# 9 Vegetation

Except for areas cleared for dwellings or pasture, most of Great Barrier Island is forest covered. However, because the forest has been burned at various times in the past, much of it is relatively young, dominated by manuka and/or kanuka (collectively referred to as 'tea-tree' or 'scrub'). Areas of remnant mature forest occur, usually in gullies and especially at higher altitudes. The summit of Hirakimata carries a remnant of unburned unlogged forest with an unusual species composition. The vegetation of the island has been mapped and classified (Table 9.1). The broad classes in Table 9.1 disguise considerable variation in composition, but provide a basis for the following description. More detail can be found in Armitage (2004).

Table 9.1. Cover of the main vegetation types on Great Barrier Island[i]. The three main classes of vegetation; scrub, forest and (mainly) herbaceous cover, are coloured brown, green and yellow respectively.

| Landcare Database-2 Vegetation types | Area ha. | % Total |
|---|---|---|
| Manuka and or kanuka scrub | 14742.18 | 53.88 |
| Broadleaved Indigenous Hardwood Forest | 6797.67 | 24.85 |
| Other Indigenous Forest | 2745.14 | 10.03 |
| Exotic Grassland | 1932.48 | 7.06 |
| Coastal Sand Dunes | 459.69 | 1.68 |
| Herbaceous Freshwater Vegetation | 225.83 | 0.83 |
| All other vegetation, urban areas, rivers etc. | 456.36 | 1.67 |
| **Totals** | **27359.36** | **100.00** |

## 'Scrub' or 'tea-tree', covering about 54% of Great Barrier Island

Tea-tree scrub, dominated by manuka or kanuka covers more than 50% of the land area of Great Barrier Island. Scrub represents areas cleared of native forest, usually by fire. Some areas were cleared by pre-European fires and are now in old kanuka, other areas are abandoned European farmland with younger kanuka or manuka.

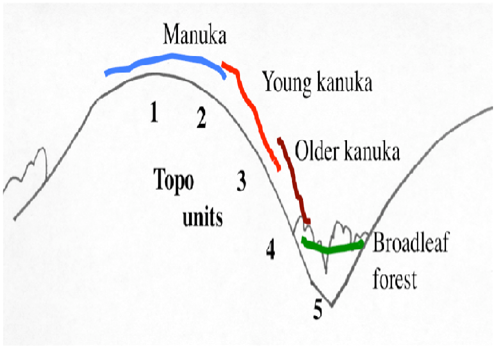
Five 'topographic units' are useful in describing the vegetation cover: ridge tops; upper slopes; mid slopes; lower slopes and gullies (or valley bottoms). These units are clearly arbitrary, and do not exactly correspond with vegetation types, which often overlap several topographic units. A common pattern on Great Barrier Island can be seen at Glenfern Sanctuary, where four intergrading but distinct vegetation types can be recognised (Fig 9.1):

- **Manuka:** dense stands of manuka and small-leaved shrub species on upper slopes and ridges, often with dry northerly exposure. This vegetation unit can be invaded by woody weeds, such as hakea (*Hakea sericea*), gorse (*Ulex europaeus*) and pines (*Pinus radiata , P. pinaster*).
- **Young kanuka:** dense stands on mid- and upper slopes, with some senescent manuka. Many of these stands are almost pure kanuka, with low species diversity.
- **Older kanuka:** mostly on mid- and lower slopes, with a rich understory including ponga (*Cyathea dealbata*) and emergent rewarewa (*Knightia excelsa*) and maire (*Nestegis lanceolata*) . Where this type occurs on upper slopes or ridges kauri (*Agathis australis*) may be present.

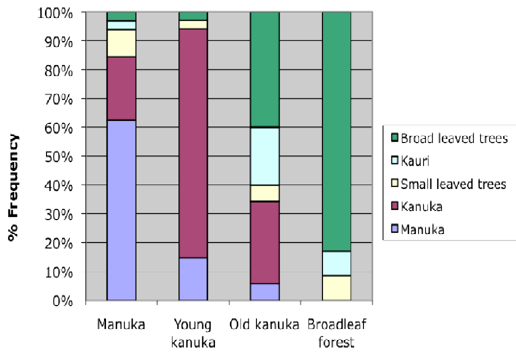
**Broadleaf forest:** mostly in gullies, with a varied canopy including tawa (*Beilschmeidia tawa*), taraire (*B. tarairi*) and kohekohe (*Dysoxylum spectabile*).

Fig 9.1. Forest types at Glenfern Sanctuary (a) distribution of the four main 'vegetation types' in relation to the five units of the topography. Topo unit 1 = ridges, unit 2 = upper slopes, unit 3 = mid-slopes, unit 4 = lower slopes, unit 5 = gullies. (b) Composition of vegetation types (each bar is divided into relative proportions of different tree categories or species according to key on right).

a




b

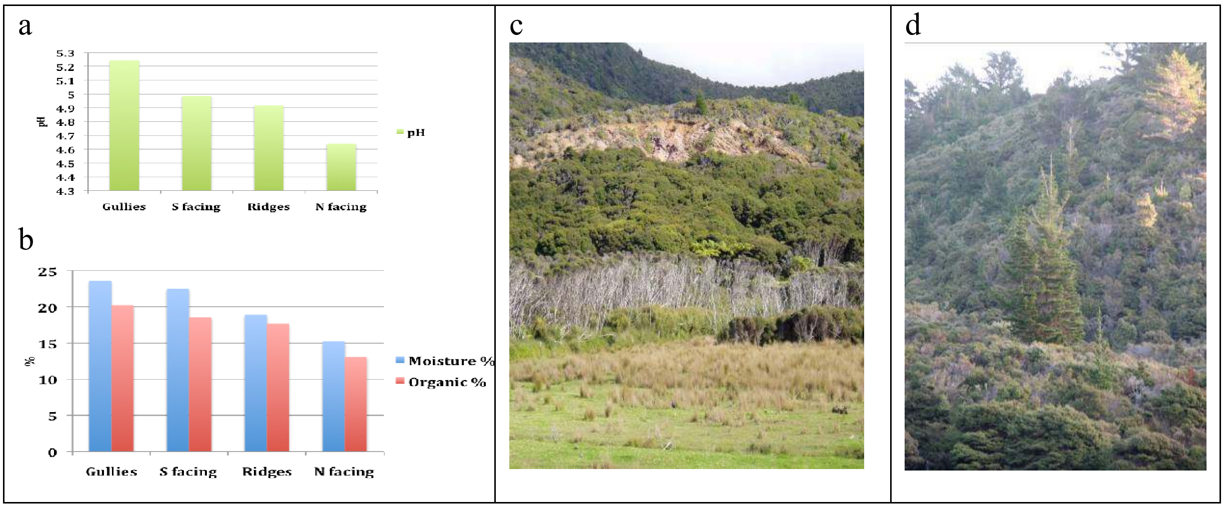



This sequence of vegetation types, with slight modifications, can be seen throughout Great Barrier Island. For example, the younger "or more fire-degraded" end of the sequence (types 1 and 2) occur at the southern end of Awana, where bare patches indicate reduced fertility due to loss of topsoil on ridges. Here low statured, slow-growing manuka dominates the ridge-lines, invaded by *Hakea sericea*, *H. gibbosa, Pinus radiata, P. pinaster*, and *Erica* species. In contrast, the relatively undamaged forest at Windy Hill comprises mainly older kanuka (vegetation type 3) currently being colonised by tree species from the broadleaf forest (type 4), which covers extensive areas in gullies and on upper south-facing slopes.

Aspect (i.e. whether north or south facing) also plays a key role in the early stages of vegetation development. On upper north facing slopes and ridges low vegetation cover exposes the dry acidic soil to the sun; at Awana this has allowed invasion by exotic trees and shrubby weeds. Pines will dominate these situations at Awana for decades or longer, but will also help to build up the depleted soil organic matter and enhance water storage. *Hakea* will be overtopped and succeeded by the faster growing and longer-lived kanuka in a few decades. The gullies and south facing slopes have been colonised by kanuka, below which are native shrubs such as rangiora (*Brachyglottis repanda*) and tree-ferns. However, at Awana, seedlings of native trees such as totara, nikau and taraire are very sparse, indicating that the natural process of return to true gully forest will require centuries.

A consequence of forest clearance and regular burning has been the loss of the upper soil layers (A and B horizons), especially from ridges and north facing upper slopes, leaving only degraded sub-soil. Currently pig rooting on steep slopes is one factor keeping the soil mobile and preventing seedling establishment. Some of the soil has accumulated in the gullies, from which it is periodically flushed onto the alluvial flats below following heavy rain. The low nutrient content and moisture-holding capacity of the remaining shallow soil has resulted in slow colonisation by manuka and kanuka. The less flammable southern slopes and gullies generally have more organic matter and soil moisture than north-facing slopes.

Fig 9.2. Soil characteristics of topographic units at Awana. (a) pH (lower values indicate more acid soil); (b) % soil moisture and organic matter; (c) bare patches on north-facing upper slopes and ridges. Mid-slope below clothed in kanuka. Alluvial flat with rushes in foreground; (d) *Pinus radiata* invading manuka and *Hakea sericea*.




*Photos: John Ogden*

The results in Fig 9.2, based on 80 surface soil samples throughout the area, clearly show the relationship between soil organic matter and moisture holding capacity. Only as vegetation develops will moisture retention capacity increase. Soil pH, reflecting nutrient status, is also low overall, but greatest in the gullies, where soil nutrients such as calcium, nitrogen and phosphorus are presumably highest too.

