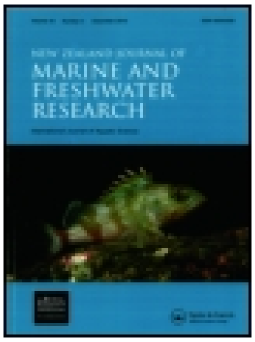

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Sedimentation patterns and catchment use change recorded in the sediments of a shallow tidal creek, Lucas Creek, Upper Waitemata Harbour, New Zealand

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Abstract Radiocarbon dating and pollen analysis have been used to date and identify changes in Lucas Creek catchment use, recorded in Holocene subsurface sediments. Holocene marine sedimentation began about 6500 years before present. Where the sediment column is thickest, maximum net sedimentation rates for the estuary are recorded as less than 1.5 mm/y for pre-Polynesian times (6500-700 years B. P.) when the catchment was forest-clad. Above this level the pollen record shows that the 1 mm/y net sedimentation rate accompanying forest clearance during Polynesian settlement (700-110 years B. P.) subsequently tripled to 3 mm/y with logging, gum digging and land clearance accompanying farming during European times (A. D. 1841 to present). Since 1854 the main channel areas of Lucas Creek have experienced no detectable sedimentation or erosion. Present-day deposition is estimated as averaging less than 2 mm/y on the tidal flat areas. Future catchment urbanisation is expected to double sediment input to Lucas Creek estuary and result in increased sediment accumulation in the lower, wider estuarine reaches and embayed areas. Larger and more frequent flood events are likely to minimise sediment accretion or cause scour in the narrow upper reaches. Urban debris will be a problem unless controlled at source.

Keywords Lucas Creek; Upper Waitemata Harbour; surface and subsurface sediments; Holocene sedimentation rates; catchment use change

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INTRODUCTION

Shallow tidal creeks in the upper reaches of harbours adjacent to urban areas form an important resource for activities such as fishing, boating and mooring. These environments have received little specific research attention from sedimentologists, yet their small size and location makes them highly susceptible to the deleterious effects caused by sediment run-off and changes in flow regime which result from catchment development and land use change. In their natural condition, estuary headwaters are characterised by a highly variable flow regime because catchment drainage is focused in these areas which modifies tidal flows (especially during floods). Land clearance by human activity associated with catchment development has been shown to increase the peakedness and frequency of catchment high flows and sediment run-off to estuarine areas (Williams 1976, Healy 1980). Once the catchment is urbanised the soil is stabilised and sediment run-off decreases. However, the peakedness of flows increases further because of the development of sealed areas and storm water systems (Williams & Brickell 1983). Macpherson (1978) attributed a considerable increase in tidal compartment in the Avon-Heathcote estuary to scour caused by this effect. Prediction of the effects of catchment use change on estuarine sedimentation patterns can be aided by examining the sediment stratigraphic record, provided one can identify suitable events and stratigraphic markers.

This paper describes the results of an investigation into natural and human influences on sedimentation patterns in a tidal creek on the fringe of Auckland City. It was undertaken as part of a wider study, aimed at predicting the likely consequences of anticipated catchment use change on the Upper Waitemata Harbour estuary, to assist managers implementing land and estuary management controls (Williams & Brickell 1983).

PHYSICAL SETTING

Lucas Creek (36° 46′ S, 174° 40′ E) is a 6 km long, funnel-shaped tidal arm of the Upper Waitemata Harbour, New Zealand (Fig. 1). It receives drainage from a catchment of 35.2 km² whose central

