Catastrophic events in New Zealand coastal environments

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Abstract

Catastrophic events recorded in selected coastal wetlands of New Zealand are reported. These date back over 6000 years, but become more well-defined in the past Millennium. Comparison between the historic and palaeoenvironmental record indicates that a reliance on the former does not include several significant nationwide events.

By highlighting the details and effects of several locally generated, nationwide catastrophic events, this report shows that the Department of Conservation needs to have a broader palaeoenvironmental context for its conservation management. This has implications for both the natural and historical coastal heritage managed by the Department. It is recommended that the Department invests science and research effort into understanding the effects that past catastrophic events have had upon the heritage that they manage. Putting a greater emphasis on the Department's understanding of where the environment is now in relation to its past will help the Department understand not only how these events have affected the natural environment, but the way that prehistoric Maori interacted with it.

1. Advice sought

1. What are the main paleoenvironmental changes (catastrophic events) recorded in selected coastal environments over the past few thousand years?

2. What are the likely causes of these catastrophic changes?

3. What, in your opinion, would be the likely effect of individual catastrophic events on coastal ecosystems, and what evidence can you provide?

4. Bearing in mind the answers given to Questions 1-3, what would be your recommendations for future scientific research by the Department with respect to underpinning conservation management?

2. Introduction

The New Zealand coast, about 18 200 km long, is both diverse and compact. Fitted around a relatively small land mass one can find a wide range of coastal environments spanning subtropical to subantarctic climate regimes.

The present coastline was established when the sea rose to roughly the present day level some 5000 to 7000 years ago (Gibb 1986). As the sea transgressed the area we now call the continental shelf, it flooded the incised topography of the mainland thereby forming estuaries, harbours and embayments. It also brought with it vast quantities of sand which formed the beaches, barriers and dunefields that now characterise large proportions of the coasts of the North and South Islands (Healy & Kirk 1992). In areas where less sediment was available, depositional landforms are much smaller or have not formed, resulting in rocky coasts such as the Marlborough Sounds and the Bay of Islands, or fjords such as those found in the far southwest of the South Island.

Tectonic activity, particularly volcanism, has been and continues to be a powerful agent in shaping the New Zealand coast. In the North Island, volcanoes have been an important source of sediment for coastal depositional landforms throughout the Quaternary. Thus, the barriers which occupy the mouths of numerous embayments along the Northland, Coromandel, Bay of Plenty and west coast of the North Island are all constructed with sediment from a volcanic source. Regional tectonism has also caused isostatic uplift along parts of the New Zealand coast, with the best examples found along the southeast and east coasts of the North Island, where raised marine terraces and stranded beaches flank the Wairarapa and Wellington coasts, most spectacularly at Turakirae Head (Berryman et al. 1992; Hull & McSaveney 1996). In the South Island the role of tectonism on the coast is less direct, but evident through uplift which has formed the mountainous terrain of the Southern Alps and led to the shedding of huge volumes of sediment into rivers which in turn have added to the broad coastal plain of the Canterbury region. In addition, parts of the New Zealand coast are known to have been affected by tsunami waves and storm surge, on more than one occasion (de Lange & Healy 1986; Goff & Chague-Goff 1999).

In addressing the request for information about the main paleoenvironmental changes (catastrophic events) recorded over the past few thousand years, it is important to select the most appropriate coastal environment for the purpose. Coastal wetlands have an ability to preserve records of long- and short-term environmental changes, such as those resulting from sea-level change, cyclones, volcanic eruptions, tsunami, storm surges, fault ruptures, and floods. Merely by buffering the land from the vagaries of coastal hazards and soaking up the overflow from the land, coastal wetlands allow scientists to read much about past environments.

What are wetlands, or perhaps more precisely, how does one define them? As with most features of the Earth's surface there are many definitions for wetlands, based upon biological, physical, hydrological and chemical factors. There are also many terms to define different types of wetlands, and this leads to confusion. Thus, for the purpose of this report, we have adopted the definition of the Environment Council (1983), which is fairly similar to that of the Resource Management Act (1991), but also includes saline and brackish as well as freshwater wetlands.

"Wetlands is a collective term for permanently or temporarily wet areas, shallow water and land-water margins. Wetlands may be fresh, brackish or saline, and are characterised in their natural state by plants and animals that are adapted to living in wet conditions" (Environment Council 1983).