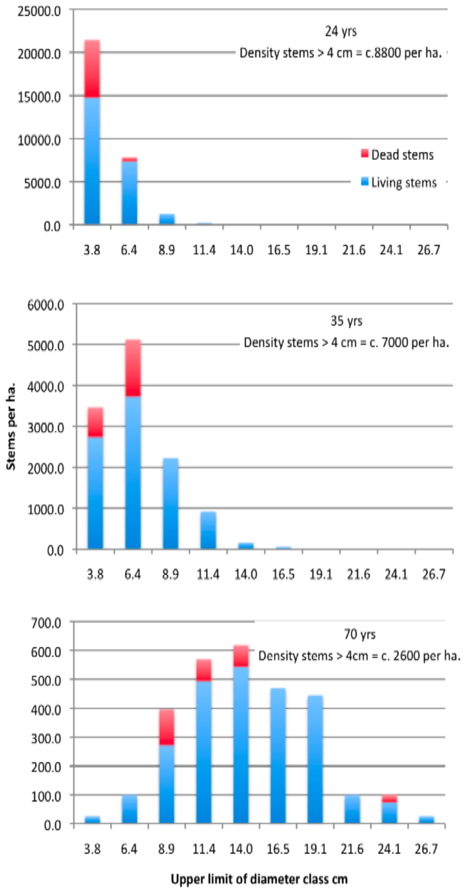
**Kanuka stand structure and development**

As height growth occurs in kanuka stands some individuals are overtopped by others and die as a result of competition for light and resources, consequently the size structure of the stand changes, and dead matter accumulates. This process of stand development, involving self-thinning and dominance by fewer and fewer bigger stems follows predictable rules. In kanuka stands on Great Barrier Island it commonly involves densities of up to 9000 stems/ha in young stands thinning to densities of < 2000 as mean top height increases from 5 to 12m (Fig 9.3).

As the smaller size classes are eliminated, the forest floor becomes available for the germination of other tree species, which later become established as the older kanuka stems die, creating openings in the canopy. This is the process of succession from scrub to more mature forest, which may be composed of conifers on less fertile soils (such as on ridges) or mixed broadleaf species elsewhere, especially in gullies.

Fig 9.3. (a) Examples of kanuka stand structure at different ages (24 – 70 year, at Whangaparapara), illustrating self-thinning. Data from Lyttle (1953). Red = dead stems, blue = live stems. (b) Early thinning stages in kanuka. (c) Intermediate stage with fern under story. (d) Mature kanuka with hardwood forest species developing under canopy.

a




b

c

d

*Photos: John Ogden*

## Kanuka scrub

The proposed adoption of a system of carbon credits, and an emissions trading scheme under New Zealand's commitment to the Kyoto Protocol, warrant discussion of the productivity of kanuka stands and their ability to sequester $CO_2$ rather than the economic feasibility of the scheme.

Growth of trees means that carbon is 'sequestered' as wood. In mature forest, dominated by kauri, podocarp, or broadleaved trees, the rate of growth (photosynthesis) is balanced by the rate of loss in respiration and dead plant parts. Over any reasonable time span (decades) and large area (hectares) there is no net change in biomass and no net carbon gain. In a young forest however, such as the widespread manuka and kanuka stands on Great Barrier Island, growth represents a real gain of carbon as biomass increases. In view of the extent of this forest type, quantitative data on its productivity and ability to sequester carbon is important.

## Carbon sequestration

Carbon sequestration refers to the 'locking up' of carbon in vegetation – largely wood. Atmospheric carbon dioxide ($CO_2$) is converted into organic products such as lignin and cellulose (the main constituents of wood) via the process of photosynthesis. Wood is roughly

50% carbon. If these plant products remain undecomposed for long periods, then this process effectively removes ('sequesters') carbon from the atmosphere. Many tree species can live for centuries (Fig 9.4). Even after death trunks and large branches decay (return carbon to the atmosphere) only slowly. Thus trees, especially fast growing trees such as pines and eucalypts, can remove a lot of atmospheric $CO_2$, and this has been seen as a way of mitigating $CO_2$ emissions from the burning of fossil fuels (which represent carbon sequestered by trees millions of years ago). The proposed emissions trading scheme in New Zealand will give 'carbon credits' for tree plantings and natural regeneration, larger than a certain area, and occurring since 1990[ii]

Fig 9.4 Cross-section of kanuka trunk with c. 25 annual rings. The rings are obscure because on Great Barrier Island kanuka grows throughout the year. Each ring represents the Carbon sequestration for that year.

*Photos: John Ogden*

Investigating the use of kanuka for firewood in 1953, R. J. Lyttle measured five plots in the Whangaparapara area and one in the Kaiarara[iii]. Lyttle's plots were carefully chosen to represent the typical growth of a kanuka stand from inception (mixed with manuka) to maturity, covering the age range from 2 to 70 years. They appear to be typical of kanuka height growth throughout the Island, which is rapid and linear for the first fifty to sixty years, but slows down to almost zero in the oldest stands (Fig 9.5). Lyttle's data allow us to estimate of the weight of carbon/hectare and the rate at which this has been accumulated (Table 9.2).

Fig 9.5. Height and estimated age of kanuka dominant stands in on Great Barrier Island. Open squares are unpublished data from stands at Glenfern Sanctuary and Windy Hill; red squares are data from Lyttle 1953.

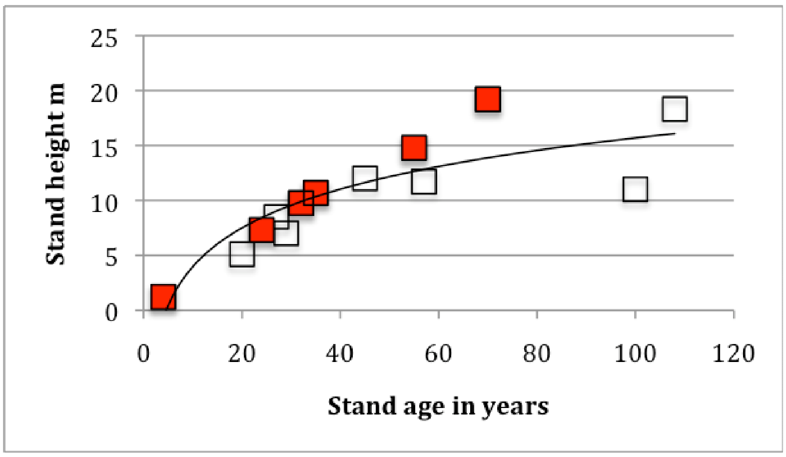


Table 9.2 Estimated Rates Of Carbon Sequestration In Kanuka Stands Of Different Ages On Great Barrier Island. Derived From Data In Lyttle 1953.

| **Stand age years** | **Stand top height m.** | **Tonnes C/ha (1)** | **Tonnes C./ha/annum (2)** | **Tonnes $CO_2$ e/ha/annum(3)** |
|---|---|---|---|---|
| 70 | 19.2 | 287.5 | 4.1 | 15.0 |
| 55 | 14.8 | 148.6 | 2.7 | 9.9 |
| 35 | 10.7 | 69.3 | 2.0 | 7.3 |
| 32 | 9.7 | 92.8 | 2.9 | 10.6 (4) |
| 24 | 7.3 | 12.8 | 0.5 | 1.8 |
| **Averages:** | **12.3** | **122.2** | **2.4** | **8.95** |

Notes: (1) assumes 1 cubic foot = 29.484kg. of which 50% is carbon; (2) total accumulated carbon divided by stand age; (3) $CO_2$ e refers to $CO_2$ equivalents, i.e. the $CO_2$ removed from the atmosphere; calculated as the previous column multiplied by 3.667. (4) High value probably indicates site variations in stem density.

The median and average values of $CO_2$ sequestration are 9.9 and 8.95 tonnes/ha/annum respectively. These figures can be compared with values of 10 – 11.4 tonnes $CO_2$ e/ha/annum ($CO_2$ 'equivalents') obtained from the Landcare Research 'Carbon-Calculator'[iv] for low – medium quality sites on Great Barrier, and with values ranging from 6.6 to 12.8 (average 7.3) tonnes $CO_2$ e/ha/annum obtained for kanuka stands by Trotter et al. (2005)[v] and Walcroft et al. (2002)[vi]. These comparisons show that the Great Barrier Island figures in Table 9.2 are within the expected ranges. Possible practical applications and economic benefits which might be obtained by applying these results to a local emissions trading scheme in future are dependent on political developments in this area at a national / international level.

Kanuka was formerly regarded as either a weedy nuisance or a firewood crop. Over the last few decades, on steep low-fertility hill country, unsuitable for farming or even pine plantations, it has become clear that the scrub cover helps to bind the soil and reduce run-off and flooding. It has also been recognised as important for honey production, and has biodiversity value in promoting the establishment of native forest. Use of kanuka for firewood may continue on Great Barrier Island, where other fuel sources are not available or expensive, although it clearly conflicts with its role in carbon sequestration and in the establishment of a more mature and less inflammable forest cover. However, kanuka scrub can now be seen as a potentially significant economic and environmental benefit for Great Barrier Island.

## Forest with various dominant tree species, covering c. 35% of Great Barrier Island

Few quantitative forest vegetation studies have been carried out on Great Barrier Island. There are data from the Northern Block[vii]Glenfern Sanctuary (already described) and Windy Hill. Kauri, tawa, taraire, kohekohe, pohutukawa (*Metrosideros excelsa*) and a range of other tree species dominate the mature forest canopy to different degrees in different places. Gradients of 'topography' and 'successional status' have already been described for the scrub cover. Here, considering mature forest, we add 'altitude'. Together, these three gradients appear to largely determine species composition: altitude, topography and fire history (Fig 9.6) interact to produce an intergrading mosaic of forest types (including the scrub already described) over much of the landscape.