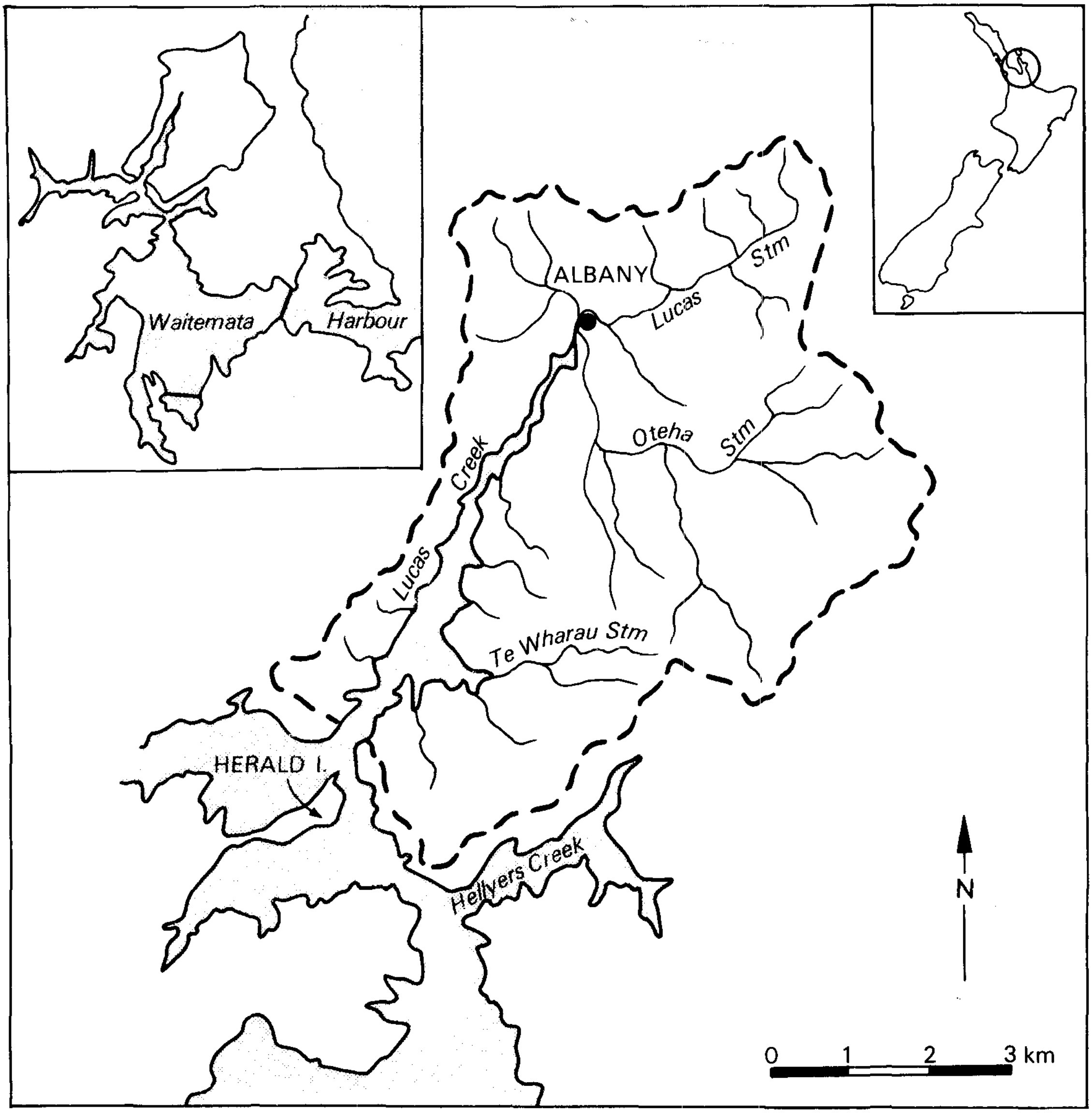


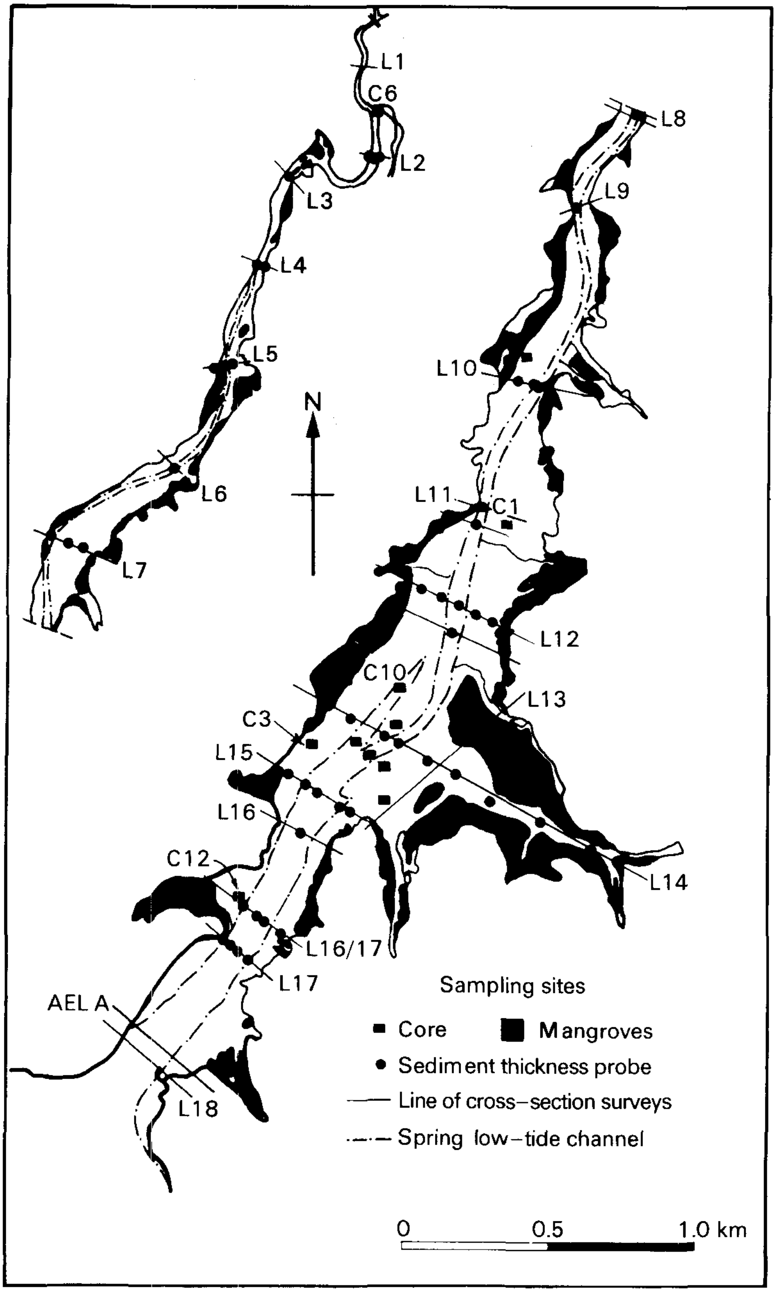
Fig. 1 Sketch map locating Lucas Creek and catchment.

undulating terraces rise to about 120 m around the basin rim. Stream flow derives mainly from the Lucas and Oteha Streams which enter the creek just below the township of Albany (Fig. 1). Located on the northern fringe of Auckland City, the largely rural catchment is expected to undergo significant urbanisation in the next 10 to 20 years (Williams & Brickell 1983).