Acknowledging that wetlands have the ability to preserve records of catastrophic events such as sea-level change, cyclones, volcanic eruptions, tsunami, storm surges, fault ruptures, and floods, it is important to delimit the nature of the report. Catastrophic events related to climate change, be they long-term such as sea level change, or short-term such as ENSO-related storm surges, cyclones and flooding have been addressed in a report earlier this year by McFadgen (2000). Therefore, we propose to concentrate on the remaining events, namely the seismic hazards of volcanic eruption, tsunami, and fault rupture.

3. Catastrophic events

It is not necessarily the primary seismic event that affects coastal environments. For example, a distant fault rupture may have no impact, but the subsequent tsunami may be devastating. With this in mind, we have listed below the possible palaeoenvironmental changes that could affect coastal environments as a result of volcanic eruptions and fault ruptures (Magnitude of about 8.0 or greater) (Table 1). Since tsunami tend to be the after-effects of seismic-related events or submarine landslides (mostly generated by earthquakes), they are addressed separately from the perspective of their locally- or distantly-generated source (Table 2).

With the exception of `ash fall', the possible impacts of volcanic eruption also fall under those of earthquakes (while the term `earthquake' refers to the shaking generated by fault rupture and not the fault rupture per se, it is used below to describe both). In the examples discussed below, evidence for ash fall is reported from only one wetland, but in the absence of palynological data it is difficult to draw any conclusions about the impact of ash fall on the coastal environment. Most studies have dealt with the impacts of ash fall on inland areas, subsequent natural forest fires, and peaks in bracken growth followed by a gradual return to forest cover (e.g.Wilmshurst & McGlone 1996). This scenario seems likely to be paralleled in coastal environments, although the impact on non-forested coastal areas is unclear. We will now concentrate primarily on the effects of earthquakes and tsunami.

Within the short period of human occupation, many parts of the country have undergone tectonic uplift or subsidence, as is evident in coastal areas by the presence of recently uplifted shorelines (e.g. Grapes & Downes 1997). Furthermore, New Zealand's coastline is at risk from tsunami generated by either local or distant tectonic events (Table 2). In historic times, seismic activity has ranged from barely detectable earthquakes and tsunami that caused no damage, to large-scale earth and sea movements capable of destroying cities and causing widespread regional disruption (e.g. 1931AD Napier earthquake (Hull 1986); 1947AD Gisborne tsunami (Eiby 1982)). There are also rare examples of catastrophic events from the Maori oral tradition, including the Mahuhu Canoe (Kaipara) and the Haowhenua event (Wellington - Best 1918).

Bearing in mind New Zealand's position astride the boundary between two major tectonic plates, the Australian and Pacific, it is to be expected that locally generated earthquakes would have impacted on the prehistoric inhabitants of the country. Furthermore, since the sea has been at or near the present level for some 7000 years, there will undoubtedly have been larger magnitude and less frequent events that have affected coastal environments prior to human occupation.

The difficulty lies in attempting to unravel the impact that these events have had on coastal environments when the further back one works in time, the less well-preserved the record becomes. Prior to the collation of the historic record, evidence for earthquakes is found primarily from fault trenching and geological interpretation of the sediments. This is of little use to our understanding of the impact of catastrophic events on coastal environments other than providing a chronology of large, local earthquakes that can be correlated with anomalous features in the sedimentary record of coastal wetlands.

Figure 1 summarises the results of research from numerous coastal wetlands around New Zealand. Each date refers to a catastrophic saltwater inundation (CSI) event, the majority of which are known to be related to large, local earthquakes. Figures 1 and 2 highlight the key faults involved, of which the Alpine, Wellington and Wairarapa Faults are the most significant.

4. Case studies

Eight catastrophic events have been identified from coastal wetlands around New Zealand (refer to Figures 1, 2 and 3). The oldest, 6300BP (years before present), has only been identified at one site. This does not necessarily imply that the event was small, but rather that there are few sites in New Zealand where this length of record exists. Furthermore, as mentioned above, sedimentary evidence deteriorates with time and it is perhaps fortuitous that this has been recorded. The most recent is the 1931AD Napier Earthquake and tsunami which, because it occurred during the historical record, has been well documented even though it was probably the least significant of the events with regard to the coastal environment.

4.1 6300BP

Whakaki and Te Paeroa Lagoons are part of an extensive wetland, lagoon and sand dune system, which forms a coastal plain a few km east of Wairoa. The coastal plain is backed by steep, dissected hills, up to 600 m in altitude, which are composed of late Tertiary siltstone and sandstone. Ota et al. (1989) suggested that the freshwater lagoons formed about 4000 years ago, and attributed the formation of the lagoons to the stabilisation of sea level and the closure of an estuary by a sandy barrier up to 20 m high separating the lagoons from the open sea. In the sediment cores taken from the lagoons, the

Whakatane (c.4800 years BP),Taupo (c.1800 years BP), and Kaharoa (c.665±15 years BP) tephras were identified (Chague-Goff et al. 1999).