**Altitudinal gradient**

Altitudinal distribution data has been obtained from Hirakimata (Mt Hobson), Tataweka and Ruahine (Mt Isaacs). Together these areas are considered representative of most of the island

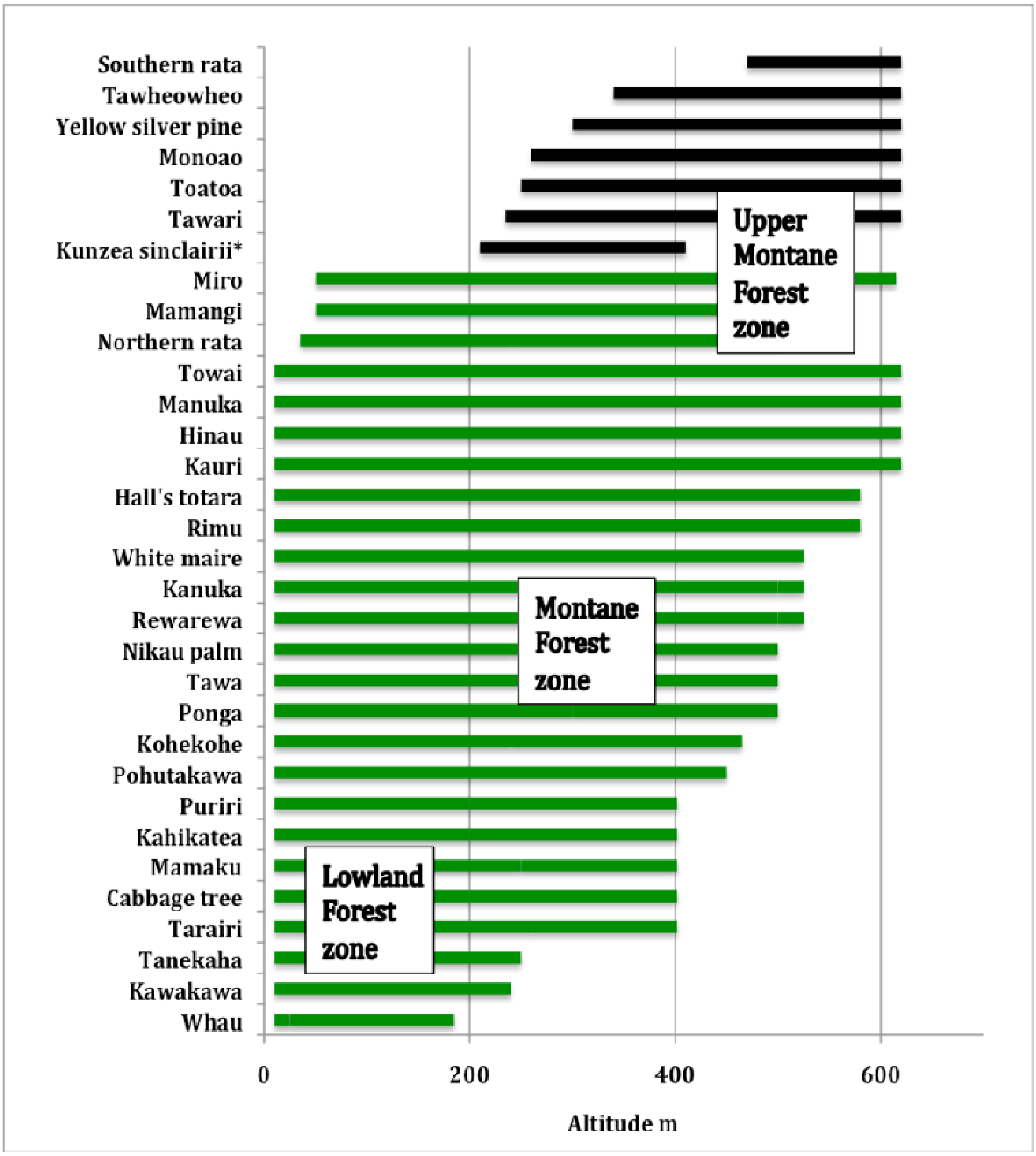
and provide a picture of the altitudinal gradient in floristic composition, which can be divided into three zones:

Zone 1: Lowland forest from sea-level to c. 200m. This zone includes a distinctive coastal fringe dominated by pohutukawa and a suite of mainly coastal shrubs. It also encompasses most of the currently or formerly cleared areas, now mainly carrying tea-tree scrub (already described).
Zone 2: Montane forest from 200 – 400m. All three mountains show similar diversity over this range, and all show a similar decline in diversity with altitude.
Zone 3: Upper montane forest from 400 – c.600m. Ruahine summit is barely into this zone, but Hirakimata slightly exceeds it. This zone is frequently cloud covered.

Fig 9.6. Summit of Hirakimata viewed from the west in 1948, showing the extent of forest removal by fire, and the remnant forest around the summit of the mountain. Note the extensive cleared areas in the lowland zone around Harataonga and Awana (far right), Rakitu just visible, upper left.

*Photo: C. Young Collection*

Fig 9.7. Distribution of selected trees, shrubs, tree ferns and nikau palm against altitude on transects from sea-level to summit of Hirakimata (627m). Black bars are species found only on Hirakimata or a few adjacent summits. Green bars are species found on all the main mountains and usually at sea-level too. Bars indicate presence only at that altitude, without reference to abundance. * *Kunzea sinclairii* is the creeping kanuka, found only on Great Barrier Island.




The upper montane forest (Zone 3) near the summit of Hirakimata includes a suite of species not found on the other summits (Fig 9.7). The vegetation includes the conifers kauri (*Agathis australis*), yellow silver pine (*Lepidothamnus intermedius*), silver pine (*Lagarostrobos colensoi*), Kirk's pine or monoao (*Halocarpus kirkii*), toatoa (*Phyllocladus glaucus*), and broadleaf trees such as tawari *Ixerba brexioides,* tawherowhero *Quintinia serrata*, and southern rata (*Metrosideros umbellata*). Hutu *Ascarina lucida,* and the soft tree fern *Cyathea smithii* are also present. The endemic shrubs *Kunzea sinclairii, Olearia allomii* and *Hebe macrocarpa* var. *rehuarum* also occur in this upper altitude group, mainly on open rocky outcrops rather than in the forest.

**Forest of the Northern Block**
Te Paparahi, including Tataweka, extending from the northern end of Whangapoua estuary to the far north of Great Barrier Island has been described by Wright & Cameron (1988) and Eady & Broome (1990). The latter recorded plant species composition in 161 plots, with 38 permanently marked for re-measurement. The study covered all three altitudinal zones, but was predominantly lowland – montane (Zones 1 and 2).

As elsewhere, the main gradient of species composition was associated with altitude[viii]. The nine forest types recognised by Eady & Broome (1990)[ix] were grouped into three classes as follows:

| Forest Type | Number of Plots | Average Altitudinal zone |
|---|---|---|
| **Conifer/hardwood forest class:** | | |
| 1.Kauri /kanuka/ponga | 11 | montane |
| **Broadleaf forest class:** | | |
| 2. Tawa/soft tree fern – ponga | 8 | upper montane |
| 3. Kohekohe – tawa – ponga - nikau | 12 | montane |
| 4. Tawa/kohekohe - nikau | 27 | montane |
| 5. Tarairi - tawa/kohekohe – nikau | 43 | lowland |
| 6. Kanuka/kohekohe/ponga | 40 | lowland |
| **Disturbed forest class:** | | |
| 7. Kanuka - manuka/ponga forest | 14 | lowland |
| 8. Pohutukawa/kohekohe open treeland | 4 | lowland |
| 9. Kanuka/ringfern fernland. | 2 | Montane |

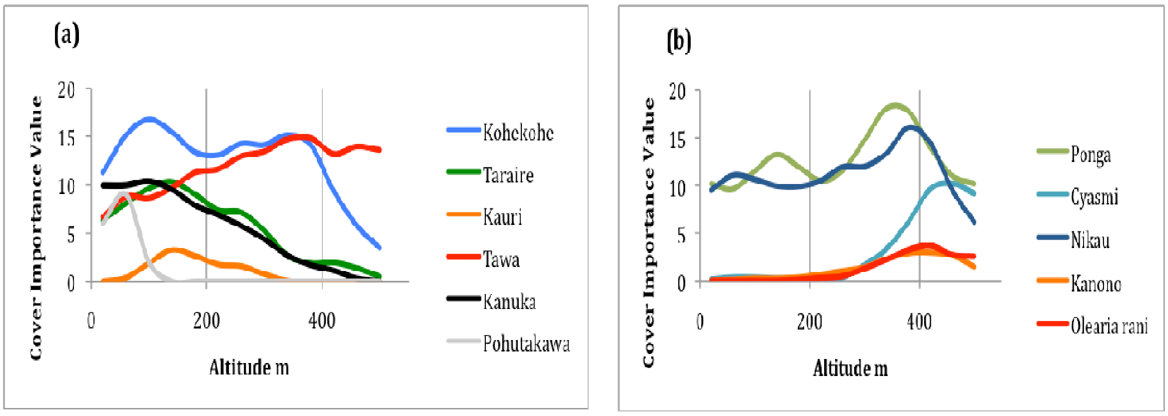
Forest type 1 (kauri forest) occurs in patches on ridges, mainly east of the main divide and in the altitudinal range c. 150 – 300m. Besides kauri, kanuka, rimu (*Dacrydium cupressinum*), miro (*Prumnopitys ferruginea*), white maire (*Nestegis lanceolata*), rewarewa (*Knightia excesa*), lancewood (*Pseudopanax crassifolius*) and mamangi[x] (*Coprosma arborea*) are abundant in the canopy and subcanopy. Ponga (*Cyathea dealbata*) is abundant in the shrub tier, and *Blechnum fraseri* occurs in the ground layer.

Forest types 2 to 6 (the broadleaf forest class) form an overlapping continuum of species composition with increasing altitude from c. 150 to c. 450m. All five types are best regarded as variants within the mid-altitude (montane) forest complex, dominated by tawa, kohekohe, or taraire, especially in gullies and on lower slopes, or kanuka, mainly on ridges and upper slopes at lower altitude. Type 2 is tawa forest with soft tree ferns (*Cyathea smithii*) present, found mainly close to the summit of Tataweka and on the higher ridges. Type 6 is dominated by emergent kanuka and covers extensive areas of Te Paparahi, predominantly at lower altitudes. It probably represents regeneration from early European or Maori fires.

