# Past, present and future evolution of coastal lagoons, Westland, New Zealand

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## Abstract

The Westland region is characterised by a very dynamic coast, with many lagoons and associated wetlands, responding rapidly to sea-level, tectonic, meteorological, human and other synergistic drivers. This research uses a multi-disciplinary approach to investigate two representative systems, Totara Lagoon and the Waikoriri Lagoon/ Shearer Swamp complex, to document their present-day geomorphology and determine the evolution and processes acting on these systems through the Holocene. The approach used is transferable and questions raised applicable to other dynamic rivermouth lagoon systems internationally. Topographic surveys were used to map current lagoon features and elevations while sediment cores document changes in the shallow stratigraphy beneath the lagoons. Cores from Shearer Swamp revealed a surficial peat layer overlying blue-grey silt and coarse beach sand, consistent with infilling and development of the swamp over an existing coastal plain. Totara Lagoon exhibited a similar pattern of fine muds and organic sediment underlain by coarse sand and gravel. Changing management practices and surrounding land uses over the past century have resulted in changes in hydrology and sediment supply to the coastal lagoon systems. Specifically, evidence suggests that artificial lagoon openings have impacted each system. Findings cast doubt on the applicability of current lagoon behaviour and management models to the Westland environments studied, with differences highlighted in this paper helping to extend understanding of rivermouth lagoon systems in New Zealand and globally.

## 1 Introduction

Rivermouth lagoons and associated coastal wetlands are dynamic environments that respond rapidly to changes in climate, sea level, tectonic and anthropogenic drivers (Cooper, 1994; Woodroffe 2003). This is particularly true of the coastal environments of Westland, New Zealand, which are characterised by a high energy coastal marine boundary, extreme weather patterns, and high sediment loads from the nearby Southern Alps (Neale et al. 2007). This paper reports preliminary observations and findings from an investigation of the dynamics and evolution of two Westland coastal rivermouth systems: Totara Lagoon and the Waikoriri Lagoon/ Shearer Swamp Complex.

The type of system that results at a given river mouth depends on the relative strengths and interactions between fluvial and marine drivers. Where fluvial processes are dominant deltas form, while estuaries occur in tidally-dominated settings (Carter and Woodroffe 1994). Lagoons commonly form on microtidal wave-dominated coasts and can be classified according to their degree of water exchange with the ocean (Kjerfve 1994; Cooper, 1994). The coastal lagoons examined in this study may be classified as 'choked' since they generally exhibit a single, semi-stable opening through which limited ocean water exchange occurs.

Choked rivermouth lagoon systems at similar latitudes on the adjacent East Coast of New Zealand are often referred to by the Māori term 'hapua' (Kirk 1991). Both Waikoriri and Totara Lagoons have been labelled hapua (Neale et al. 2007) and there is pressure to manage these systems using models developed for the East Coast hapua such as: Kirk (1991); Kirk and Lauder (2000); Todd (1982).

As described by Kirk and Lauder (2000), these lagoons have a long, narrow waterbody oriented parallel to the coast, which is predominantly freshwater and separated from the ocean by a narrow barrier of typically coarse sediment. The barrier forms as a result of longshore drift, offsetting the river mouth and leading to the formation of the lagoon water body. Fluvial processes dominate hapua solely during flood events, at which time the barrier may be breached opposite the river channel, bypassing the lagoon (Kirk 1991; Todd 1983). Similar lagoons occur on high-energy, wave-dominated coasts worldwide (Hart 2007).

The dynamics and processes operating in lagoons on New Zealand's East Coast have been extensively researched and documented (e.g. Kirk 1991; Kirk and Lauder 2000; Hart 2007; Hart 2009; Todd 1983) but further research is needed on systems elsewhere in order to understand their diversity, identify commonalities and assess the transferability of existing management models.

Compared to other New Zealand regions, little published coastal research has been produced for Westland (Hesp et al. 1999). As such, the region's coastal environments and history are not documented or understood to a level whereby informed management decisions and plans can be made (Goff et al. 2003).

