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Mangroves of New Zealand LC

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Abstract

Mangroves of New Zealand is a regional ecosystem subgroup (level 4 unit of the IUCN Global Ecosystem Typology). It includes the marine ecoregions of Central New Zealand, Northeastern New Zealand and Three Kings-North Cape. Their mapped extent in 2018 was 281.7 to 296.2 km2, representing 0.2% of the global mangrove area. The biota is characterized by a single species: *Avicennia marina* subsp. *australasica.*

New Zealand's mangroves represent the southernmost global limit of mangroves and are classified as temperate formations. Typically, they thrive in monostands on estuarine mudflats and the lower reaches of rivers in the northern part of North Island.

New Zealand's mangrove ecosystems differ significantly from tropical ones in terms of their lower biodiversity. Unique pressures and drivers of change are leading to mangrove range expansion rather contraction. Thus, research and management are geared towards addressing mangrove expansion: there is a need for comprehensive catchment management to reduce the influx of silt into estuaries; and management efforts to prevent loss of nearby salt-marsh ecosystems and the resulting impacts of mangrove colonisation on the amenity and recreation values of sandy-beach areas.

Today, New Zealand's mangroves cover at least 23% more than our broad estimation for 1970. However, the mangrove net area change was -3.0% between 1996 and 2018. If this trend continues, an overall change of +6.2% is projected over the next 50 years. Under a high sea-level rise scenario (IPCC RCP8.5) ≈-16.5% of the area currently covered by mangroves would be submerged by 2060. Moreover, 0.48% of the province's mangrove ecosystem is undergoing degradation. This may increase to 1.4% within a 50-year period, based on a vegetation index decay analysis. Possible changes to land use and sediment fluxes in catchments draining into estuaries represent further uncertainties in predictions. Overall, the New Zealand mangrove ecosystem is assessed as **Least Concern (LC).**

Citation:

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Keywords:

Mangroves; Red List of ecosystems; ecosystem collapse; threats.

Ecosystem classification:

MFT1.2 Intertidal forests and shrublands

Assessment's distribution:

New Zealand province

Summary of the assessment:

Criterion	A	B	C	D	E	Overall
Subcriterion 1	**LC**	**LC**	**DD**	**DD**	**NE**	
Subcriterion 2	**LC**	**LC**	**LC**	**LC**	**NE**	**LC**
Subcriterion 3	**DD**	**LC**	**DD**	**DD**	**NE**	

LC: Least Concern, DD Data Deficient, NE: Not Evaluated

Mangroves of New Zealand LC

1. Ecosystem Classification

IUCN Global Ecosystem Typology (version 2.1, Keith *et al.*, 2022):

Transitional Marine-Freshwater-Terrestrial realm

MFT1 Brackish tidal biome

MFT1.2 Intertidal forests and shrublands

MFT1.2_4_MP_53m Mangroves of New Zealand

Avicennia marina subsp. australasica in a tidal inlet, Rawene, Northland. The formerly forested hills now support extensive sheep and beef farming provide the elevated sediment levels supporting mangrove expansion (Photo credit: Jeffrey McNeill).

IUCN Habitats Classification Scheme (version 3.1, IUCN 2012):

1 Forest

1.7 Forest – Subtropical/tropical mangrove vegetation above high tide level **below water level* [1]

12 Marine Intertidal

12.7 Mangrove Submerged Roots

[1] Note on the original classification scheme. This habitat should include mangrove vegetation below water level. Mangroves have spread into warm temperate regions to a limited extent and may occasionally occur in supratidal areas. However, the vast majority of the world's mangroves are found in tropical/subtropical intertidal areas.