Forest types 7 – 9 are all disturbed by fire and/or grazing. Type 7 is dominated by tea-tree 'scrub', reflecting clearance for pasture last century, at the lower end of the altitudinal sequence (sea-level to c. 200m). As described under 'scrub', manuka often forms a 15 – 30m wide band along ridge crests, merging into kanuka on the upper slopes. Type 8 is open pohutukawa forest on cliff edges or cleared areas around Rangiwhakaea Bay. Type 9 represents recent forest clearance and grazing at various altitudes.

Fig 9.8 shows the relative cover of the main canopy species with altitude in Te Paparahi. The method of recording 'cover importance value' on Fig 9.8 tends to over-emphasise shade tolerant species which have foliage in many height class (e.g. kohekohe) compared to those which do not (e.g. kanuka). Below 200m altitude kohekohe, taraire, and tawa dominate. Kanuka dominates dry slopes and ridges exposed to the north or west, and pohutukawa the cliff-top coastal fringe. Kauri is present as scattered stands, predominantly on ridges. Between 200 and 400m taraire and kanuka decline, while tawa increases. Tree ferns and palms also increase. Above 400m kohekohe importance declines rapidly, and the canopy is composed of tawa, with a dense fern and shrub under storey. The soft tree fern (*Cyathea smithii*) is characteristic of the upper forests on Tataweka, especially in cooler south facing gullies.

Fig 9.8 Altitudinal distributions, Te Paparahi. Redrawn from data in Eady & Broome (1990)[xi]. Smoothed importance values are based on canopy cover in seven height classes. (a) Main canopy trees; (b) Tree ferns, palm and two under-storey species.




## Kauri forest

This is a distinctive association of species present in patches on ridges and upper north-facing slopes within the montane zone. Kauri patches are almost certainly sites of ancient disturbance, by fire, cyclone or soil slipping. In the central part of Great Barrier Island stands of pole sized kauri ('rickers'), arising since fires in the late 19th or early twentieth, century are a feature of the ridges. So much kauri biomass was logged (Fig 9.10) that it is now difficult to get a clear picture of the pre-European forests, but the changing species composition in kauri stands, occurring over several centuries as dense stands thin out to a few huge survivors, has been described elsewhere[xii]. Some of the trees in Glenfern Sanctuary date from the 1700's, while much older trees were logged throughout the central area of the Island early in the twentieth century. The soil pathogen, *Phyophthora* taxon *Agathis* (PTA) is a new threat to the regenerating ricker stands[xiii] .

Fig 9.9. Kauri forest on Great Barrier – stages in forest development.

a

Kauri seedling under kanuka, Harataonga.

b

Kauri 'rickers' emerging through old kanuka, Harataonga.

c

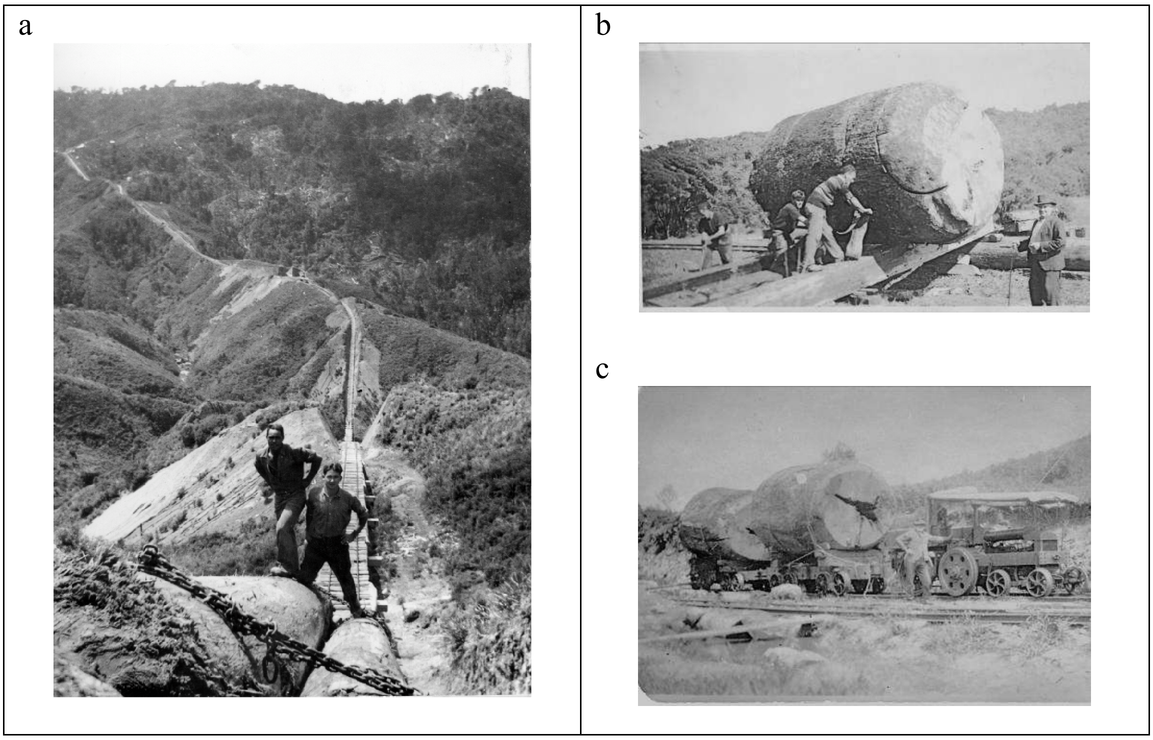
"A mighty kauri tree" 1934. This tree was probably c. 600 years old when felled.

*Photos: John Ogden(a.& b.); C. Young Collection*

## Mature forest at Windy Hill

At the opposite end of Great Barrier Island to Tataweka, the vegetation of Windy Hill has some features in common and some marked differences – the absence of kauri and soft tree fern being notable. Old mature kanuka is a feature of much of the Windy Hill area, representing re-growth from farmland or burned forest abandoned early last century (before 1940). Many of the large old kanuka are now falling in storms, and the vegetation appears to be progressing towards the 'mature' forest composition. At Windy Hill this latter forest type comprises a much greater area and compositional diversity than that at Glenfern; it probably equates to the broadleaf forest continuum described over the same altitude at Te Paparahi, especially forest type 5 (Taraire-tawa/kohekohe-nikau). Taraire (*Beilschmeidia tarairi*), and *Coprosma arborea* are much commoner at Windy Hill than at Glenfern. Throughout the lowland zone on Great Barrier Island, where undisturbed forest remains, the same suite of broadleaf canopy species, including kohekohe, tawa, taraire and puriri is present in damp gullies and lower slopes . Nikau palms are prevalent in the sub-canopy. Some of the wetter areas at Windy Hill have small patches of kahikatea (*Dacrycarpus dacrydioides*) and pukatea (*Laurelia novaezelaniaea*), with abundant epiphytes, especially kiekie (*Freycinettia banksii*).

Fig 9.10 The kauri forests of yester-year. (a) The tramway between Awana and Whangaparapara, with kauri logs chained to trolley; note cleared landscape. (b) Timber-jacking large kauri logs. (c) Logs arriving at Whangaparapara landing. (All photos taken in 1930s).



*Photos: C. Young collection*

**General patterns in the montane forests**

The montane zone (200 – 400m) was mostly not cleared for farming, although fires certainly penetrated it and kanuka dominated forest is frequent. Overall however the vegetation is less disturbed than that in the lowland zone, and presumably reflects more closely the pre-human forest cover. At Te Paparahi, Windy Hill, and Ruahine, taraire, tawa and kohekohe are present as canopy trees through-out, forming a forest continuum in which tawa replaces taraire with increasing altitude. Taraire dominated forest is also more frequent on drier slopes, often with a north-western aspect, while tawa and kohekohe predominate on the eastern side of the island divide. Although diversity declines and the composition changes with increasing altitude distinct 'communities' are hard to define. The differentiation between aspects, ridges and gullies, so clear at lower altitudes, is here more gradual and subtle, although it can still be readily observed in the distribution of some species, such as nikau, tree-ferns and supple-jack (*Rhipogonum scandens*) in gullies.

**Vegetation cover of rocky coastal slopes and cliffs**

Excepting the broad eastern bays discussed below, and the heads of some of the western harbours, the coastal vegetation zone of Great Barrier Island comprises coastal cliffs and headlands, usually backed by steep slopes covered in forest or scrub. The characteristic coastal tree is pohutukawa (*Metrosideros excelsa*). This species is capable of withstanding salt-laden winds and occasional inundation by seawater. The trees live for centuries, their extensive root systems binding together otherwise crumbling headlands and stacks. Typical coastal-fringe forest also includes, nikau palm (*Rhopalostylis sapida*), taraire (*Beilschmeidia taraire*), kohekohe (*Dysoxylum spectabile*), broad-leaved tawa (*Beilschmeidia tawaroa*), and puriri (*Vitex lucens*). Less frequent are tawapou (*Pouteria costata*) and karaka (*Corynocarpus laevigatus*). The coastal forests have a high diversity of associated sub-canopy trees, climbers and under-storey shrubs. Mahoe (*Melicytus ramiflorus*) and mapou (*Myrsine australis*) are common in the sub-canopy. Prostrate or wind-shorn shrubs of manuka and kanuka are also common, forming extensive heathlands in some exposed situations. Sea stacks carry taupata (*Coprosma repens*), *Melicytus novae-zelandiae* and herbaceous monocots, especially flax. Dense stands of pohutukawa usually have only a sparse understorey, but flax, kawakawa (*Macropiper excelsum*), rangiora (*Brachyglottis repanda*) , karo (*Pittosporum crassifolium*), houpara (*Pseudopanax lessonii*) and hangehange (*Geniostoma rupestris*) are characteristic species. Kowhai (*Sophora microphylla*) occurs mainly in sheltered locations.

