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A marine to freshwater sediment succession from Kowhai Beach wetland, Northland: implications for Holocene sea level

Helen Hicks[1] **and Scott L. Nichol**[1]

Abstract An infilled wetland located behind coastal dunes in north-east Northland is used to reconstruct a local history of environmental change spanning early Holocene (c. 7000 yr BP) to modern time. Proxy indicators (sediment texture, diatoms and pollen) provide evidence for a transition from marginal marine- to brackish- to freshwater-conditions in the wetland. Radiocarbon ages constrain the chronology of this succession to 7880–7430 cal. yr BP for the early period of marine conditions, 3570–3210 cal. yr BP for the latter brackish phase and 1060–800 cal. yr BP for the change to freshwater conditions. Within this succession, the diatom record preserves a strong brackish signal at core depths above the limit of the modern tidal range. This is presented as preliminary evidence for a mid-Holocene sea level highstand for northern New Zealand of approximately 1.2 m above present mean sea level.

Keywords diatoms; ^{14}C dating; highstand; palynology; sea level; sediments; stratigraphy

INTRODUCTION

The characteristics of sedimentary successions that constitute the coastal depositional record are controlled by the interplay between sea level, sediment supply and accommodation space. Studies of the facies that comprise these sedimentary successions traditionally focus on shoreface, beach and dune environments and associated marine-dominated processes (e.g., Curray 1964; Kraft 1971; Thom 1983; Davis & Clifton 1987; Roy et al. 1994). In general, these particular environments do not always preserve a detailed record of environmental change in adjacent terrestrial systems. In contrast, back-barrier environments (wetlands, swamps, marshes and lagoons) do have the potential to record details of environmental change in both coastal and terrestrial systems, particularly responses to sea-level change (Nichol et al. 2007).

For the New Zealand coast, there has been little effort to use back-barrier environments to study environmental change, nor to resolve Holocene sea-level history beyond that established by Gibb (1986). Noticeably absent has been any attempt to establish evidence for a mid-Holocene highstand in sea level, a phenomenon now well documented for other coasts in the SW Pacific (e.g., Woodroffe et al. 1995; Baker & Haworth 1997, 2000; Nunn 1998; Sloss et al. in press). This paper addresses these matters via a case study of a back-barrier wetland in northern New Zealand. The study objectives are to investigate the sensitivity of the wetland to marine and terrestrial influences, and to test for evidence of a sea-level highstand using a multiproxy analysis of the sediment record.

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THE STUDY AREA

Kowhai Beach is located on the east coast of Te Aupouri Peninsula, Northland, at 34°47.12′S, 173°09.05′E (Fig. 1). The shoreline is characterised by a 2.1 km long sandy beach with cliffed, rocky headlands formed in greywacke. The beach is backed by Holocene dunes that are actively transgressing podzolised dune sands of inferred Pleistocene age (Hicks 1983), that rise to a maximum elevation of 25 m above present mean sea level (PMSL). At the southern end of the beach a freshwater wetland is enclosed by the Pleistocene dunes and the edge of the headland at Perforated Point (Fig. 1). Elevation surveys of sample sites used for this study show the wetland is 3–4 m above PMSL and field observations confirm that the wetland is isolated from regular tidal exchange. The only outlet is via Omianga Stream, which maintains ephemeral flow to the open coast. The catchment for the wetland covers an area of 3.5 km^2 rising to a maximum elevation of 120 m. Mean tidal range on the open coast is microtidal, ranging from 1.2 m on neaps to 1.8 m on spring tides. Wave energy on this coast is low to moderate with a modal wave height of c. 1 m and storm surge less than 2 m (Pickrill & Mitchell 1979; Moir et al. 1986).

Previous palaeo-environmental research on Te Aupouri Peninsula includes studies of coastal sediment types and sources (Schofield 1970; Ricketts 1979), geomorphic mapping of dune systems and palaeosols (Hicks 1983) and shallow stratigraphic studies of wetlands to document regional vegetation history (Dodson et al. 1988; Enright et al. 1988; Newnham et al. 1993; Ogden et al. 1993; Elliot et al. 1995, 1998; Horrocks et al. 2001, 2007). These works established the Late Quaternary age for much of the surface and near-surface depositional sequences on the peninsula. A key characteristic of the region is the inferred tectonic stability during the Late Quaternary, based on the absence of uplifted coastal terraces (Pillans 1986). Te Aupouri Peninsula is therefore a highly suitable locality to study coastal sediment records of marine-terrestrial interactions and, in particular, evidence for a mid-Holocene highstand of sea level.

FIELD AND LABORATORY METHODS

Multiproxy analysis was utilised to reconstruct the history of Kowhai Beach wetland. Four continuous sediment cores were collected in 7 m aluminium tubes (76 mm diameter) using a vibracoring system, with compaction measured before retrieval. Core sites were chosen along the northern arm of the wetland where access was possible and manual probing, using a gouge auger, showed sediment thickness was at least 4 m. Penetration depth of cores ranged from 4.2 to 5.8 m, with compaction of 15–24% (Fig. 2). Core sites were levelled to local mean sea level using a Sokkia Total Station instrument to within ±5 cm and positions recorded by differential GPS to within ±1 m.

In the laboratory, cores were split, described and photographed. One core, KB4, was chosen for detailed analysis because it recovered the thickest and most varied facies succession. This core was subsampled at intervals of 2–10 cm, depending on sediment variability, for sediment analysis and organic content, as well as fossil diatom and pollen extractions (Fig. 3 shows subsample depths).

