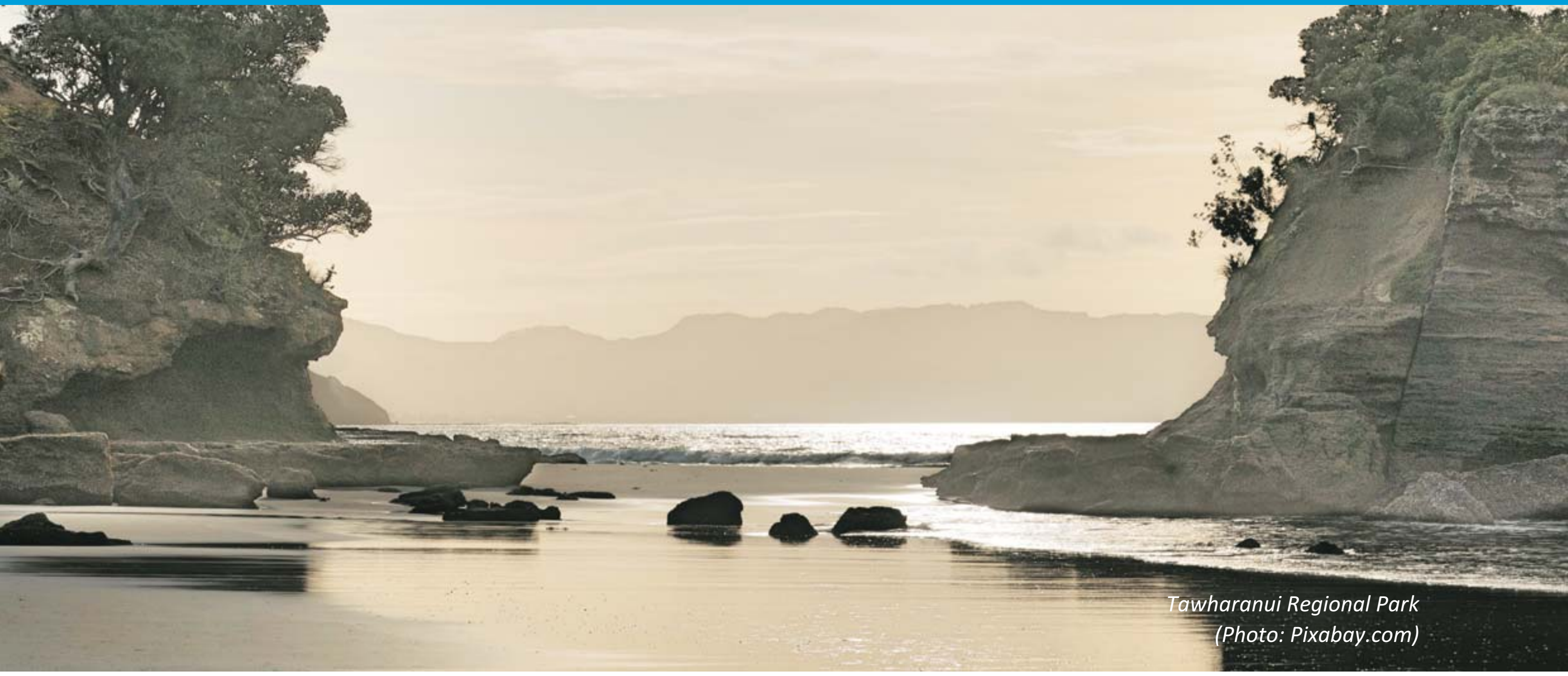
4 Advances in coastal science



Tawharanui Regional Park
(Photo: Pixabay.com)

The use of historic and contemporary coastal-change data for adaptation decision making

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Introduction

Effective planning for coastal adaptation to sea-level rise (SLR) requires anticipating the future rate of SLR and the likely morphological response of the coast, both of which are uncertain. The science of coastal flooding under SLR is relatively advanced, but the effects of SLR on future coastal change (erosion and accretion) are less well understood. This is a significant gap in our knowledge that has relevance for decision making about the impacts of SLR on communities and the things they value. This article introduces how historic imagery from New Zealand's Crown Archive and recent satellite imagery are being used to consistently map plan-form coastal changes around Aotearoa over the past 80 years. This is the first national erosion stock take since the pioneering work of Gibb (1978) and is being conducted within the Coastal Programme of the Resilience to Nature's Challenges (RNC) National Science Challenge. The national coastal-change database will be publicly available by the end of 2024. Now in the middle stages of the project, we take the opportunity in this article to discuss the emerging dataset, its capacity to identify erosion hotspots and provide focus for monitoring, and the baseline it forms on which to ground future projections of coastal erosion for adaptation decision making.

