| Journal of Coastal Research | 11 | 4 | 1294–1308 | Fort Lauderdale, Florida | Fall 1995 |
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# Infilling Rates of a Steepland Catchment Estuary, Whangamata, New Zealand

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**ABSTRACT**

SHEFFIELD, A.T.; HEALY, T.R., and McGLONE, M.S., 1995. Infilling rates of a steepland catchment estuary, Whangamata, New Zealand. *Journal of Coastal Research*, 11(4), 1294–1308. Fort Lauderdale (Florida). ISSN 0749-0208.

Apparent sedimentation rates for the Whangamata Harbour, a barrier-enclosed estuarine lagoon on the eastern Coromandel coast of New Zealand, were assessed from three cores taken at representative locations within the estuary. Palynology was utilised to interpret vegetation changes in the catchment during the last 6,000 years; $^{210}Pb$ dating was applied to the upper sediment layers to infer changes over the last 100 years, and $^{14}C$ dating of shell beds within the estuary was undertaken to obtain actual dates. Apparent sedimentation rates were found to have increased from 0.1 mm $yr^{-1}$ in pre-Polynesian times (~700 BP), to 0.3 mm $yr^{-1}$ evidently due to Polynesian agricultural practises. After the 1880's, rates increased dramatically to 11 mm $yr^{-1}$, which is attributed to European clearance of the relatively steep catchment, and more recently, the development and felling of commercial exotic forestry. Future rapid estuarine infilling may be offset by accelerated sea-level rise.

ADDITIONAL INDEX WORDS: *Estuarine sedimentation rates, $^{14}C$, $^{210}Pb$, palynology.*

## INTRODUCTION

The east Coromandel Peninsula exhibits a range of rapidly infilling estuaries (ABRAHAMSON, 1987), from some that are completely infilled as at Hotwater Beach and Opoutere to the north, to those that are in a lesser state of infilling as at Whangamata.

Whangamata Harbour is situated on the east Coromandel coast, 29 km north of the major port of Tauranga (Figure 1). The 3.8 km long Holocene sandy barrier spit encloses a small meso-tidal estuarine lagoon to the north which is connected to the sea by a narrow elongated entrance channel (Figure 2). The Holocene barrier dunes have been developed as a holiday resort village, typical of similar embayed barrier systems on this coast (HEALY and DELL, 1987). The Whangamata Harbour is a small estuary some 5 km long and 2 km wide, carved into a catchment of Miocene propylitised spheroidal rhyolites. The sub-catchments draining into the estuary cover some 56 km², with ridge elevations typically 300 m, rising to 690 m. Valley slopes are steep and easily erodible due to the weathered and hydrothermally altered regolith.

In the late 1980's, the residents of Whangamata expressed concern that extensive logging of exotic forests may have had detrimental effects on the estuary. Increased sedimentation may lead to a reduced tidal prism, thereby inducing further inlet instability and navigation problems near the entrance (SHEFFIELD, 1991). As Whangamata is a valued resort for recreational boating and commercial fishing, the stability of the tidal inlet entrance to the harbour is of considerable interest, as has been outlined in SHEFFIELD *et al.* (1991). Accordingly, the Whangamata Community Council initiated a study in 1989 to obtain baseline information against which to monitor future change.

The purpose of this paper is to review the factors affecting a barrier-enclosed estuarine lagoon surrounded by a steepland catchment and to report the variation in sedimentation rates in relation to catchment usage and historical environmental change in the course of the late Holocene.

*94193 received and accepted in revision 29 September 1994.*

## LAND USE CHANGES AFFECTING WHANGAMATA ESTUARINE SEDIMENTATION

When the early Polynesian (Maori) arrived in the Coromandel, the catchment consisted of coastal forest containing a great variety of trees and shrubs, but dominated by the podocarp rimu (*Dacrydium cupressinum*) (McGlone, 1983).

### Maori Settlement

Based on palynological evidence, it is believed that the first Maori people settled and cleared the Whangamata estuary area, like many other areas in the North Island; approximately 800–600 years ago (McGlone, 1983, 1988, 1989). Although it is feasible that the area was first occupied at some time between 1000 BP to 300 BP, artifacts found on the Coromandel coast date from the 12th–15th centuries (Easedale and Jacomb, 1982). Accordingly the age adopted during this study was 700 ± 100 BP. The Coromandel Peninsula was densely populated in parts by the Maori due to its abundant seafood, warm climate and long kumara (sweet potato) growing season. Archaeological investigations indicate a change in the cultural activities at Whangamata, reported by Harrison (1988) 'two strikingly different cultural layers stratigraphically separated by sterile sand. In each case the lower layer contained large flightless bird (moa) bones and archaic artifacts, whereas the upper layer consisted predominantly of lenses of concentrated bivalve shell (clam) midden of 19th century age at Whangamata and 17th or 18th century at the adjacent Tairua Harbour.'

While cultivation was restricted to the coastal fringe and generally had little impact on the forest of the Coromandel Ranges, flax (*Phormium tenax*) cutting was centered around coastal swamps. Agriculture was of the slash and burn type, where bush was cleared and trees felled in the winter, dried, and burned in mid-summer enriching the soil for kumara growing. After two years the ground was left to regenerate into fern for four years (Harrison, 1988). This practice prevented forest regeneration and resulted in the growth of secondary species such as bracken. Bracken root was a staple of Maori diet in nearly all areas of New Zealand.

### European Occupation—Kauri Logging, Gum Digging and Mining

In the 1880's, both the Otahu (Parakiwai) River to the south and the Wharekawa River to the north were used to float sawn logs to the coast. The Wentworth River, which enters the Whangamata estuary, was unsuitable for this purpose because of its waterfalls; hence the Whangamata Harbour did not experience the spasmodic flooding necessary to flush timber to the sea (Sale, 1978). Another activity affecting levels of sediment entering the harbour was mining. In 1887 goldmining commenced at the Goldwater claim on the Wairoa Stream, a small tributary of the Wentworth River, which was worked until 1909. At one stage 200–300 people worked at a site on the Wentworth River itself, until mining finally terminated in 1925. Early European occupation was a period of intense land use change, as the bush was cleared and burned. Sale (1978) noted that these activities, in conjunction with steep relief, high annual rainfall and vulnerability of the land to erosion, resulted in severe soil erosion problems.