Sediment size was measured using a laser diffraction particle sizer (Malvern Mastersizer 2000), with samples pre-treated with 30% hydrogen peroxide to remove organic material. Organic content of sediment was determined by the Loss-On-Ignition (LOI) technique, with samples combusted at 550°C for 6 h. Pollen analysis was carried out on 20 samples from KB4. Sample preparation followed standard palynological techniques outlined by Moore et al. (1991) and slides were scanned to identify dominant taxa and general pollen zones as indicators of broad environmental change, including human disturbance to local forests. Detailed pollen counting was not conducted for this study because it was beyond the main objective and the

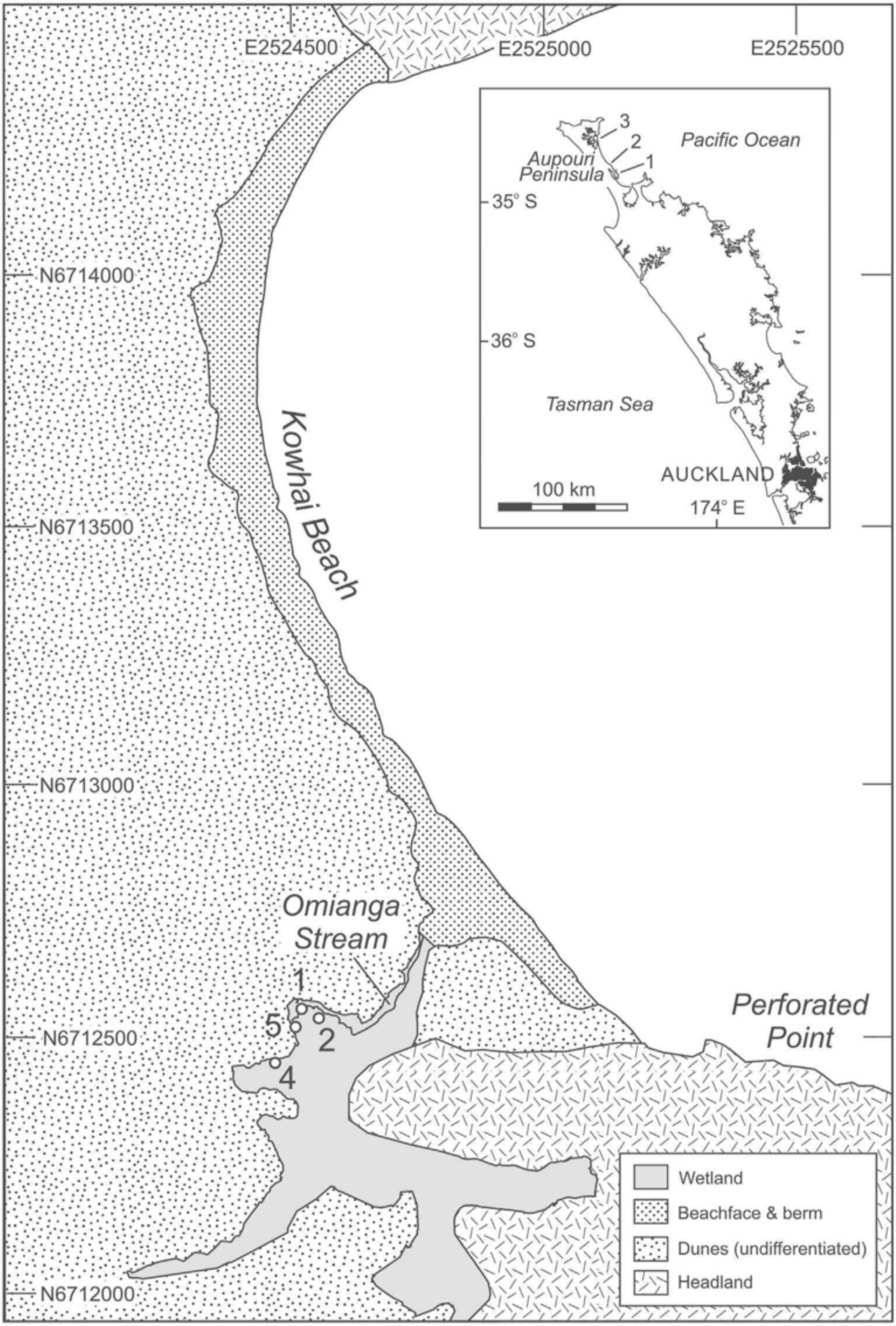

Fig. 1 Map of Kowhai Beach, wetland and dunes (undifferentiated active Holocene and podzolised Pleistocene dunes), showing locations of cores collected for this study (New Zealand map grid co-ordinates). Inset map shows Northland region indicating sites mentioned in text: 1, Kowhai Beach; 2, Rarawa Beach; 3, Kokota (Parengarenga Harbour).

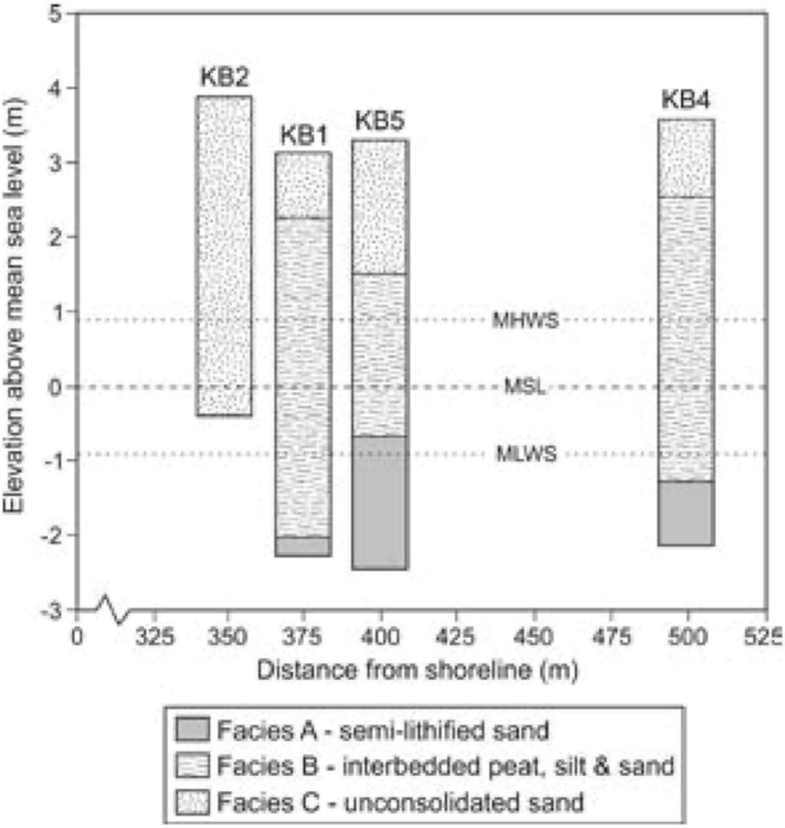

Fig. 2 Generalised stratigraphy of Kowhai wetland showing thickness and elevation of the three main sediment facies adjusted for compaction, as follows: KB1, 130 cm; KB2, 70 cm; KB4, 86 cm; KB5, 102 cm. Mean sea level and spring tide heights are also plotted, based on New Zealand Nautical Almanac data for Houhora Harbour entrance (Land Information New Zealand 2007).

regional vegetation history is well documented (e.g., Dodson et al. 1988; Horrocks et al. 2007).