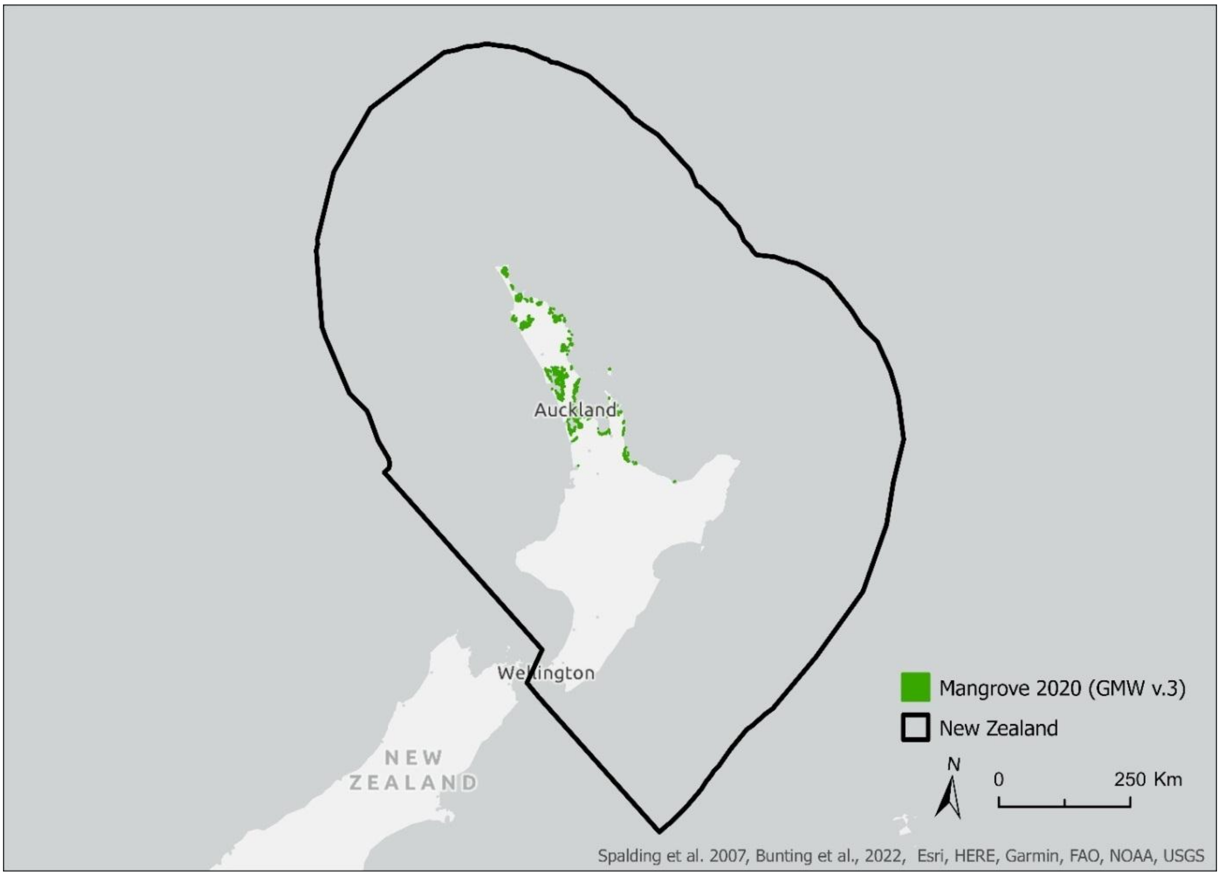

Figure 1. The distribution of mangroves in New Zealand (shown in green). Source: 2020 Mangrove extent extracted from Bunting *et al.,* 2022. Province limits modified from Spalding *et al.,* 2007.

2. Ecosystem Description

Spatial distribution

The 'Mangroves of New Zealand' includes intertidal forest and shrublands of the marine ecoregions of Central New Zealand, Northeastern New Zealand and Three Kings-North Cape that extend across New Zealand (Figure 1).

The estimated extent of mangroves in this province is between 281.7* and 296.2** km^2 (2020 data), representing about 0.2% of the global mangrove area. There has been a -3.0* to 2.0** % net area change since 1996 (*Manaaki Whenua Landcare Research, 2019 [LCDB v.5]; **Bunting *et al.,* 2022).

Mangroves grow naturally in the northern half of New Zealand's North Island from 35°27'S in the far north to 38°05'S at Kawhia on the west coast and 38°03'S at Ohiwa Harbour on the east coast near the global southern range limit of mangroves. A naturalised population in the Uawa River Estuary, Tologa Bay, at 38° 23' is now well-established, extending the range further south than has generally been recognised.

Biotic components of the ecosystem (characteristic native biota)

The mangroves of New Zealand are consistent with other temperate mangrove forests, being significantly less biologically diverse than tropical mangrove forests, with only one recorded true mangrove plant species, the Grey Mangrove (*Avicennia marina* subsp. *australasica*), which forms monostands. It is characterised by having two distinct growth forms with taller tree-like mangroves found predominantly near the seaward fringe and along tidal channels, and dwarf shrub-like mangroves in the interior and at higher latitudes (Suyadi, *et al*., 2020). The seagrass (*Zostera muelleri*), although in the IUCN Red List of Threatened Species (IUCN, 2022), is not found in the mangrove forests, but rather is threatened by the mangroves expanding into seagrass habitat.

New Zealand has no native terrestrial mammals and no large animal species associated with mangrove habitats in the Red List of Threatened Species database (IUCN, 2022) have been observed within this province (GBIF, 2022). However, some 47 native and introduced bird species have been recorded using New Zealand mangrove habitat (Bell and Blayney, 2017) including 11 species considered at risk, or threatened in New Zealand as defined by Robertson *et al*. (2017) (See Annex 2). None of these birds are directly dependent on mangroves, but rather they utilise diverse habitats including mangroves.