In 1916 extensive clearing of vegetation around

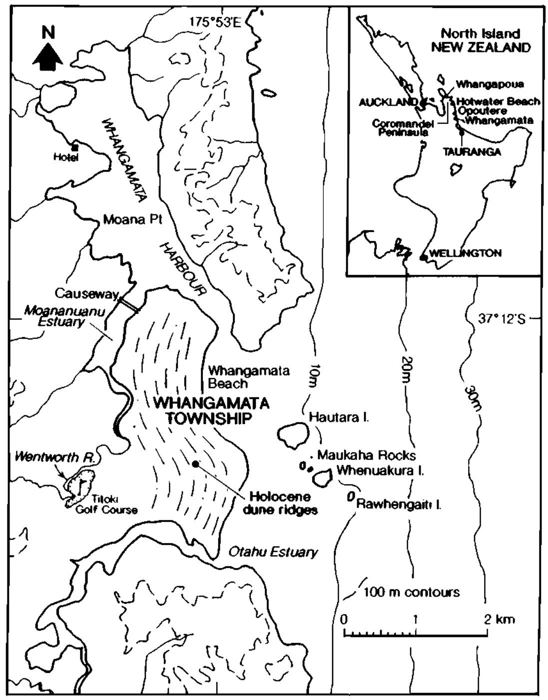


Figure 1. Whangamata, located on the eastern Coromandel, New Zealand, consists of a series of low Holocene barrier dune ridges, formed by wave action into a cuspate foreland in the lee of Hauturu Island. Only a small part of the catchment is represented on the map.

Figure 2. An oblique view to the south of the Whangamata Harbour.

the Whangamata estuary for sedentary farming began. An early resident, Norman Palmer, stated in his journal: 'The disadvantages of the Whangamata district were poor access and heavy rainfall. After clearing, heavy rain on the steeper country brought down slips and caused erosion. It also leached out of the soil nutritional elements which were either washed out to sea or deposited on the limited areas of the alluvial flats' (WILLIAMSON, 1988). Dairying was established and expanded as access improved, and in the 1970's horticultural farming became established (HARRISON, 1988).

### Forestry Development

The environmental effects of logging and mining prompted debate in the Coromandel in the early 20th century and led to the planting of exotic forests in the depression years of the 1930's. Planting commenced in Whangamata in the late 1920's and early 1930's on the western margins of the harbour. These exotic forests have been felled once and are presently producing their second crop of trees. Further planting has continued to the present day, including parts of the eastern margins of the harbour.

Development of a resource such as forestry which involves modifying the vegetation and soils of steep slopes has ramifications for the harbour. Episodes of high rainfall erode unstable weathered regolith and transport it into the estuary. Experience with steepland forestry operations in New Zealand indicates that poor forestry logging procedures increase soil erosion and sediment runoff (O'LAUGHNAN, 1979, 1985). HUME and DAHM (1991) found that, in catchments such as Whangapoua (which possesses similar geology to Whangamata), the following changes may occur in the harbour during logging operations: surficial sediment change which may affect the ecology; suspension of finer sediments altering light levels and consequent biological productivity; and greater turbidity resulting in less aesthetically pleasing waters and greater rates of sediment deposition.

Work on a similar environment, culminating in the WAITEMATA HARBOUR REPORT (1983), found that re-forestation led to a decrease in sediment input and erosion; and that during periods when no tree felling occurred in the forestry catchment to the north of Auckland, the streams had the highest water quality in that area. It seems well established that when forest is being felled the harbour downstream experiences a deluge of sediment from off the land, which is transported and deposited during large rainfall events.

## ESTUARINE SEDIMENT TEXTURAL DISTRIBUTION PATTERNS

Some 150 surficial samples from the Whangamata Harbour were analysed to ascertain the modern sediment textural patterns. New Zealand barrier-enclosed estuaries and estuarine lagoons are characterised by a predominance of sand (HEALY and KIRK, 1982) and sands prevailed throughout the harbour including the uppermost reaches and were modified by muds and gravels at stream entrances on the estuary margins. The mean grain size (Figure 3) ranged from coarse sand at the entrance accompanying shell lag deposits, through medium sand in the inlet area, to fine sand over the majority of the inter-tidal flats.

As a result of textural and mineralogical analysis (SHEFFIELD, 1991), the sediments in the Whangamata Harbour were inferred to be a combination of: (1) fluvial sands, gravels and muds derived from the breakdown of the catchment volcanic rocks and the erosion of tephras in the hinterland and; (2) marine-derived sediments swept in off the inner shelf during the post-glacial marine transgression (BRADSHAW, 1991) and; (3) modern biogenic material.

## CORING AND SAMPLE DATING TECHNIQUES

Three cores (Figure 3) were collected as detailed in SHEFFIELD (1991). The "Boatramp" core was taken in what was inferred to be Holocene barrier sediments, and the "Causeway" core taken adjacent to a roadway crossing the intertidal flats, which appears to have been the cause of marked recent sedimentation. The "Sandflats" core in the upper reaches of the estuary represented the control because of its location away from factors facilitating accelerated deposition (harbour works and pleasure boating activities). Subsample ages were estimated using palynology, $^{14}C$ and $^{210}Pb$ dating techniques.

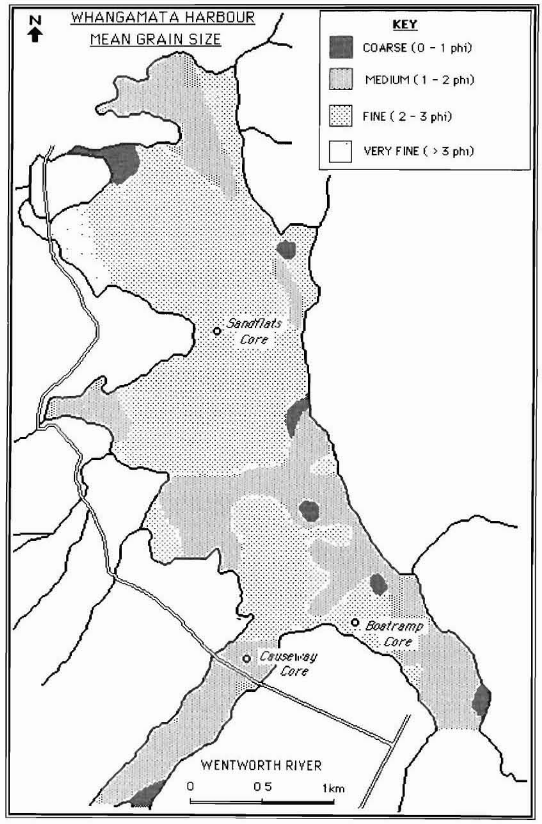


Figure 3. Mean grain size of Whangamata Harbour sediments, in relation to the localities of the three cores taken.