The CSI about 6300 years BP is characterised by a gravel unit that thins landward and decreases in particle size to sand, within a sequence consisting mainly of brackish estuarine mud. Diatom assemblages indicate a marked change from shallow brackish estuarine deposition to fully marine (in the gravel/sand unit) returning to brackish conditions above. The marine influence in this unit is also shown by the presence of marine dinoflagellates and a peak in Na/Rb. Although sedimentological, chemical and paleontological (in particular diatoms) evidence indicates it is a CSI, and probably represents a tsunami deposit since it had to overtop a 20 m high barrier, the propagating mechanism is unclear. Geochemical indicators of saltwater inundation in the sediment show that saline poisoning would have had a lasting impact on the brackish lagoon. The deposit and its geochemical signature can be traced over 2 km inland, into the backing foothills, although the water would have travelled considerably further inland (e.g. Chague-Goff et al. 1999) inundating the surrounding vegetation.

The mere fact that there is still evidence for this event suggests that it had significant impact on the coastal environment. Hawke's Bay is acknowledged for its susceptibility to impact from volcanic eruption, earthquake and tsunami. Some preliminary hydrodynamic modelling of long waves in Hawke Bay indicates that there is a focusing of energy at Wairoa (Lewis et al. 1999). Natural and historic heritage at or near the coast in this region must therefore be considered at extreme risk.

4.2 5000BP AND 3000BP

Both these events were recorded in the same coastal wetland at Okupe Lagoon, Kapiti Island (Goff et al. 2000b) (Figure 3). The 5000BP event occurred prior to the mid-Holocene highstand (Gibb 1986) and to enter the lagoon had to overtop the surrounding boulder bank that was about 6.0 m high at the time.To leave a recognisable deposit though, the wave had to be over 10 m high (Lowe & de Lange, 2000). There is no clear evidence for the effect that this has upon the coastal environment, but subsequent events provide some clarity. Like the 6300BP event, there is no clear generating mechanism, and while it seems most probable that this was generated by local fault rupture, it is termed a CSI.

The 3000BP event was locally significant. A local earthquake uplifted the lagoon by 1.5-3.0 m and the subsequent tsunami exceeded 10 m in height. A new boulder beach formed as a direct result of this event, the lagoon became completely isolated from the sea and for a short period of time went from completely marine to freshwater, prior to establishing a brackish faunal assemblage. While locally extremely significant, there are no data to indicate whether the effects were felt more extensively along the west coast (Goff et al. 2000b).

4.3 1900BP

This was a tsunami inundation generated by the Taupo eruption and recorded in the wetlands of Kapiti Island and Abel Tasman National Park (Figure 3). Lowe & de Lange (2000) believe this event to have been widespread, although interestingly evidence from coastal wetlands suggests that it is not as significant as more recent events. This is possibly a function of loss of record with age, and on-going work indicates that the Taupo eruption may have had a more ubiquitous nationwide impact, with accelerated coastal dune building phases, river aggradation and forest destruction (e.g. Grant 1985). It seems likely that more comprehensive evidence about the extent and impact of this evidence will be forthcoming.

4.4 1220AD

While this is recorded in the coastal environment as a tsunami in the wetlands of both Abel Tasman National Park and Kapiti Island, the source is linked to near-synchronous ruptures of both the Wellington and Alpine Faults. There is considerable evidence for this being of nationwide significance, with contemporaneous widespread forest destruction, river aggradation and accelerated coastal dune building (e.g. Wardle 1963; Grant 1985; McFadgen 1985). However, while these events are contemporaneous, there has been some mistaken linkage with apparent climate change that is yet to be resolved. While we have erred on the side of caution and considered this to be a relatively small event, the dashed ellipse in Figure 3 appears to be more realistic. This has widespread and devastating impact on the coastal environment, and would probably have involved all elements mentioned in Table 1 under earthquake to some degree.