The aim of this research is to investigate two representative Westland lagoon systems to begin to document their evolution over the late Holocene and relate this to their contemporary geomorphology and dynamics. The two systems differ in size, dynamics and contemporary catchment landuse characteristics but share the same Holocene coastal progradation plain, making comparisons across a range of timescales interesting. A multidisciplinary approach is employed to investigate their evolution, structure, and processes, the use of several complementary techniques allowing a more-robust and coherent set of results from which to construct recent and past behaviours.

## 2 Study area

The physical environment and climate of Westland is determined by the location and orientation of the New Zealand landmass. Its coast spans 600 km, is aligned northeast to southwest and is exposed to prevailing westerly weather systems from the 'Roaring Forties'. The open coast of this region experiences a very high-energy wave climate, further enhanced by the close proximity of the continental shelf to the coast (Neale et al. 2007). The region is situated in a transition zone where sub-tropical waters meet the colder waters of the sub-Antarctic Southern Ocean. Littoral drift is predominantly in a northward direction.

The Westland climate is temperate, moist and relatively mild but with extremely high levels of precipitation: an average 2500 mm annually along the piedmont, increasing to over 12 000 mm in the mountains (Moar and McKeller 2001). Frequent intense precipitation events induce high levels of erosion and sediment transport to the coast from the Southern Alps. Due to the short distance between the mountains and coast, transport and river flow response times are short, floods arriving at the coast less than four hours after upper catchment precipitation.

Totara Lagoon and the Waikoriri Lagoon/ Shearer Swamp Complex were chosen based on their Westland location, proximity to each other, high conservation value and comparatively low levels of hard-engineering modification. Both systems are subject to small to moderate mean fluvial inputs, with baseflows less than 50 $m^3 s^{-1}$.

Shearer Swamp is a large, freshwater wetland occupying 135 ha of narrow coastal plain south of Ross township and Mikonui River (Figure 1). Its vegetation includes several wetland classes: fen, swamp, bog, coastal lagoon (Department of Conservation, DOC, 2003). It is low-lying (less than 3 m above mean sea level, AMSL) and slopes gently down towards the coast from east to west. This wetland is bounded by well-developed native bush to the north and east, and by several small streams including Granite Creek to the south and Waikoriri Creek to the west. These two creeks meet at the southwest corner of the swamp, around 100 m inland from the sea. Their combined channel is joined by Black Creek, before draining through Waikoriri Lagoon. Sediments in the wetland consist of muds and peat, the latter of which has been recorded to a depth of 3.5 m (Davoren 1978).

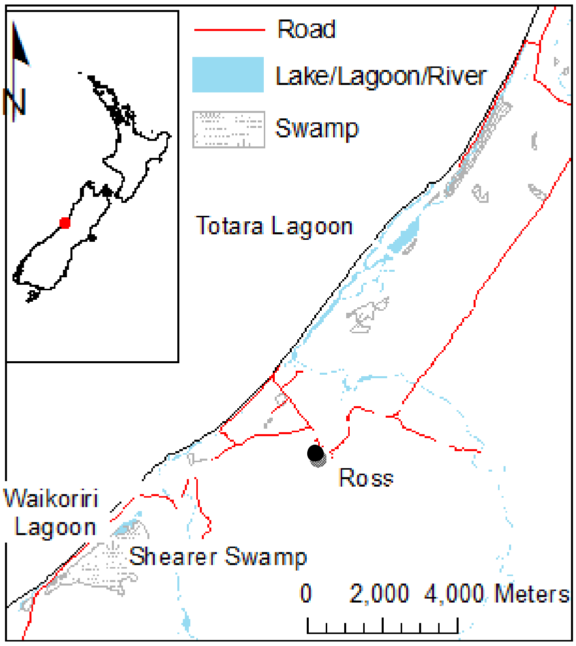

Figure 1. Location map showing Totara Lagoon and the Shearer Swamp/Waikoriri Lagoon Complex, Westland, New Zealand.