Coastal communities have been extensively changed through the almost total elimination of sea-bird (petrel and shearwater) colonies and through fire. Both of these processes must have lead to loss of soil nutrients through much reduced input in the first case, and extensive soil erosion in the second. Consequently the coastal cliff and steep-slope vegetation is probably very different from that present in pre-Maori times. Atkinson[xiv] (2004) has described the successions occurring after fire, emphasising the importance of mahoe on fertile, and mapou on less fertile sites.

**Landscape pattern and future trends in the lowland zone (0 – 200m)**

Some clear generalisations can be made from the case studies described above. All four areas mentioned -Te Paparahi, Windy Hill, Glenfern and Awana - were partially cleared for farming last century, and their current vegetation cover demonstrates a sequence of regeneration on formerly burned land, with remnant areas of pre-European forest. In the order given above they form a sequence from the least disturbed (Te Paparahi) to the most devastated (Awana).

Within the formerly cleared or farmed areas of Great Barrier Island, the pattern of manuka on exposed ridges and upper northerly slopes, and remnant broadleaf forest patches in the gullies and lower south-facing slopes, is common. Manuka is usually the pioneer species invading open grassland on the cessation of burning or grazing, usually followed by kanuka a decade or so later. Because it is longer-lived, and grows taller than manuka, kanuka comes to dominate the mixture. This process of replacement of manuka by kanuka is much slower on the ridges, probably because manuka is more tolerant of the low soil fertility and generally harsher conditions there. Kanuka replaces manuka on the better soils of mid- and lower slopes, and is currently the commonest tree species on the Island. However, over a century, kanuka is itself replaced by other tree species, which germinate and grow in its protective shade. Consequently, stands of kanuka are frequently ‘nurse crops’ for more diverse forest communities, which vary in composition depending on site history, topography and aspect, and to some extent on the proximity of seed sources and dispersers such as pigeons. These processes of succession, and the survival of remnant forest patches in damper areas protected from fire, readily explain the landscape pattern in much of the lowland zone of Great Barrier Island.

The lowland forests have been largely destroyed by fire over two periods. The first occasion was by Maori burning c. 700 years ago, and the second was by Europeans, mostly between 1840 and 1940[xv]. As a consequence much soil has been lost from the hinterland, especially from ridges, which generally burn more frequently and intensely than lower slopes or damp gullies. Repeated fire has re-distributed soil nutrients, which have been heavily depleted on ridges, but replenished in gullies and sediment traps such as alluvial flats and swamps. This process has generated the widespread vegetation/soil/topography pattern of shallow, dry, low-fertility soil on ridges carrying manuka, mid-slopes dominated by kanuka, and remnant unburned broadleaf forest on deeper soils accumulating in lower gullies. This spatial pattern is also a temporal pattern of replacement, with different rates of change on different topographic landscape units. Where kanuka replaces manuka on the better soils of mid- and lower slopes, it is itself replaced by other tree species, which germinate and grow in its protective shade (Fig 9.11).

Fig 9.11. Regeneration of broadleaf forest species under mature kanuka. (a) Mapou (*Myrsine australis*) (left) and hangehange (*Gensiostoma ligustrifolia*) (right); (b) puriri (*Vitex lucens*) (left) and taraire (*Beilschmeidia tarairi*) (right); (c) kohekohe (*Dysoxylum spectabile).*


*Photos: John Ogden*

The elimination of the original forest cover by fire, has resulted in extensive areas of low fertility soils carrying manuka scrub, now being invaded by exotic woody weeds such as *Hakea*, gorse and pines. Both the native manuka and the invading weedy species are highly inflammable, and generally survive fires or readily re-seed into burned areas, rendering them even more vulnerable to fire in future. This is a positive-feedback system (Fig 9.12) in which fire leads to progressively more fire-prone vegetation and the elimination of the broad-leaved forest tree species. Only by preventing fire for a century or more will there be any likelihood of a return to the original forest on such areas.

In the absence of fire, the process of transition between the vegetation types has been studied at both Glenfern Sanctuary and Windy Hill. The method was to designate 'replacement species' (established seedlings or saplings) close to randomly chosen mature canopy trees. The assumption is that, if this process is done frequently enough, and with additional information about tree longevity, it is possible to construct a 'replacement matrix', showing the probabilities of each tree species being replaced by every other species in future. Such a matrix allows us to predict those species likely to increase or decrease in future.

The results from Glenfern Sanctuary and Windy Hill (Fig 9.13) indicate that manuka, kanuka, mamangi (*Coprosma arborea*) and rangiora (*Brachyglottis repanda*) are likely to decline, while broadleaved species, such as tawa, taraire and kohekohe, along with nikau palms, are likely to increase. The only surprises were a predicted small decline in tawa (*Beilschmeidia tawa*) at Windy Hill, and in puriri (*Vitex lucens*), at Glenfern Sanctuary. The latter species may rely on vegetative re-sprouting rather than new individuals. Overall these two sets of results support the supposed trend of kanuka scrub being replaced by broadleaved forest. As large quantities of seeds of some of these species are known to be eaten by rats, it is likely that the rate of change is currently being slowed down by the presence of rats. For example at Windy Hill and Glenfern Sanctuary there are at least four times as many Nikau seedlings in broadleaf forest trapped for rats, as there are in similar untrapped areas (see references in Environmental News 4, 2005).

Fig 9.12. Relationships between forest cover and fire history. The vegetation types recognised at Glenfern Sanctuary are indicated (yellow) to show their relationship to the fire cycle. The Awana study area and much of the lower altitude tea-tree scrub throughout Great Barrier Island, lies in the open circle to the right, where fire feedback loops promote further fires. Broadleaf forest types (eg. at Te Paparahi) are in the left-hand oval. Fire-promoting weeds shown in red.

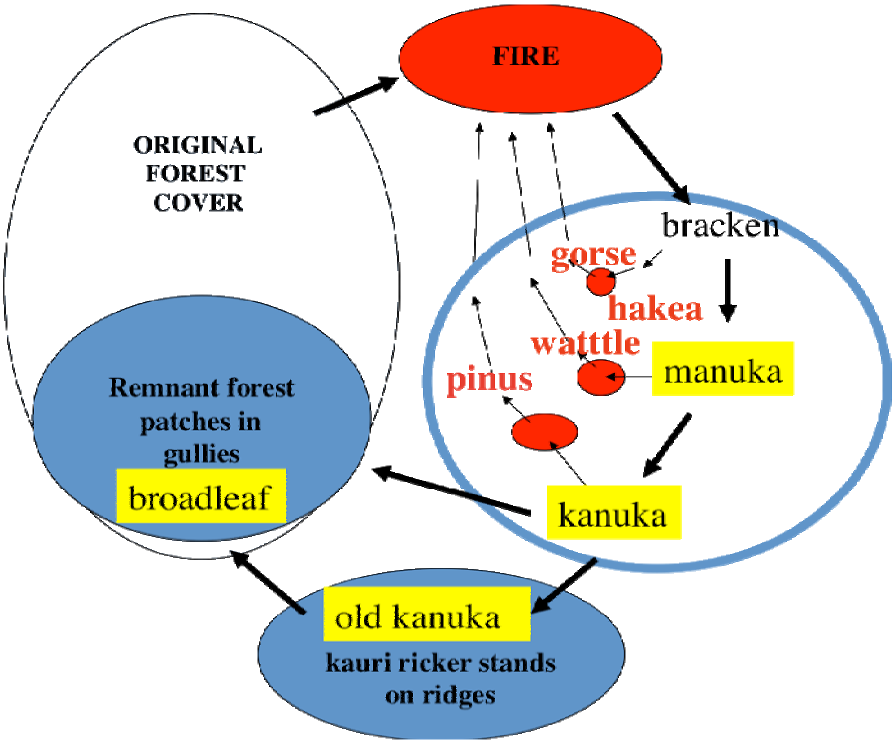
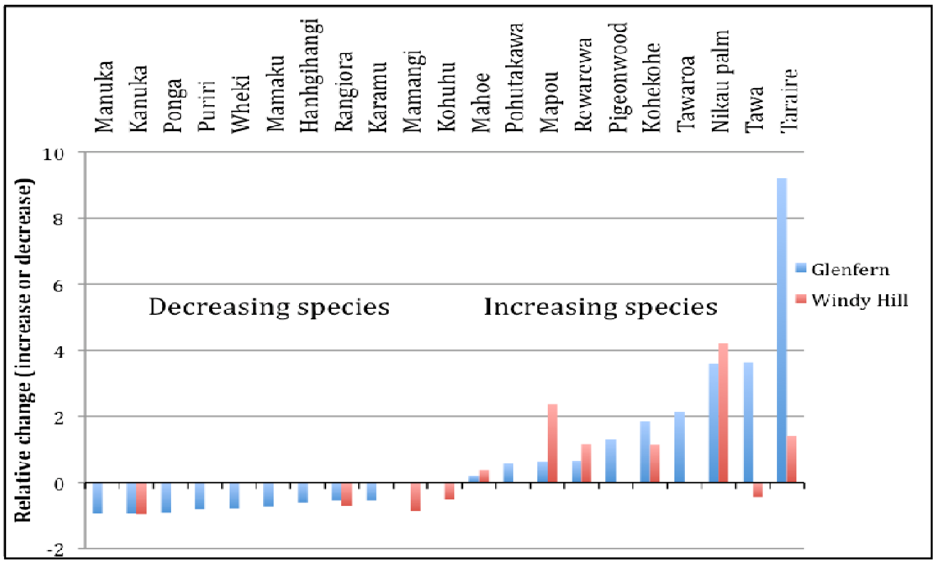



Fig 9.13. Combined results from matrix analyses, showing likely future vegetation trends at Glenfern Sanctuary [xvi] and Windy Hill[xvii].