Seventeen samples were extracted from core KB4 for diatom analysis. Samples were selected to represent all sediment types and major transitions. Sample preparation followed the procedure of Battarbee (1986), with organics removed using 30% hydrogen peroxide in a warm water bath, followed by removal of clay and fine silt by repeated centrifuge and rinsing in distilled water. Diatom counts of at least 300 valves per slide were completed, with identification based on standard floras (Van der Werff & Huls 1957–64; Foged 1979; Krammer & Lange-Bertalot 1991–97; Krammer 2000). Diatoms were classified according to salinity preference using the halobian scheme of Hustedt (1953), comprising polyhalobian (>30‰ salinity), mesohalobian (0.2–30‰ salinity), oligohalobian (<0.2‰ salinity) and halophobian (c. 0‰ salinity) groups. Diatoms were also classified into lifeform type, comprising benthic, epontic (attached to a substratum, e.g., plants), tychoplanktonic (occur in water column but derived from another habitat) and planktonic forms (Denys 1991).

Age control was obtained for core KB4 using three peat samples submitted to the University of Waikato Radiocarbon Dating Laboratory. Calibration of radiocarbon ages was done using Oxcal software version 3.1 (Bronk Ramsay 2005), based on Southern Hemisphere atmospheric data (McCormac et al. 2004), with results reported here at 95.4% probability level.

Sample depths reported for analytical results from core KB4 have not been corrected for core compaction because sediment compression is unlikely to be linear with depth, nor equal for different sediment types. However, the thickness of wetland deposits is known, based on depth to a hard and dry sand deposit recovered by gouge auger. On this basis, the de-compacted sediment thickness was calculated for core KB4 and used to construct a summary plot of facies thickness and diatom salinity zones in relation to PMSL.

RESULTS

Facies analysis

Three facies are identified for the Kowhai wetland sedimentary infill (Fig. 2, 3).

Facies A

This facies was recovered at the base of three cores from varied depths. It comprises massive, orange-brown sub-lithified sand that is fine-grained and well to moderately well sorted. In cores KB1, 4 and 5 the top of this facies occurs 0.6– 2 m below PMSL and ranges in thickness from 0.2–1.7 m, but is presumably thicker due to the base of this deposit not being recovered. From observation, the sand also contains local concentrations of *in situ* root material, and burrow traces (Fig. 3). The upper surface of this facies forms a well defined, sharp contact with Facies B.

Facies B

This facies comprises interbeds of peat, silt and laminated sand. Muddy silt dominates the lower part of the deposit with sandy peat dominating the upper part. Organic material includes *in situ* root material and rafted wood fragments, with the latter associated with granule-sized pumice clasts. Laminated sand interbeds range in thickness from 0.2–40 cm, with two sand populations recognised (Fig. 4). Sand-type I is medium-grained (mean: 310–325 μm), moderately well sorted and stained yellow to yellow-grey with depth. It was recovered in all cores. Sand-type II was only recovered in core KB4 where it is fine-grained (mean: 205–230 μm), moderately well sorted and distinctively white.

In core KB4, Facies B is 295 cm thick with a sharp basal contact at 400 cm depth (Fig. 3). Finely laminated white sand is preserved in the lower 140 cm, forming well sorted beds 0.5–40 cm thick with silt flasers toward the base of the deposit. Above the white sand, yellow sand is interbedded with peaty mud. The proportion of mud increases up-core from 4 to 76% and organic content varies between 34 and 54%. Some sand interbeds also contain pumice clasts, such as the interval between 156 and 145 cm (Fig. 3). In core KB5, Facies B is 120 cm thick and is in erosional contact with Facies A as evidenced by clasts of coffee rock within yellow-grey sand. The top part of the deposit is dominated by sandy peat and mud, with pumice and wood fragments.

Table 1 Sample details and results for radiocarbon age determinations for Kowhai Beach wetland core KB4.

Sample depth (cm)	Lab code	Material	Conventional ^{14}C age (yr BP)	Calibrated ^{14}C age (yr BP)[1]
99	Wk-17123	Sandy peat	1075 ± 55	1060–800
140	Wk-17124	Sandy peat	3228 ± 71	3570–3210
354	Wk-17125	Peaty sand	6860 ± 134	7880–7430

[1] Calibration made with OxCal version 3.4 software using the marine dataset (Stuiver et al. 1998) and a Delta-R value of 12 ± 15.

