Wetland processes and data storage, with particular reference to Great Barrier Island

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Abstract
The wetlands of New Zealand are diverse ecosystems which have suffered massive decline due to man's activities. Much of this (e.g. drainage) has been obvious and intentional, but some, such as increased sedimentation rates following forest clearance, has been long-term and insidious. These processes are described with examples from Great Barrier Island. I emphasise the role of wetlands as systems which store environmental data about the past and integrate processes from whole catchments. Hydroseral succession and the development of raised bogs are described, and a few important terms explained. The abundance of wood in bogs in New Zealand is noted and its significance as a climatic data store referred to. Rates of sedimentation and peat accumulation are presented. At Whangapoua estuary, mangroves (*Avicennia marina*), are succeeded by open herbaceous communities (salt meadow) at their landward edges. The succession from open seawater, through mangroves and salt meadow to oligotrophic manuka (*Leptospermum scoparium*) swamp is described. Eutrophic communities, mostly dominated by *Typha orientalis*, occur in the fresh-water streams feeding into the system. The significance of *Baumea juncea,* as a switch plant, facilitating the transition from marine to freshwater communities is emphasised.

Keywords: Lucy Cranwell, succession, hydrosere, Whangapoua, Great Barrier Island, peat accumulation, carbon sequestration, sedimentation, forest clearance, catchment dynamics.

Introduction
This article is based on the Lucy Cranwell Lecture "Coastal Wetlands on Great Barrier Island" delivered on 7th October 2009 at the Auckland Museum by the author. Parts of it are also based on the Great Barrier Island State of Environment Report (2010), which can be accessed on line at: www.gbict.co.nz. Lucy Cranwell was a pioneer in the science of palynology in New Zealand (Anon 2000, Cameron 2000), and she is commemorated in the Auckland Botanical Society through the Lucy Cranwell Student Research Fund to support student botanical research, and annually, the Lucy Cranwell Lecture.

The wetland ecosystems of New Zealand are diverse in form and vegetation cover; a whole book has been devoted to their classification and description (Johnson & Gerbeaux 2004). Even the useful summary by Hunt (2007: p.21-25) covers four pages. This article will not get bogged down in this typology, but rather it will attempt to outline the main processes common to most wetlands and explain some of the rather obscure terminology (see also: Johnson & Brooke 1989: p.5). I emphasise the importance of wetlands as systems which store environmental data about the past, integrating processes from whole catchments. Examples are drawn from fieldwork on Great Barrier Island.

One of the main reasons for the increased interest in wetlands in recent years has been the realisation that vast areas of wetland have disappeared as fertile lowlands have been cleared, drained, and burned to produce productive farmland. It is generally accepted that less than 10% of the wetlands present when Europeans arrived here, remain today. Wetlands continue to be drained, filled in, or 'reclaimed' to extend areas for agriculture, housing, rubbish dumps and golf courses. For example, in the recent amendments to the 2006 District Plan (Hauraki Gulf Islands Section), there were twelve submissions involving wetlands (Land Unit 4) on Great Barrier Island. Of these, ten were reclassified, usually (eight cases) as 'alluvial flats' (Land Unit 3). While some of this was correcting earlier misclassification, in most cases it effectively removed the wetland from protection against further drainage and development. With this loss goes loss of habitat for plants, native fishes, invertebrates and birds. For example the bittern (*Botaurus poiciloptilus*) has probably become 'extinct' as a breeding bird on Great Barrier since the 1990s, although individual birds are still seen every year.

Wetlands as parts of a catchment

Wetlands cannot be treated in isolation; they are part of the hydrologic cycle of the catchment in which they occur. To this extent they reflect changes occurring in that catchment, and they faithfully record most of these events in sediments. The low-lying coastal areas of eastern Great Barrier, comprising the environs of Medlands, Claris, Awana and Whangapoua estuary, are farmed (Fig 1). The soils are mostly dune sands, or drained peaty soils derived from wetlands. Although these landforms have different vegetation covers, they 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 and barrier dune systems 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 in-filled with fine sediment and peat deposits, creating rear-dune swamps. The drainage of these wetlands last century created most of the alluvial flats now used for farming. Because the ground-water level under the barrier dunes is related to the level of the rear-dune swamp, it follows that drainage or engineering works in one part of such a system can have unforseen consequences elsewhere. Dune destabilisation occurred on Great Barrier following swamp drainage. This also happened elsewhere in New Zealand, though due possibly to the long lags in time as the landscape re-adjusted to the changed hydrology, this linkage seems to have rarely been appreciated.