Twenty-three species in the IUCN Red List of Threatened Species database (IUCN, 2022) are associated with New Zealand's mangroves, 19 of which are birds (Annex 2). Two bird species, the Pied Shag (*Phalacrocorax varius*) and Banded Rail (*Gallirallus philippensis*), are also in the IUCN Red List database. However, the Red List overstates the risks these species face in New Zealand. Some, such as the endemic grey warbler (*Gerygone igata*), are widespread and not threatened. Many of the bird species are migrants, most of which are vagrants or stragglers observed as a few isolated individuals or pairs throughout the country in any one season. A few, while considered native, are recently self-introduced. For example, the White-faced Heron (*Egretta novaehollandiae*) established itself in the 1940s; the Silvereye (*Zosterops lateralis*) colonised New Zealand from Australia in the 1850s and is now one of New Zealand's most abundant and widespread bird species (nzbirdsonline.org.nz).

Mangroves of northern New Zealand support high abundance of small common estuarine fishes, but species diversity is low compared to other estuarine habitats (Morrison *et al*., 2002; Morrison and Carbines, 2006). These species are not primarily associated with mangrove habitats but utilise a range of seascape environments. Notably, the co-occurrence of mangroves and nearby seagrass habitats has been found to support a higher abundance and diversity of juvenile fishes (Morrisey *et al*., 2007).

The species of benthic macrofauna associated with mangroves are also found in other coastal ecosystems. They include the abundant endemic tunnelling mud crab (*Austrohelice crassa*; synonym: *Helice crassa*). The endemic estuarine mud snail (*Amphibola crenata*), a former food source for coastal Māori people, is also widely distributed and abundant. Three endemic insect species are found in mangroves, including the *Planotortrix avicenniae* moth (Family Tortricidae), which is found only in mangrove forests.

Mangroves in New Zealand typically form monostands. Omanaia River Estuary, North Island (Photo credit: Jeffrey McNeill).

Mangroves invading mudflats created following the construction of a marina, Whangamata, Coromandel Peninsula (Photo credit: Jeffrey McNeill)

Mangroves fringing an estuary, Mangemangeroa inlet, Auckland (Photo credit: Jeffrey McNeill).

Abiotic Components of the Ecosystem

Regional mangrove distributions are influenced by interactions among landscape position, rainfall, hydrology, sea level, sediment dynamics, and storm-driven processes. Rainfall and sediment supply from rivers and currents promote mangrove establishment and persistence, while waves and large tidal currents destabilise and erode mangrove substrata, mediating local-scale dynamics in ecosystem distributions (Horstman *et al*., 2018). High rainfall reduces salinity stress and increases nutrient loading from adjacent catchments, while tidal flushing also regulates salinity.

Mangroves in New Zealand primarily grow in estuarine muddy sediments, although smaller stands of trees can be found in regions with sandy substrata. Land use and vegetation cover have changed considerably in the catchments behind these estuaries over the last 150 years. Most lowland forest has been replaced by extensive farming. Subsequently, much of this land adjacent or near urban centres has been converted into urban land uses. These land changes and subsequent uses have raised silt production significantly, increasing the area of mudflats available for mangrove colonisation at the expense of pre-existing sandy coastline habitat and seagrass ecosystems (Burns and Ogden, 1985). Increasing nutrient inputs to the marine environment have also created favourable environments for expansion (Horstman *et al*., 2018).

Climate is a key control in determining mangrove distribution and density. Mangroves are tropical to warm temperate climate plants intolerant of cold. Frosts and extreme cold weather limit mangrove establishment and growth, and cooler climatic conditions have been important in limiting the southwards expansion of mangroves in New Zealand. However, New Zealand has experienced increasingly warm climatic conditions over the last two decades with the top-four warmest years on record occurring since 2016. Minimum temperatures have also been rising. In part, these warmer conditions reflect global climate change. 2022 was also the third consecutive year of the La Niña driver of regional climate, resulting in warmer ocean temperatures around New Zealand, while the Indian Ocean Dipole helped to drive up air temperatures near the coast (NIWA, 2022). These recent warmer climatic conditions can be expected to assist mangrove colonisation and gap-filling in estuaries towards the mangrove's southern geographical limits, further aiding the increase in mangrove area in New Zealand. Mangroves at the southern natural limits of their distribution are now expanding in extent in parts of Ohiwa, Raglan and Kawhia harbours. Mangroves planted further south in the Uawa River estuary can now be considered naturalised.