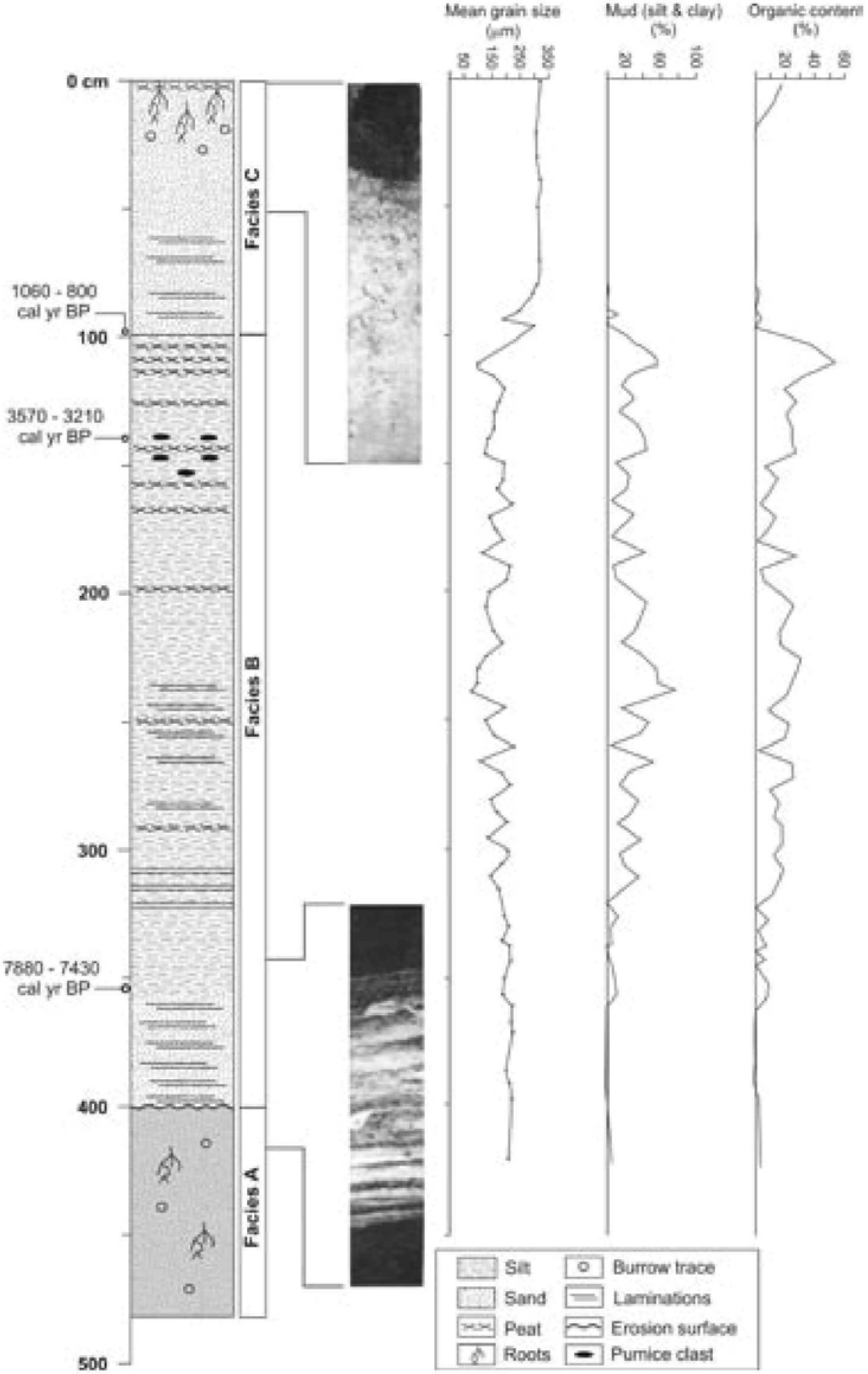

Fig. 3 Core log and representative photos for Kowhai Beach wetland core KB4, also showing calibrated radiocarbon ages (conventional ages are shown in Table 1). Core depths shown here have not been corrected for compaction of 86 cm.

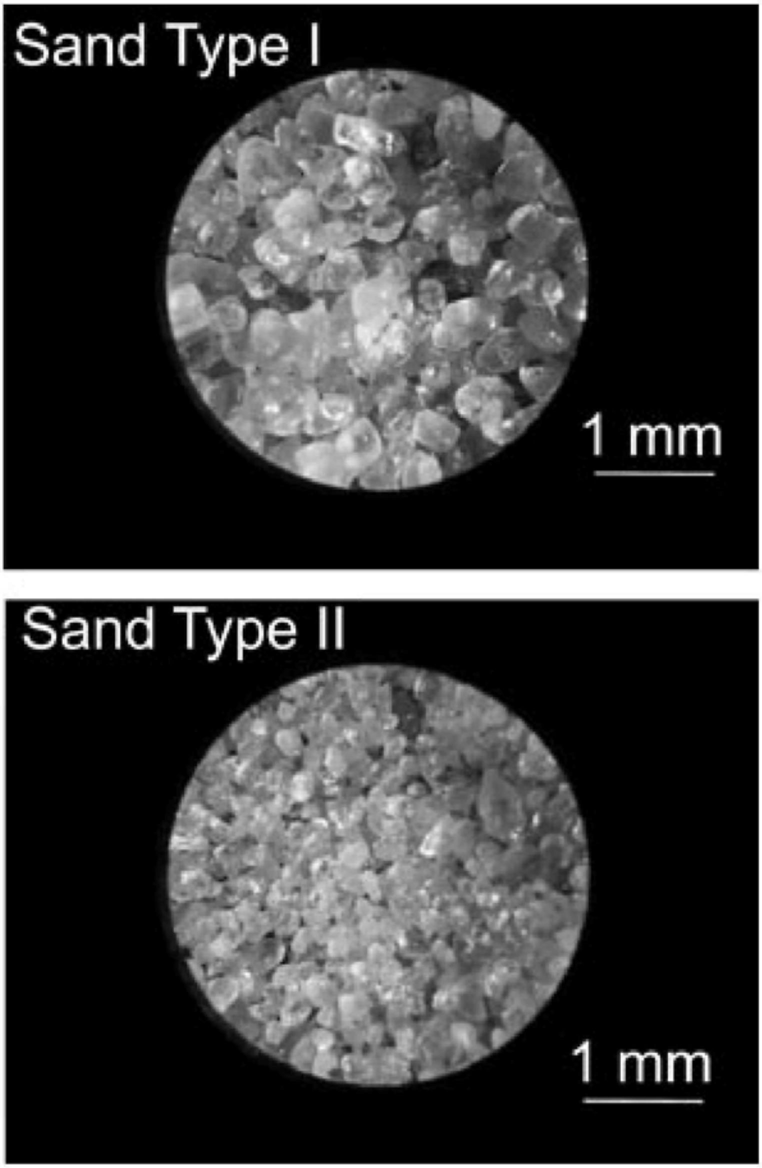

Fig. 4 Photomicrographs of sand Type I and Type II from core KB4, showing contrast in grain size.

Three radiocarbon dates were obtained on peat from Facies B in core KB4 (Table 1, Fig. 3). Calibrated ages range from 7880 to 7430 cal. yr BP at 354 cm depth, to 3570–3210 cal. yr BP at 140 cm, and 1060–800 cal. yr BP at 99 cm depth.