### Palynological Dating

Pollen and spores within estuarine sediments reflect the vegetation of the surrounding areas. The introduction of new species, clearing of the land since human habitation and sedimentation rate changes may be identified from palynologic changes in a vertical core, assuming sediments are younger than those below them.

Samples were taken at 0.10 m intervals, being vertically restricted to a few centimetres. Sample treatment involved disaggregation and the removal of some humic acids in 10% KOH; boiling in 40% HF to dissolve silicates; acetolysis (9 parts acetic anhydride: 1 part concentrated $H_2SO_4$) to remove cellulosic compounds; chlorine bleaching to remove lignin and most organic material; and

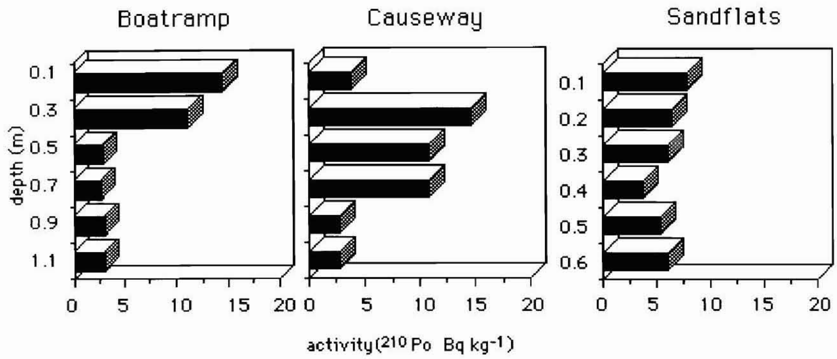


Figure 4. $^{210}$Po levels of three cores in the Whangamata Estuary. The boatramp core had reached background levels at lesser depths than the causeway core indicating slower sedimentation rates. Sedimentation was slowest in the sandflats core as all samples had stabilised to a background level.

then the mounting of residue in glycerine jelly. The residue is composed of pollen, spores, charcoal, some lignaceous minerals and HF resistant minerals.

Ease of identification (and hence accuracy) is lessened when the palynomorphs have been corroded in soils by agents such as fungi and bacteria, before being reworked, transported by water and incorporated into estuarine sediments. Nearly all the palynomorphs showed some corrosion. Bioturbation and mixing during core penetration may blur sediment horizons; however, the coarse nature of the sampling intervals in this case minimised the possibility of contamination. Spores and pollen may also have been differentially transported via river/tidal currents and wind but are assumed to reflect the vegetation of the immediate surrounding area.

### $^{14}$C Dating

$^{14}$C dating was carried out at the University of Waikato's Carbon Dating Laboratory. The vast majority of identifiable shell consisted of the common cockle *Austrovenus stutchburyi*. Explanation of sample treatment methodology and possible sources of error in the carbon dating process are given in HOGG (1982). A minimum of 20 g to 35 g of clean shell sample was required to obtain an accurate date.

### $^{210}$Pb Dating

$^{210}$Pb has a half life of 22 years; therefore this method was selected to investigate the sedimentation rates over the past 100 years. WISE (1980) noted that the greatest potential of the technique may lie in the study of source areas of sediment, especially that associated with the erosion of soil and consequent denudation rates. $^{210}$Pb measurements have been used in the past to estimate marine sedimentation rates (FRIEDLANDER *et al.*, 1964; KRISHNASWAMY *et al.*, 1971; KIODE *et al.*, 1972; LUND-HANSEN, 1991).

$^{210}$Pb is washed out of the atmosphere by precipitation, and that falling into the estuary is incorporated into the accumulating sediments. The annual deposition of $^{210}$Pb from the atmosphere appears to be relatively constant (CROZAZ *et al.*, 1964). A limiting, but poorly understood factor of this dating method is the diffusion of $^{210}$Pb within the sedimentary column, controlled by the mechanism of absorption of $^{210}$Pb into the sediment. Other limiting factors which affect the reliability of dates are the path of $^{210}$Pb through the environment and how much $^{210}$Pb a catchment contributes to estuarine sediments through runoff.

#### (1) Sampling Interval

Six 25 g bulk samples were taken at 0.10 m intervals down the causeway and sandflat cores, and 0.20 m intervals down the boatramp core as the uniform sands were assumed to possess a greater sedimentation rate. The top layer of sediment has lost $^{222}$Rn and therefore possesses a lower $^{210}$Pb content than normal, therefore the uppermost sample was taken 0.10 m below the surface in each case.

#### (2) $^{210}$Pb Analysis

The $^{210}$Pb level was measured using its $^{210}$Po daughter. The $^{226}$Ra level was not measured even