Key processes and interactions

Mangroves act as structural engineers possessing traits such as pneumatophores, salt excretion glands, vivipary, and propagule buoyancy that promote survival and recruitment in poorly aerated, saline, mobile, and tidally inundated substrata. These trees exhibit high efficiency in nitrogen use and nutrient resorption. Mangroves produce large amounts of detritus (e.g., leaves, twigs, and bark), which is either buried in waterlogged sediments, or consumed by crabs and then decomposed further by meiofauna, fungi and bacteria to produce mangrove detritus as a protein- and nutrient-rich food source for other consumers in the mangrove and coastal food web. However, the decay of mangrove litter in New Zealand is around an order of magnitude slower than in tropical mangrove ecosystems (Gladstone-Gallagher *et al*., 2014).

Mangrove ecosystems also serve as major blue carbon sinks, incorporating organic matter into sediments and living biomass. There has been no definitive national assessment of carbon stored within New Zealand mangroves forests. Several recent local allometric studies (Bulmer *et al.*, 2016; Suyadi, *et al*., 2020; Tran *et al*., 2017) show considerable variation in their findings with total carbon storage ranging from 60 to 117 t ha^{-1} (Appendix 3). With this caveat, extrapolation of their findings suggests that New Zealand's mangroves store a national carbon mass of between 2.8 and 3.4 million tonnes.

Mangroves also modify their physical environment. The presence of trees, branches, leaves, and roots introduces drag in the water column, which reduces mean flows and attenuates waves. Wider forests (order of 100s of metres wide) can also dissipate long waves and storm surges (Montgomery *et al*., 2019). This reduction of hydrodynamic energy reduces resuspension of sediments from the seafloor and enhances the settling of fine particles. However, on smaller scales, the presences of submerged root structures can create turbulent eddies and promote localised scouring. This alteration of the hydrodynamic and sediment transport regimes can modify the substratum composition and bathymetry within and surrounding mangrove stands.

Aerial images of Orewa Estuary, Auckland: 1955, 2010 and 2023 showing urban expansion and areal expansion of mangroves over nearly 70 years (Photo credits: Whites Aviation Collection, Alexander Turnbull Library; Auckland Council; Google Maps).

3. Ecosystem Threats and vulnerabilities

Main threatening process and pathways to degradation

Mangrove deforestation arises from various factors, including aquaculture, urbanization, associated coastal development, and pollution stemming from domestic, industrial, and agricultural land use. The location of mangrove forests within intertidal areas renders them vulnerable to predicted sea-level rise caused by climate change. Tropical storms can damage mangrove forests through direct defoliation and destruction of trees, as well as through the mass mortality of animal communities within the ecosystem.

Historically, New Zealand mangrove forests suffered loss primarily from land reclamation for extensive farming from the 1920s until 1977 when they were protected by law. In response to subsequent expansion, areas recently colonised by mangroves have been cleared by local communities with the aim of protecting adjacent ecosystems and their amenity values by removing recent mangrove colonists (Glover *et al*, 2022; Stokes *et al*., 2023). Some 330 ha of mangroves have been approved for removal since 1994 and it is likely that the same area again has been removed without authorisation, or about 2.3% of total the mangrove area (De Satgé, 2021). However, such management interventions are expensive and with no guarantee that mangrove clearance will be sustainable. However, local-scale assessments show more granular change with losses in some places more than offset by gains in others. For example, mangroves and mixed saltmarsh-mangrove habitats in some areas of the southern part of Kaipara Harbour were lost due to reclamation, while there were gains in the northern part of around 41% between 1977 and 2002, resulting in a net increase for the harbour of 11% (Swales *et al*., 2011). The LCDB v.5 data show that between 1996 and 2018 some 38 ha were added to the area under mangroves by their expansion into sand and gravel, and estuarine mud areas. At the same time, 70 ha were lost primarily to herbaceous saline (57 ha) and estuarine (6 ha) cover, most likely as the result of mangrove clearance. Overall, there was a net loss of 30 ha (0.1%) over this 22-year period.

Mangrove removal, Omokoroa, Bay of Plenty in 2010 (Photo credit: Bay of Plenty Regional Council (Braden Rowson)).

Definition of the collapsed state of the ecosystem

Mangroves, acting as structural engineers, possess specialized traits that facilitate high nitrogen use efficiency and nutrient resorption, influencing critical processes and functions within their ecosystem. Ecosystem collapse is recognized when the tree cover of diagnostic true mangrove species declines to zero (100% loss).

Mangrove ecosystems exhibit remarkable dynamism, with species distributions adapting to local shifts in sediment distribution, tidal patterns, and variations in local inundation and salinity gradients. Disruptive processes can trigger shifts in this dynamism, potentially leading to ecosystem collapse, which may cause the following changes: a) restrictions on recruitment and survival of diagnostic true mangroves due to adverse climatic conditions (e.g., low temperatures); b) alterations in rainfall, river inputs, waves, and tidal currents that destabilize and erode substrata and physically impact on mangroves; c) shifts in rainfall patterns and tidal flushing altering the salinity regime and nutrient loading, thereby impacting overall survival.