Common processes

All wetlands are temporary; they are being gradually filled with sediments. While this may take centuries or longer for big lakes, it occurs quite rapidly in small shallow water bodies. Lake in-fill has two main components – allogenic and autogenic. The former refers to the physical input of material from the surroundings – sedimentation. Autogenic means the biological factors which cause infilling, generally referred to as plant succession. Plant successions occur on a variety of open substrates; that occurring in wetlands is often called a 'hydrosere' (Fig. 2 (a)).

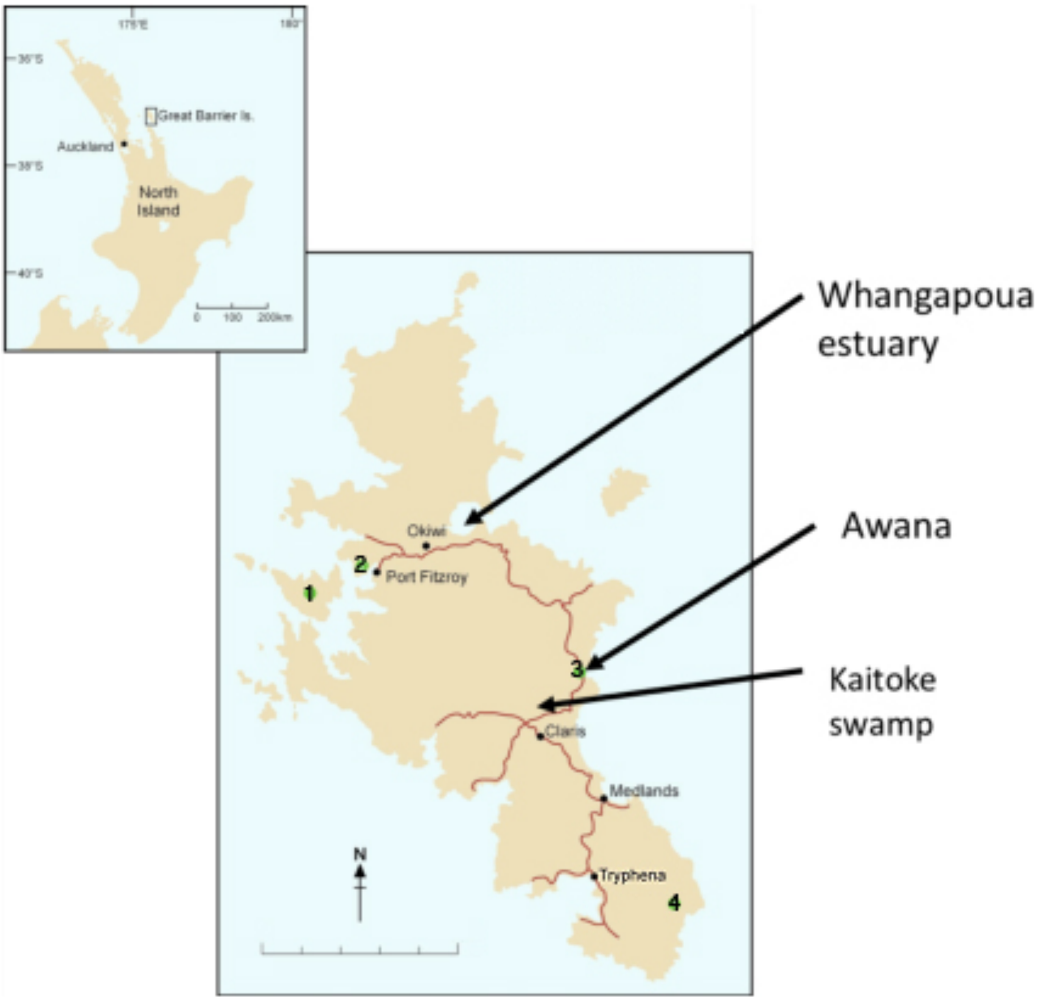

Fig. 1. Map of Great Barrier Island showing places mentioned in text and main areas of swamp, or former swamp. 1. Motukaikoura Island Trust, 2. Glenfern Sanctuary Trust, 3. Awana Catchment Trust, 4. Little Windy Hill Catchment Trust.