Historical coastal-change analyses are a cornerstone of large-scale coastal erosion assessments, and national-scale mapping projects have been conducted in several countries (e.g., United States Geological Survey National Assessment of Shoreline Change Project, United Kingdom Shoreline Management Plans). New Zealand lacks an up-to-date national historic coastal change dataset. The last large-scale assessment was conducted by Gibb (1978), who deciphered historical coastal change using a range of data including cadastral plans, hydrographic charts, vertical aerial photographs, field measurements, and information supplied by people living near the coast. The momentous task of bringing these data together represents one of the most important milestones in coastal management in New Zealand. In total, erosion and accretion rates were reported for 471 locations around New Zealand. We have reproduced Gibb's (1978) Figure 6 (see Figure 1), which shows impressive national coverage and relatively few significant gaps. This mapping confirmed that historic erosion and accretion had generally occurred at rates between 0.5 and 4.0 m/y, with maximum erosion and accretion rates of ~-25 m/y and ~+70 m/y (North Head Kaipara and Farewell Spit), and maximum cliff erosion rates of 2.3 and 3.5 m/y, reported from Cape Turnagain and Ngapotiki.

Since Gibb's (1978) pioneering study, coastal change analyses within New Zealand have tended to focus on short-term (event-scale) aspects of beach erosion and recovery (see Bryan et al., 2008). Notable exceptions include multi-decadal case-study analyses of coastal change at Waihi Beach (Harry and Healy, 1978), the west coast of Auckland (Williams, 1977; Blue and Kench, 2016), Mokau spit, New Brighton