4.5 1450AD

By far the most well documented of all catastrophic events on the coast, this was first reported as a tsunami in Abel Tasman National Park (Goff & Chague-Goff 1999). It has subsequently been reported as a tsunami as far afield as Great Barrier Island (Nichol et al. 2000) in the north, and probably Okarito in the south (S. Nichol, pers. comm., November 2000) (Figure 3). The coastal wetland tsunami sites are detailed and dated in Figure 1, and these coincide with near-synchronous ruptures of the Alpine (Figures 1 and 2), Wellington (Figure 2), Hope (ENE of the Alpine Fault) and Palliser-Kaiwhata (SE of the Wairarapa coast) Faults, and the Napier Syncline (Hull 1986; Ota et al. 1987; Cowan & McGlone 1991;Van Dissen & Berryman 1996;Yetton 1998). Furthermore, nationwide signals of river aggradation (Grant 1985), accelerated coastal dune building (McFadgen 1985) and abandonment of prehistoric coastal settlements (Goff et al. 2000a; Goff & McFadgen in press) indicate that this event had a major impact on coastal environments. While the natural coastal heritage was clearly affected by this event, perhaps the most telling evidence is in the abandonment of coastal settlements, evidence that has not yet been found for the previous 1220AD event possibly because it preceded Maori settlement.

Therefore, the 1450AD event is not only a significant coastal catastrophe, but also serves as a key chronological marker for prehistoric Maori occupation of the coast.

This event appears to be the source of the Maori legends referred to by Lambert (1925) in Napier, by Best (1918) in Wellington as the Haowhenua event, and in Kaipara as the Mahuhu Canoe. Similarly, there has been considerable archaeological research carried out around the coast that identifies, but does not discuss, anomalous sterile sedimentary units (often associated with reworking by water) that mark the abandonment of prehistoric Maori coastal sites (e.g. Leach & Hamel 1981). A recent reassessment at one site, Te Ika amaru Bay (Figure 2), reassigned a Plaggen (Anthropic) soil as tsunami deposit (Goff & McFadgen, in press).

The significance of this event to the natural and historic coastal heritage of New Zealand cannot be overstated.

4.6 1855AD

This event has been well documented because it sits within the historical record. An exhaustive account is provided by Grapes & Downes (1997), but in summary the impact on the coastal environment is as follows:

The earthquake (Magnitude 8+) was centred close to Wellington on the Wairarapa fault (Figure 2). It was felt as far afield as Auckland and Dunedin. Landslides occurred over an area of 135 000 km2, with the most intensive landslip damage covering an area of 52 000 km2. Slips, up to 500 km away from the epicentre (Bull 1996), dammed rivers and streams, which later burst, sometimes causing extensive flooding. In all cases, a considerable amount of sediment was released, choking streams and rivers, and fine sediment inundated the inshore environment, smothering shellfish beds in estuarine sandy shore environments. Numerous lakes and lagoons were drained, leaving large numbers of eels and other freshwater fauna stranded and dead. About one-third of the vegetation was stripped from the western side of the Rimutuka Ranges (Figure 2). Uplift at the coast ranged up to 6 m near Turakirae Head (Figure 2), killing intertidal food sources. Cliff collapse behind the coastal platform between Waitotara and Castlepoint (Figure 1) and fissuring of the ground impeded travellers and communications. Some coastal flats were furrowed and cracked, with mass movement of the ground towards the sea.

Fish were stranded on shore by the subsequent tsunami, and many dead fish that were seen floating in Cook Strait were presumed to have been killed by rapid pressure changes. Inundation by the tsunami resulted in the destruction of coastal vegetation by saline poisoning. At least one Maori village was probably destroyed at Palliser Bay, and large expanses of coastal land were inundated with sediment and organic matter, with seawater penetrating over 1.5 km inland in places (Goff et al. 1998). Tsunami inundation is likely to have rendered coastal gardens and soil unproductive for at least one, and probably more, growing seasons.

It is fortuitous that we have the historical data because this gives us an understanding of the relative nature and extent of the catastrophe (Figure 3). Furthermore, palaeoenvironmental evidence of the 1855AD event can be compared with earlier events because they can all be found in one place. While it was clearly devastating to the coastal environment, both human and natural, it is relatively insignificant when compared with evidence for both the 1450AD and 1220AD events (Goff et al. 2000b). This serves as a useful guide when attempting to assess the likely effects of individual events. It is by far the most significant event in the historical database, but is probably the most insignificant in the palaeoenvironmental one.

4.7 1931AD

The "Hawke's Bay Earthquake", which had a magnitude of 7.8, resulted in an uplift of one to two metres of Ahuriri Lagoon, reducing it to about two-thirds of its original size (Figure 3). Tsunami inundation was minimal. The 1931 earthquake significantly altered the sedimentary environment of the lower estuary, but was only detectable in the upper estuary using micropalaeontological data (foraminifera), which indicated a change in salinity and tidal level, and a subsequent change in ecosystem characteristics (Chague-Goff et al. 2000).