Classical hydroseres begin with plants mostly floating on the open water (or growing on the bottom in shallow clear lakes). Water lilies (*Nuphar* spp. and duck-weeds (*Spirodela* and *Lemna* spp.) are the common examples. This phase is followed by rooted plants, often with very different submerged, floating and emergent leaves (e.g. some native and introduced *Ranunculus* spp.). As sediments build up bigger leaved emergent plants dominate (e.g. *Carex* spp., *Typha orientalis, Phormium tenax*). Eventually native shrubs and trees become established, such as cabbage trees (*Cordyline australis*) , swamp maire (*Syzygium maire*) and kahikatea (*Dacrycarpus dacrydioides*). The process, or some parts of it, can be very rapid. For example at Pukepuke Lagoon in the Manawatu dune lakes, 90% (142 ha.) of the open-water area was lost between 1872 and 1968, and in the latter year *Typha* was gaining nearly 1 ha per year of the 15 ha remaining (Ogden & Caithness 1982).

Although allogenic and autogenic inputs will vary considerably between situations, there is a general tendency for the former to be gradually replaced by the latter as the succession proceeds. However, when catchment changes cause increased flooding and sediment input into swamps, the successional process is altered, and may be reversed. The relatively recent spread of *Typha* at Kaitoke Swamp (and in many other swamps in New Zealand) seems to be an example of just such a reversal due to increased flooding and nutrient input following deforestation and burning.

Growing as they do in full sunlight and with abundant supplies of moisture and nutrients, many early successional swamp plants are highly productive. For example, *Typha* at Kaitoke Swamp, and in the Manawatu, produces up to 3 m.tons.ha^{-1} of dry matter per annum (Pegman & Ogden 2005, 2006). In still water oxygen is rapidly depleted by the growth of microscopic plants, tiny invertebrates and bacteria, so that not all the plant material reaching the surface each year can be decomposed and this accumulates beneath the water. Once a former lake basin is filled with sediments and undecomposed plant material, parts of it may no longer regularly receive water (and nutrients) from the incoming streams. These areas are usually near the centre of the system, which consequently becomes depleted in nutrients and develops a new flora, more able to cope with the low nutrient conditions. This can rapidly create a 'positive feedback' loop, because these low-nutrient tolerant ('oligotrophic') species continue to add plant material to the surface, which consequently builds up and becomes even more isolated from the nutrient-rich input water. Eventually the surface forms a 'raised bog', built up of semi-decomposed plant material ('peat'), receiving distilled water (rain) only. This change in surface form tends to displace the input stream to a marginal positional, called a 'lag stream'. Consequently, acidic peat bogs may be circled by more diverse and nutrient rich areas, sometimes called 'fens'.

