reach such fires.

Tracks entail some habitat disturbance. This must also be traded off against the reduced risk of habitat disturbance by fire on a much greater area of land.

## 10.3 FIREBREAKS

The existing firebreaks give ready access to the southern half of the wetland for firefighting. They may be wide enough to act as barriers to the spread of minor fires at ground level, although in 1997 there was slash on the ground and some regrowth.

There are not enough firebreaks running north–south across the wetland to prevent a major conflagration from spreading. Three firebreaks run north–south across the coastal foredunes, but these are becoming overgrown. Scrub on these foredunes is a likely external source for fire to spread into the wetland. There is a particular risk that this scrub will be intentionally fired from time to time to ‘improve’ access by marijuana cultivators crossing from East Beach.

The existing firebreaks do not appear wide enough to act as barriers to fire spreading at canopy level. Widening them to perhaps 50–100 m would entail substantial habitat disturbance and would still not protect against fire spread by wind-blown sparks.

Firebreaks, through improving public access, may increase the risk of accidental or intentional burning.

## 10.4 WATERHOLES

The existing waterholes provide water for firefighting close to tracks where helicopters can be landed, hoses laid out, and firefighters transported quickly. However, more waterholes are needed, preferably at spacings of about 4 km to give a 2 km operating radius for a helicopter with a monsoon bucket.

The present waterholes are fairly small excavations in peat that go down to the underlying sand hardpan. When the water table is above the peat, water will drain into them as fast as it is pumped or scooped out. If the water table is below the peat, the holes could be emptied by a pump or monsoon bucket faster than they would refill.

## 10.5 OTHER WATER SOURCES

The wetlands have several natural water sources which could be used for firefighting: Lake Waikaramu, the small lakes north and east of Waikaramu, and ponds on permanently waterlogged deep peat in the northern half of the wetland. Few of the natural water bodies in the wetland have track access, which is absolutely essential for fast entry and rapid evacuation by firefighters.

Some of the ponds in the north of the wetland could be accessed by constructing a track along the landward edge of the coastal foredunes, where there is a low-angle, dry sand slope between the dunes and the peat.

Seasonal lakes (Waikaramu and its neighbours) would be a reliable source of water except in dry summers when the water table drops below their bed. Track access and helicopter pads could be installed near the lakes, by short branch tracks off Lake Road and the airstrip track.

Outside the wetland, there are two perennial lakes—Waiparera to the west and Rotokawau to the east—which offer unlimited water for firefighting.

Groundwater bores to the artesian water table, though expensive, would be another way to obtain water for firefighting. Flow rates in bores to the west, used for irrigation, range from 230 000 to 114 000 litres an hour. The lower rates might not be sufficient to replenish a monsoon bucket every few minutes. Drilling costs $100 a metre, and the deep aquifer is at a depth of c. 60 m.

## 10.6 OTHER APPROACHES TO THE CONTROL OF FIRE HAZARD

Fixed-wing aircraft such as topdressers can be modified to dump water on fires, and at least one such modified aircraft is commercially available in New Zealand. Such an aircraft could be operated from the former Kaurex airstrip if tall wattle scrub is cleared from around it. Water could be piped to the strip some 500 m from the waterhole on the Lake Waikaramu outlet drain. This waterhole is gravity-fed by water flowing down the drain from the lake and offers a good supply source as long as the water table does not drop below the lake bed in a dry summer.

Kaimaumau, if considered in isolation, would not justify a commercial operator placing such an aircraft in the district. However, Juken Nissho has firefighting requirements for some 25 000 hectares of pine forest immediately to the west, as well as several other forest blocks in the hills between Kaitaia and Mangonui. Given that the Northland Regional Council also has responsibilities for fire control, cooperative purchase of a firefighting aircraft, to be operated under contract by a local commercial pilot, could be worth investigating.

Partly drained wetland south of the Lake Road boundary, on properties owned by Messrs Vuksich and Radojkovich, is presently under dense wattle scrub from which fires could spread. Again, frequent public use of this land for hunting, illicit cannabis cultivation, kauri gum fossicking, etc., increases the risk of accidental or intentional fire. Development into pasture, which is much less likely to carry a fire, would improve protection of the less-modified wetlands under DOC's stewardship north of the Lake Road boundary.