Waikoriri Lagoon forms the outlet to the sea that drains Shearer Swamp. The lagoon waterbody covers up to 6 ha, is up to 30 m wide and extends up to 4 km north from the Granite-Waikoriri Creek confluence. It occupies a swale between the beach and foredune, separated from Shearer Swamp by a series of low-lying dune ridges. Seaward of the lagoon the beach forms a barrier, between 20 m and 80 m wide, consisting of coarse sand with small amounts of gravel and fine sand. Waikoriri Lagoon is very dynamic, its outlet migrating rapidly and frequently and its waterbody ranging from its full extent to absent. This variability is produced by a combination of natural processes, such as storm and flood events, and anthropogenic influences, including artificial outlet breaching.

In contrast to Waikoriri Lagoon, Totara Lagoon comprises a large and relatively permanent lagoon system, presently stretching 10 km north from Totara River near Ross (Figure 1). Its waterbody is long, narrow and bifurcating, with a surface area of around 100 ha (Neale et al. 2007). This lagoon is mainly fed by Totara River, and currently discharges to the sea at its

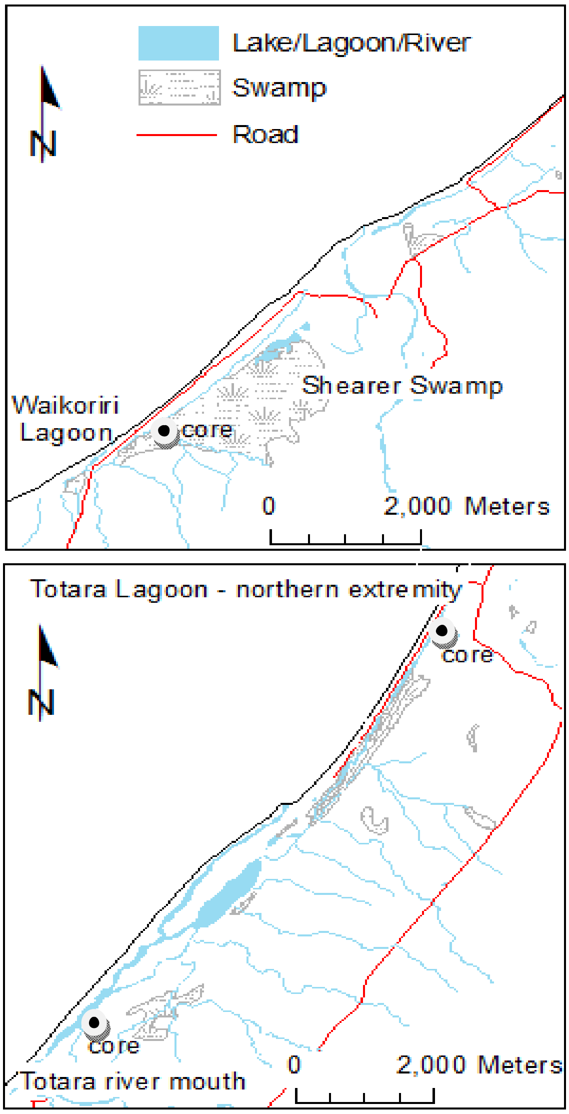

Figure 2. Detail and extent of the study areas, including sediment core sampling locations.

southern end. In the recent past the lagoon mouth has been offset up to 6 km north. A number of smaller creeks feed into the lagoon north of main river-lagoon confluence. There is a significant tidal influence in this lagoon under its current configuration, with strong tidal currents extending several kilometres up the waterbody and diluted seawater detectable at its northern end. Totara Lagoon is separated from the sea by a sandy barrier beach, with low and sparsely vegetated dunes in the south and steeper, more heavily-vegetated dunes in the north. Remnants of dune blowouts and old outlet channels are observable along the barrier up to and including the present northern end of the water body.

## 3 Methods

Four site visits were undertaken from 09/2008 to 03/2009 at intervals of several months. Fieldwork included observations and photographs of outlet position and detailed surveying and coring.