The main estuary channel (Fig. 1 and 2) deepens from about 2 m (at MHWS) in the headwaters to about 5 m (at MHWS) near the entrance where a 7 m submarine cliff marks the connection with the main Upper Waitemata Harbour channel (Hydrographic Branch, R. N. Z. N. 1975). At low tide 70% of the total area is exposed as low-gradient intertidal mud banks whose upper levels are extensively colonised by mangroves (Fig. 2).

Because the tidal range varies from about 3 m (spring) to 2 m (neap) at the entrance to Lucas Creek, there is a substantial difference between the

Fig. 2 Locations of sediment cores, sediment thickness probes and lines of surveyed cross sections.



spring (2.370×10^6 m^3) and neap (1.623×10^6 m^3) tidal prisms (Williams & Rutherford 1983). The time of high water is similar throughout the inlet, but from half ebb tide, rock and rubble bars in the headwaters (up stream of L10) pond tidal waters and impede ebb tide drainage so that low water level does not fall below mean tide level (Johnston 1980, Williams & Rutherford 1983).

METHODS

Although large areas of intertidal flats are exposed at low water, direct examination and measurement of sediments is made difficult by low water clarity, and the thick soft muddy sediments which make access on foot extremely difficult. Surficial sediments were sampled at 12 locations (Fig. 3) by box dredge sampler. The raw samples were split while wet and the mud was separated from the coarser fraction by wet sieving. Textural characteristics were determined by dry sieving the sand and gravel fractions, and by pipette analysis of the mud fraction (Fry & Hume 1983).

The thickness of unconsolidated Holocene sediments in Lucas Creek was determined by probing the sediments with steel rods from a boat moored on the surveyed lines of section (Fig. 2). Sudden resistance to penetration or a sample of consolidated basement sediment collected by an auger on the tip of the rods provided evidence of basement contact.

Twelve short cores (50 mm diameter) were collected from Lucas Creek (Fig. 2) using a hand-operated corer from a boat anchored in shallow water or driven aground at the water's edge. The contents of the plastic split liners were checked in the field, then sealed and returned to the laboratory for more detailed examination. A check for core compression was possible at some sites where hard layers such as shell or basement material were present in the cores (e.g., Fig. 5: C1 and C10). Here the measured core sediment length above the hard layer was compared to the length determined by probing the sediment down to the same layer with a steel rod. In general, compression was undetectable in the short cores given the limited accuracy of the comparative techniques. Sufficient quantity of shell material from rare layers of shell was collected for radiocarbon dating, by accumulating shell from the same levels from several cores taken at selected sites.

Samples for pollen analysis were split from selected cores and prepared by standard techniques. Samples 2–3 cm^3 in size were warmed in 10% potassium hydroxide to remove humic compounds, boiled in an acetic anhydride-sulphuric acid mixture for four minutes to destroy cellulosic compounds, and heated in hydrofluoric acid (40%) for 1–2 hours to remove silica. A strong chlorine bleach was used to remove abundant lignin in the preparations. Preparations were mounted in glycerine jelly, and pollen was identified and counted. An average of 220 pollen grains and spores of terrestrial plants were counted for each level. Biological corrosion had affected most pollen grains and spores in the core and thus the results were subject to some degree of inaccuracy.

RESULTS

Physical sedimentology

Surficial sediments are generally fine-grained, being largely muds and sandy muds (Fig. 3). The mudbank sediments are coarser than the channel sediments, while the shoreline embayments are dominated by muds. Overall, dead and living animals and plants are not significant components of Lucas Creek sediments, $CaCO_3$ and carbonaceous material being generally less than 4% dry weight (Bioresearches 1981; Fry & Hume 1983). Shelly lag gravels occur locally in the Te Wharau Stream embayment and Lucas Creek entrance areas (Fig. 1) where tidal currents are strong.

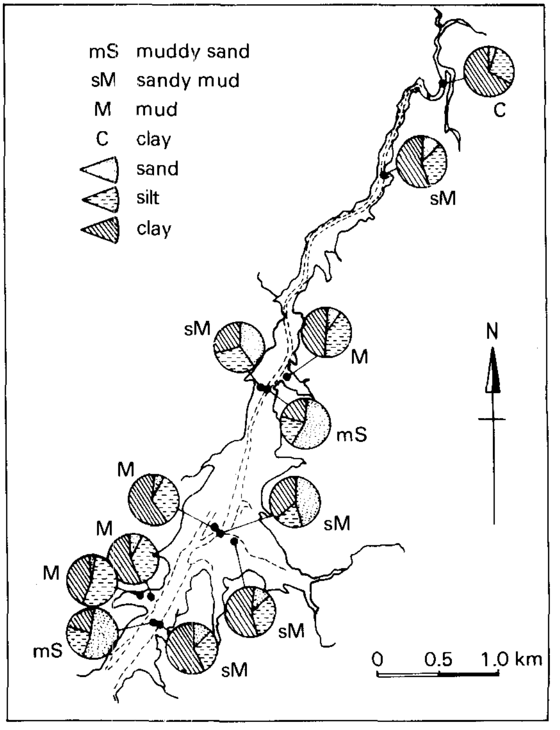


Fig. 3 Location of surficial sediment samples in Lucas Creek. The pie diagrams show the relative proportions of sand, silt and clay at each site. The textural classes are after Folk (1968).