This is a fairly significant earthquake in the historical record and human culture of New Zealand. It caused more than 250 deaths and extensive structural damage in the City of Napier (Hull 1990). However, like the 1855AD event, it reveals little of significance in the record of coastal wetlands, which are the most sensitive recorders of such events. Once again, it puts the significance of earlier events in context.

4.8 1868AD

All the examples given above are from locally generated earthquakes. The most recent ones were fairly large, but had a local impact only. It is only when examining the palaeoenvironmental record that the significance of locally generated, nationwide events becomes apparent.

This last example is of the worst distantly-derived event in historical time (Figure 3). It affected most of the east coast of the country, but the Chatham Islands were by far the most severely impacted. The tsunami was up to 10 m high, moved boulders of up to 500 kg, and completely destroyed a coastal Maori settlement and some European houses at Cape Pattison. The Maori abandoned the site and have never returned. While inundation occurred on the mainland, reports of damage to vegetation are limited compared to those of damage to coastal properties (de Lange & Healy 1986).

5. Summary and Conclusions

Paleotsunami research carried out over the past few years shows that the sedimentary evidence of, one tsunami in particular is prominent in the records of all coastal wetlands studied to date, an event that occurred around 1450AD (e.g. Goff & McFadgen in press). The ubiquitous nature of the 1450AD event suggests that this and possibly the 1220AD, were of nationwide significance. Comparison of the evidence between sites and between events indicates that nothing that has occurred in the historic record is as significant as these earlier catastrophes. While historical events such as the 1855AD earthquake and its after-effects have been regionally and even nationally devastating to the coastal environment, this has been a relatively minor event compared to those over the past few thousand years.

This raises several key points:

- Previous catastrophic events of nationwide significance have taken place along a coastline that has been relatively pristine. If a similar event was to occur today, ecosystem recovery is unlikely to return to pre-event conditions. The introduction of exotic pests and plants over the past 150 years or so has seen a marked change in ecosystem resilience. There are probably many rare flora and fauna in coastal environments that would be unlikely to survive an event of this magnitude.

- The palaeoenvironmental record provides a much needed context for the work of the Department. The Department should underpin its conservation management with the acknowledgment that, as far as we know, catastrophic events of nationwide significance occur about once every 250-500 years. This will help focus attention on the key issues with regard to coastal environments.

- Acknowledging that nationwide catastrophic events occur about once every 250-500 years, it is imperative for the Department to realise that conservancy-wide catastrophic events will occur more frequently, about every 50-100 years. Therefore, there is a need for at least two levels of risk assessment, at a National and a Conservancy level. Conservation management of both the natural and historic heritage must be addressed at these two levels.

- The identification of two key chronological markers (1220AD and 1450AD) in the archaeological record serves three purposes related to the future scientific research by the Department with respect to underpinning conservation management:

  - If a similar event to 1450AD were to occur today, there would be widespread destruction and loss of historical heritage sites.

  - The 1450AD event occurred at a time associated with significant change in Maori culture and settlement patterns. There was a move from bays to headlands, a change from open to fortified villages, and a change from Archaic to Classic. How are these all interrelated?

- The fact that chronological markers exist should provide a catalyst to re-evaluate past archaeological records of coastal sites. Site abandonment, re-occupation, or initial occupation should be examined to understand how they relate to these events.

- From the research undertaken to date, there is a clear signal of a significant underlying palaeoenvironmental theme and context that is missing from the Department's conservation management. This applies to both the human and natural heritage of New Zealand, and in many ways the results from studies of coastal environments indicate that the two are closely interrelated.

7. Recommendations

1. A past record of catastrophic events exists in coastal archaeological sites - this has an important bearing on our historic heritage and should be investigated and understood because it has implications for conservation management.

2. There is a need to understand the palaeoenvironmental aspects of conservation management - the interplay between earth and natural sciences in both our natural and historic heritage.

   The Department needs to understand which past processes have influenced the existing natural environment that it manages and what the implications of these ongoing processes are for future management.

3. Putting a greater emphasis on the Department's understanding of where the environment is now in relation to its past will help the Department understand not only how these events have impacted the natural environment, but the way that prehistoric Maori interacted with it.

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Table 1.
Possible impact of volcanic eruptions and earthquakes on the coastal environment.