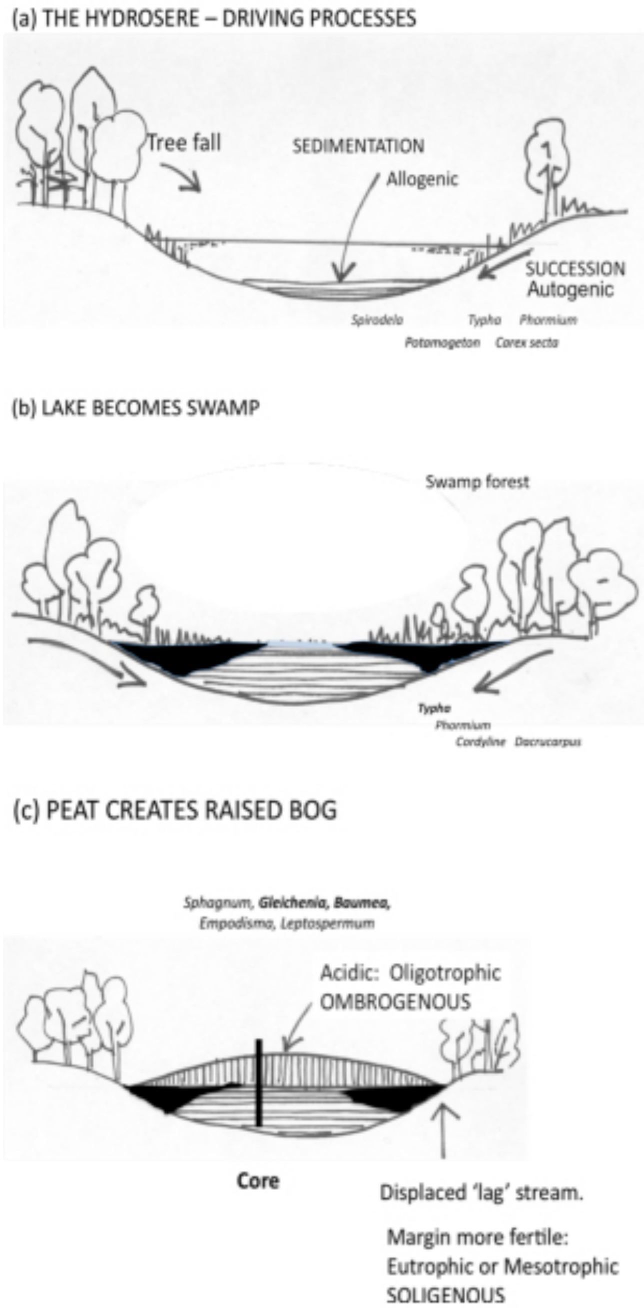

Fig. 2. Diagram showing the processes of hydroseral succession and the formation of raised bogs. Horizontal lines indicate mainly allogenic sedimentation, black mainly autogenic. Vertical stripes indicate the growth of the raised ombrogenous bog.

Acidic peat bogs are also called 'ombrogenous' bogs; in New Zealand they are often dominated by *Sphagnum, Empodisma* and *Gleichenia*. On Great Barrier Island there are no true raised bogs, but the beginnings of the process are evident. Manuka often colonises such areas, forming a low 'shrub bog' with *Gleichenia, Baumea* spp., and *Tetraria capillaris*. These areas are acidic, usually with a pH below 5. Less acidic bogs, regularly flooded by nutrient rich water bearing inorganic sediments from the surrounding catchment, are said to be 'soligenous' or ‘eutrophic’, with a pH usually above 5. (Fig. 2c). Intermediate conditions (‘mesotrophic’) occur of course, and indeed the main characteristic of swamp systems such as Kaitoke is that they are dynamic, constantly changing in species composition as the hydrologic characteristics of the input streams vary in response to man-made or natural changes in the catchment.

Rates of sediment and peat accumulation.

Studies at Whangapoua estuary indicate that rates of sediment accumulation (allogenic input) are strongly dependent on the forest cover of the catchment. During the early phase of Maori occupation (see below) sediment input more than doubled from c. 0.5 to c. 1.0mm. yr^{-1}. About 48% of this accumulation was organic matter due to plant succession. Later, European forest clearance probably resulted in sediments trapped in the surrounding freshwater swamps moving into the estuary, causing further sediment build up and accelerating the spread of mangroves (Ogden et al. 2006). During European times about 54% of the sediment was organic matter, as expected from the increased autogenic input as succession proceeded.

Peat accumulation was studied at Kaitoke swamp by Pegman & Ogden (2005, 2006). Annual productivity ($Kg.m^2$. yr^{-1}) was estimated by sequential harvests and weighings of all parts (including underground roots and rhizomes) of *Typha, Gleichenia* and *Baumea* growing in pure stands. This enabled the amount of dead material added to the swamp by these species to be estimated. The amount actually accumulated as peat was obtained by placing known dry weights of the different plant material in plastic mesh bags, above, on, or beneath, the swamp surface. These samples were collected and reweighed after varying lengths of time. The results (Table 1) clearly show that, although the eutrophic *Typha orientalis* is by far the most productive, oligotrophic species such as *Baumea juncea* and *Gleichenia dicarpa* contribute far more to peat accumulation. Nearly three-quarters (72%) of the annual productivity of *Baumea juncea* in the stands studied remained in the system as peat.

Species	Productivity $kg.m^2.yr^{-1}$	Peat accumulation $Kg.m^2.yr^{-1}$	% Annual productivity added to peat after 8 years
Typha orientalis	3.0	0.19	6.5
Baumea juncea	1.4	0.99	72.0
Gleichenia dicarpa	0.5	0.22	43.0

Table 1. Productivity and peat (dry matter) accumulation rates on Kaitoke Swamp. Decomposition is predicted to be so slow as to be effectively zero after eight years. (after Pegman & Ogden 2005. 2006).