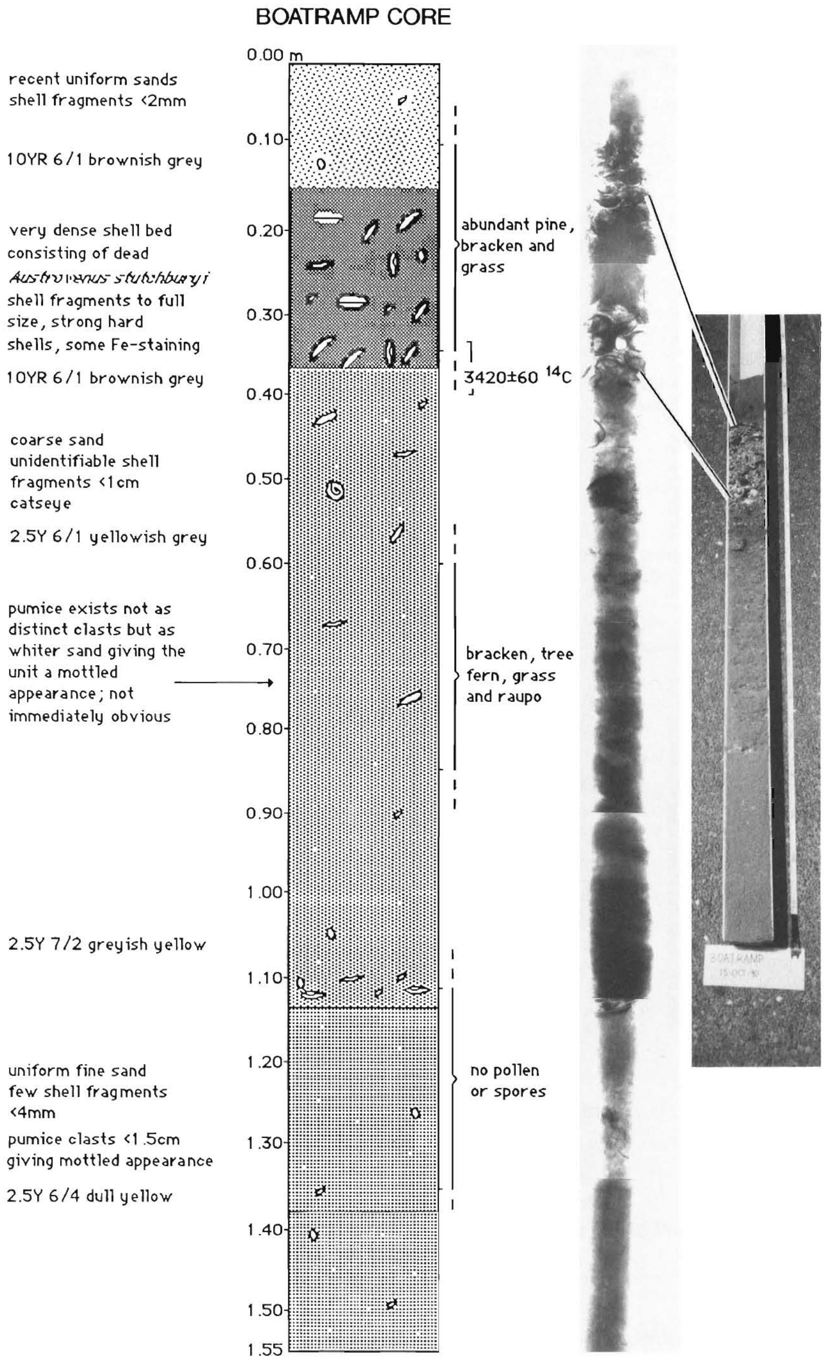


Figure 5. Some 1.5 m of sediments are inferred to have been deposited since the 1900's in the boatramp core, including reworked estuarine shell. The rapid sedimentation rate is attributed to channel migration. Maunsell colour notations are used.

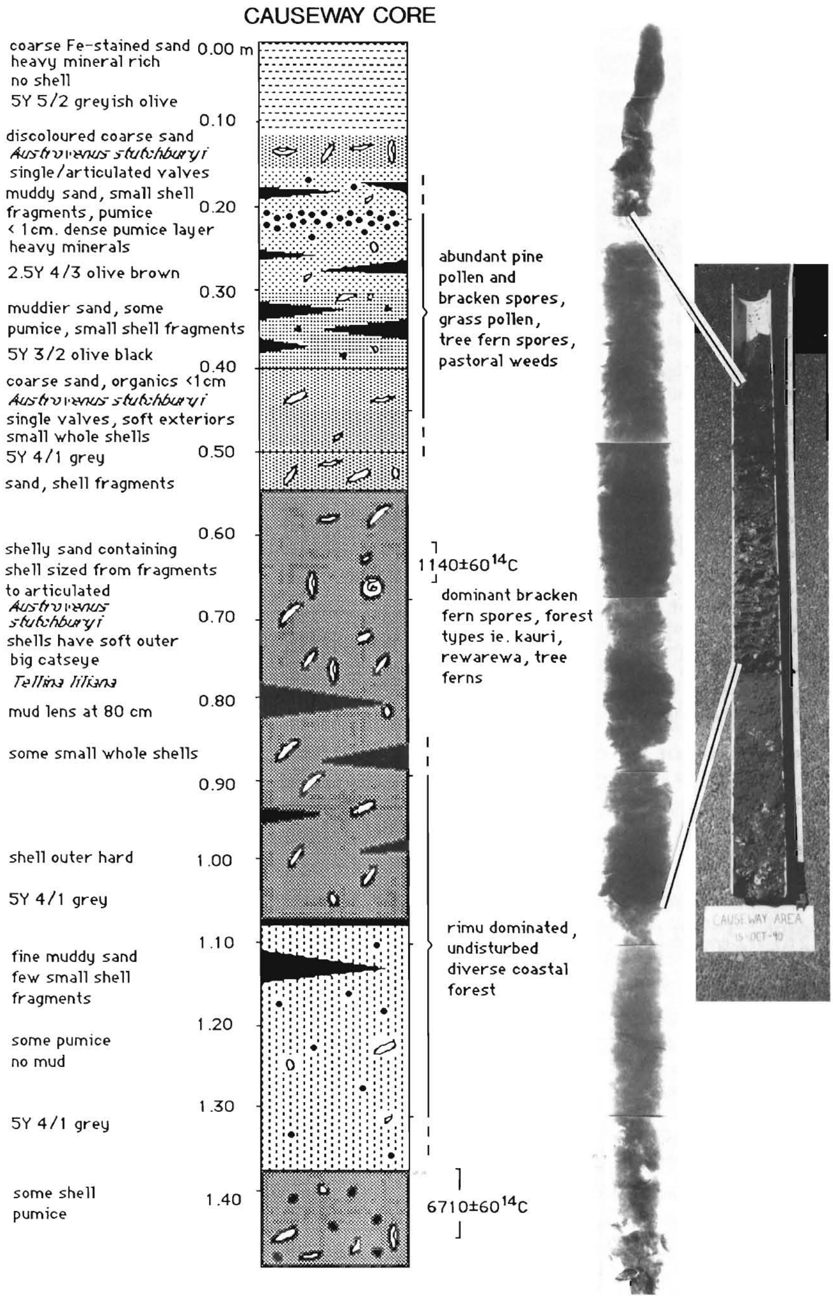


Figure 6. Sediments adjacent to the causeway exhibit the evolution of an estuarine catchment from diverse coastal forest to modification by Polynesians, to the introduction of European vegetation and exotic forestry. Maunsell colour notations are used.