Palaeoenvironmental change	Possible impact on coast
1. *Volcanic eruption*	• Tsunami (also see Table 2): i) destruction of nearshore shellfish beds ii) saltwater inundation of coastal vegetation/ crops - widespread loss of forest/vegetation iii) destruction of coastal settlements, loss of archaeological sites iv) Fish stranded on beaches v) Saltwater can penetrate kilometres inland causing saline poisoning of riparian and wetland vegetation • Increased sediment input from local rivers: i) Smothering of estuarine/nearshore shellfish beds ii) Increased river flooding, accelerated change in coastal morphology • Acceleration in local dune building: i) Smothering of coastal vegetation ii) Burial of archaeological sites • Ash fall: i) Widespread natural fires, loss of vegetation ii) Complete burial of coastal vegetation communities iii) Possible irreversible change in physical and chemical parameters of coastal ecosystem pH, burial by ash, ground- and surface water flow regimes
2. Earthquake/Fault Rupture	• Tsunami (as above) • Increased sediment input from local rivers (as above) • Acceleration in local dune building (as above) • Landslides - up to 500 km away from epicentre (Bull, 1996): i) collapse of coastal cliffs ii) damming of rivers and streams which later burst, causing extensive flooding iii) Widespread vegetation loss as it is smothered by sediment, or removed by landslides • Uplift of coast (e.g. Turakirae Head) killing intertidal flora/fauna • Subsidence of coast causing saawater to fill the accommodation space - see `Tsunami' • Sand boiling - change in groundwater flow • Groundshaking: i) Liquefaction of ground, loss of soil to the sea ii) Forest collapse • Fish die from raid pressure changes in the sea

Table 2. Comparison between distantly and locally derived tsunami.

Tsunami	Details
1. Distantly generated	• Mainly South American sources • Comprise majority of the historical tsunami database for New Zealand Primarily affect the east coast of New Zealand • Maximum wave height about 10.0 m - Chatham Islands, 5.0 m - Lyttelton • ***Recurrence interval. e.g. Christchurch -1 every 12 years, wave heights from 0.5-5.0 m*** • Last significant event (5.0 m or higher): 1960, max. wave height - 5.0 m • Relatively small, affecting a considerable length of coastline
2. Locally-generated	Terrestrial and offshore sources - fault ruptures and landslides Poorly represented in historical database - only reported when seen Potential to affect any part of coastline, but normally only local impact ***Historic database:*** ***i) Max. wave height - >10.0 m -1947, East Coast*** ***ii) Recurrence interval - unknown*** • ***Palaeotsunami database:*** ***i) Max. wave height -15+m - c.1450, nationwide*** ***ii) Recurrence interval - Nationwide -1 every 250-500years, wave height 10.0-15.0 m*** Last significant event (5.0 m or higher): 1855 - 10.0 m, penetrated up to 1.5 km inland • Relatively large, probably affects short lengths of coastline (that are prone to earthquake- and landslide-generated tsunami) more commonly than is currently known. • Nationwide impacts: i) Based upon historic database - perceived to be minimal ii) Based upon palaeoenvironmental database - extremely significant and linked with clusters of large, local earthquakes