Facies C

This facies is characterised by medium sand that is well to moderately well sorted and massive, except for laminae of organic material concentrated toward the base of the deposit (Fig. 3). The sand forms a sharp basal contact with Facies B and toward the surface becomes organic rich (up to 18%) with *in situ* roots through most of the deposit. In core KB4, Facies C is 1 m

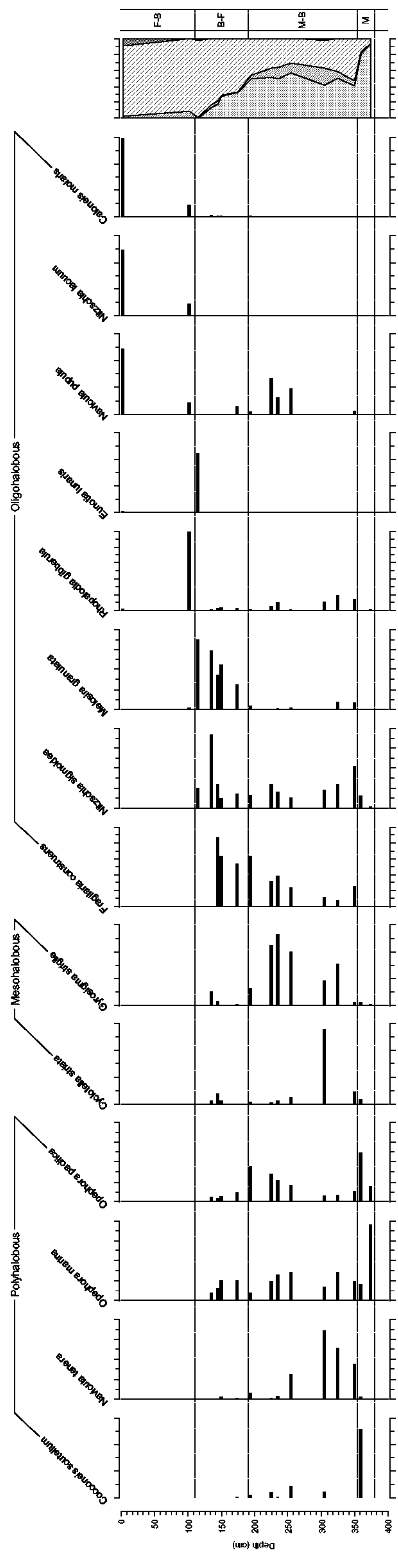

Fig. 5 Summary plot of diatom profile in core KB4, showing dominant taxa arranged into salinity groups based on the halobian scheme of Hustedt (1953). Key to cumulative plot of salinity groups: 1, polyhalobous (>30‰); 2, mesohalobous (0.2–30‰); 3, oligohalobous (<0.2‰); 4, halophobous (c. 0‰).

thick and has an upward coarsening trend as shown by increased mean grain size (194–324 µm) and decreased mud content. In other cores this deposit is 1–2 m thick and composed all of core KB2 (4.3 m), where it is at maximum observed thickness (Fig. 2).

Diatoms

From the 17 samples prepared for diatom analysis from core KB4, 85 species were identified. Preservation of diatom valves is highest in Facies B, particularly in the silt and peat interbeds. For two samples of sandy peat, sub-optimum counts of 44 (103 cm) and 197 (115 cm) diatom valves were reached and a zero count at 93 cm. Remaining samples yielded counts >300 and from this data four diatom zones are recognised (Fig. 5).

Zone A (375–360 cm)

This zone is associated with muddy silt from which 18 diatom species are identified. Two taxa dominate the count; *Opephora marina* (76% of count at 375 cm) and *Opephora pacifica* (50% of count at 360 cm), with the sum dominated by whole valves (>75% of count) (Fig. 6). Both species are polyhalobous, having preference for marine-brackish to marine conditions and epontic in lifeform. The preservation of fresh and fresh-brackish tolerant species is low in this zone, with 11 taxa contributing less than 20% of the diatom sum.

Zone B (360–195 cm)

This zone spans an interval of Facies B that incorporates seven samples from interbeds of silty peat and sand. A total of 47 diatom species are identified, with a strong presence of marine-tolerant polyhalobous (*O. pacifica*) and marine-brackish mesohalobous taxa (*O. marina*, *Navicula tenera* and *Gyrosigma strigile*; the latter two are benthic types). Marine diatoms range from 40 to 56% of the assemblage and the marine-brackish group varies between 4 and 21%, with a tendency