A Trimble R8 Geographical Navigational Satellite System (GNSS) was used in tracking mode, with points recorded at 5 s intervals, to survey representative sections of the sites' topography. These included the Totara lagoon mouth, central and northern reaches, the entire Waikoriri lagoon and sample elevation points west to east across Shearer Swamp. Where possible, transects were taken across the lagoon channels, surrounding banks and adjacent areas. From this data a digital elevation model (DEM) of the surveyed areas was constructed using the ESRI *ArcGis* software programme. Profiles across the seaward dunes and the lagoon channels were constructed for several locations.

In order to investigate the shallow stratigraphy of each site, sediment cores were taken with a hammer corer, from sites at the northern and southern ends of Totara Lagoon and from the western edge of Shearer Swamp adjacent to Waikoriri Creek (Figure 2). Locations were documented using a handheld Geographic Positioning System (GPS). Several cores were taken from each site to ensure the consistent character and lateral continuity of the observed sedimentary units. Surface sediments were infiltrated by roots in the top several centimetres, which were discarded prior to sampling. Core compaction was estimated by measuring the difference between hole depth and core length. The cores were split lengthwise in the laboratory and their stratigraphy was examined. Sediment texture was measured using a laser particle sizer for four samples from each core, at depths of 30, 150, 300 and 450 mm. Further samples at these depths were analysed for organic content using the Loss on Ignition (LOI) technique, as detailed by Lewis and McConchie, 1994. Samples were oven dried at 105 °C for 24 hours, weighed, then placed in a furnace at 450 °C overnight, cooled and weighed again. The loss of mass is attributable to organic matter combustion, thus providing a rough estimate of organic content.

## 4 Results

### 4.1 Outlet dynamics

The extent and form of Waikoriri Lagoon changed dramatically on a variety of spatial and temporal scales throughout the study period, affecting the hydrology of southern Shearer Swamp. In September 2008, the lagoon outlet was located 2.5 km north of the point where the combined Granite and Black Creeks intersect the beach. The lagoon waterbody extended a further 1 km north from this opening and water levels in the lagoon, creek and southern Shearer Swamp were relatively high. Three weeks later, in October, the barrier was breached opposite the Granite/Black Creek confluence, causing the former, northern outlet to be abandoned and the lagoon waterbody to drain completely. This breach occurred during a combined river-flood/ sea-storm event, but allegedly was initiated artificially using a digger.

Two and a half months later, in December 2008, this outlet was still operative, the lagoon channel remaining dry. Three months on, in March 2009, a wedge of sediment had started to build across the stream outlet with material supplied and reworked by longshore drift. The water level had risen in the creek channel behind this obstruction as well as throughout southern Shearer Swamp, with the lagoon outlet becoming diagonally oriented through the barrier and offset 20 m north. On a smaller scale, this opening was observed on occasion to migrate north and south along the coast by up to 10 m per day.

In contrast, the extent and form of most of Totara Lagoon changed little over the study period, with significant changes observed only around the southern rivermouth/ lagoon opening area. For the duration of the observation period the lagoon opening remained at the southern end of the waterbody where the river approaches the coast. From September through December 2008 this outlet was very open to the ocean, with ocean water and wave ingress occurring at high tidal stages. A sea storm on December 6th caused only a minor sediment redistribution within the rivermouth/ lagoon opening area. Six months later, in March 2009, a wedge of sediment had been deposited at the Totara River mouth, re-aligning the outlet channel on a diagonal from river to ocean towards the north. This longshore drift deposit did not prevent the river from effectively discharging to the sea, nor lead to a wholesale outlet migration. By late March the sediment wedge had increased in size, narrowing the outlet channel.

## 4.2 Lagoon topography

Waikoriri Lagoon is bounded by two series of dunes, to seaward 4 to 6 m above sea level (ASL) high dunes and to landward up to 8.7 m ASL high dunes (Figure 3a). The seaward dunes comprise accumulations of sand with some pebbles, free from stabilising vegetation. The landward margin dunes separate the lagoon from Shearer Swamp and comprise a series of well-vegetated shore-parallel Holocene ridges (Figure 3b). The elevation of the water surface where Waikoriri Lagoon intersects with Shearer Swamp is between 4.5 and 5 m ASL. The bed of the lagoon waterbody is free from major obstructions throughout its length, meaning that lagoon water is able to flow along this channel without topographic restriction.