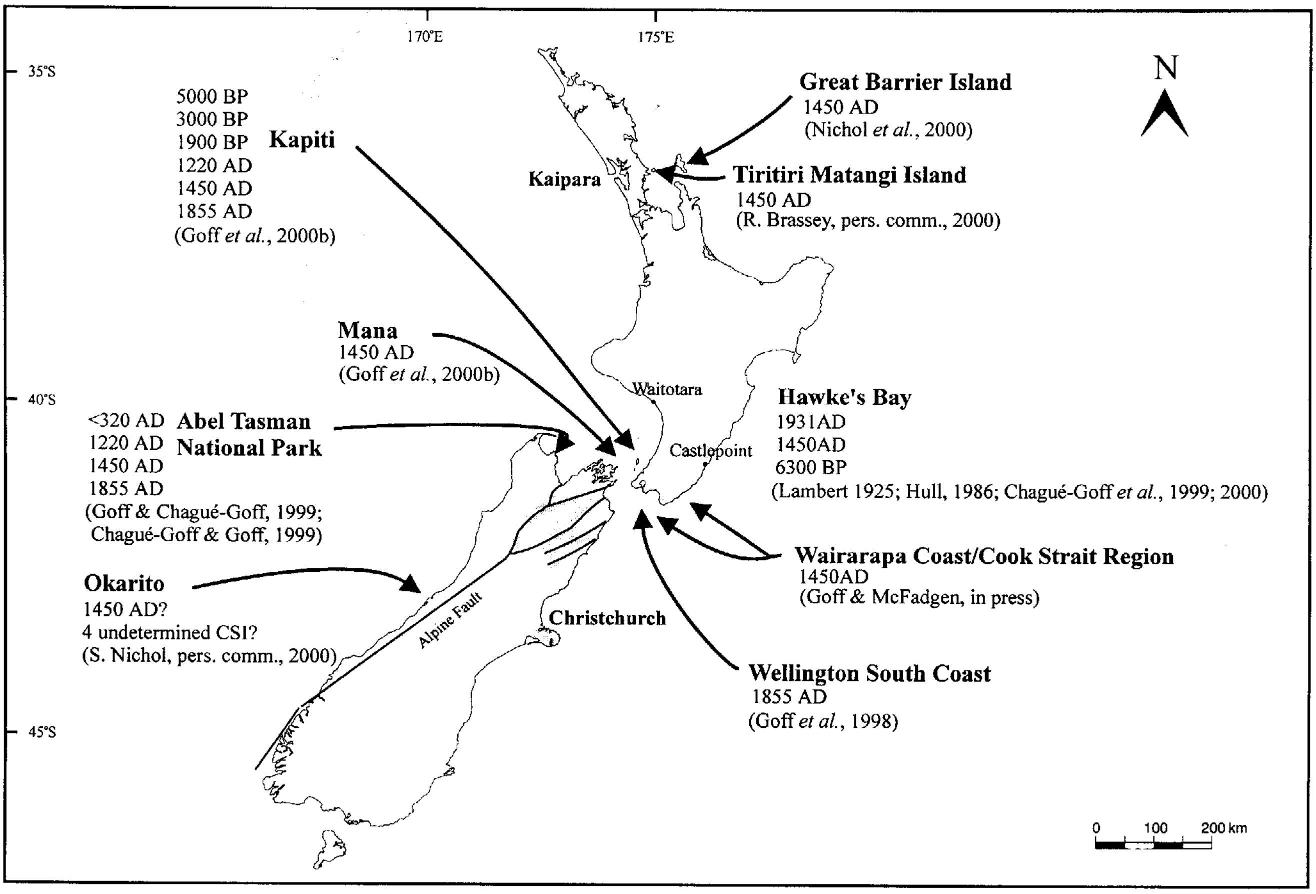

Figure 1: Summary of catastrophic events recorded in coastal wetlands ('BP' refers to dendrocalibrated radiocarbon years before present)

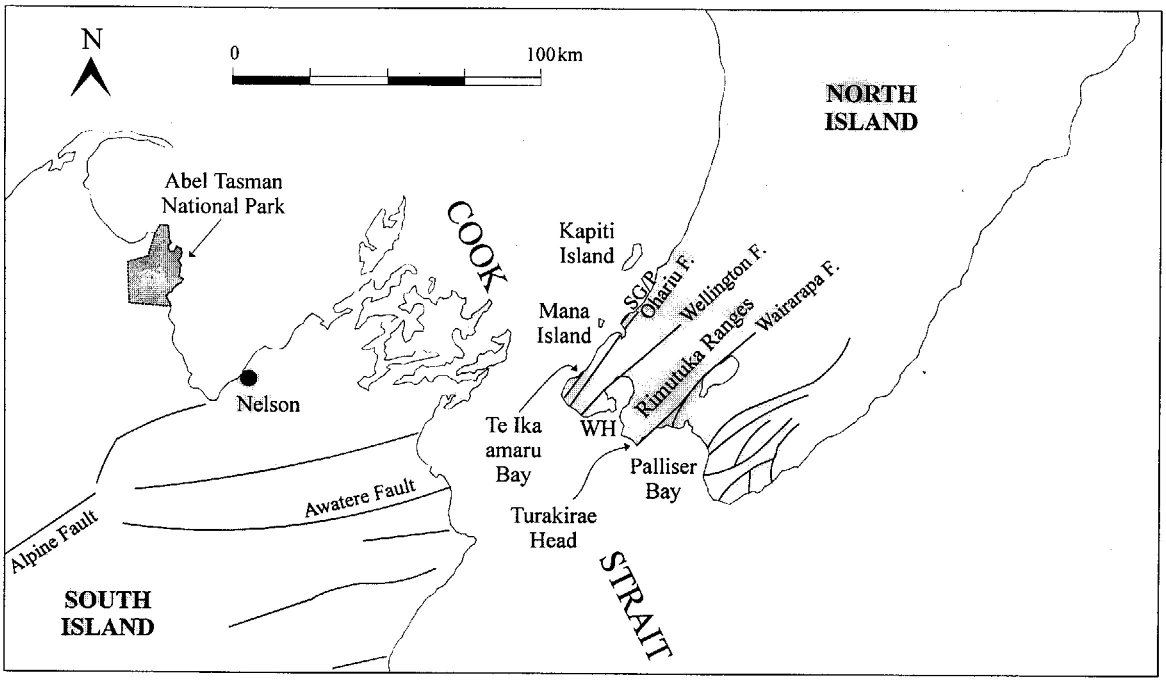

Figure 2: Detail of Cook Strait showing key faults (WH = Wellington Harbour; SG/P = Shepherd's Gully/Pukerua Fault; F = Fault)