New Zealand's coastline is vulnerable to tsunamis because of the country's position on the Pacific 'Ring of Fire'. Written records suggest that at least 68 tsunamis have reached New Zealand shores since written records began in the 1840s. Of these, six generated waves over 5 m high (Downs *et al*., 2017). These events have the potential to impact some mangrove stands, albeit very infrequently. Earthquakes and volcanoes similarly pose low probability, but high local impact threats to mangroves. Although New Zealand's climate is changing with increased incidence of high-impact weather events, there is as yet no evidence of their significant impact on mangroves.

Threat Classification

IUCN Threat Classification (version 3.3; IUCN-CMP, 2022) relevant to mangroves of the New Zealand province:

2. Agriculture & aquaculture

- 2.1 2.3 Livestock farming & ranching

4. Transportation & service corridors

- 4.1 Roads & railroads

6. Human intrusions & disturbance

- 6.3 Work & other activities: management and clearance of recently colonised stands to maintain access, amenity and restore pre-mangrove colonisation ecosystems

10. Geological events

- 10.1 Volcanoes
- 10.2 Earthquakes/tsunamis

11. Climate change & severe weather

- 11.1 Habitat shifting & alteration

4. Ecosystem Assessment

Criterion A: Reduction in Geographic Distribution

Subcriterion A1 measures the trend in ecosystem extent during the last 50-year time window. Unfortunately, there is currently no common regional dataset that provides information for the target area in 1970. However, country-level estimates of mangrove extent can be used to extrapolate the trend between

1970 and 2020. Accordingly, we compiled reliable published sources (see appendix 4) that contain information on mangrove area estimates close to 1970 (both before and after). However, the estimated values for 1970 should be considered only indicative (see appendix 4 for further details of the methods and limitations).

We also used data from the first comprehensive assessment of New Zealand mangrove cover using imagery captured primary from 1979 to 1981. New Zealand had been losing mangrove area up to 1977 when a change of law protected mangroves. Subsequently, the area under mangroves has expanded substantially. 1977 can therefore be seen as an inflexion point: thus the 1981 data provide a more accurate baseline for measuring recent change in geographic distribution. We also estimated the New Zealand mangrove area from 1996 to 2020, using the most recent version of the Global Mangrove Watch (GMW v3.0) spatial dataset. The mangrove area in the province (and in the corresponding countries) was corrected for both omission and commission errors, utilizing the equations in Bunting *et al.* (2022).

Results from the analysis of subcriterion A1 (Annex 4) show that the New Zealand mangrove province has increased approximately ~3.2% of its mangrove area over the last 50 years (1970-2020). However, the New Zealand data for 1980 to 2018 show a much greater increase of at least 18% over this period and changes have been much greater in places. For example, Suyadi *et al*. (2019) found that the area of intertidal mudflat habitat providing potential for mangrove colonisation doubled from 14,193 ha to 28,764 ha in Auckland between 1974 and 2014. Particularly rapid expansion has occurred in locations such as the Firth of Thames where some 11 km^2 of mudflat has been colonised by mangroves since the early 1960s (Swales *et al*., 2015).

Given that the change in geographic distribution is positive, the ecosystem is assessed as **Least Concern (LC)** under subcriterion A1.

Mangroves of New Zealand	Area 2020* (Km^2)	Area 1970* (Km^2)	Net area Change (Km^2)	% Net Area Change	Rate of change (%/year)
	296.2	287	9.2	3.2	0.06
	281.7**	198.3 – 230.0**	5.1 – 8.3	18 - 30	0.47 – 0.79

** Details on the methods and references used to estimate the mangrove area in 1970 are listed in appendix 4. Total mangrove area in 2020 is based on the Global Mangrove Watch Version 3 (GMW v3.0) dataset.*
***Total mangrove area based on NCC (1984) and LCDB v.5(2018) datasets.*

Subcriterion A2 measures the change in ecosystem extent in any 50-year period, including from the present to the future: The New Zealand province mangroves show a net area change of 2.0% (1996-2020) based on the Global Mangrove Watch time series (Bunting *et al.*, 2022). This value reflects the offset between areas gained (+ 0.4%/year) and lost (- 0.3%/year).

However, the use of linear regression to model future extent of mangroves in New Zealand may not be appropriate (fig 2, Linear regression R^2=0.4, exponential R^2=0.4). Its use assumes past drivers for expansion will continue to operate in the future. For New Zealand this is not the case: growth is dependent upon habitat creation suitable for colonisation. That will be limited by area available for modification. Further, climate change modelling of one catchment suggests that the mangrove area could increase without catchment mitigation measures but that it could decrease if activities such as carbon-sequestration forestry were to reduce silt inputs into estuaries. Linear regression also assumes that the points are normally distributed, and these points are not, so that the line is not as significant as indicated. Rather the significance is likely driven by the two outliers.the New Zealand mangrove ecosystem is assessed as **Data Deficient (DD)** under subcriterion A2.