Peat may accumulate in swamps for thousands of years, suggesting that swamps are good at storing carbon over long periods – much longer than trees. For example, using the rates in Table 1, a pure stand of *Baumea juncea* would sequester the equivalent of 18.4 tonnes of CO_2 per year. For comparison, the best estimate of carbon sequestration for (70 year old) kanuka (*Kunzea ericoides*) forest on Great Barrier Island is 15.0 tonnes CO_2 equivalent per year, and the overall average for this type of forest, c. 8.9 tonnes (Ogden & Westbrooke 2010).

Wetlands as data-storage systems

The mainly inorganic sediment in a lake basin, or the peat of a raised bog, accumulates year by year. Various biological materials may be deposited and preserved in such situations, where they can be dated relatively by depth, or absolutely by techniques such as radio-carbon dating. Thus wetlands store information about the surrounding environment. One of the most remarkable of these data stores is plant pollen, and it’s study comprises the science called palynology, pioneered in New Zealand by Lucy Cranwell. Palynology works because (1) most plants produce large quantities of pollen; (2) the cell wall of the pollen grain is almost indestructible; (3) the cell walls of different species (or genera) of plants are usually quite different, so that they can be identified. Thus it is possible to extract pollen from peat samples, identify it and quantify it - i.e. count the relative proportions of different species. While there is more to it than that (!) it is generally possible to reconstruct the composition of the surrounding vegetation, and that on the swamp surface, at different times in the past, from the pollen preserved in the sediments.

Sediments are usually sampled using some type of device which extracts a core, which can then be examined for sediment changes and volcanic ashes, sampled for pollen (and other preserved material), and radio-carbon dated. Numerous such core samples have been taken from swamps on Great Barrier Island, and considerable detail about the last 6000 years of vegetation change has been gathered (Horrocks et al. 1999, 2000a, b, 2001; Deng et al. 2004, 2006a,b). In almost all these cores the biggest change in species composition occurred about 700 years ago, coincident with the arrival of Polynesian (Maori) people (Wilmshurst et al. 2008). This 'signature' in the pollen record comprises a dramatic fall in the pollen of tree species, coincident with an equally dramatic increase in microscopic charcoal particles, bracken spores and grass pollen. This clearly indicates forest destruction by fire, and the spread of bracken fern and herbaceous plants (grass) in a more open environment. It is accompanied by an increase in sedimentation rate (e.g. at Whangapoua estuary; Ogden et al. 2006) as run-off increases. European arrival on Great Barrier is indicated by the presence of exotic pollen (*Plantago, Betula, Taraxacum*) in the upper layers, and another phase of sediment increase as the landscape was logged and cleared for farming.

Wood in Swamps

In New Zealand the end product of hydroseral succession, even on ombrogenous bogs such as Pakahi in Westland, seems to be some form of scrub or forest cover. Consequently many older bogs have a significant amount of wood preserved in them. This is particularly evident in the 'kauri swamps' of Northland, where huge logs of ancient kauri are preserved in swamps. Many of these pre-date the last Glacial period, although those in the Waikato lowlands mostly represent the time of rapid sea level rise in the early Holocene (Ogden et al. 1992). Kauri trunks have in some cases been added to such swamps due to falling in from the margins (e.g. Trig road swamp; Ogden et al. 1993) , but in other cases the trees must have been growing on the swamp surface during a period in which it was firm enough to hold them (D'Costa et al. 2009a,b). Whichever is the case, it is evident from the quantity of trunks in some swamps that falling trees represent a substantial addition of organic matter, and may be responsible for most of the peat build-up in some cases. While tree-fall may constitute a complicating factor in the interpretation of the stratigraphy, the trees themselves store important information in their annual rings. This study is called dendrochronology and it has led to considerable understanding of past climates, because the information is stored in an annual format which can be correlated with present day climatic parameters and, in principle, dated exactly (e.g. Turney et al. 2007, 2010).