## Various mainly herbaceous vegetation types, covering c.11% of Great Barrier Island

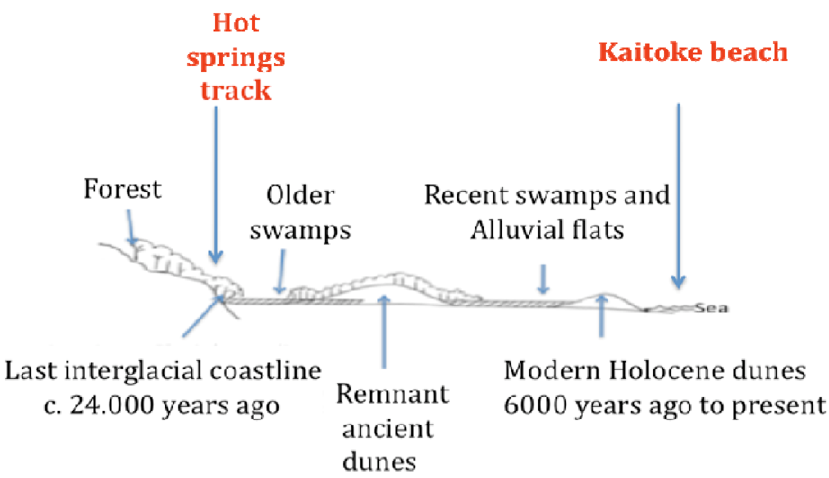
**Origins and vegetation of recent coastal ecosystems**

The low-lying coastal areas of eastern Great Barrier Island, comprising the environs of Medlands, Claris, Awana and Whangapoua estuary, are farmed. The soils are dune sands, stream deposits, or drained peaty soils derived from wetlands. These landforms have different vegetation cover, but share a common origin.

After the last Glacial period (c. 22,000 years ago) sea-levels rose, and the former coastal plain was flooded. Sandbars built up across the bays, and the freshwater streams were partially dammed, creating tidal lagoons behind the dunes. When sea-levels eventually stabilised c. 6000 years ago, these were gradually infilled with fine sediment and peat deposits, creating rear-dune swamps. The drainage of these wetlands last century created the alluvial flats now used for farming.

Sea-level shifts have actually occurred several times over the last 125 thousand years, so that remnants of older dunes are also present (Fig 9.14). The central dune system in Kaitoke Swamp, and the elongate dune (currently in pasture) to the west of the alluvial flats behind Kaitoke beach, belong to an early phase of lower sea-level. These older dunes are composed of finer (more degraded) sand, with a lower fertility due to prolonged leaching.

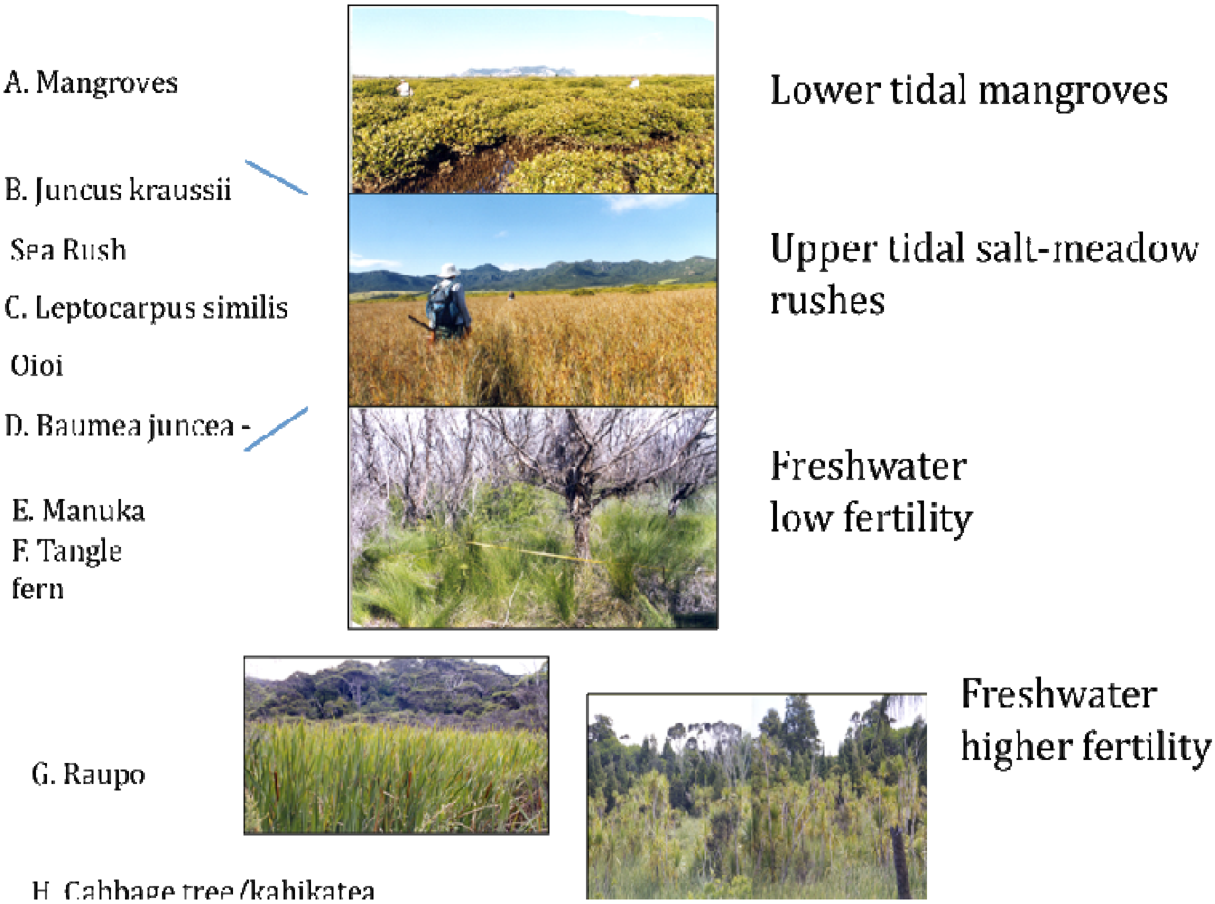
Fig 9.14. Diagrammatic landscape, showing the relationships between ancient and modern dune systems and the associated swamps (e.g. from the Hot Springs track at the rear of Kaitoke swamp to the northern end of Kaitoke beach).




**Freshwater and saline wetlands**

Wetlands are "areas where water is the dominant environmental factor" (Hunt 2007). Wetland vegetation has been described at Kaitoke Swamp (Rutherford 1998) and Whangapoua (Deng et al. 2004; Ogden et al. 2006) (Figs 9.15 & 9.16). Deng recognised eight plant communities falling within the freshwater and saline categories[xviii]. These communities are zoned in the Whangapoua estuary, with the zonation representing a succession - a sequential change in vegetation composition as the estuary has filled with sediments over the last 700 years. Eelgrass (*Zostera novaezelandica*) and mangroves (*Avicennia marina*) are the first 'terrestrial' plants to colonise the mudflats (community A). Behind them is a zone in which sea rush (*Juncus krausii*), oioi (*Leptocarpus similis*) and *Baumea juncea* form an intergrading sequence of rush-like plants in the upper tidal salt meadow. *Baumea juncea*[xix], occupies a critical position, overlapping the saline and freshwater parts of the system. This species is highly productive of plant material, especially underground, where a dense matt of rhizomes and roots holds the sediment together. This plant material is very slow to decompose, and accumulates as peaty organic matter in the soil, helping to raise the surface level above the high-tide mark (Pegman et al. 2006)[xx].

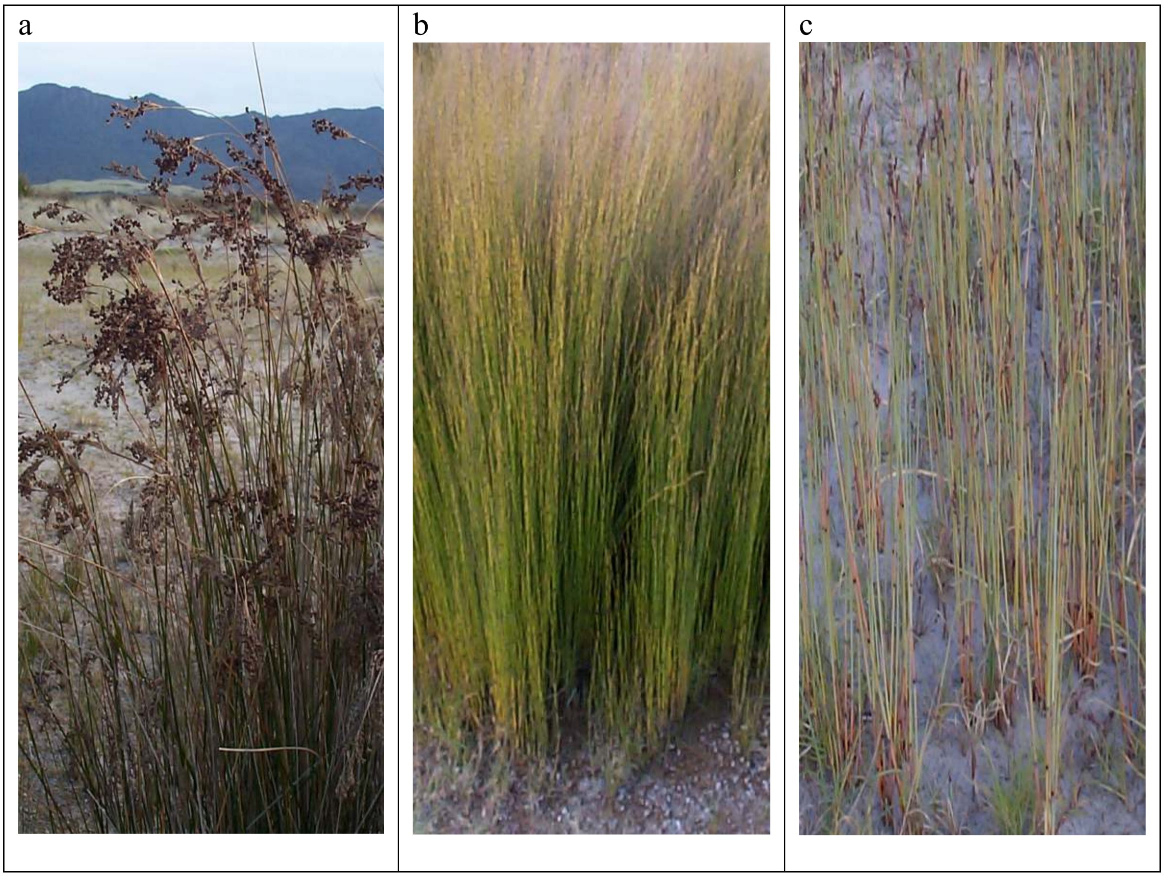
Fig 9.15. Vegetation classification of Whangapoua estuary[xxi]. The common or latin name of the main species in each community (left) is given, grouped into categories (right). Photos show typical examples, tangle fern not shown.