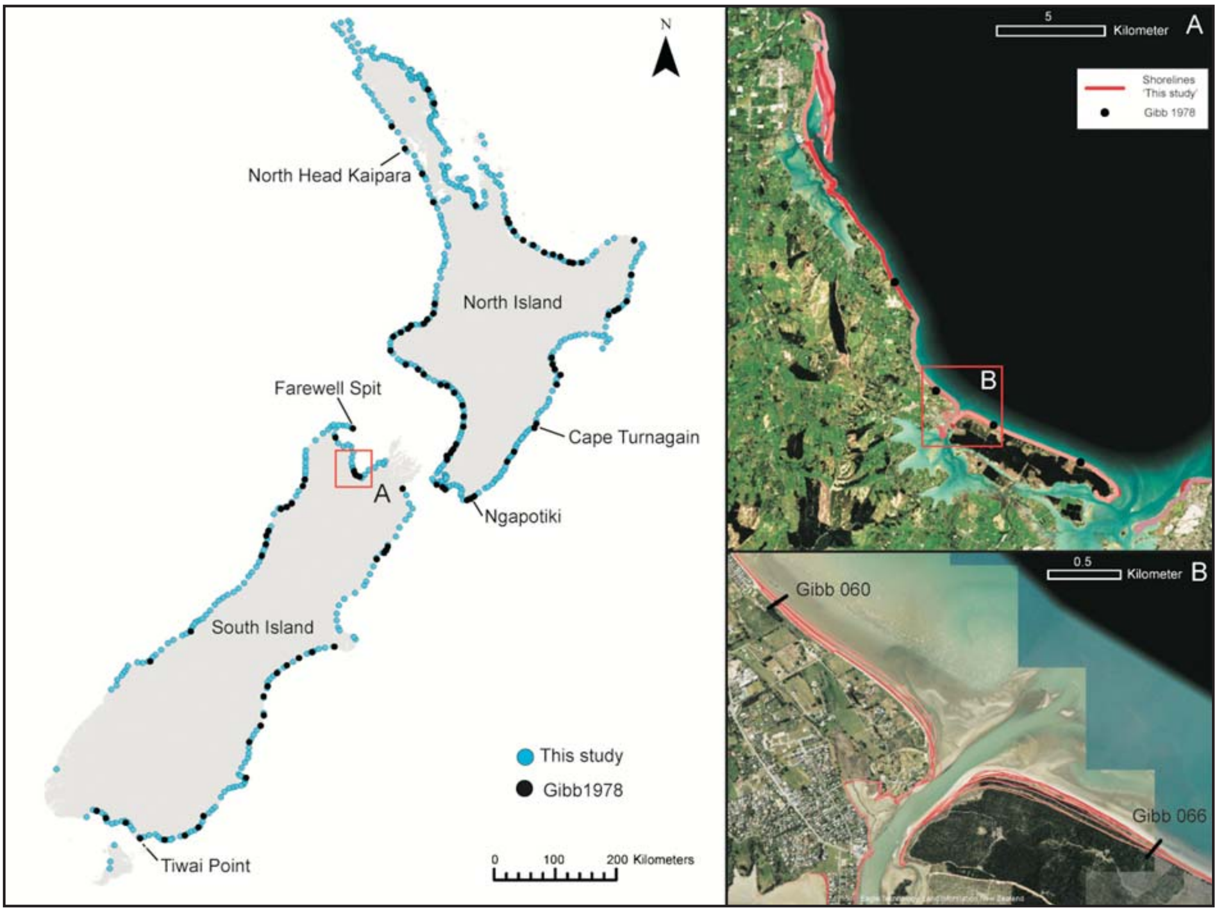


Figure 1: Location map showing every fifth transect mapped by Gibb (1978) and 'Area of Interest' centroids being mapped in the Resilience Challenge Coastal programme. Panels A and B draw attention to the continuous alongshore shoreline indicators mapped in the current study in contrast to Gibb's (1978) coastal-change rates collected at discrete point locations.

spit, and Ohiwa spit (Bryan et al., 2008). Many other local- to regional-scale coastal change studies have been conducted by multiple operators in response to the periodic requirement of councils to produce coastal hazard plans, and some of this material is available in technical reports. However, this fragmented and sporadic approach lacks a consistent methodology and reporting standards. Hence, it is impossible to comprehensively report on coastal erosion at national scale.

As part of the Coastal Programme within the RNC, we are developing a publicly available database that quantifies coastal-change patterns at national scale. We have begun releasing these data and, by the end of 2024, we will provide a national web-portal showing historic and contemporary coastal change data. This represents a significant step-change in data quality and availability for New Zealand. Now in the middle stage of the project we reflect here on how users can best utilise this dataset to improve coastal adaptation decision making. Below we briefly outline our approach, discuss issues associated with reliably and consistently identifying a 'shoreline' indicator, present a case-study illustrating the value of consistent, concomitant analyses of coastal-change data derived from both historical photographs and satellite images, and reflect on the relevance of the new dataset for science and for decision making.

Database compilation and 'shoreline' mapping

We divided New Zealand into Areas of Interest (AOIs) about 5 km in length. These areas comprise all open-coast beaches (inner harbour coasts are not mapped) and also soft cliffs where erosion rates are measurably high over the historical period (hard-rock cliffs are omitted). For each AOI we obtain all available historical photographs from New Zealand's Crown Archive from https://retrolens.co.nz and for selected AOIs we obtain satellite imagery from the past ~20 years from Maxar (https://www.maxar.com). Images are georeferenced by identifying temporally stable ground control points (GCPs), such as infrastructure, stable rocks, and fence lines. In areas where accurate GCPs are unavailable we use the autoregistration method (based on spectral similarity between ungeoreferenced images and overlapping georeferenced images), manually deleting inaccurate automated links. For beaches we select low elevation GCPs, whereas for cliffs we select GCPs near the cliff top as our aim is to map cliff-top erosion. For consistency, digitising is conducted by a single operator at a uniform scale (1:1000-1:2000) based on image resolution. The total uncertainty is then calculated based on errors associated with pixel resolution, rectification and digitising (Romine et al., 2009). The Digital Shoreline Analysis System (DSAS) (Thieler et al., 2009) is then used to analyse and report rates of coastal change.

Figure 1 illustrates that the national mapping coverage is considerably broader than was possible in Gibb's (1978) work, and it is now also possible to map a near-continuous shoreline indicator along-shore. A key decision point lies in choosing and mapping a meaningful coastal feature that is visible on images. There is no single 'correct' shoreline (Boak and Turner, 2005) and multiple indicators or proxies might be chosen for different types of coastal landforms. It is important that users of coastal-change data understand the different types of features that can be mapped, each with associated limitations. A lot of recent effort has been placed in automatically detecting the instantaneous water line (IWL) in satellite images using remote sensing algorithms that can detect the change between water and land. The technique is appealing because the IWL shoreline proxy can be rapidly automatically mapped at national to global scales (e.g., Luijendijk et al., 2018). However, this proxy is very sensitive to short-term environmental sensitivity, like fluctuations in wave runup that can be large on gently sloping beaches that are exposed to large waves. Hence, a large number of images are required to detect the average waterline position with confidence. The high-water line (HWL) is another shoreline proxy that can sometimes be mapped on historical images by a change in sand colour (e.g., Langfelder et al., 1970; Dolan et al., 1980), but often it is not visible or can be easily confused with other markers (Crowell et al., 1991). Like the IWL, this proxy is sensitive to short-term environmental variability such as anomalously high or low tides, or raised mean sea level during storms (Morton and Speed, 1998).