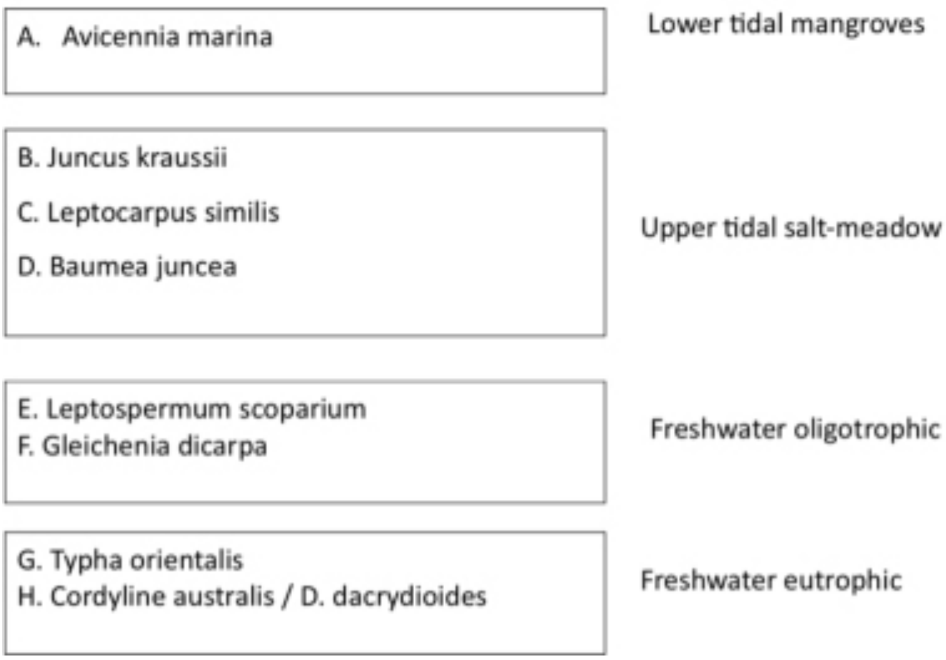

Fig. 3. The main zonal communities recognised by Deng (2004) at Whangapoua estuary.

Succession on Whangapoua estuary

The vegetation pattern and succession at Whangapoua estuary has been described in detail by Cameron (1999), Deng et al. (2004, 2006a, b), and is reviewed in the Great Barrier State of Environment Report (www.gbict.co.nz).

In a classic hydrosere, the different groups of plant species follow each other sequentially, gradually extending inwards across the former water surface as it shallows. Consequently the succession is visible as a series of concentric vegetation zones. An aerial view of the Whangapoua estuary, or a lateral one from Mabey Road, clearly shows such a pattern of zonation: inner mangroves give way to a salt meadow area of 'rush-like' plants, which in turn grade into a manuka canopy with *Gleichenia dicarpa* and *Tetraria capillacea* below. Even further back, where the fresh water streams enter, there are swamps with *Typha orientalis, Carex* spp., and *Cordyline australis*. Some of these have narrow borders of kahikatea (*Dacrycarpus dacrydioides*).

There were three stages to Deng's (2006a,b) research. The first was to describe the pattern of zonation as objectively as possible using numerical techniques of classification and ordination applied to vegetation composition data from plots, placed along transect lines across the swamp. This established that eight main plant communities – dominated by particular species – could be recognised (Fig. 3; small areas of other communities recognised by Cameron (1999) were not included). These eight could be further grouped into four categories, two of which represented the marine tidal system. Within the upper tidal salt meadow community the proportions of *Juncus kraussii, Apodasmia similis* and *Baumea juncea* shifted, with the latter at the landward edge and consequently flooded only briefly at high tide. The other two main categories were dominated by freshwater inputs and rarely invaded by the sea. In this pair, the distinction seemed to be between the more oligotrophic central estuary area, and the eutrophic marginal swamps in the shallow valleys feeding the estuary. The second stage of the work was to establish that the 'pollen rain' sampled from mud or soil surfaces in the vegetation plots actually reflected the vegetation growing on them. This was