*Photos: Yanbin Deng*

Sea water rarely penetrates beyond the *Baumea juncea* zone, and from this point a more varied succession occurs, influenced by the nature of the fresh-water input. Where fresh-water stream flushing is infrequent, and the main water supply is from rainfall, relatively low fertility peaty soils develop, with tangle fern (*Gleichenia dicarpa*), manuka (*Leptospermum scoparium*), other species of *Baumea*, and *Tetraria capillacea* (Community F in Fig 9.15). This mixed low fertility ('oligotrophic') community can persist for many thousands of years (eg at Awana; Horrocks et al. 1999) gradually building up a woody peat, rarely flooded by streams or the sea. As a consequence of peat build up in the centre of swamps, inflowing streams start to flow around the margins, where the influx of fine sediments maintains fertility and freshwater higher fertility ('eutrophic') communities develop[xxii].

Fig 9.16. Key species of the salt meadow communities: Left to right: (a) sea rush, *(Juncus krausii);* (b) oioi *(Leptocarpus similis); (c) Baumea juncea.* The sequence is from most frequently flooded by tide (left) to least frequently (right).




*Photos: John Ogden*

The freshwater swamps also undergo succession, with the sequence from large macrophytes, such as raupo (*Typha*) and sedges (*Carex* spp.), to cabbage trees (*Cordyline australis*) and flax (*Phormium tenax*) and eventually true forest dominated by kahikatea (*Dacrycapus dacrydioides* – community H). This sequence may have been largely driven by forest clearance and fire, providing an abundant supply of sediments and nutrients during the last 700 years, and especially since aerial topdressing in the late 1900's. The pattern is recognised throughout New Zealand. [xxiii]

These eight vegetation types can be seen, with slight variations, in Kaitoke swamp, which covers c. 320 ha., and is the largest wetland close to Auckland (Rutherford 1998). Here, the freshwater sequence is represented by more diverse plant associations and the mangrove zone is absent apart from a few trees bordering the Kaitoke creek. Mangroves, and small areas of salt meadow, also occur at the heads of some of the western harbours (e.g. Whangaparapara, Wairahi and Port Fitzroy).

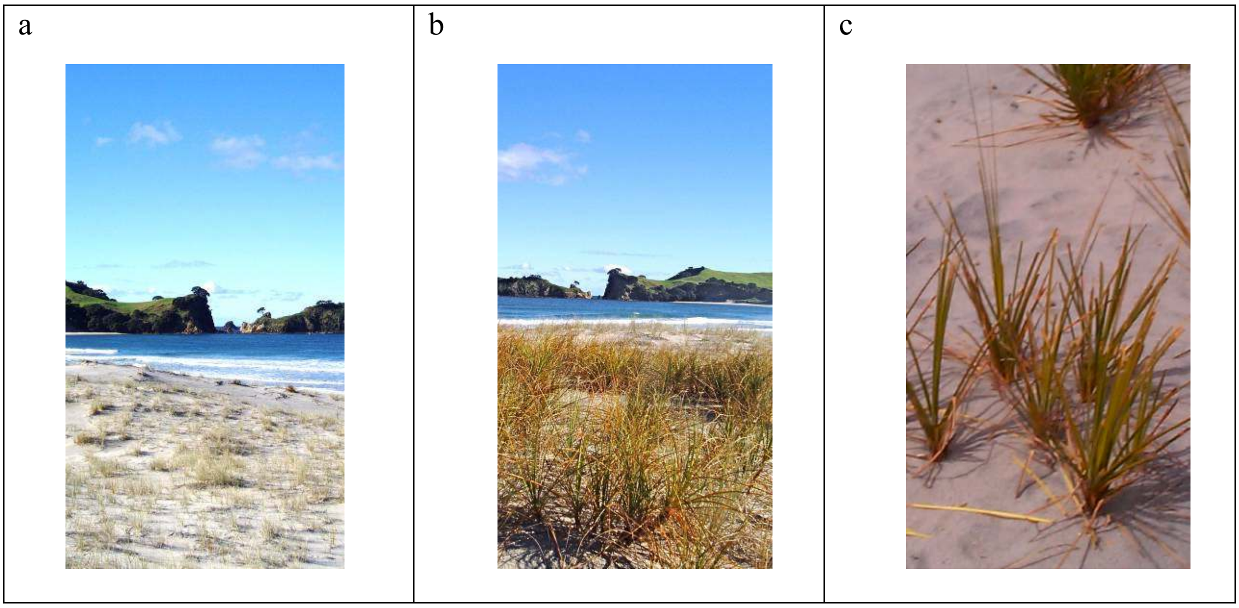
**Alluvial flats**

The drained wetlands behind the dunes on eastern Great Barrier Island are generally referred to as alluvial flats. In the past they must have had peaty soil overlying the present surface, and in some cases they carried kahikatea forest. Now they are pastures, with a wide range of exotic grasses, rushes and sedges. Where they were peaty, their surfaces have been lowered due to shrinkage and peat oxidation. This lowering is c. one metre at Awana. As a consequence they are flood prone, and in some areas they are so close to sea-level that saline water has re-entered them (e.g. at Whangapoua and southern Kaitoke) reversing the successional process.

**Dunes and dune flats**

The coastal dunes also form time sequences, with the youngest unstable dunes behind the beach (Fig 9.17) and older dunes, with more diverse vegetation, further back. A fairly complete sequence can be seen at the northern end of Kaitoke, but the native vegetation is much modified by rabbits, pigs and exotic plants, especially *Hakea* and *Pinus radiata* (originally planted for stabilisation) on the older dunes (Armitage 2005).

Fig 9.17. Native vegetation on fore-dunes – Palmer's beach. (a) *Spinifex hirsutus*; (b) pingao (*Desmoschoenus spiralis*); (c) pingao with shoots eaten by rabbits.




*Photos: John Ogden*

The outer dunes carry a sparse vegetation of Spinifex (*Spinifex hirsutus*) and pingao (*Desmoschoenus spiralis*) , with coastal bindweed (*Calystegia soldanella*), shrubby tauhinau (*Cassinia leptophylla*), pohuehue (*Muehlenbeckia complexa*) and sand coprosma (*Coprosma acerosa*) further back. At Kaitoke there are areas of marram grass (*Ammophila arenaria*) planted in attempts at stabilisation. The rare grass *Austrofestuca littoralis* also occurs on the eastern dunes. As dunes move inland they leave sand-flats, where the sand is deflated to the level of the local water-table. These flats are frequently flooded, and carry wetland vegetation, such as the *Selliera* dominated swards mentioned earlier or salt meadow species. At Awana, southern Kaitoke and Medlands the coastal dune is broad and sand-flats are absent. Here the landward side of the dunes has been cleared of pohuehue and invasive lupines, and is now developed for grazing or housing.

**Other coastal communities**

A rare plant community referred to as 'Stream mouth herb fields' has been described from the north-east Coast of Great Barrier Island (Wright & Cameron 1988). This comprises a low turf including such rarities as *Fuchsia procumbens, Ophioglossum peltatum, Leptinella dioica* and *Plantago raoulii*. This community is of limited extent and is currently threatened by the spread of large weeds such as pampas.

## Summary - Vegetation

**The scrublands**

- Fifty four percent (54%) of the land area of Great Barrier Island is currently covered in ‘scrub’, composed predominantly of manuka and kanuka.
- Manuka is mainly on poorer soils on ridges (and in swamps), while kanuka is on better soils in mid-slope situations.
- Kanuka, coming into the succession later and living longer, replaces manuka over time in most situations.

**Invasion by woody weeds and increased risk of fire**

- On degraded soils on ridges manuka height growth is slow (c. 5 cm/year), allowing invasion by exotic woody weeds, such as gorse, pines and hakea.
- Invasive woody weeds are adapted to fire and are highly inflammable, thus greatly increasing the fire risk. Fire reduces soil nutrients and vegetation cover, allowing more invasions by woody weeds, thus further increasing fire-risk in future. This is a ‘positive feedback loop’ in which fires become more frequent as the vegetation degrades and soil nutrients are lost.
- The differentiation of soil depth, fertility and moisture-holding capacity between ridges and gullies, and hence the vegetation pattern, has been accentuated by fires, which have been more intense and frequent on north-facing slopes and ridges, causing nutrient loss and soil erosion there.

**The kanuka – mature forest transition**

- Kanuka stands gradually thin out, and mature stands (70 – 100 years), are colonized by longer-lived canopy trees.
- The species colonizing kanuka are mainly broadleaf tree species, palms and tree ferns on better soils, and mainly conifers (kauri and tanekaha) on poor ridge-top soils.
- Using transition matrix techniques, the ‘successional’ change from kanuka dominance to more varied broadleaf forest in future has been demonstrated at both Glenfern Sanctuary and Windy Hill.
- The positive-feedback system (Fig 9.12), in which fire leads to progressively more fire-prone vegetation and the elimination of the broad-leaved forest tree species, implies that the prevention of fire for a century or more is necessary for a return to the original forest on areas currently in scrub.