For the national coastal-change database we have chosen to map the 'edge of vegetation' (EOV) as our coastal change indicator on sand beaches. Gibb (1978) also used EOV to map historical coastal change around New Zealand. On sand coasts the EOV often comprises dune vegetation and coincides with the toe of the foredune or the top of an erosion scarp in a foredune. We chose this indicator because EOV change is less sensitive to short-term noise from variations in tidal and wave conditions (Morton and Speed, 1998), and more likely to reflect longer-term erosion and accretion patterns. However, the EOV indicator is sensitive to vegetation type and climatic differences between locations. We mitigate this effect by mapping within discrete AOIs such that the EOV indicator is internally consistent for that site. Other sources of interpretation error are possible, which we discuss further below. For rock coasts, it can be useful to map the cliff toe, but this is often obscured in images by the shadow of the cliff. The cliff top is generally more obvious, and we have chosen this coastal change indicator for sections of the coast we have mapped to date. As yet we have not mapped gravel coasts, but as with sand and cliff coasts, once an indicator is selected, the same indicator will be mapped within each AOI to ensure temporal consistency.

National coastal-change database: who might use this, and how might it be used?

When complete, users will be able to download shapefiles showing historical coastal-change data over several decades from most of the open-coast of New Zealand where rates of change are detectable. A broad range of stakeholders might utilise these data, including national to local government, insurers, various government authorities such as Waka Kotahi NZ Transport Agency, landowners, iwi, hapū and whānau.

National to local scale coastal erosion assessment

Benefits of the dataset will accrue from national to regional and local scales. A key feature of our approach concerns our method of upscaling from local to national. A lot of current scientific effort is afforded to large-scale (global and national) automated assessments (e.g., Luijendijk et al., 2018), but the resolution of these mapping efforts is typically too coarse to enable useful local analyses. We have mapped at local 'AOI-scale', meaning that we have quality data that matches the needs of local site assessments. This will help in minimising interpretation errors. For instance, the growth of vegetation on dunes leads to shoreward movement of the mapped EOV indicator, but this mode of accretion could represent contrasting drivers. In some cases, excess sediment supply to the coastal area might drive the development of vegetated embryonic foredunes, but in other situations dunes might be planted or naturally revegetated, and in these cases the apparent EOV accretion might be unrelated to the local sediment budget, rather reflecting vegetation dynamics. Hence, careful interpretation at the AOI scale will be required to avoid misrepresenting different modes of accretion.

Applying a consistent repeatable method at each AOI allows us to build a comprehensive and consistent nationwide coastal-change database that will then be analysed with other datasets (e.g., buildings and infrastructure, archaeological and cultural sites) to enable national coastal erosion risk assessment. Large-scale analyses may trigger detailed regional and local-scale analyses. For instance, the national coastal-change database will reveal coastal erosion hotspots that could then be prioritised based on environmental, cultural and social coastal vulnerability assessments, with subsequent application of Dynamic Adaptive Pathways Planning (DAPP) assessments and potentially more intensive monitoring (e.g., repeat LiDAR scan). One example is provided in Box 1, which shows the EOV coastal-change indicator from Tiwai Point, Southland. In this example, a concerning recent erosion trajectory between 2013-2020 is revealed from satellite imagery, but this stands in stark contrast to the longer-term coastal-change trend mapped from historical photographs. In Box 1 we ask whether the recent erosion trend may represent a decadal-scale phase that has occurred in the past, but been missed by infrequent sampling, or whether the current erosion trend might continue in the future?