Holocene marine sediments overlie an irregular basement of Pleistocene sandstones and show considerable spatial variation in thickness (Fig. 2 and 4). The thin veneer of sediment on the channel flanks in the upper reaches of Lucas Creek (Fig. 4: L2 and L5) thickens towards the entrance where soft muds up to 10 m thick have accumulated in a western embayment backwater (Fig. 4: L16/17). A large wedge of sediment has accumulated in the Te Wharau Stream embayment.

Selected core logs (Fig. 5) show that the upper 1 m of Lucas Creek sediments consist of interbedded units of layered and massive (unstratified) fine sands, silts and muds. Most units have traces of carbonaceous material disseminated throughout,

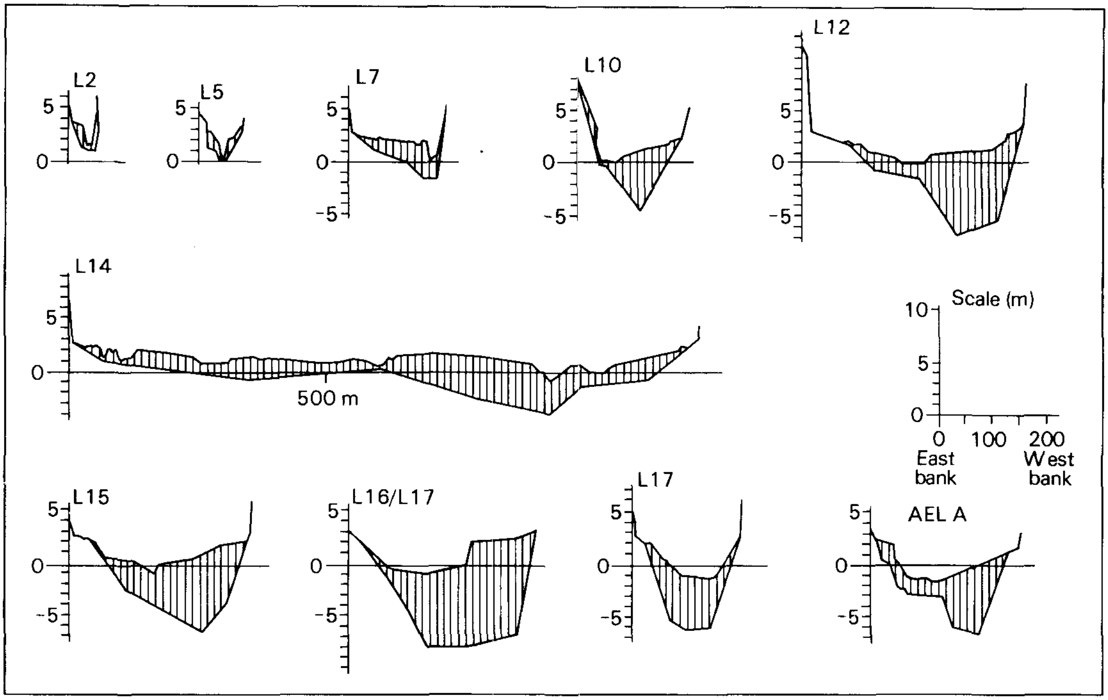


Fig. 4 Thickness of unconsolidated Holocene sediments in Lucas Creek (looking toward estuary entrance) determined by probing sediment with steel rods at selected locations (Fig. 2). Note that the location of the present-day channel does not always coincide in plan with the buried paleochannel, e.g., at L10. Survey made in April 1980.

and in places thin layers of fibrous carbonaceous material separate the units. Units containing shell material are generally rare.

Core stratigraphy (Fig. 5) varies markedly from place to place and readily correlatable units are absent. Core 6, from the upper reaches of Lucas Creek, shows largely massive units of silt. Cores 1 and 10 from channel and tidal flat areas further down the estuary show more complex interstratified units of sand, silt and organic material and shell debris is more common, possibly reflecting channel migration and fluctuating sediment supply to these wider channel areas. Pleistocene sandstones sampled at the base of Holocene unconsolidated sediments are conspicuous limonite stained, mottled, extensively bored, silty sands (Core 1). High up on the tidal flats in a muddy embayment, Core 12 shows massive mud deposits reflecting slow accumulation from suspension in an area of very low current velocity.

The numerous volcanic cones and craters that mark the Auckland landscape testify to intermittent volcanic activity on the Auckland isthmus since about 40 000 years B. P. (Searle 1964, 1965). Even though eruptions continued over the more recent period when Upper Waitemata Harbour sediments were being deposited, none of the Lucas or Hellyers Creek cores showed evidence for eruptions in the form of tephra layers which are commonly useful marker beds in terrestrial and lake deposits. This could in large part be due to the fact that the amount of tephra erupted from the individual centres was small or that tide, flood events and biogenic reworking redistributed volcanogenic debris.