**Kanuka and Carbon sequestration**

- Kanuka stands older than c. 30 years sequester 9 – 10 tonnes $CO_2$ equivalent/ha/annum.
- Kanuka has a variety of economic values, including firewood and honey production, but carbon sequestration may become significant in future.

**Broadleaf forests**

- Broadleaf and broadleaf-conifer forest types cover c. 25% of Great Barrier Island, with species composition varying according to altitude, topography, soil fertility, and successional status (time since last major disturbance).
- The mixed broadleaf forest below 200m altitude has largely been destroyed or altered and is now in kanuka scrub; otherwise species diversity is greatest in the lowland forest and generally declines with increasing altitude.

- The forest pattern has been described in the Te Paparahi area, where three forest classes were recognised: conifer/hardwood forest, broadleaf forest and disturbed forest (including scrub).
- Within these classes, nine intergrading forest types were described on the basis of varying composition and dominance by kauri, tawa, kohekohe, taraire, kanuka and pohutukawa.
- Formerly lowland broadleaf forest formed a mosaic of varying composition, including the above species, nikau palms and tree ferns, and was widespread from sea-level to c. 400m, providing a model for the restoration of scrub and abandoned farmland.

**Kauri forest – an ecosystem at risk?**

- Kauri forest was formerly extensive over the central part of Great Barrier Island, but was largely destroyed by logging – which was the backbone of the economy until c. 1930.
- Current kauri ricker stands on ridges are largely regeneration following fires in the late nineteenth and early twentieth centuries
- A few unburned remnant stands of mature kauri remain, mainly near the summit of Hirakimata.
- In some cases these stands may be at risk from the spread of *Phyophthora* taxon *Agathis* (PTA)

**Vegetation of Hirakimata**

- A unique association of conifers and other tree species occupies the upper part of Hirakimata (above 400m), which appears to have been neither burned nor logged.
- The upper Hirakimata conifer forest is dominated by yellow silver pine, toatoa, kauri and Kirk's pine, and resembles forest which once covered larger areas of the North Island, and as such can be considered a 'relict' forest type.
- Several species of limited distribution, including two Great Barrier Island endemic shrubs, occur in this upper zone of Hirakimata.

**Historical influence of fire – erosion and Eutrophication**

- There have been two major periods of forest destruction by fire: the first was c. 700 years ago, soon after Maori arrival on Great Barrier Island, while the second corresponded with early European land clearance for farming, mining and kauri logging.
- Soil and nutrients eroded from upper slopes accumulate in valleys, swamps and estuaries, causing sedimentation and eutrophication (fertilization) of water bodies.

**Vegetation of the coastal cliffs**

- Coastal forest is characterised by pohutukawa (*Metrosideros excelsa*), nikau palm (*Rhopalostylis sapida*), taraire (*Beilschmeidia tarairi*), kohekohe (*Dysoxylum spectabile*), broad-leaved tawa (*Beilschmeidia tawaroa*), and puriri (*Vitex lucens*), with a high diversity of associated sub-canopy trees, climbers and shrubs.
- Coastal communities have been extensively changed through extensive browsing by goats and the elimination of sea-bird (petrel and shearwater) colonies and fire, leading to loss of soil nutrient input and erosion.

**Herbaceous vegetation types**

- Herbaceous vegetation types, including on dunes, wetlands and alluvial flats, cover c. 11% of Great Barrier Island.

- Most herbaceous vegetation is either on coastal land formed since sea-level stabilisation c. 6000 years ago, or else on lower slopes cleared of forest cover by Europeans.

**The wetlands**

- Patterns of vegetation zonation on the largest freshwater swamp (Kaitoke), and at Whangapoua estuary, reflect historical increases in sediment and nutrient input, as a consequence of fires and forest clearances generated by human activities in the surrounding catchments.
- Eight intergrading plant communities have been described from Whangapoua estuary, dominated respectively by: mangroves (*Avicennia marina*), sea-rush (*Juncus krausii*), oioi (*Leptocarpus similis*), Baumea (*Baumea juncea*), manuka (*Leptospermum scoparium*), tangle fern (*Gleichenia dicarpa*), raupo (*Typha orientalis*) and Cabbage trees (*Cordyline australis*). The first four communities above are tidal to varying degrees, while the last four are freshwater.
- The composition of the freshwater plant communities is largely dependent on the nutrient content of the water input; where this is mainly from rainfall (rather than stream flow) acidic conditions develop leading to peat deposits and 'oligotrophic' plant communities (e.g. tangle fern).
- Extensive Raupo expansion indicates increased fertility ('eutrophication') through fire and fertiliser use in the catchments.
- Swamp forest, dominated by kahikatea (*Dacrycarpus dacrydioides*) has been almost eliminated from Great Barrier Island by fire and drainage.
- Drainage of the rear-dune swamps created most of the alluvial flats. Continued peat oxidation and drainage has further lowered the surface of these flats, which are now mostly close to sea-level and vulnerable to flooding after heavy rain.

**The coastal dunes**

- Sand-dunes are a feature of the eastern coastline. They comprise the dunes themselves, and the intervening 'flats', where sand is ablated by the wind to the average level of the water-table. Consequently these flats are often flooded in winter, and carry some wetland species.

**Other rare plant communities**

- The stream-mouth herb fields of north-eastern Great Barrier Island contain some rare plant species which are currently at risk from introduced weeds.
- In some locations mobile dunes have spread inland during historic times as a consequence of vegetation destruction through changes to the water table and grazing, and some of these areas have been planted with marram grass and pines.
- Areas of truly natural vegetation are now almost absent from the dunes, which have been highly modified by grazing (especially by rabbits) and introduced weeds.
- The vegetation sequence from Spinifex (*S. hisutus*) and Pingao (*Desmoschoenus spiralis*) on the fore-dunes, to the shrubby cover of the rear-dunes can be seen at Whangapoua and the northern end of Kaitoke beach.
- Pingao appears to be at serious risk of elimination unless rabbit control is continued at a high level.
- The rare grass *Austrofestuca littoralis* still occurs on the eastern dunes.

i From data in Landcare Database-2.

ii This scheme is currently being reviewed.

iii Lyttle, R. J. 1953. *Report on tea-tree – Great Barrier Island. Ranger's Proficiency Course No. 2. Auckland Conservancy* A1164554. Obtained from Dept. of Conservation, Port Fitzroy.

iv Landcare carbon-calculator: www/landcareresearch.co.nz [home>services>carbon-calculator].

v Trotter, C. *et al 2005 Afforestation*/reforestation of New Zealand's marginal pastoral lands by indigenous scrublands: potential for Kyoto forest sinks. *Annals of Forestry Science* 62: 865-871. / Walcroft, A. et al. 2002. Biomass accumulation in young regenerating scrubland ecosystems on marginal pastoral farmland. *Landcare Research Contract Report LC 0102/121. June 2002.* Pp. 16.

vi Wright, A. E. & Cameron, E. K. 1985. Botanical features of north eastern Great Barrier Island, Hauraki Gulf, New Zealand. *Journal of the Royal Society of New Zealand* 15(3):251-278./ Eadie, FM; Broome, KG. 1990. Ecological Survey of Northern Bush, Great Barrier Island 1986/87. *Auckland Conservancy Technical Report Series No. 4*. Department of Conservation. Pp 86.

vii Ibid

viii The authors recognize nine vegetation types, and these were apparently marked onto an NZMS 270(1:25,000) topographical base map, although this map has not been located.

ix Called kanono by Eady & Broome (1990); Fig 9. 6.

x Ogden, J. & Stewart, G. H. 1995. Community dynamics of the New Zealand conifers. In: Entight, N. J. & Hill, R. S. (Eds.).Pp.81-119. *The Ecology of the Southern Conifers*. Melbourne University Press.

xi Eadie, FM; Broome, KG. 1990. Ecological Survey of Northern Bush, Great Barrier Island 1986/87. *Auckland Conservancy Technical Report Series No. 4*. Department of Conservation. Pp 86.

xii see: www.kauridieback.co.nz

xiii Atkinson, I. A. E. 2004. Successional processes induced by fires on the northern offshore islands of New Zealand. *New Zealand Journal of Ecology*, 28(2): 181- 193.

xiv Ogden, J., Deng, Y., Horrocks, M., Nichol, S. & Anderson, S. 2006. Sequential impacts of Polynesian and European settlement on vegetation and environmental processes recorded in sediments at Whangapoua Estuary, Great Barrier Island, New Zealand. *Regional Environmental Change* 6: 25-40.

xv Perry, G. & Ogden, J. 2005-2008. Unpublished data. In preparation

xvi Davy, L. 2009.(Forest structure and rat population dynamics at Windy Hill, Great Barrier Island). Unpublished MSc. Thesis. University of Auckland.

xvii A further community, comprising a low growing sward of *Selliera radicans, Samolus repens* and was recognised by: Cameron. E K. 1999. Botany of the Whangapoua wetlands and dunes, northeastern Great Barrier Island. *Journal of the Auckland Botanical Society* 54: 56-6

xviii A stiff blue-green rush-like plant with no common name. See Fig. 9.11.

xix Pegman, A. P. McK. & Ogden, J. 2006. Productivity-decomposition dynamics of *Baumea juncea and Gleichenia dicarpa* at Kaitoke Swamp, Great Barrier Island, New Zealand. *New Zealand Journal of Botany* 44: 261-271.

xx

xxi Based on: Deng, Y., Ogden, J., Horrocks, M., Anderson, S. & Nichol, S. L. 2004. The vegetation sequence at Whangapoua Estuary, Great Barrier Island, New Zealand. *New Zealand Journal of Botany*.42**:** 565-588

xxii Eutrophication is the process of increasing nutrients (fertility) in swamps and other water bodies. The other extreme, when nutrients are depleted, creates 'oligotrophic' swamps.

xxiii Ogden, J. & Caithness, T.A. 1982. The history and present vegetation of the macrophyte swamp at Pukepuke Lagoon. *New Zealand Journal of Ecology* 5: 108 - 120.