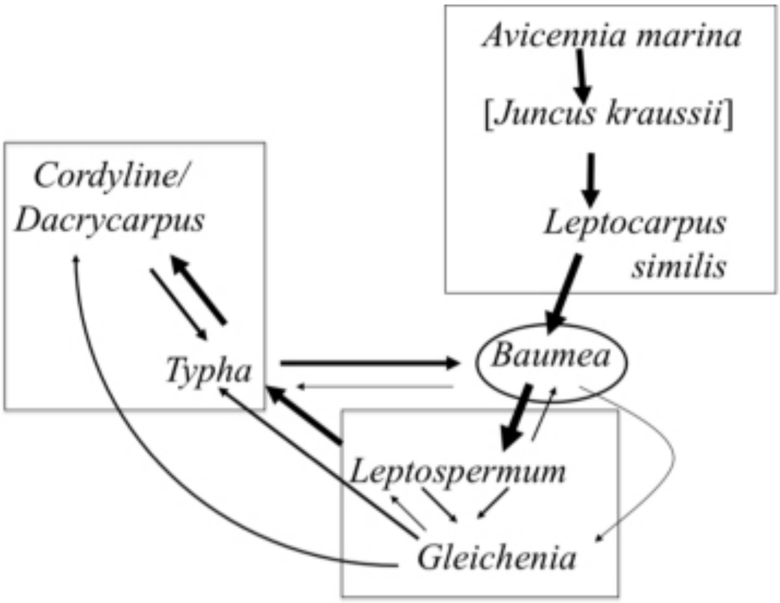

Fig. 4. The successional pathways at Whangapoua. Arrow thickness is approximately equivalent to the probability of transition from one state to the next. Note that the *Juncus krausii* stage is inferred from the existing vegetation because the pollen of this species is not well preserved. *Baumea* is circled to indicate its pivotal role in the transition from marine to fresh-water communities.

necessary because different plant species produce vastly different amounts of pollen, so that it is necessary to 'calibrate' the pollen input against the actual vegetation in order to interpret the preserved pollen proportions. In this case the pollen always reflected the vegetation from which it originated, so that the sedimentary sequence could be interpreted with confidence.

To ascertain that the vegetation zonation did indeed reflect a temporal succession cores needed to be taken. It was anticipated that cores in the supposedly older part of the system (further back) would show evidence of earlier successional stages with depth. Consequently the third stage of the research was to take cores from different places throughout the estuary and marginal swamps, plot their pollen profiles and get them dated. A total of eleven cores were taken, giving a good picture of the overall vegetation change.

The main result from this was to demonstrate that, at Whangapoua, unlike Kaitoke (Horrocks 2000b), the main infilling phase dated from the arrival of people c. 1280 AD. Before this most of the current flat land area of the estuarine swamp was tidal. The sequence of vegetation colonisation, occurring as infilling proceeded, is represented by peaks in the abundance of different pollen types with decreasing depth in the cores. The sequence was as anticipated in most cases: marine silt with shells, representing open sea water at the base of the core, followed by peaks in the pollen of *Avicennia, Baumea, Leptospermum* and finally *Typha* and *Cordyline,* or traces of *Dacrycarpus* pollen near the surface. However, not all cores showed this exactly, and there were indications of 'reversals' in some cases. This variation between the sequences allowed the construction of a 'transition matrix' showing the number of times any one vegetation type appeared to be followed by another. This, represented in Fig. 4, is a more realistic way of understanding the successional process on the estuary, which is 'linear' only in the early marine stage, and becomes progressively more variable as species diversity and environmental heterogeneity increase through time. Of course this is still going on, and at quite a rapid rate at present to judge from mangrove spread visible from old aerial photographs.A point worth noting is that the transition from the 'marine' to the 'freshwater' part of the succession is represented in the sediments by a rather sudden break in sediment type, and a hiatus in time. This is because between the two there is the tidal phase, during which sediments may be eroded or disturbed. Because mangrove (*Avicennia*) pollen is quite sparse even under mangroves, the results do not add much to the chicken/egg debate about the role of mangroves in the infilling of estuaries. However, it is clear that the mangroves do not *create* fine inorganic sediment, which must come into the system from elsewhere. It seems likely that they will reduce water movement, thus increasing sediments deposition. But it should be noted that, in the normal course of events, open salt meadow will eventually spread out into former mangrove areas. The rate of such change will vary in different situations, and has not been measured on Great Barrier. Key plants in the transition from the marine (mangrove) to freshwater phase are *Apodasmia similis* and *Baumea juncea*. The latter especially appears to be very tolerant of widely different hydrologic conditions, and annually produces much dead matter, which is not readily decomposed. Thus, this species may be a fundamental 'switch' plant, which, by adding organic matter raises the soil above normal tide level, facilitating the transition from a marine to freshwater system.