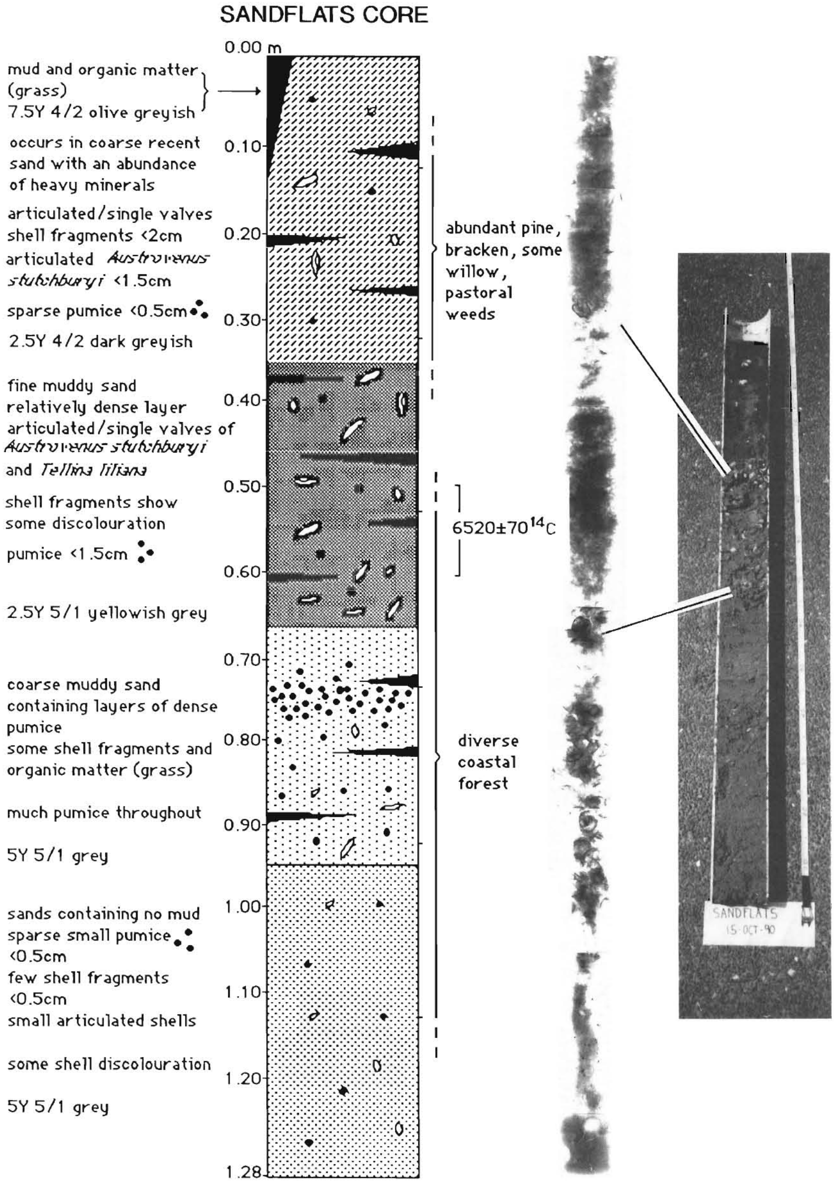


Figure 7. Sediments on the sandflats accumulated slowly from 6000–3000 BP, increasing rapidly in the uppermost 0.35 m, attributed to land clearance and forestry development. Maunsell colour notations are used.

though this can have an effect on heterogeneous cores such as these if it varies widely. While this should be considered during the interpretation, it is this $^{226}$Ra activity which places the 100 year limit of 'accuracy' on the $^{210}$Pb dating method. The samples were dried, weighed, and leached with 6 M HCL for one hour at 100 °C, when $^{209}$Po tracer was added to monitor yield results. The calculations were based upon the activities per kilogram total, less the shell material which was leached during the process (APPLEBY and OLDFIELD, 1978).

Table 1. *Identification of pollen and spores from three cores in the Whangamata Harbour (analysis by M.S. McGlone).*

| Depth (m) | Vegetation | Cause of Change | Average Rate of Sedimentation | |
|---|---|---|---|---|
| | Boatramp Core | | | |
| 0.10 | abundant pine pollen, | forestry, | 19.8 mm yr$^{-1}$ | |
| 0.35 | some bracken and grass | channel migration | | 1940s |
| 0.60 | bracken and corroded tree fern | landuse change, | 18 mm yr$^{-1}$ | |
| | spores dominant, | channel | | |
| 0.85 | some grass and raupo | migration | | |
| 1.12 | no pollen or spores | rapid | 18 mm yr$^{-1}$ | |
| 1.35 | | sedimentation | | 1920s |
| | Causeway Core | | | |
| 0.22 | pine pollen and bracken | forestry, | | |
| | fern spores dominant, | European landuse | 11 mm yr$^{-1}$ | |
| | considerable grass pollen | | | |
| 0.44 | and tree fern spores, | | | |
| | traces of pastoral weeds | | | 1940s |
| 0.66 | bracken fern spores | Maori land | | |
| | dominant, considerable | clearance | 0.28 mm yr$^{-1}$ | |
| | forest types, including | | | |
| | kauri, rewarewa and tree | | | |
| | ferns | | | 1140 |
| 0.88 | abundant tree fern spores | undisturbed | | |
| | and pollen of a great | coastal forest | | |
| | variety of forest trees | | 0.06 mm yr$^{-1}$ | |
| 1.10 | and shrubs, rimu being | | | |
| 1.32 | dominant | | | 6710 |
| | Sandflats Core | | | |
| 0.13 | pine and bracken | forestry | 6.6 mm yr$^{-1}$ | |
| | abundant, some willow | | | |
| 0.33 | introduced pastoral weeds | European | | |
| | | landuse | | 1940s |
| *0.43* | *inferred Maori horizon* | | 0.31 mm yr$^{-1}$ | |
| | | | | 1300 |
| 0.53 | abundant pollen of forest | undisturbed | | |
| 0.73 | types indicating a | coastal | | |
| | diverse coastal forest | forest | 0.35 mm yr$^{-1}$ | |
| 0.93 | | | | |
| 1.13 | | | | 3000 |

Table 2. *$^{14}C$ dates for four samples from Whangamata Harbour sub-surface sediments.*

| | Location | | |
|---|---|---|---|
| | Boatramp | Causeway | Sandflats |
| Depth (m) | 0.37–0.40 | 0.63–0.67 | 0.50–0.60 |
| $^{14}C$ date | 3,420 ± 60 | 1,140 ± 60 | 6,520 ± 70 |
| Depth (m) | — | 1.38–1.43 | — |
| $^{14}C$ date | | 6,710 ± 70 | |

## RESULTS

The results of the palynological investigations, $^{14}C$, $^{210}Pb$ dating are presented in Tables 1, 2 and 3. As shown in Figure 4, the $^{210}Po$ levels decrease with depth. The boatramp core had reached background levels by 0.5 m. The uppermost sample in the causeway core is suspected to be reworked older sediment and as a result was not used in the calculations of age. Levels in the causeway core reached background levels by 0.9 m depth. The sandflats core appeared to possess a slow sedimentation rate shown by all samples stabilising at the background level. Figures 5, 6, and 7 are the core log, descriptions, x-ray and photograph. Interpretation of each core follows.