Unlike Waikoriri Lagoon, the geomorphology of Totara Lagoon varies substantially between the northern and southern ends of the system. Dune profiles exhibit crest heights in the north between 10 and 13 m ASL while those to the south peak at only 6 to 7.5 m ASL. These dunes become progressively steeper and more heavily vegetated towards the north (Figure 3c and d).

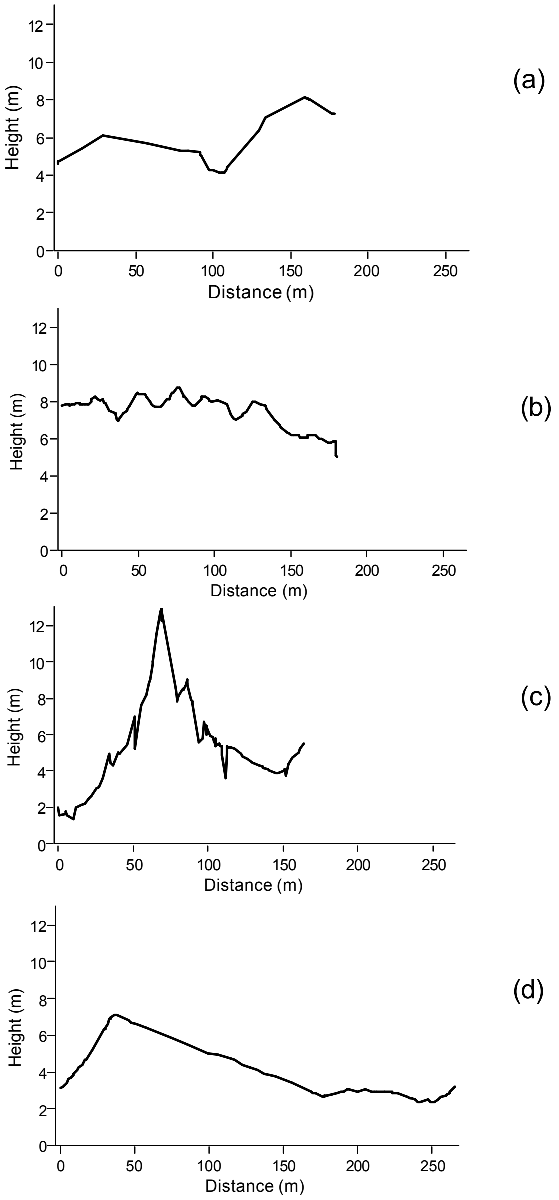

Figure 3. Representative cross-sectional dune profiles from the two field sites including:
(a) Waikoriri Lagoon seaward dune ridge, channel and landward dune ridge,
(b) relic dune ridges east of Shearer Swamp,
(c) the steep, narrow seaward dune ridge at the northern end of Totara Lagoon, and
(d) low, rounded dunes at the southern end of Totara Lagoon.

Totara Lagoon occupies a coast-parallel channel that is relatively shallow, wide and well-flushed in the south, becoming narrower, deeper and muddier in the north. The central reaches of the lagoon bifurcate, with islands of established vegetation separating two main channels. The northern third of this lagoon is choked by rushes growing across the channel at several points, limiting water and sediment exchanges below the surface of the water column such that this end appears relatively stagnant at <1 m depth.

### 4.3 Stratigraphy and sediment texture

The cores extracted from both sites ranged from 0.5 to 0.65 m in length and showed consistent sedimentary units between cores. Differences between hole depth and core length, a guide to core compression, ranged from 0.07 to 0.14 m.

The Shearer Swamp core surface sediments consisted of dark brown mud with significant living organic content, underlain by a sharply contacting unit of low-organic blue-grey silt at a depth of 0.05 m below the surface (Figure 4a). The silt was underlain by a dark brown peat layer at a depth of 0.235 m below the surface. At 0.27 m below the surface an organic-rich, brown, poorly-sorted, medium-grained sand layer occurred. This contained micro-layers of peat in the top half of the unit, eventually giving way entirely to sand, preventing the corer from penetrating further (Figure 4a).