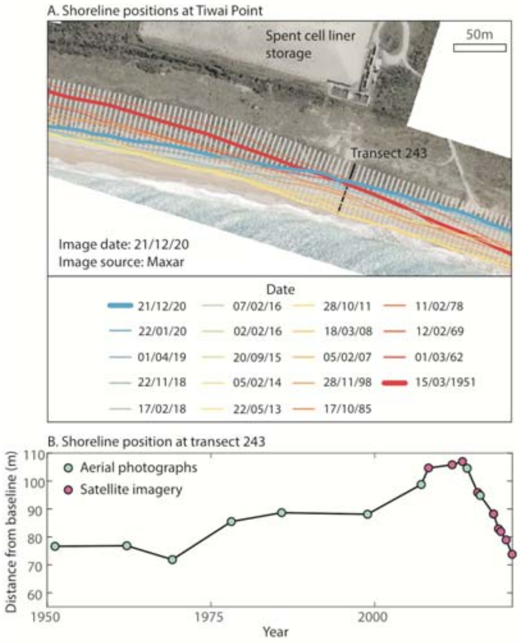
Understanding coastal change

Coastal systems are highly complex, involving multiple interactions. A key scientific aim of the RNC project is to use the national historical coastal-change database to better understand drivers of coastal change and how they might interact with SLR. Key analyses will involve considering national coastal-change change patterns alongside other national datasets, including sea-level change (https://searise.takiwa.co) and wave climate (https://coastalhub.science). It will be possible to identify sections of New Zealand's coast that have on-going systemic patterns of coastal change that are relatively predictable, in contrast to other sections that exhibit behaviour that is difficult to unravel.

The coastal-change database will provide a much-needed baseline against which to evaluate future change. Results from Northland show that a high proportion of east coast beaches have been remarkably stable over the past 80 years, despite historic SLR (Dickson et al., 2022). It is possible that there is inertia within the beach system that must be overcome before significant observable change manifests, or the effect of historic SLR may have been offset by sediment

Box 1: Coastal change at Tiwai Point

For much of New Zealand, the historic aerial photograph archive enables mapping of two to five ‘Edge of Vegetation’ (EOV) shoreline indicators between the late 1930s to 2010, with a further two to four lines from more recent photography. In the RNC project at selected sites we have improved the frequency of coastal-change mapping over the last 10 to 15 years using high-resolution optical satellite imagery. The number of satellites in orbit is ever-increasing and near-daily acquisition of 30 cm resolution imagery will be possible by late 2022. The usefulness of high-cadence imagery is evident at Tiwai Point where concern has been raised over the impact of erosion on toxic spent cell liner waste stored on the dunes near New Zealand’s only aluminum smelter. Nine EOV shorelines were mapped from historic aerial photographs and ten were mapped from satellite imagery between 2008 and 2020. Interpretation of coastal change closest to the landfill using only aerial photographs indicates slight accretion between 1951 and 2016, but the addition of satellite data indicates (a) slight overall net erosion since 1951 and (b) rapid erosion between 2013 and 2020. Is the 2013-2020 erosion period a decadal-scale phase that has occurred in the past, but has been missed by infrequent sampling, or will the current erosion trend continue in the future? Given the potential environmental impacts of erosion at this site, the coastal-change dataset should be supplemented with more intensive monitoring at sub-annual timescales (e.g., regular high-resolution satellite images and potentially volumetric monitoring with repeat LiDAR).



supply to the coast. However, the rate of SLR is accelerating and thresholds will eventually be reached and historically stable coasts may begin eroding (Le Cozannet et al., 2015). The new database will provide a necessary baseline against which this change can be detected. Modelling of the potential drivers for such thresholds and the conditions that may signal change is coming would greatly help decision makers better understand the conditions to plan for. Modelling such coastal systems and using these to inform DAPP stress testing of decisions and adaptation actions would be a fruitful next step using the database.

At the scale of individual AOIs, scientists and engineers will be able to utilise the database to inform future erosion projections under SLR. It is important that such models are process-based and can incorporate a dynamic component to account for accelerating SLR (e.g. Walkden and Hall, 2005; Dickson et al., 2007), because the past is not necessarily going to be a good guide to the future due to the acceleration of SLR. In a New Zealand context, the coastal-change dataset will support the types of probabilistic projections for sand coasts that are already standard in the technical advice that various engineering consultants provide to councils around New Zealand (e.g., Shand et al., 2015). Ultimately these data can be used in the development of planning tools for managing coastal risk such as setback lines, rolling easements, the management of retreat from the coast where needed and other dynamic planning instruments based on DAPP and for a range of community adaptation planning processes (e.g., Ryan et al., 2022).

Conclusion

Historic photographs and satellite imagery are currently being used to consistently map coastal change around Aotearoa from the late 1930s to the present day. This work presents the first national coastal erosion assessment since Gibb’s (1978) benchmark study. The national coastal-change database will be available by the end of 2024. Predominantly we have mapped the ‘edge of vegetation’, which is less sensitive to short-term fluctuations than the ‘instantaneous water line’ that can be automatically extracted from satellite imagery. A broad range of stakeholders can utilise the data being produced, which is suitable for local-, regional- and national-scale analyses. With accelerating rates of sea-level rise, the dataset provides an important new baseline on which to ground future projections of coastal erosion for adaptation decision making.

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