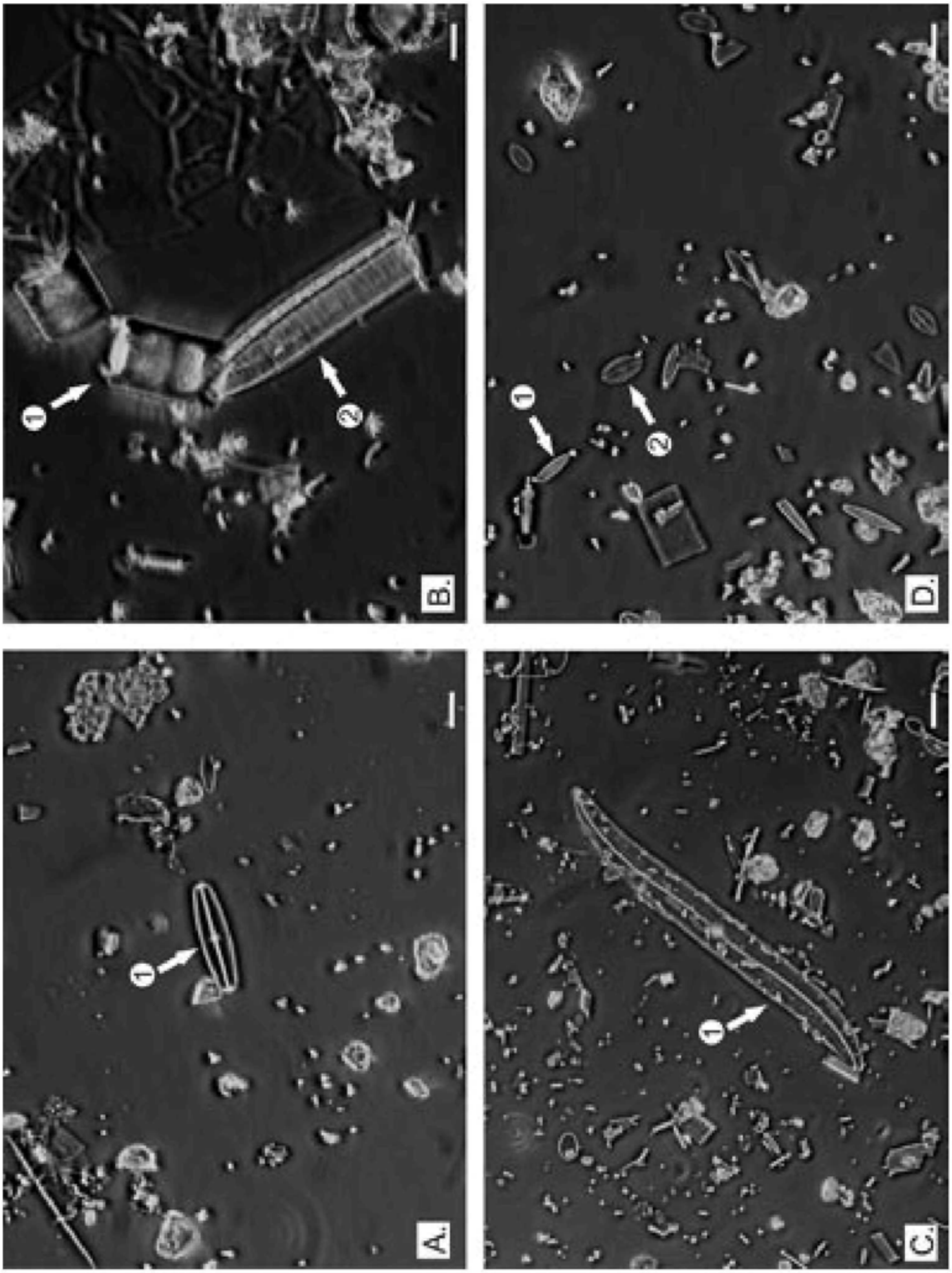

Fig. 6 Photomicrographs of dominant diatom taxa from core KB4 shown using phase contrast objective, showing: **A**, 1 *Navicula pupula* from 3 cm depth; **B**, 1 *Melosira granulata*, 2 *Nitzchia sigmoidea* from 145 cm depth; **C**, 1 *Gyrosigma strigile* from 255 cm depth; **D**, 1 *Opephora pacifica*, 2 *Cocconeis scutellum* from 360 cm depth. White scale bar 10 microns.

toward lower values with decreasing depth. Brackish-tolerant species of the oligohalobous group (e.g., *Fragilaria construens*; epontic) comprise 31–53% of the count with peak values toward the lower and upper depths of this zone. Freshwater species of the halophobous group are only present as minor constituents (2% at 305 cm depth). The proportion of whole valves is variable through the zone, ranging from 57 to 80% of the diatom sum but lacking any trend.

Zone C (195–115 cm)

Four samples represent this diatom zone, within which 39 species are identified in association with silt and peat interbeds. The zone is distinguished from zone B by a marked decrease in polyhalobous taxa (*O. pacifica* and *O. marina*) to 13% of the diatom count at 135 cm depth. Mesohalobous species are also in low concentration, peaking at c. 4% at 145 cm. The dominant salinity group in the zone are oligohalobous diatoms, which increase from 67 to 83% of the count up-core. Key taxa in this group include *Melosira granulata* (epontic), *Fragilaria construens* and *Nitzschia sigmoida* (benthic) (Fig. 6). Salt intolerant (halophobous) diatom species are present in two samples (150 and 145 cm) but only as a trace (<1%). The proportion of whole valves decreases from 65% at 195 cm to 18% at 135 cm.

Zone D (115–3 cm)

This zone spans the top of Facies B and all of Facies C, with sand as the dominant sediment type and diatom abundance accordingly low. Three samples yielded 42 diatom species that record a distinct change in salinity regime. In particular, the genus *Opephora* (including O. *marina*, *O. pacifica* and *O. martyi*) is absent, signalling a change from marine to marine-brackish conditions. The zone is dominated by a group of 34 taxa (dominated by *Caloneis molaris*, *Nitzschia lacuum* and *Navicula pupula* (Fig. 6); all benthic lifeforms and 57–80% whole) of the oligohalobous group that together comprise more than 90% of the diatom sum. Halophobous (salt intolerant) species are present (e.g., *Frustulia rhomboids*; benthic), with peak concentration of 8% at 3 cm depth.

Pollen

Four pollen zones are recognised from slide scans of samples from Facies B and C in core KB4.

Zone 1 (420–300 cm)

The lower interval of Facies B, where sand is interbedded with silty peat, preserves a pollen profile dominated by taxa of local swamp vegetation, notably *Typha* (bulrush) with some *Leucopogon* (shrub). The profile also records a regional pollen signal of tall forest dominated by *Dacrydium* (rimu), *Prumnopitys* (matai), *Nothofagus menziesii* (silverbeech), *Phyllocladus* and *Nestiges*. Sub-canopy forest plants include *Ascarina*, *Rhopalostylis* (nikau palm) and *Cyathea dealbata* (tree fern).

Zone 2 (300–120 cm)

Above 300 cm depth, the pollen types extracted from Facies B sediments record a change to marine-brackish water conditions in the wetland, as evidenced by *Cyperaceae* (club rush), *Apiaceae* and *Restionaceae* and *Zostera* (eel grass), with *Restionaceae* dominating above 240 cm depth. The composition of surrounding forest is similar to zone 1 with the addition of *Quintinia*, *Psedowintera* and *Mysine*, as sub-canopy vegetation. *Agathis australis* (kauri) is also recorded at 140 cm depth. *Peasia* (fern) is present as a record of ground cover, associated with an increase in herbaceous pollen species, such as *Astelia*. Charcoal was also noted, the largest fragment 76 μm in diameter.

Zone 3 (120–20 cm)

This pollen zone spans the upper part of Facies B (silt) and most of Facies C (sand). The pollen profile records a decline in conifer-hardwood and swamp vegetation above 120 cm depth. Charcoal content is greater than in zone 2 with most of the fragments in the size range 125–250 µm. Fern spores (*Pteridium*) are present only as a trace in the lower part of the zone, but increase above 80 cm depth in conjunction with *Knightia* (a fire favouring species) and the addition of *Asteraceae* pollen. The local swamp pollen taxa include *Phormium tenax* (flax) and the disturbance species *Anthoceros* (a genus of hornworts).

Zone 4 (20–2.5 cm)

Within the organic-rich sands of Facies C, traces of *Pinus* (pine) and *Poaceae* (grass) appear at 20 cm depth and increase dramatically above 10 cm. *Taraxacum* (daisy) is also abundant and fern spores such as *Lycopodium varium* increase through this zone. Charcoal fragments are also preserved, mostly as silt sized particles (20–25 µm) but ranging up to 75 µm diameter.