### Boatramp Core

Palynological analysis found sediment east of the Whangamata boatramp at <1.5 m depth to be no older than the 1900's, as the absence of any pollen, spores, or shells from 1.35–1.0 m depth (Figure 5) indicated a rapid influx of eroded material). Between 1.0 and 0.5 m, bracken and corroded tree fern spores dominated along with raupo, grasses and introduced species, indicative of European habitation. The uppermost 0.5 m contained species dominated by exotic pine pollen with minor bracken spores and grass pollen, a sign that these sediments had been deposited since the 1940's when the first planted exotics reached maturity. Only one layer at 0.37 to 0.40 m was $^{14}C$ dated owing to the low incidence of shell in the remainder of the core and gave an age of 3,420 ± 60 years. $^{210}Pb$ levels, however, placed sediments above and below this layer in the 1970's and 1920's respectively. The shell bed is thus likely to have been reworked and deposited into the younger sediments. $^{210}Pb$ excesses decreased to background levels for the lower four samples, indicating that sediment below 0.5 m was emplaced earlier than the 1920's. Sediments at 1.5 m depth could have been laid down rapidly owing to an influx of sediment from the catchment. However considering the lack of organic matter it is more likely that a change in channel configuration resulted in the main channel migrating to the east. The sedimentation rate then slowed allowing the deposition of shell fragments, until the rapid deposition of a reworked shell layer originating from elsewhere in the estuary 0.10 m below the present surface. This layer was covered in 10–15 cm of recent sandy sediment.

### Causeway Core

A shell bed at the base of the causeway core (1.43–1.38 m) was $^{14}C$ dated at 6710 ± 70 BP (Figure 6). This bed may be *in situ,* as palynologic analysis showed undisturbed rimu (*Dacrydium cupressinum*) dominated coastal forest was identified from 1.32 m to approximately 0.75 m depth.

At 0.66 m, the dominance of bracken spores revealed the extensive spread of bracken, encouraged by firing and clearance of the forest by Maori settlers. Kauri (*Agathis australis*), rewarewa (*Knightia excelsa*) and tree ferns were also present. The shell layer at 0.67–0.63 m was $^{14}C$ dated at 1,140 ± 60 years above the 'Maori horizon' identified by palynology. This is most likely to have arisen through bioturbation, although it is possible that the Maori did inhabit the Coromandel up to 1,000 years ago (EASEDALE and JACOMB, 1982; HARRISON, 1988).

Table 3. *$^{210}Pb$ dates from three cores in the Whangamata Harbour. The sedimentation rate applies between a layer and the one above and is calculated in mm $yr^{-1}$.*

| Location | Sediment Depth (m) | $^{210}Po$ (Bq/kg) | Age | Date Approx. | Date Calc. | Sedimentation Rate (mm $yr^{-1}$) |
|---|---|---|---|---|---|---|
| Boatramp | 0.10 | 14.5 ± 0.2 | 0 | 1980's | 1981 | ~ |
| | 0.30 | 11.1 ± 0.2 | 9 | 1970's | 1972 | 22.2 |
| | 0.50 | 2.9 ± 0.1 | 52 | 1920's | 1929 | 4.7 |
| | 0.70 | 2.7 ± 0.1 | 54 | 1920's | 1927 | ~ |
| | 0.90 | 3.0 ± 0.1 | ~ | ~ | ~ | ~ |
| | 1.10 | 3.0 ± 0.1 | ~ | ~ | ~ | ~ |
| Causeway | 0.10 | 3.8 ± 0.1 | ~ | ~ | ~ | ~ |
| | 0.20 | 14.7 ± 0.3 | 0 | 1980's | 1980 | ~ |
| | 0.30 | 10.8 ± 0.2 | 10 | 1970's | 1970 | 20.0 |
| | 0.40 | 10.8 ± 0.2 | 10 | 1970's | 1970 | 10.0 |
| | 0.50 | 2.7 ± 0.1 | 55 | 1920's | 1925 | 2.0 |
| | 0.60 | 2.7 ± 0.1 | 55 | 1920's | 1925 | ~ |
| Sandflats | 0.10 | 7.8 ± 0.1 | 0 | 1980's | 1984 | ~ |
| | 0.20 | 6.5 ± 0.1 | 6 | 1970's | 1978 | 10.0 |
| | 0.30 | 6.0 ± 0.1 | 8 | 1920's | 1976 | 2.0 |
| | 0.40 | 3.7 ± 0.1 | 24 | ~ | 1960 | ~ |
| | 0.50 | 5.4 ± 0.1 | ~ | ~ | ~ | ~ |
| | 0.60 | 6.0 ± 0.1 | ~ | ~ | ~ | ~ |

The upper 0.50 m of sediment contained an abundance of pine pollen and bracken spores, and considerable amounts of grass pollen, tree fern spores and traces of pastoral weeds. $^{210}Pb$ dating indicated that background levels were reached by 0.70 m, *i.e.,* sediment above 0.70 m has been deposited since the 1920's. The low level measured in the uppermost sample could indicate reworking of old sediments, deposited rapidly since the construction of the causeway.

Sediments at 1.5 m depth in the Moanaanuanu Estuary are typical of undisturbed coastal forest, and are consequently dated 6000–1300 BP. A discontinuity at 1.0 m depth may be related to the sea reaching its highest level at 4000 BP, then grading into beds containing articulated shells and shell fragments. Maori influence occurred at 0.66

m depth although shell was dated above this at 1140 BP. Sands from 0.40 m depth are recent sediment containing an abundance of pine pollen reflecting the influence of forestry in the area.

### Sandflats Core

Although the age of sediment lower than 0.5 m is not completely certain, kauri and rewarewa pollen analysis suggests that these sediments were probably younger than 3000 BP and definitely older than 700 years because of the absence of any sign of deforestation (Figure 7). Shells at 0.60 to 0.50 m depth dated at 6,520 ± 70 years of age. There was an insufficient accumulation of shell in the remainder of the core to warrant further dating. The dated layer could possibly be *in situ* as it was contained within a period characterised by diverse coastal forest, but palynological analysis suggests that <3000 BP is more probable, indicating that the shell may be reworked. The sediments beneath did not show a marked boundary change into Pleistocene sediments, and it is unlikely that 0.75 m of recent sediment was laid down before 6500 BP as sea-level was just reaching this height (GIBB, 1986). Therefore it is concluded that this bed is a reworked shell layer.

The upper 0.5 m of sediment appears to have been deposited since the 1940's, owing to the abundance of pine pollen and bracken spores, some willow, and introduced pastoral weed pollen. $^{210}Pb$ in the core maintained background levels, indicative of a slow rate of sedimentation, *i.e.*, at 0.10–0.20 m the sediments are at least 50 years old.