Where to see it

The zonation on the Whangapoua swamp can be seen from Mabey Road, but getting into the swamp from there is difficult and requires permission to cross private farmland from the Mabey family. Access to the mangroves (and the remainder with persistence) can be obtained also from the Okiwi spit, or the Okiwi campsite, both managed by the Department of Conservation. The easiest access to Kaitoke Swamp is along the hotsprings track which traverses the inland edge of the swamp. Many interesting plants can be seen along this track, including at least five species of *Baumea*! The Kaitoke swamp can also be accessed from the Whangaparapara Road, which follows a changing vegetation sequence from oligotrophic swamp with *Gleichenia, Leptospermum* and *Baumea* (near the golfcourse) to soligenous swamp forest with *Typha orientalis, Phormium tenax*, *Freycinetia banksii, Cordyline australis* and *Dacrycapus dacrydioides* at the start of the hotsprings track. From the road there is a lag stream and head-high *Bulboschoenus fluviatilis, Typha*, and *Calystegia sepium* to get through. The 'marine end' of the sequence (with *Juncus kraussii*, *Apodasmia similis, Plagianthus divaricata,* etc.) can be viewed at Kaitoke bridge on the road from Claris to Awana. For accommodation on Great Barrier check out: www. Greatbarrier.aucklandnz.com.

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Field Trip Report: Marie Neverman Reserve, South Head, 15 May 2010

Kristy Hall

Attendees: Ewen Cameron, Lisa Clapperton, Steve Cook, Bev Davidson, Geoff Davidson (leader), Oscar Grant, Simon Grant, Kristy Hall, Peter Hutton, Helen Lindsay, James Luty, Sandra Maclean, Christine Major, John Millett, Colleen Newton, Juliet Richmond, Josh Salter, Claire Stevens, Val Tomlinson, Mike Wilcox, Maureen Young.

The motivation to visit Marie Neverman Reserve was provided by Geoff Davidson, one of our members and a trustee of the NZ Native Forests Restoration Trust (NZNFRT). In 2009 the Trust purchased 22.3 ha of land at Tupare, a lifestyle block subdivision located on the South Kaipara Peninsula near Shelly Beach. This was the first purchase by the Native Forest Restoration Trust in the Auckland region.

The original 22.3 ha property consists of 8 ha of pasture with 14 ha of lake and wetland. The purchase of the site, previously known as Leighton's Dam or Tupare Swamp was made possible by bequests and donations to the Trust. The reserve was named after the late Marie Neverman, who hoped that her bequest could be used to preserve bird habitat within the Auckland or Gisborne regions where she had lived and worked. The Trust was also looking to protect more areas of wetland, and as the property was identified by the Ornithological Society as significant habitat for wetland birds, this was a perfect fit. The total purchase price was $1,050,000 involving more than $300,000 from Marie Neverman.

Following the original purchase, the Trust focussed on the adjacent 113 ha of poorly drained pasture scarcely above sea level that had the potential to connect the Marie Newman Reserve to the Kaipara Harbour. In addition to rank pasture, the site included areas of mangroves and saltmarsh, coastal vegetation of regional and national significance (Haggitt et al., 2008). The Native Forests Restoration Trust decided to purchase this neighbouring property and approached various organisations, including the Auckland Botanical Society, to support their cause. The property had already been protected by a Rodney District Council Conservation Covenant, which reduced the purchase price to a meagre $200,000. The purchase of this property was completed in July 2010, expanding Marie Neverman Reserve to a total of 135 ha.

Fig. 1. Marie Neverman Reserve includes a 14 ha man-made lake (right), 113 ha of former saltmarsh (background) as well as 8 ha of pasture Photo : Robin Kerr, Harcourts Real Estate, 15 May 2010.

A keen group of 21 turned out for the Auckland Botanical Society field trip on Saturday 15 May 2010. The weather was uncooperative, but as we were botanising a wetland in May, rain was not unexpected. The trip began around the western shores of the lake, a man made structure which has been formed by damming and digging out the upper reaches of Parekawa Creek. The reserve is home to many waterfowl, including threatened species such as bittern, dabchick and fernbird. Nest boxes have been erected to support the breeding success of grey duck,