Depositional history

At the height of the last glacial period, the Otiran (20 000–18 000 years B. P., Milliman & Emery 1968), eustatic sea level stood about 120 m below the present sea level and the ancestral Waitemata River extended from its headwaters to meet the sea near Great Barrier Island on what is now the edge of the continental shelf (Gregory & Thompson 1973). Bore logs and seismic profiles across the Waitemata Harbour show the ancient topography through which the river flowed to be very irregular, perhaps with precipitous buried slopes comparable to those cliffs and steep-walled valleys that can be seen about the Waitemata Harbour shores today (Hicks & Kibblewhite 1976).

Radiocarbon dates of shells of estuarine fauna (*Austrovenus stutchburyi*) from a sediment core near the entrance in Hellyers Creek (Fig. 1) show that marine sedimentation in the Upper Waitemata Harbour began about 6460 years B. P. (Wk 250, Old T½; Hume 1983), coinciding with the culmination of the postglacial marine transgression in New Zealand (Gibb in press). Similar shell material dated from one Lucas Creek core (Fig. 2 and 5: L10) demonstrates that sedimentation was already occurring 1.7 km up stream of the entrance opposite the Te Wharau Stream by 5730 years B. P. (Wk 251, Old T½).

Where Holocene marine sediments are thickest (Fig. 4: L16/17), the lower 9 m sediments pre-date Polynesian arrival (700 years B. P., see later) giving a net average sedimentation rate for the 6500–700 years B. P. period of about 1.5 mm/y. It is probable that the sedimentation rate was not uniform over this long period: sedimentation was probably initially rapid following the eustatic sea level rise to the present sea level at about 6500 years B. P. (Gibb in press), and then much slower than 1.5 mm/y.

Changes in catchment use are recorded in the pollen in sediments, but only clearly where the sediment column is thickest. In the upper 1 m of the 10 m thick sequence at Lucas Core 12 (Fig. 5 and 6), the pollen diagram records changes in catchment vegetation that equate firstly with Polynesian settlement and secondly with European settlement.

Pollen preservation in the sediments is not good, and the relatively high levels of corroded spores found suggests that much of the pollen and spore material was first deposited in soils in the catchment and then transported by water to the site. Occasional grains of the extinct beech *Nothofagus brassii* in surficial sediments indicate that a proportion of the pollen may be reworked from subsurface sediments. Sporadic occurrences of exotic pollen types, e.g., pine below the European horizon, and substantial amounts of *Ascarina* pollen derived from a plant now rare in the district in the uppermost section of core, suggest there has been some bioturbation after placement or mixing during corer penetration. This is consistent with the lack of tephra layers as mentioned earlier. However, changes in the vegetation are well enough reflected in the pollen diagram to give an adequate means of dating the sediments.

The basal sample from Core C12 (Fig. 5 and 6) shows an undisturbed forest-clad catchment. Kauri (*Agathis australis*), rata (*Metrosideros* spp.) and several species of tall tree podocarps were dominant over a diverse community of hardwood trees and tree ferns. Between the 1.0 m and 0.8 m levels (Fig. 6), Polynesian fires had reduced much of the surrounding landscape to bracken-dominated fernland. At the 0.4 m level, bracken fernland began to decline along with some forest trees as European logging and clearance for farming commenced. A variety of exotic trees (including pines and willows) were planted and weeds of arable land (plantain, dandelion) became established.

These two rather abrupt changes in the vegetation of the catchment and surrounding districts can be dated with reasonable accuracy. Polynesian burnings reduced a very large area of New Zealand to fernland or grassland between 900 and 400 years B. P. (McGlone 1983). The Auckland region, being fertile land, was probably among the first to be

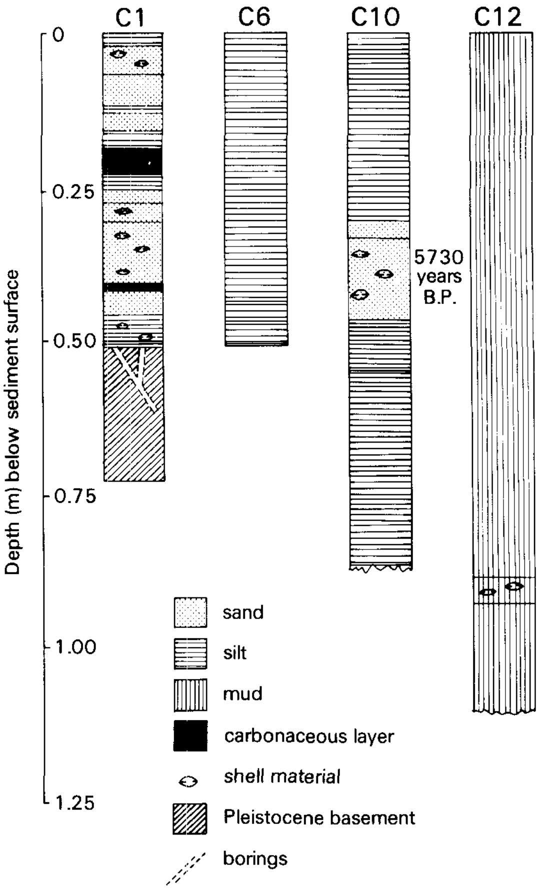


Fig. 5 Logs of short cores taken from four sites in Lucas Creek (Fig. 2). Core 10 shows a layer where cockles (*Austrovenus stutchburyi*) were radiocarbon-dated to 5730 years B. P. Pollen counts were made on splits from the top 1 m of Core 12 where the unconsolidated sediment is over 10 m thick. The sediment surface level relative to Waitemata Harbour chart datum for each core is: C1 = 1.2 m, C6 = 2.0 m, C10 = 0.2 m, C12 = 1.2 m.