Sediments at 1.0 m depth in the intertidal area of the mid-harbour accumulated relatively slowly from 3000–6000 BP. Pumice occurred in beds from 0.96–0.65 m. Rapid sedimentation in the uppermost 0.35 m of sandy sediment is attributed to land clearance and forestry development based on the abundant pine pollen.

## RATES OF SEDIMENTATION IN THE WHANGAMATA HARBOUR

The sedimentation rate is calculated by measuring the thickness of material deposited since 'known' estimations of age, *i.e.*, marker beds, dated shells and distinctive faunal assemblages. The amount of compaction that sediment has undergone is difficult to estimate, and it was not possible to determine a suitable correction factor for adjusting rates of compaction. The effect of compaction is that even if no actual change in the sedimentation rate occurred, the apparent rate would increase. The differences in real sedimentation rates are likely to be smaller than differences in the actual rates; however, unless otherwise stated, the calculated rates are apparent and not actual. Various sources contribute to the sediments within the estuary, including: the decomposition and excretory products of marine plants and animals; wind transported material; domestic and industrial effluent and solid wastes; and material transported by flood tides from the ocean. Erosion of the hinterland and stream channels also adds alluvium.

Hallmarks of European occupation and land clearance in the palynologic record are bracken, grass and weed dominated samples of which there are few, indicating that while the early European did not have the greatest impact on sedimentation rates it is nevertheless visible in the sediments. Timber milling, extraction of gum and mining may have increased catchment erosion and consequently generated sediment which accelerated estuarine infilling. This would have occurred in the Whangamata estuary from the 1870's to the 1920's, when sedentary farming became established, which is less harsh on the landscape and consequently results in lower sedimentation rates. Clearance and planting of exotic pine began in the Whangamata catchment in the late 1920's; therefore mature pine pollen would have been present from the early 1940's. Palynology showed that there has been a good deal of sedimentation in the recent past, probably since the 1940's.

The sandflats core represented quiet estuarine conditions, or the control in this case. The rate of sedimentation on the upper inter-tidal flats since the sea-level stabilised about 6000 BP, assuming that rewarewa and kauri place a 3000 BP limit on calculations (MCGLONE, 1983), was 0.35 mm $yr^{-1}$, which increased to 6.60 mm $yr^{-1}$ in European times (Table 4). $^{210}Pb$ dating indicated an increase from ~2 mm $yr^{-1}$ from the 1920's–1970's to ~10 mm $yr^{-1}$ from the 1970's to the 1980's.

The causeway core provided the most complete record, showing a rate of 0.06 mm $yr^{-1}$ from the sea-level still-stand until the arrival of the Maori, when sedimentation rates increased to 0.28 mm $yr^{-1}$ attributable to Polynesian deforestation. European influence increased the rate to 11 mm $yr^{-1}$, which may be due in part to the construction of the causeway increasing rates since 1976. This theory is supported by the high $^{210}Pb$ levels in the upper 0.40 m, in which the sedimentation rate increased from 2 mm $yr^{-1}$ from the 1920's to the

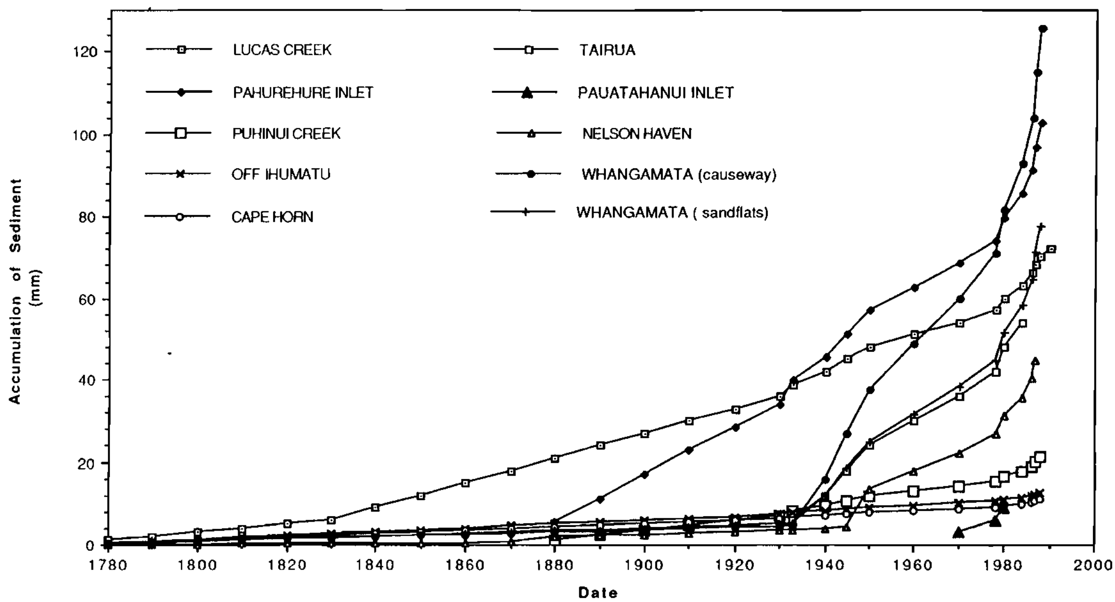


Figure 8. Accumulation rates for various New Zealand estuaries (referred to in Table 4).

1970's, to ~15 mm $yr^{-1}$ from the 1970's to the 1980's.

The younger boatramp core sediments showed rates at 18 mm $yr^{-1}$ since the 1920's increasing slightly to 19.8 mm $yr^{-1}$ since the 1940's. The former high rate may have been caused by European land use increasing sedimentation rates, but is more likely to be attributed to lateral movement of the channel. The latter rate appears to have been caused by forestry development and general land use change in the catchment as the sediment contained plentiful pine pollen, grass pollen and bracken spores. $^{210}Pb$ levels also registered an increase from ~2 mm $yr^{-1}$ from the 1920's to the 1970's to ~10 mm $yr^{-1}$ after the 1970's.

## COMPARISON WITH OTHER NEW ZEALAND ESTUARIES

Table 4 from HUME and DAHM (1991) and SHEFFIELD (1991) presents sedimentation rates from various inter-tidal environments of some New Zealand (including Whangamata) and overseas estuaries. The data from this table are formulated into Figure 8. Whangamata sedimentation rates are comparable with those found in other studies. Notably, rates of 11 mm $yr^{-1}$ are higher than those usually recorded in estuaries but similar to rates in the adjacent Tairua catchment (HUME and GIBB, 1987).