INTERPRETATION

Sediments

Facies A

The basal facies in the Kowhai wetland infill is interpreted as a dune podzol soil. This is based on the strongly oxidised state of the well sorted fine sand that forms the deposit. In particular, the dark, orange-brown colour of this facies is an indicator that humic acids and soluble irons have stained and cemented the sand, a property that is consistent with the B-horizon of a podzol. We note that the leached A-horizon has not been preserved. Sands of similar weathered appearance outcrop in the dunes surrounding Kowhai wetland where they form a highly dissected local topography, also lacking A-horizon material. In core samples, the sharp contact between Facies A and B is therefore interpreted as subsurface continuation of this irregular topography across which the wetland has formed.

Facies B

The transition to unconsolidated mixed sand, silt and peat deposits of Facies B is interpreted as evidence for sedimentation under conditions of impeded drainage. The onset of wetland conditions at Kowhai appears to be synchronous with Holocene post glacial sea-level rise. This is based on the radiocarbon age of 7880–7430 cal. yr BP on peat toward the base of Facies B (core KB4). However, this age pre-dates the accepted timing for near-present sea level on the New Zealand coast by c. 1 ka (Gibb 1986). This result implies that sea level was nonetheless sufficiently high by c. 7.5 ka to have initiated a base level change in local drainage networks, causing ponding in lowland areas in association with sediment accumulation at the present shoreline to form the beach-dune system. Sediment supply clearly fluctuated during the formation of Facies B, as evidenced by the distinct interbedding of peat and silt with sand. That is, we interpret peat and silt deposits as the product of autochthonous wetland sedimentation from plant growth and local in-washing of fines, whereas the sand beds are seen as either wind-blown or water-transported sediments sourced from adjacent dunes and the beach. Because sand beds have low silt and organic content and are in sharp contact with peat-silt beds, it is likely that deposition was episodic and probably rapid. Variation in the thickness of Facies B between our cores is interpreted to relate to controls imposed by the irregular topography of buried palaeo-dunes (Fig. 2).

Facies C

This sand-dominated facies is interpreted as the product of late-Holocene to modern aeolian transport from adjacent dunes into the wetland. This is based on a radiocarbon age of 1060–800 cal. yr BP from the base of Facies C in core KB4. Criteria for interpreting the sand as wind-blown include elevation of core sites, which range from 3 to 4 m above PMSL and therefore above storm surge limits, and the mix of organic material with sand as evidence that the sediment surface was partially vegetated and therefore sub-aerial.

Diatoms

The four diatom zones reported for core KB4 are summarised into two phases of contrasting salinity for Kowhai wetland, as follows:

Marine-brackish phase (Zones A and B)

From the base of sediment Facies B (375 cm) to 195 cm depth the diatom assemblage records a change from polyhalobous-dominant taxa to mixed polyhalobous-mesohalobous types, as indicators of a reduction in palaeo-salinity from >30‰ to 0.2–30‰. On this basis, we conclude that Kowhai wetland had a permanent to semi-permanent connection to the open coast, allowing regular tidal exchange. However, the presence of oligohalobous species suggests that the wetland was not exclusively tide-influenced, but did have some freshwater input. In addition, because the dominant taxa are epontic and benthic lifeform types in unbroken condition, we interpret the diatom assemblage as autochthonous and not transported from seaward, as would be evident in a planktonic-rich flora.

Fresh-brackish phase (Zones C and D)

A further decline in salinity of the wetland is evident from diatom zones C and D that we combine to represent the fresh-brackish phase in wetland development. This interval extends from 195 cm depth to the surface of core KB4. The onset of this phase of reduced salinity occurs at 195 cm, marked by decrease of polyhalobous and mesohalobous diatoms and a major increase in oligohalobous species. This trend is sustained through this phase so that toward the modern surface the diatom assemblage is dominated by oligohalobous species. Clearly, tidal inundation did not occur during this phase of deposition due to accretion of the sediment surface to supratidal levels. Again, whole valves dominate the diatom assemblage as evidence for *in situ* production rather than transport from external sources.

Pollen

The four pollen zones in core KB4 are used here to recognise three phases of vegetation history in Kowhai wetland.

Pre-human phase (Base of core to 120 cm)

Pollen zones one and two are combined to represent the pre-human period of wetland development at Kowhai. Radiocarbon ages for this interval span early Holocene (7880–7430 cal. yr BP) to late Holocene (1060–800 cal. yr BP) time, with the pollen record showing dominance by conifer and hardwood forest. The pollen record also shows a transition to marine-influenced conditions in the wetland, with seagrass (*Zostera*) and salt marsh (*Cyperaceae*, *Apiaceae* and *Restionaceae*) taxa present in succession. Some age control on this transition is given by a radiocarbon age of 3570–3210 cal. yr BP for sandy peat at 140 cm depth.

Polynesian phase (120–20 cm)

Pollen zone three is interpreted as a record of disturbance to local vegetation, induced by human activity. The decline in conifer and hardwood forest pollen at 120 cm depth and the increase in relatively coarse (125–250 µm) microscopic charcoal, are offered as evidence for local forest clearing by burning. Further, the increase in bracken fern spores (*Pteridium*) and *Knightia* is consistent with a more open forest cover. A maximum age for this Polynesian phase in wetland history is given by the radiocarbon age of 1060–800 cal. yr BP from 99 cm depth in core KB4. This is consistent with Elliot et al. (1995), who suggest an age of c. 900 yr BP for the start of anthropogenic deforestation in Northland.

European phase (20–0 cm)

Pollen zone four is interpreted as the European phase in Kowhai wetland history. This period is distinguished from the Polynesian phase by the presence of *Pinus* and *Poaceae* within the upper 20 cm. Both are exotic species that were introduced by Europeans in the mid to 19th century (Dodson et al. 1988). Other pollen indicators of disturbance include *Taraxacum* (daisy) and *Lycopodium varium*, plus abundant charcoal as evidence for regional and local fire events.

DISCUSSION

Kowhai wetland preserves a detailed record of coastal change that incorporates marine transgression, variable sediment fluxes from local and external sources, transition to a freshwater system, and evidence of human impact. In the context of the relatively sheltered setting for the wetland, aspects of the sedimentary succession raise two important questions regarding palaeo-environmental conditions: (i) What was the source and transport mechanism for sand interbeds in Facies B?; and (ii) Is there evidence for a higher-than-present sea level in the Kowhai sediment record?