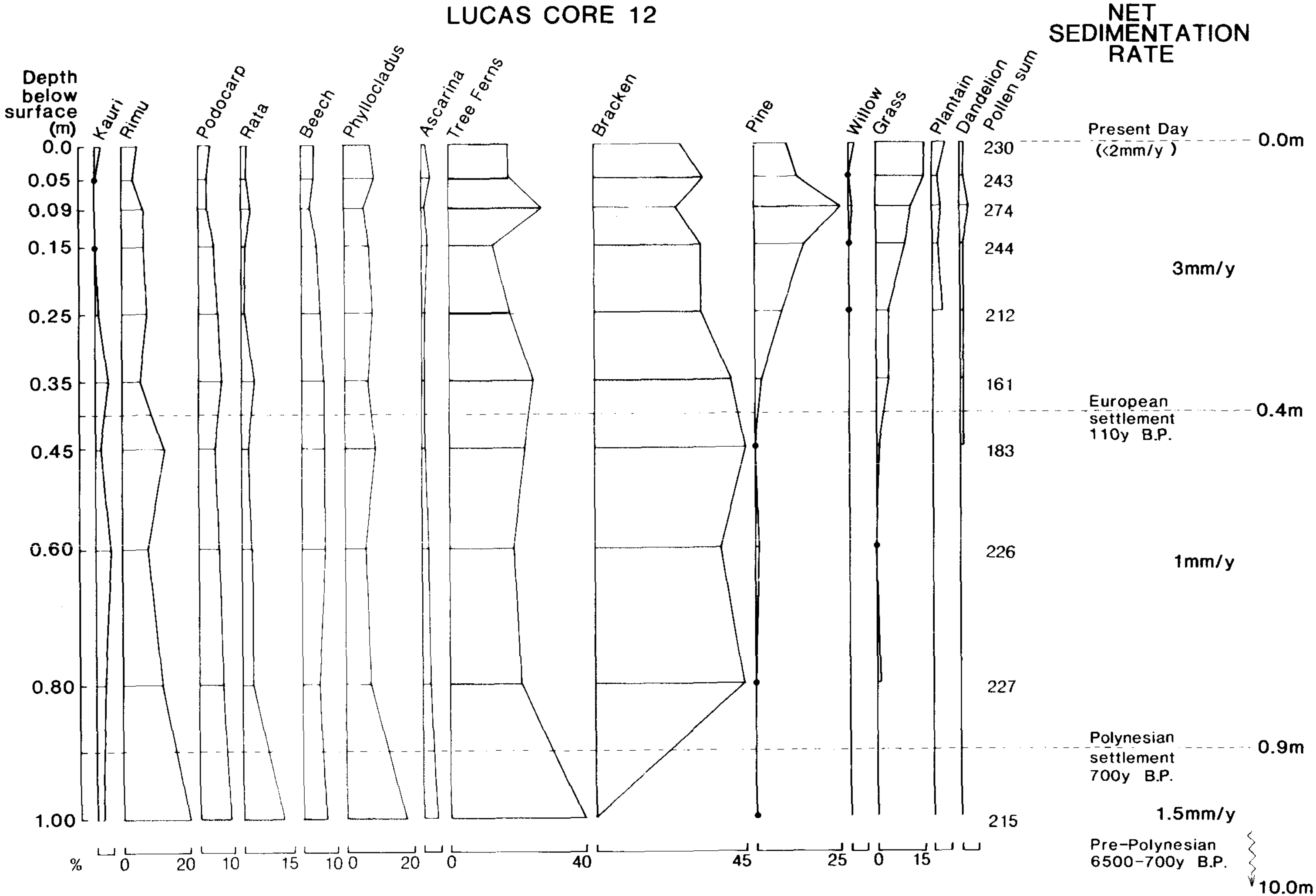


Fig. 6 Pollen diagram from the 1 m long Lucas Core 12, sampled near the entrance to Lucas Creek (Fig. 2). Values given as percentages of the pollen sum which includes all terrestrial plants, but excludes all spores with the exception of bracken; •, percentages less than 1%. European and Polynesian settlement horizons estimated from pollen changes are indicated along with derived net sedimentation rates for each period. Pollen below 1 m in C12 were examined but not counted.

cleared, although we have no accurate dates for this event. Intensive deforestation of similar areas took place between 800 and 600 years B. P. and we infer a date of 700 $\pm$ 100 years B. P. for the deforestation of the Auckland region. The net sedimentation rate for the Polynesian period is 1 mm/y at C12 (Fig. 6).

In A. D. 1840 (110 years B. P.), Europeans surveyed the Upper Waitemata Harbour and in A. D. 1841 purchased large blocks of land from the Maori people (Schriven 1981). Timber milling operations began as early as A. D. 1841 and, along with gum digging, proceeded rapidly. The destruction of remaining forest by fire and timber haulage, pit digging associated with kauri gum exploitation, and the modification of stream banks (to straighten the line of flow to assist log transport) would have resulted in substantially increased catchment erosion and sediment transport to Lucas Creek — at least until a new vegetation cover could establish itself. It is difficult to determine when forest clearance finished in the Upper Waitemata Harbour catchment, but it was nearly A. D. 1870 before farming became significant (Schriven 1981). Land use changes by the Europeans are reflected both in the pollen assemblage in the sediments and perhaps in the three-fold increase (to 3 mm/y) in sedimentation rate (Fig. 6) recorded in the sediment column at C12. The sedimentation rates are lower than the 4–8 mm/y recorded for the 1933-present period on tidal flats in Tairua Estuary, eastern Coromandel (Hume & Gibb in press).