Sedimentation rates for Whangamata may have been under-estimated if substantial periods of erosion of estuarine sediments have taken place. However, sediments within the cores grade uniformly into the next layer except for one clear discontinuity in the causeway core at 1.08 m depth. This occurred before human occupation of the area and does not affect the calculation of sedimentation rates. Sediment samples were coarsely spaced; therefore confirmation of the estimated rates may be obtained by sampling further cores at smaller intervals.

HUME and DAHM (1991) utilised palynologic and $^{14}C$ dating methods on two cores from Whangapoua Harbour, four from Coromandel Harbour, and three off Thames in the Hauraki Gulf. They found sedimentation rates increased from 0.1 mm $yr^{-1}$ during pre-Polynesian times to 0.3–2.8 mm $yr^{-1}$ as land use changed owing to European influence, in some sites by as much as 25–45 times. There was also some, although not conclusive, indication of an increase in sedimentation for parts of the Whangapoua Harbour since 1950, when exotic forests were established.

HARRISON (1988) noted 'Cutting of forests has the potential for major impact on the Whanga-

Table 4. *Estuarine sedimentation rates in various New Zealand estuaries (from* HUME *and* DAHM*, 1991) and* SHEFFIELD *(1991).*

| Location | Depositional Environment | Time Interval | Sedimentation Rate (mm yr$^{-1}$) |
|---|---|---|---|
| Drury Creek Manukau Hr. | tidal creek, muds, intertidal | 1950–1987 | 5 |
| | | 1880–1945 | 7 |
| Lucas Creek Manukau Hr. | tidal creek, muds, intertidal | present day | 2 |
| | | 1840–1986 | 3 |
| | | 700–110 BP | 1 |
| | | 6500–700 BP | 1.5 |
| Pahurehure Inlet Manukau Hr. | tidal creek, muds, intertidal | 110 BP–1988 | 5.7 |
| Puhinui Creek Manukau Hr. | tidal creek entrance, intertidal sandy mud | 110 BP–1988 | 1.2 |
| Off Ihumatao Manukau Hr. | middle harbour, intertidal, fine sand | 1000 BP–1988 | 0.46 |
| | | 5000 BP–1988 | 0.09 |
| Cape Horn Manukau Hr. | middle harbour, intertidal, fine sand | 600 BP–1988 | 0.4 |
| Tairua | middle harbour, intertidal, sandy | 1933–1984 | 6 |
| Pauatahanui Inlet | sandy, intertidal | 1978 | 3 |
| Nelson Haven | middle harbour, intertidal, sandy | 1950–1987 | 4.5 |
| | | 110 BP–1950 | 1.3 |
| | | 700–110 BP | 0.06 |
| | | 1400–700 BP | 0.18 |
| Temperate latitude estuaries | bays and estuaries | <1000 BP | 2–4 |
| Whangamata Hr. | causeway, muddy sand, intertidal | 1940–1990 AD | 11.0 |
| | | 1140 BP–1940 AD | 0.28 |
| | | 6710–1140 BP | 0.06 |
| Whangamata Hr. | boatramp, intertidal sandy | 1940–1990 AD | 19.8* |
| | | 1920–1940 AD | 18.0* |
| Whangamata Hr. | sandflats, intertidal, muddy sand | 1940–1990 AD | 6.6 |
| | | 1300 BP–1940 AD | 0.31 |
| | | 3000–1300 BP | 0.35 |

The asterisk attributes the rate principally to channel migration, not sediment accumulation.

poua estuary in the 1990's. For example a 1.5–2.0 year rainfall event in the Tairua forest in 1983 eroded a log landing area causing a sediment yield 3,000 times larger than from an uncut adjacent catchment. Higher than normal sediment yields were sustained for 3 years following this event.' Tairua catchment is 280 km$^2$ in size and consists of Coromandel Group and Quaternary tephras, hence is similar in composition to the Whangamata catchment. 'The weathered rock and tephra (in Tairua) are extremely susceptible to erosion and landslip once the vegetation cover is removed' (HUME and GIBB, 1987). HUME and GIBB (1987) used a 'wooden floor' from a now defunct timber mill as a marker bed in the Tairua Harbour. They noted that over the lower reaches of the estuary, accumulation of sediments was highly variable. Since 1933, between 2 and 22 mm yr$^{-1}$ of sediment had accumulated at a net average rate of 6 mm yr$^{-1}$, which is similar to rates reported by CLARK and PATTERSON (1984), for inter-tidal salt marsh from eastern Long Island.

Earlier surveys by HUME (1983) in the Waitemata Harbour near Auckland (2 mm yr$^{-1}$) and PICKRILL (1979) at Pauatahanui inlet, New Zealand (3 mm yr$^{-1}$) produced net average rates of only half this value (HARRISON, 1988). In the upper Waitemata Harbour sedimentation occurred rapidly, hence the top few meters represent sediments deposited less than 6000 BP, comparable to Whangamata Harbour. $^{14}C$ results in the Waitemata Harbour showed a doubling of sedimentation rate from 1070 BP to present.

From the above discussion, it is evident that maximum sedimentation rates of 6–11 mm yr$^{-1}$ for Whangamata Harbour are suggestive of tidal prism reduction leading to lower currents through the entrance and increased difficulty for navigation by the numerous vessels which use the harbour. Should such infilling rates be maintained, it is evident that much of the present harbour would become unnavigable within a few hundred years. Even allowing for a possible anthropogenically induced sea-level rise of perhaps 0.50 m by the year 2100, this is clearly insufficient to counter the effective rate of sedimentation infilling.

## SUMMARY AND CONCLUSIONS

Whangamata Harbour is surrounded by a moderately steep catchment subject to erosion, causing rapid harbour infilling. Investigation of vertical sedimentation rates using a combination of palynological, $^{210}$Pb and $^{14}$C dating techniques indicated that late Holocene, but pre-Polynesian rates (prior to 1000 BP), were about 0.1 mm yr$^{-1}$. After the arrival of the Polynesian peoples and initial land clearance, rates increased to 0.3 mm yr$^{-1}$. Since 1880, European activities such as logging, mining and farming induced marked impact on the vegetation and resulted in highly accelerated sedimentation rates of 6–11 mm yr$^{-1}$. This suggests that the resulting reduction in the tidal prism will exacerbate navigation difficulties through the tidal inlet to the harbour in the near future and that much of the estuary could become infilled within several hundred years. The effects may be lessened however by the projected rise in sea-level.

## ACKNOWLEDGEMENTS

The Whangamata Community Council is commended for its forethought in initiating this study and providing financial assistance.

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