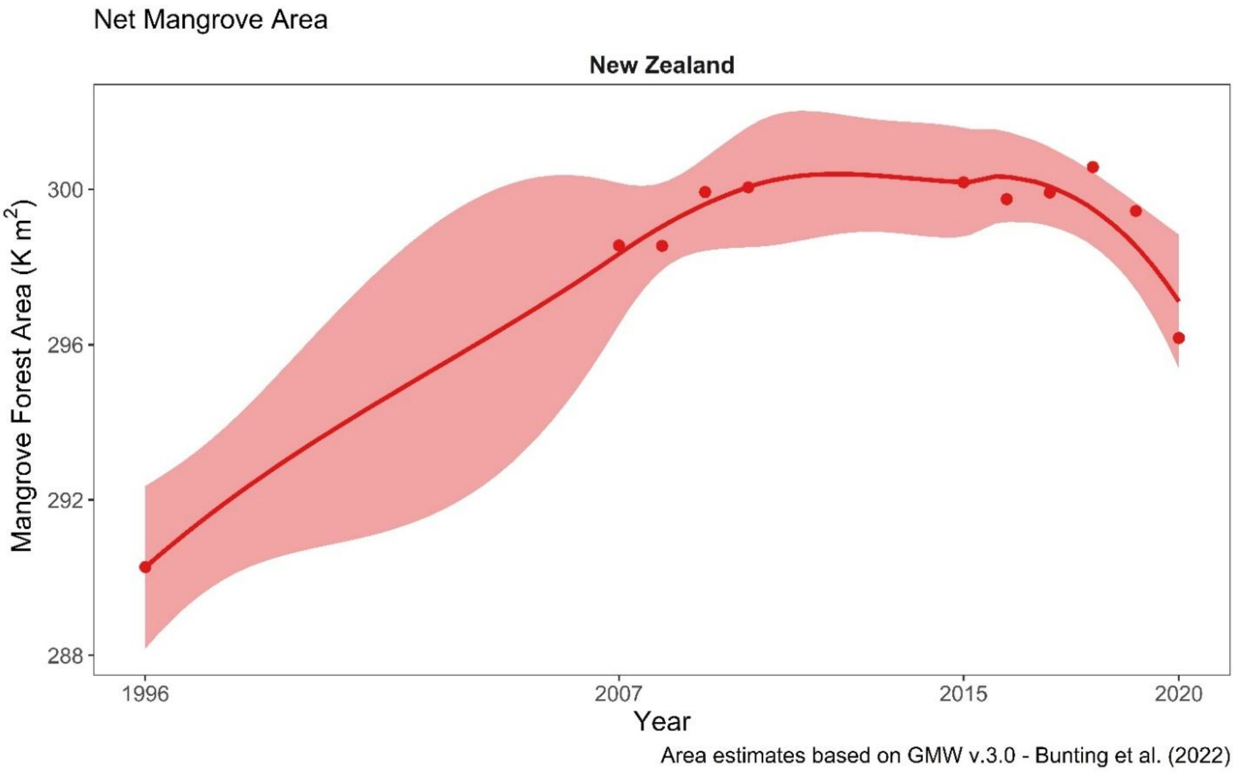

Figure 2. New Zealand mangrove ecosystem between 1996 to 2020. Circles represent the province mangrove area between 1996 and 2020 based on the GMW v3.0 dataset and equations in Bunting *et al.*, (2022). The solid line and shaded area are the loess smoothing and 95% confidence intervals.

Subcriterion A3 measures changes in mangrove area since 1750. Unfortunately, there are no reliable data on the mangrove extent for the entire province during this period, and therefore the New Zealand mangrove ecosystem is classified as **Data Deficient (DD)** for this subcriterion.

Overall, the ecosystem is assessed as **Least Concern (LC)** under criterion A.

Criterion B: Restricted Geographic Distribution

Criterion B measures the risk of ecosystem collapse associated with restricted geographical distribution, based on standard metrics (Extent of Occurrence EOO, Area of Occupancy AOO, and Threat-defined locations). These parameters were calculated based on the 2020 New Zealand province mangrove extent (GMW v3)

Province	Extent of Occurrence EOO (Km^2)	Area of Occupancy (AOO) ≥ 1%	Criterion B
New Zealand	48796.8	100	**LC**

For 2020, the AOO and EOO were measured as 191 grid cells 10 x 10 km and 48796.8 km^2, respectively (Figure 3). Excluding from the AOO those grid cells that contain patches of mangrove forest that account for less than 1% of the grid cell area, (< 1 Km^2), the AOO is measured as **100, 10 x 10 km grid cells** (Figure 3, red grids).