In other intertidal parts of the estuary where Holocene sediments are thin (e.g., Fig. 2: C3) the pollen record of the last 700 years is compressed and blurred in the upper 10 cm or so of sediment. In these areas, input material has probably been flushed from the system despite the large increase in sediment input responsible for a three-fold increase in net sedimentation rate recorded in the sediment column in some sheltered parts of Lucas Creek. A comparison of historical soundings in the central channel of the creek (Hume 1983) indicates little net sedimentation or erosion over the last 125 years (A. D. 1854–1979).

The thickness of unconsolidated Holocene marine sediments in Lucas Creek at L10, L12, L15, L16/17 and AELA (Fig. 4) shows that down stream of L9 (Fig. 2) the existing channel does not coincide with the channel bed cut into basement material (i.e., the original stream before drowning by the postglacial marine transgression) and that the paleochannel lay closer to the western bank — indicating lateral channel migration of over 100 m since sedimentation began some 6500 years B. P. Cores show changing lithologies at some sites (e.g., Fig. 5) that could be due to either lateral channel migration and associated change in depositional environment, or catchment condition change. Comparison of vertical aerial photographs dated 1950, 1969, and 1979 show no significant changes in channel position. It is likely that the gentle channel meanders migrate laterally and that the time scale for changes are in the order of hundreds of years.

Present-day sedimentation

The geological, pedological and morphological characteristics of the catchment (Jessen 1983) and field examination of stream channel deposits confirm that the bulk of sediment transported by the streams is suspended mud and very fine sand. Relatively little bedload material enters the creek headwaters (Hume 1983), and none enters the estuary via the entrance because of the barrier formed by the 7 m submarine cliff and the rock headlands that minimise longshore drift.

Suspended sediments originate primarily from the Lucas and Oteha Stream catchments (Fig. 1) which discharge into the headwaters of Lucas Creek (Van Roon 1983). Assuming the bulk of sediment is transported to the estuary in suspension load, a crude estimate of the *maximum* average annual sedimentation rates in Lucas Creek estuary can be made from the Lucas and Oteha Streams suspended solids input data which were 3971 t in 1980 and 794 t in 1981 (Van Roon 1983). If all of this was transported to the estuary and deposited over the intertidal area, the resulting sedimentation rate would average about 2 mm/y. This estimate should be regarded as a maximum because over a tidal cycle about 50% of the water (including suspended solids) flushed from Lucas Creek does not return (Williams & Rutherford 1983). Also during floods dense sediment plumes extend well down-harbour from the mouth of Lucas Creek, indicating that a large part of the fluvial input is transported out of Lucas Creek to the Lower Waitemata Harbour. By way of comparison Pickrill (1979) estimated that two-thirds of the sediment input to Pauatahanui Inlet is flushed to the open sea. The estimated maximum rate for present-day deposition in Lucas Creek is slightly less than the 3 mm/y determined from the core data (Fig. 6). It is similar to present-day net rates of 2.9 mm/y deposition measured for intertidal areas at Pauatahanui Inlet (Pickrill 1979), and compares favourably with values for other temperate-latitude estuaries where typical rates are 2–3 mm/y (Rusnack 1967; Skempton 1970).

The sediment input data and field observations suggest that floods play a significant role in determining sediment distribution patterns and may explain some of the features observed in the cores. For instance, 72% of the 1980 sediment input resulted from a one-day discharge (15 March 1980) associated with cyclone "Sina" (Van Roon 1983).

The next largest storm produced 7% of the 1980 load on 20 July 1980, contributing 86% to the 1980 sediment yield in seven flow days (2% of the annual flow duration time). The total sediment yield for 1980 was nearly five times that for 1981, primarily due to the cyclone "Sina" event. The cyclone alone produced 3½ times the 1981 total sediment yield. The Lucas Stream record shows similar features.

Field observations in Lucas Creek following floods showed tidal flat sediments stripped to a depth of 30 cm about the base of mangrove shrubs immediately up stream of L5 (Fig. 2), and that flood debris (presumably trees) cut 10–15 cm deep grooves along the tidal flats parallel to the channel axis (Hume 1983). These observations help explain the thin sediment cover found in the upper reaches of the estuary (Fig. 4), which represent the sum total of sediment deposit since eustatic sea level culminated at the present sea level in New Zealand at 6500 $\pm$ 100 years B. P. (Gibb in press). Sediment reworking by floods could also help explain the absence of tephra or other correlatable layers in the sediments.

Even though floods carry the bulk of sediments to the estuary and flood-assisted currents strip sediments in the headwaters, the episodicity of these events is not readily distinguished in subsurface sediments. Present-day changes in catchment use from rural to urban are reflected in the accumulation of small amounts of unsightly "urban debris", such as construction and roading metal, concrete, and objects of glass, metal, wood, or plastic, particularly in the headwaters of Lucas Creek.