Sand sources

Two types of sand are identified from Facies B, differentiated on the basis of colour and mean grain size. Sand-type I (medium yellow sand) closely resembles the modern sand on Kowhai Beach and dunes, which incorporate reworked stained quartz and feldspar locally derived from Pleistocene dune podzols. Sand-type II (fine white sand) has a modern analogue in the Parengarenga Sand Facies (Schofield 1970) that forms beaches and barriers to the north of Kowhai Beach (e.g., Rarawa and Kokota; Fig. 1) and occurs on the inner shelf in adjacent Henderson Bay (Dick 2005). The preservation of Parengarenga Sand (type II) deposits in Kowhai wetland implies that transport into the wetland was episodic and did not involve mixing with pre-existing beach-dune sand (type I). For this to occur, sand transport from the open coast along an open tidal inlet to the wetland is inferred. This is supported by diatom evidence that shows a strong marine signal through this interval. That the Parengarenga sand type is only preserved in the lower section of Facies B is evidence that this mechanism became less efficient over time and eventually shut down as the wetland infilled with sediment and the tidal inlet closed.

Sea-level implications

The strong marine influence in Kowhai wetland during the early to mid stage of infilling may also be indirect evidence for slightly higher sea level at the time. A highstand of sea level during the mid-Holocene has not been well documented for New Zealand, however, it is now generally accepted for other coasts in the SW Pacific, including eastern Australia (Beaman et

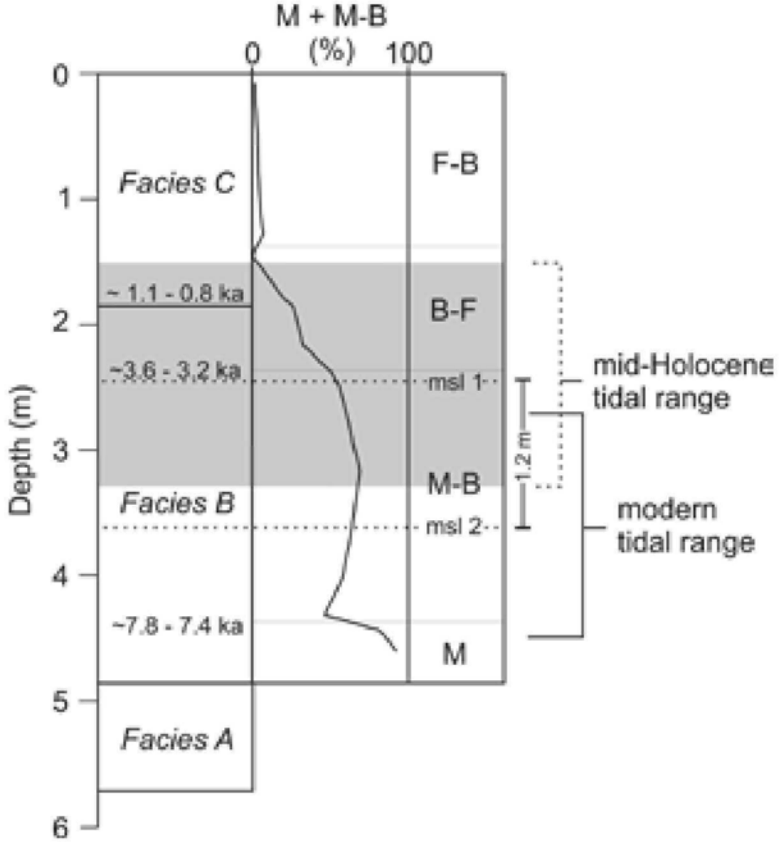

Fig. 7 Inferred mid-Holocene sea-level highstand for Kowhai Beach wetland, based on palaeo-salinity zones from diatom record in core KB4 using de-compacted sediment thicknesses (M, marine; B, brackish; F, freshwater diatoms). Calibrated radiocarbon ages are also shown. The mid-Holocene and modern tidal range represent mean spring tidal range for this coast (msl 1, mid-Holocene mean sea level; msl 2, present mean sea level). Using this reference frame, mean sea level during the highstand is estimated at c. 1.2 m above present mean sea level.

al. 1994; Baker and Haworth 1997, 2000; Sloss et al. in press), Lord Howe Island (Woodroffe et al. 1995) and Fiji (Nunn 1998). Sea-level curves for these coasts show a highstand in the range 1.5–2 m above PMSL. The strongest sea level proxy we have in the Kowhai data is the diatom record. Figure 7 presents a summary of diatom salinity zones for core KB4 plotted against de-compacted sediment thicknesses for the Holocene sediment fill (Facies B and C) and PMSL. It is evident from this plot that the brackish-fresh diatom zone and the upper part of the marine-brackish zone are above the modern tidal range, a point strengthened by the fact that core site KB4 is 500 m inland. Clearly, a higher sea level would have allowed regular tidal incursion into Kowhai wetland. Thus, by positioning the modern tidal range so that it brackets the brackish-fresh diatom zone in core KB4 provides an estimated mean sea level of 1.2 m above PMSL at c. 3.2 ka (Fig. 7). Subsequent withdrawal of sea level to its present position is recorded in the sharp decline in marine and brackish diatoms toward the Facies B–C contact, dated to c. 1 ka. While this sea-level interpretation is based on limited evidence, it is sufficiently compelling to warrant application of other analytical techniques (e.g., foram-based transfer functions; Hayward et al. 1999) at this and similar sites, to strengthen the case for a mid-Holocene higher sea level in northern New Zealand.

CONCLUSION

The Holocene environmental history of Kowhai Beach wetland incorporates a detailed record of coastal sedimentation influenced by sea-level change, fluctuations in depositional energy and human impact. Locally, the site holds valuable evidence for the transition from marine-influenced to freshwater conditions and attendant botanical changes. As such, it offers a useful model for forecasting changes in other wetlands that are at less advanced stage of infill. At the regional scale, this study of Kowhai wetland has produced useful new insights into the issues concerning sediment sources and transport mechanisms for coastal landforms, and introduced the possibility that these systems may yield a more refined record of Holocene sea-level. It is therefore timely to revisit the Holocene sea-level curve for New Zealand (Gibb 1986), with a focus on refining the resolution of the curve and adding to this preliminary evidence for a mid-Holocene sea level highstand.

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