The southern end of Totara Lagoon presented a comparatively simple stratigraphy. Surface sediments were organic-rich medium-brown mud, with a gradational contact at a depth of 0.08 m below the surface between the top layer and a similar unit of brown mud beneath. The latter contained occasional wood fragments and was underlain at a depth of 0.43 m below the surface by a medium-brown, poorly-sorted, coarse-grained sand and fine gravel layer. The thickness of this layer is unknown as it continued beneath the maximum core depth (Figure 4b).

The substrate at the northern end of Totara Lagoon was relatively sandy. Sediments between the surface and 0.3 m depth consisted of organic-rich dark-brown mud. Underneath this layer was a unit of dark-brown, muddy, medium-grained sand with occasional wood fragments. A gradational contact occurred between this unit and a grey, medium- to coarse-grained quartz sand layer between 0.26 and 0.33 m below the surface. This unit was underlain by a sharply contacting brown-grey fine-grained sand layer at a depth of 0.45 m below the surface (Figure 4c).

## 5 Interpretation and discussion

Significant differences in size and form exist between the Shearer Swamp/Waikoriri Lagoon complex and Totara Lagoon. Results reveal that these differences extend to both past and present lagoon dynamics and stability, with each system responding to coastal and catchment processes at different scales. The variation in contemporary responses is likely a product of their different spatial scales as well as of variations in their fluvial inputs, lagoon channel dimensions and topography.