Considering the very high number of threat-defined-locations, there is no evidence of plausible catastrophic threats leading to potential disappearance of mangroves across their extent.

As a result, the New Zealand mangrove ecosystem is assessed as **Least Concern** under criterion B.

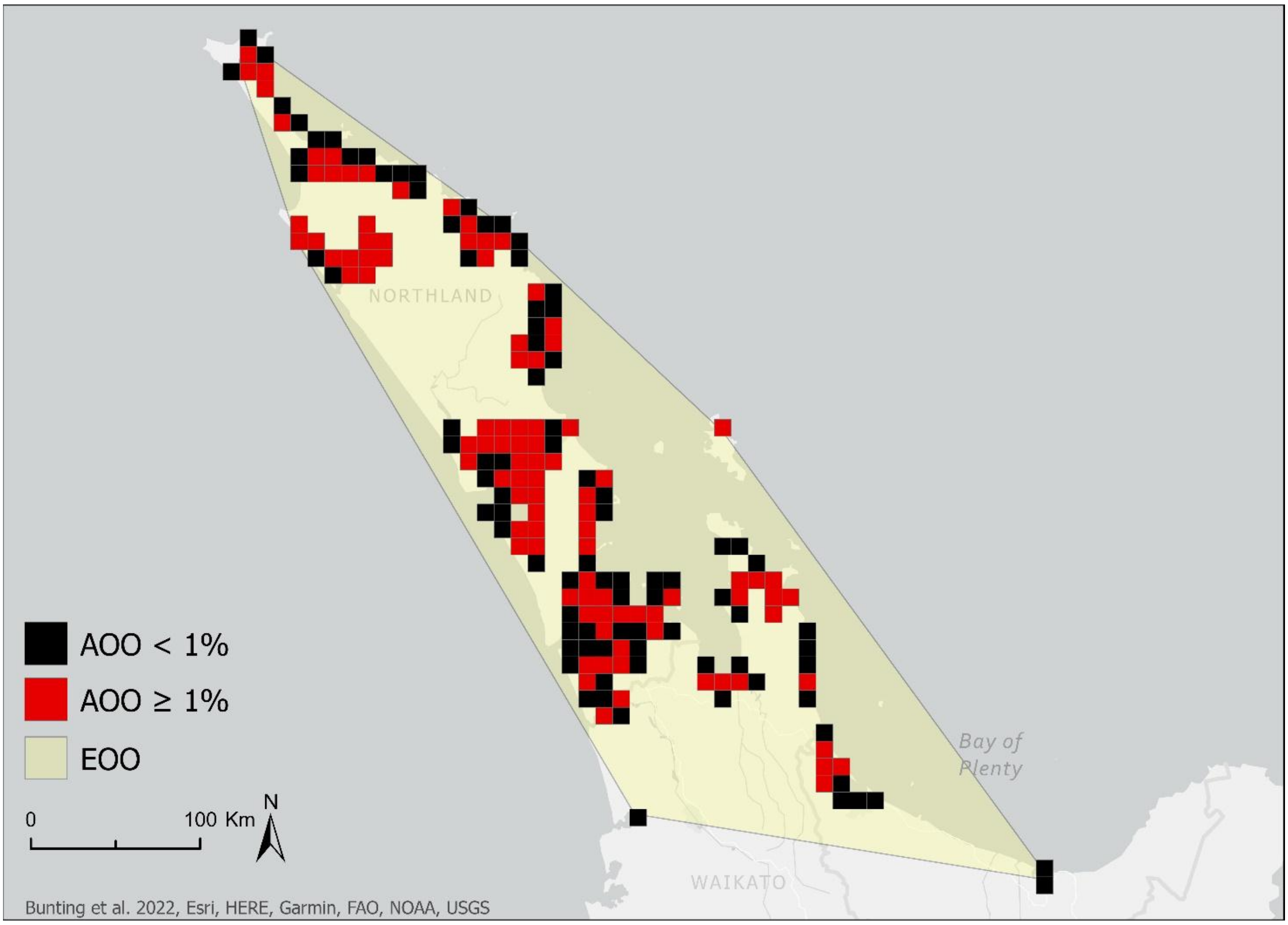

Figure 3. The New Zealand mangrove Extent Of Occurrence (EOO) and Area Of Occupancy (AOO) in 2020. Estimates based on 2020 GMW v3.0 spatial layer (Bunting *et al.*, 2022). The red 10 x 10 km grids (n=100.) are more than 1% covered by the ecosystem, and the black grids <1% (n= 91).

Criterion C: Environmental degradation

Criterion C measures the environmental change of abiotic variables necessary to support the ecosystem.

Subcriterion C1 measures environmental degradation over the past 50 years. There are no reliable data to evaluate this subcriterion for the entire province, and therefore the New Zealand mangrove ecosystem is classified as **Data Deficient (DD)** for subcriterion C1.