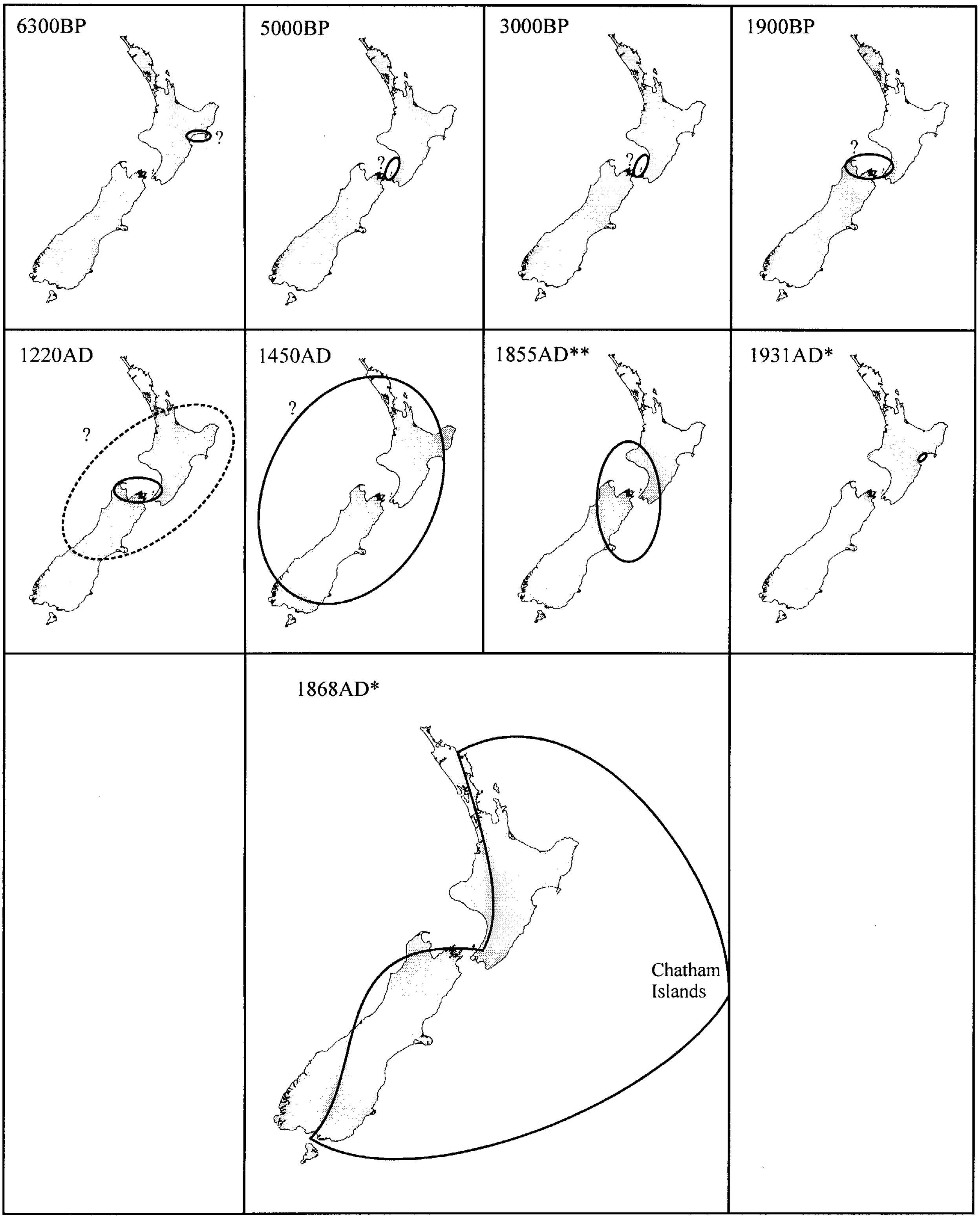

Figure 3: Approximate extent of impact on coastal environment based upon current palaeoenvironmental and historical data (*Includes evidence from de Lange & Healy, 1986; **Includes evidence from de Lange & Healy, 1986; Grapes & Downes, 1997)