The preceding comments also apply to a small area of disturbed wetland, currently designated as Conservation Area, between the Aspin drain and State Highway 1 at Motutangi.

We have no information on whether the use of the fire-retardant 'Firetrol', when sprayed on vegetation, would adversely affect the growth of native plants. It consists mainly of ammonium phosphate, which, because of its solubility, may contribute undesirable amounts of nitrogen to the wetland. A trial application along a firebreak could be monitored to determine its effects and perhaps also its effectiveness. Similarly, a trial application of Class A firefighting foam would provide an opportunity to measure its effects on wetland vegetation.

## 10.7 SUMMARY OF FIRE HAZARD CONTROL

The Kaitaia Field Centre has successfully contained minor outbreaks of fire since 1989, but will have difficulty containing a major outbreak in dry conditions. An effective fire contingency plan, i.e. one which has the necessary resources financed and in place ***before*** a fire, is advisable. The plan could include:

(1) Enough all-weather vehicle access tracks for DOC staff and firefighters to respond quickly. This may entail opening tracks along proposed roads at the western (Motutangi) and eastern (Otiaia) ends of the wetland, to supplement the present circuitous access routes (Norton Road–Terrible Ridge–Airstrip Road, Vuksich Race–Norton Road–Lake Road, Radojkovich Race-–ake Road).

(2)Vehicle access and helicopter landing pads at water sources spaced close enough for a helicopter to cover the wetland in 2 km operating circles. Reliable water sources are likely to be two permanent lakes (Waiparera and Rotokawau) outside conservation land, a small permanent lake north of Waikaramu, and ponds in the northern wetland close to the coastal foredunes. Less reliable sources, probably still worth accessing, are Lake Waikaramu, the unnamed seasonal lakes east of Waikaramu, and waterholes dug in peat alongside access tracks. The Selwyn and Aspin Drains, and also the Motutangi

Stream, could be used as reliable water sources at the wetland's north-west end.

(3) Adequate stocks, on the spot, of pipes, pumps and generators, fire-retardant chemicals, protective clothing, and breathing equipment.

Land development on partly drained wetland in private ownership south of Lake Road could improve fire control. This would remove one of the major external fire sources and contribute towards fire protection in the less-modified wetlands under DOC's stewardship north of Lake Road. Provided that the owners undertake drainage and scrub clearance in ways that do not impinge on the Scientific Reserve and Conservation Area, DOC could support and encourage these activities on private land.

Some of the present firebreaks could be maintained as access tracks, but a fire contingency plan should not view them as a reliable means to prevent fire spread, given the risk that sparks and fire-fronts could be blown across them by strong winds or thermal air turbulence.

# 11. Rationalisation of land boundaries

The eastern boundary of the Scientific Reserve cuts right through the Waihuahua catchment which contains the least modified part of the whole wetland. At present the land east of the boundary is designated as Conservation Area but its management requirements are not essentially different from those of the Scientific Reserve. There is thus a strong case for including the whole of the wetland east of the Reserve within the boundaries of an extended Scientific Reserve. At the time when the original recommendations for the Reserve boundaries were made by an interdepartmental committee (Department of Lands and Survey 1983) this option was not open to them, because areas east of the Reserve were at that time subject to a mining licence (C.C. Ogle, pers. comm.).

Lake Waikaramu lies to the south of the Waihuahua catchment, separated from it by the Lake Road ridge. It is an interesting geological feature in its own right, being the best preserved example of a seasonal lake formed within ancient dunes. It originated when soil-forming processes gradually rendered the sand impermeable and resulting collection of water within interdune hollows led to replacement of the original kauri forest (whose stumps can still be seen) by sedge swamps and then a lake. Wave action has accumulated concentric rings of silica sand around the lake and, in places where wind has piled sand on the lee side of the lake, lunette (moon-shaped) dunes have formed. Lake Ohia, although more accessible and better known than Lake Waikaramu, is not as well preserved.

We suspect that the plant and animal communities of this ancient lake and the gentle slopes forming its shores are undescribed and undervalued. For example, because seasonally this wetland supports abundant frogs, it could provide a vital food source for bitterns. The lake bed is dominated by native species but the shoreline slopes are covered in mixtures of Sydney golden wattle, kanuka, gorse and woolly nightshade.