DISCUSSION

Comparison of our knowledge of existing patterns of sedimentation with Lucas Creek with predicted changes in catchment use (Moody 1983) and sediment yield (Van Roon 1983), and comparison with similar situations, permit an estimate to be made of the likely impact of catchment use change on sedimentation in Lucas Creek.

In the neighbouring Hellyers Creek (Fig. 1), catchment urbanisation has probably been the cause of locally increased sedimentation rates to 6 mm/y along the south-eastern shore (Hume 1983). Williams (1976) and Beca Carter Hollings & Ferner Limited (1978) describe severe siltation in a marina at the mouth of the Wairau Creek estuary on Auckland's North Shore, attributed to high sediment run-off associated with urban development. Sediment run-off, although reducing after the urban construction phase, remained unexpectedly high (Williams 1976). Healy (1980) reported increased sediment yields from the Browns subcatchment of the Pauatahanui Inlet (Porirua) which was undergoing a phase of development and localised build-up of sediment on tidal flats adjacent to the stream mouths. Macpherson (1978) described substantial changes in the tidal compartment in the Avon-Heathcote estuary which he attributed largely to catchment urbanisation. A decrease in tidal prism from about 8×10^6 m^3 (1850) to about 5×10^6 m^3 (1875–1910) was attributed to sediment run-off and estuary infilling resulting from early urban growth. A subsequent increase in tidal compartment to about 11×10^6 m^3 (1975) was correlated with scour of sediment from the estuary resulting from higher peak storm flows because of an increase in impervious areas and storm water reticulation. However, in a subsequent study Findlay (1981) disputes there was ever a decrease in tidal prism in the 1875–1910 period and finds no correlation between the growth of Christchurch and increase in the estuaries tidal compartment in the post-1930 period.

Urbanisation in the Albany Basin will more than double sediment input to Lucas Creek by the year 2000 (Van Roon 1983). This is likely to lead to increased sedimentation rates in Lucas Creek, particularly during the construction phase. The sites where deposition will occur in Lucas Creek are easier to predict than the amount of sediment that will be deposited. Deposition will be concentrated in those areas of low environmental energy such as the present tidal flats and mangrove embayments as at present. Sedimentation would be expected to take place in the vicinity of L6 and L7 (Fig. 2) and downstream of L10, particularly in the Te Wharau delta area (L12–L15) because channel widening will cause a reduction in tidal velocity resulting in sediment deposition. The more peaked flood hydrographs that accompany urbanisation (e.g., Williams 1976) will extend the limit of freshwater influence further down the estuary, resulting in sedimentation maxima nearer the mouth for comparable pre-urbanisation storm events. Sedimentation could result in lateral migration of the channel in the wide estuarine reach between L11 and L15. Further up stream the channel is too restricted by bedrock to move appreciably.

Urbanisation in the Lucas Creek catchment will give rise to more frequent, high-peak flows of short duration (Smith 1985) because of an increased percentage of impervious surface area over the catchment due to roofing, pavements, roads and storm water reticulation. It is predicted that this will increase the frequency and magnitude of intermittent sediment stripping events in the reaches of the estuary up stream of L7 and will result in very low or negative net sedimentation rates. Stripping of the upper layers of sediment and channel bank scour will continue during both the constructional and completed stages of urbanisation. In the narrow upper reaches of Wairau Creek estuary for example, floods have caused severe bank erosion and channel scour (Hume 1983). Massive reductions in tidal compartment like those described by Macpherson (1978) do not seem likely.

Observations in Auckland's urbanised estuaries show that a potentially serious problem is the accumulation of urban debris such as construction and roading metal, concrete, tree and shrub debris, and objects of glass, metal, wood, or plastic in the system which detract from the estuaries' visual appearance. Entrapment at source is the only effective solution to this problem.

CONCLUSIONS

The thickness of Holocene marine sandy muds and muddy sands in Lucas Creek varies from zero in the headwaters to more than 10 m near the entrance, showing marked spatial variation about the estuary. Marine sedimentation began in Lucas Creek about 6500 years B. P. and where the sediment column is thickest, net sedimentation rates vary from less than 1.5 mm/y in pre-Polynesian times (6500–700 years B. P.), to 1 mm/y during Polynesian settlement (700–110 years B. P.), increasing to 3 mm/y for European settlement (110 years B. P.-present) and decreasing to less than 2 mm/y for the present day. Present-day sedimentation rates are similar to those reported for Pauatahanui Inlet and comparable to those found in other temperature-latitude estuaries.

Changes in catchment use are recorded in pollen species in the sediments that show in turn: initial forest clearance by the Polynesian; large-scale forest and scrub clearance accompanying logging and gum digging; and land clearance for farming in European times, which tripled the sedimentation rate in the estuary. Present-day changes in catchment use from rural to urban are reflected in urban debris that litters the tidal flats.

Catchment urbanisation is expected to double suspended sediment input to Lucas Creek. The present distribution pattern of sediments in the estuary suggests that increased sedimentation is likely to occur in the lower broader reaches and embayed areas of the estuary; flood waters will continue to minimise sediment accretion or cause all scour in the narrow upper reaches. Urban debris will be a problem unless controlled at source.

The effect of changes in catchment use on sedimentation rates in estuaries can be effectively mapped using pollen markers but only in sheltered areas where sedimentation rates are high and there has been little reworking. In estuaries adjoining city areas, urban debris will in time form a useful stratigraphic and catchment use marker.

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