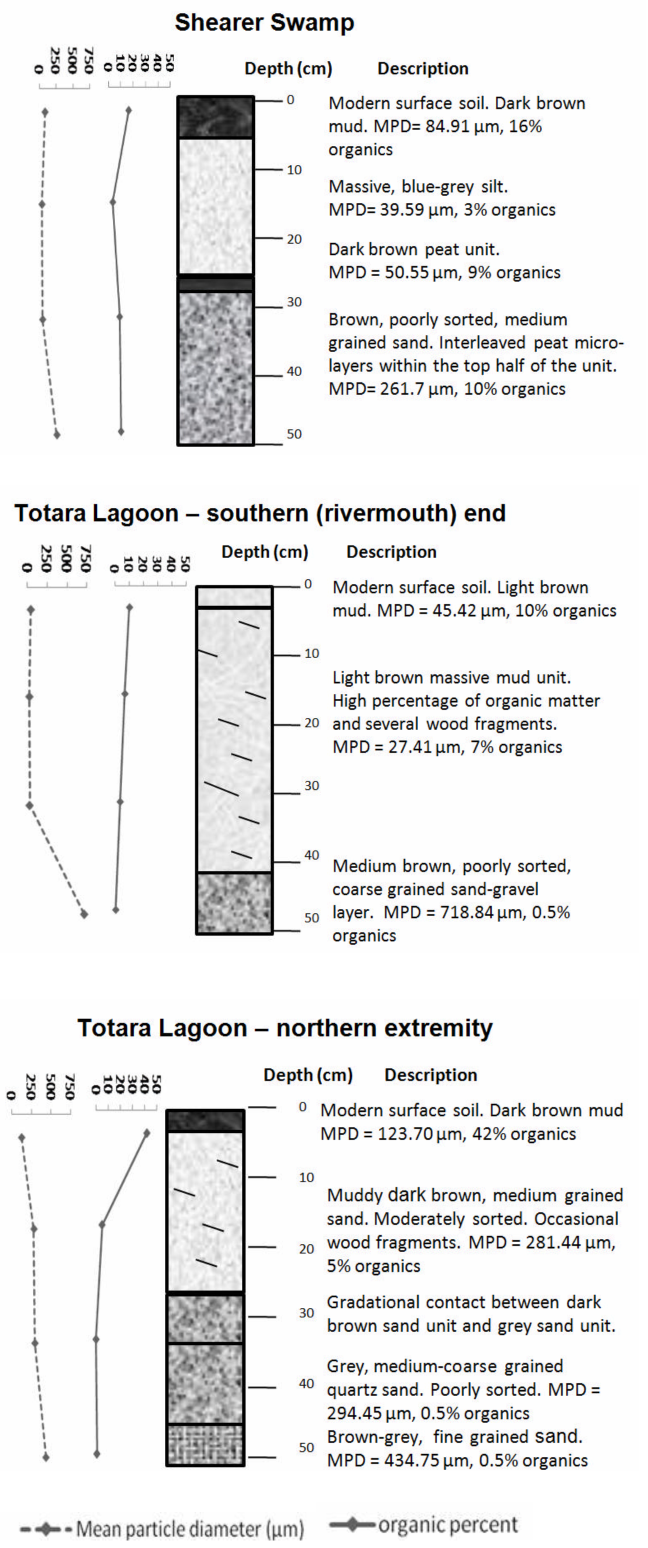

Figure 4. Stratigraphy and sediment texture of sediment cores taken from the three lagoon sample sites shown in Figure 2. MPD = Mean particle diameter (µm)

### 5.1 Stratigraphy

The core stratigraphy found in Shearer Swamp can be interpreted as a gradual change over time from a marine environment to the current low-energy freshwater wetland. The blue-grey silt layer represents either an estuarine type environment or a freshwater setting. Future microfossil analysis will determine the salinity of the depositional environment, confirming which of these two conclusions is correct. In contrast, the sandy cores taken from northern Totara Lagoon indicate that the extent of this waterbody has fluctuated, often not reaching as far north as at present. The presence of an empty, grassed channel extending north from the present northern end of the lagoon shows that the lagoon has also elongated beyond its current extent.

Behind Totara Lagoon lies a lateral moraine deposited during the last glacial maximum, around 14 000 years ago (Suggate et al. 1978), which has been cut by marine processes at some later stage. This is likely to have taken place during the Holocene sea level highstand 6000 years ago, which can be interpreted as the maximum age for the development of these seaward lagoon systems. The shallow stratigraphies from both lagoons show evidence of changes in depositional environment over time, but absolute ages for these transitions have yet to be determined. The rate of deposition and, therefore, the time period sampled in the cores will be determined in the next phase of this study.

### 5.2 Present day dynamics

A recognised characteristic of most East Coast hapua-type systems is the formation of a coarse, permeable, mixed sand and gravel barrier beach between the rivermouth lagoon waterbody and sea (Kirk 1991; Kirk and Lauder 2000). Such barriers exhibit the characteristic stepped morphology, plunging breaker line and dual-transport systems of mixed sand and gravel beaches identified by Kirk (1980). In contrast, the barriers of Totara and Waikoriri Lagoons are finer, consisting mainly of coarse sands with a few pebble layers. As a result, the permeability of these Westland lagoon barriers is far less than, for example, that of the Rakaia barrier as described by Kirk (1991). Permeability of lagoon barriers is an important factor controlling the amount of freshwater available to discharge through, and maintain, the outlet, thereby affecting thresholds of lagoon response to river flow and resultant lagoon dynamics such as closure, migration and breaching.

The Waikoriri and Totara Lagoon barriers also exhibit typical characteristics of reflective sandy beaches (e.g. Short 1999) rather than mixed sand and gravel beach features (e.g. Kirk 1980). They exhibit several lines of breakers, a narrow but energy-dissipating surf zone, with sand dominating the steep backshore, foreshore, small foreshore step, and nearshore. Observed differences in barrier beach sediment texture, form and permeability between the study sites and those described in East Coast hapua models raise questions as to how such models can be effectively applied to understand and manage sandier rivermouth lagoons such as those examined in Westland.

In terms of present day dynamics, Totara Lagoon was found to be more stable than Waikoriri Lagoon as revealed by the level of vegetation present along channel margins. Anecdotal evidence and aerial photographs also show that the position of the Totara outlet has changed little in recent years, suggesting the dynamics of this lagoon operate over longer time scales than those of Waikoriri Lagoon.