Lake Waikaramu is at present designated as unoccupied Crown Land. Because it is a wetland related to, yet distinct from, the main Kaimaumau wetland, we consider that the most appropriate way of managing it is inclusion within the boundaries of the Scientific Reserve, even if it is not physically connected. Comparable lake-bed habitats once present at Lake Ohia have been either seriously degraded or lost.

There are substantial botanical values associated with Block 5 (Land Allocation Block S.O. 61611/no. 5) at the north-western corner of the Scientific Reserve (cf. Clunie 1988). For this reason we consider that the Block 5 wetland should be added to the Scientific Reserve, at least as far west as the Aspin Drain. The portion of the block lying between the Aspin Drain and the State Highway has been greatly modified and appears to have a low conservation value. Subject to a botanical survey confirming this supposition, we recommend that this part of

Block 5 is excluded from the reserve and the large firebreak, that presently divides the block in half, be repositioned at a new boundary along the Aspin Drain.

The young sand dunes behind East Beach, which stretch from the Houhora Heads to the Rangaunu Harbour, are designated as a Conservation Area. Insofar as these dunes are sources for a number of weeds that are or could become problems within the Scientific Reserve, or the extensions proposed above, the management of the young dunes must be compatible with that of the wetland. The outstanding potential problem here is Sydney golden wattle, which is apparently only now gaining a foothold on these dunes (see Section 4.3.2). Anderson et al. (1984) recommended that East Beach and Kaimaumau be managed as an integrated unit. We consider that other management requirements of the dunes, particularly those associated with recreation, are not appropriate for the wetland.

During the survey we became aware of various areas of privately owned land near the Kaimaumau wetland that might be available for purchase by the Crown for reserve purposes. It was beyond our brief to examine these, but the principle remains that no such area should be purchased without scientific evaluation of its conservation values in relation to the core Scientific Reserve.

# 12. Community liaison

Since the 1970s there have been some fairly strong feelings, on the part of local residents, about the need to develop useful farmland from the swamps. There have been equally strong feelings, on the part of DOC staff and their predecessors in previous government agencies, about the need to preserve a habitat that, although disturbed, still contains many rare plants, birds, geckos and fish. The 1984 partition of former Lands and Survey blocks into areas for reservation and development does not seem to have resolved the issue. Clearly some local residents still doubt the conservation value of DOC's Scientific Reserve and Conservation Area. Equally, some DOC staff question the value of land development on blocks purchased by local farmers from Landcorp in 1993. While there is good cooperation on issues such as access and fire control, there still seems to be a great deal of suspicion by local landowners that DOC's management of the wetland will detrimentally affect their farms. DOC staff seem to fear that land development operations such as drainage and scrub clearance will have adverse impacts on the wetland.

In our view, the situation could be considerably improved by better communication between DOC and local residents. We have sensed that many local residents feel somewhat shut out from decision-making about how 'their swamps' will be managed. If the wetland's conservation values are explained to them, and if DOC's plans to maintain and restore habitat are discussed with them, there is a good chance that locals will come to appreciate and support what DOC is trying to achieve.

Communication is a two-way process; there is also scope for local community groups to consult DOC more about matters of common interest. If the local Drainage Committees seek DOC's views about the district drainage plans currently being prepared, this could help ensure that future drainage work proceeds in a way that adequately balances farm drainage with wetland conservation. Fire control is another area where agencies such as forest owners could benefit from involving DOC in cooperative planning and resourcing.

It was not part of our brief to suggest methods for improving community liaison. Nevertheless we recommend that DOC:

- releases copies of this report to community groups and local residents,
- holds a public meeting to discuss its plans for managing the wetland.

As a second step, we recommend that DOC take the initiative of offering the local community opportunities to learn about the significance of Kaimaumau, and to become involved in its management. Ways to do this include:

- holding field days to view the range of plants and birds that are present,
- involving local schools,
- weed clearance by volunteers (possibly with restorative planting in the future).

Various local residents have indicated to us that their response would be positive. All these initiatives take time and money to arrange but could pay a good dividend in the form of greater understanding and goodwill.

# 13. Acknowledgements

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