Hapua systems with moderate fluvial inputs in relation to marine processes are subject to frequent state changes and often possess long outlet channels (Hart 2009). Both systems researched here are subject to small to moderate mean fluvial inputs (<50 $m^3 s^{-1}$ baseflow), and thus can be expected to exhibit outlet migration relatively frequently. Waikoriri Lagoon is a somewhat unusual case in that it often manages to maintain an opening to the ocean despite very small fluvial discharges. This is likely due to the relative impermeability of its barrier sediments, which inhibit beach throughflow, thereby maintaining channel flow.

Hart (1999) developed a theoretical model of hapua behaviour, which depicts the state and response of the lagoon outlet to variations in the balance between river discharge and wave height. Most of the observed Waikoriri Lagoon dynamics (outlet migration, lagoon shrinkage in response to breaching) appear to fit into this model. However, the October breach likely resulted from a combined river-flood/ sea-storm event plus human intervention. The latter variable is not explicitly included in this model.

The observed dynamics of Totara Lagoon resemble a subset of those described for hapua, when an outlet to sea is maintained opposite the main river channel. During this stage of the hapua behavioural cycle described by Todd (1983) and Kirk (1991), tidal and wave ingress can occur at high tide. However, unlike in the cyclical model, this state has been maintained at the mouth of Totara River for several years. This suggests that Totara Lagoon is presently in an estuarine phase.

Topographic evidence and local knowledge indicate that in the recent past Totara Lagoon has exhibited several of the other hapua states described in East Coast models: for example, an elongated freshwater lagoon with an outlet offset several kilometres from the point where the river enters the lagoon. Evidence also suggests that the persistence of the lagoon outlet opposite the main river channel, unusual in East Coast hapua on rivers with similar baseflows, may be due to the relative impermeability of the sand barrier as well as to human intervention, maintaining the southern opening via artificial breaches.

Another example of a river mouth which switches between extended periods operating as an estuary and hapua occurs on the Ashley River in north Canterbury. The behaviour of this feature and of Totara Lagoon shows that hapua and estuaries are likely two ends of a rivermouth spectrum between tidal and wave domination (Hart et al. 2009), with some lagoons moving back and forth between these two end points.

As indicated earlier, the West Coast region is unusual in the rapid response and relaxation time of rivers to precipitation events, with river flood events lasting hours rather than days. From the preliminary results reported in this initial study it is unclear what effect, if any, these catchment characteristics have on lagoons relative to the prolonged flood events of the of East Coast river mouths. One hypothesis is that combined sea-storm/ river-flood events are likely to be more frequent and important in Westland lagoon environments compared to on the East Coast since the catchment precipitation that creates river floods in the latter setting is usually spatially and temporally removed from coastal precipitation events. This topic is an area in which future research will be focussed.

The two systems examined here show varying degrees of typical hapua behaviour as described in East Coast models, but do not specifically meet the defining criteria in terms of barrier composition and morphology and fluvial influences. Questions remain surrounding the functional and management classifications of these coastal lagoons within both national and international contexts. Further research is needed to assess commonalities between systems and determine the applicability of existing conceptual models to different systems.

## 6 Conclusions

Two choked coastal lagoon systems in Westland, New Zealand, were investigated in order to document their present-day dynamics and determine their late Holocene evolutionary and depositional environments. Waikoriri Lagoon is a small, very dynamic hapua-type lagoon, which is backed by a large hydraulically-connected wetland and which exhibits outlet migration on short temporal scales (days to months). Stratigraphic cores from Shearer Swamp show changes from sand through peat, to silt, to mud, indicating a progression from a marine to lower energy, possibly estuarine, environment prior to formation of the swamp.

Totara Lagoon is a more stable feature which experiences outlet migration over periods of months to years. Comparisons of stratigraphy between the north and south ends of this lagoon confirm that, although there has been a lagoon or associated swamp environment continually present in the south above a layer of marine sands, the northern end of this lagoon has, at times, dried out or extended. This rivermouth appears estuarine today but to have exhibited hapua features and behaviour in the recent past.

This study highlights that there is much scope for further research into the processes operating in river mouths on wave dominated coasts in order to add to our understanding of the complex set of environments labeled ‘coastal lagoons’.

## 7 Acknowledgements

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