Subcriterion C2 measures environmental degradation in the future, or over any 50-year period, including from the present. In this context, the impact of future sea-level rise (SLR) on mangrove ecosystems was assessed by adopting the methodology presented by Schuerch *et al.* (2018). The published model was designed to calculate both absolute and relative change in the extent of wetland ecosystems under various regional SLR scenarios (i.e. medium: RCP 4.5 and high: RCP 8.5), with consideration for sediment accretion. Therefore, the Schuerch *et al*. (2018) model was applied to the New Zealand mangrove ecosystem boundary, using the spatial extent in 2010 (Giri *et al.*, 2011) and assuming mangrove landward migration was not possible.

Recent modelling the impacts of climate change assumes sediment supply continues at present levels (Schuerch *et al*., 2018) or declines because of dams constructed on rivers that restrict sediment supply (Lovelock *et al*., 2015). However, these assumptions may not hold in New Zealand. No river systems in the northern part of the North Island are suitable for damming. Rather, climate-change driven sediment fluxes may rely more on land-use changes within catchments. For example, modelling for the Firth of Thames (McBride *et al*, 2016) found water depths in the Firth over time are projected to be relatively independent of ICCP Representative Concentration Pathway scenarios but depend strongly on land use in the catchment. Under present extensive farming land use, up to 100% increase in mangrove habitat is projected in suitable areas, with a decrease of habitat in subtidal areas. Conversely, a reduction in habitat can be expected for areas presently marginal for mangroves if sediment supply decreases as land landowners respond to increases in global carbon prices by converting agricultural land to plantation forestry, shrubland and fallow land.

According to the results of Schuerch *et al.*, (2018) considered by above arguments as too pessimistic, under an extreme sea-level rise scenario of 1.1-m rise by 2100, the projected submerged area is ~ -16.5% by 2060, which remains below the 30% risk threshold. Therefore, considering that no mangrove recruitment can occur in a submerged system (100% relative severity), but that -16.5% of the ecosystem extent will be affected by SLR, the New Zealand mangrove ecosystem is assessed as **Least Concern** (**LC**) for subcriterion C2.

Subcriterion C3 measures change in abiotic variables since 1750. There is a lack of reliable historic data on environmental degradation covering the entire province, and therefore the New Zealand province is classified as Data Deficient (DD) for this subcriterion.

Overall, the ecosystem is assessed as **Least Concern** (**LC**) under criterion C.

Criterion D: Disruption of biotic processes or interactions

The global mangrove degradation map developed by Worthington and Spalding (2018) was used to assess the level of biotic degradation in the New Zealand province. This map is based on degradation metrics calculated from vegetation indices (NDVI, EVI, SAVI, NDMI) using Landsat time series (≈2000 and 2017). These indices represent vegetation greenness and moisture condition.

Mangrove degradation was calculated at a pixel scale (30m resolution), on areas intersecting with the 2017 mangrove extent map (GMW v2). Mangrove pixels were classified as degraded if two conditions were met: 1) at least 10 out of 12 degradation indices showed a decrease of more than 40% compared to the previous period; and 2) all twelve indices did not recover to within 20% of their pre-2000 value (detailed methods and data are available at: maps.oceanwealth.org/mangrove-restoration/). The decay in vegetation indices has been used to identify mangrove degradation and abrupt changes, including mangrove die-back events, clearcutting, fire damage, and logging; as well as to track mangrove regeneration (Lovelock *et al.,* 2017; Santana, 2018; Murray *et al.*, 2020; Aljahdali *et al.*, 2021; Lee *et al.*, 2021). However, it is important to consider that changes observed in the vegetation indices can also be influenced by data artifacts (Akbar *et al.*, 2020). Therefore, a relative severity level of more than 50%, but less than 80%, was assumed.

The results from this analysis show that over a period of 17 years (~2000 to 2017), 0.5% of the New Zealand mangrove area is classified as degraded, resulting in an average annual rate of degradation of 0.03%. Assuming this trend remains constant, +1.4% of the New Zealand mangrove area will be classified as degraded over a 50-year period. Since less than 30% of the ecosystem will meet the category thresholds for criterion D, the New Zealand mangrove province is assessed as **Least Concern (LC)** under subcriterion D2b.

No data were found to assess the disruption of biotic processes and degradation over the past 50 years (subcriterion D1) or since 1750 (subcriterion D3). Thus, both subcriteria are classified as **Data Deficient (DD).**

Overall, the New Zealand ecosystem remains **Least Concern (LC)** under criterion D.

Criterion E: Quantitative Risk

No model was used to quantitatively assess the risk of ecosystem collapse for this ecosystem; hence criterion E was **Not Evaluated (NE)**.

5. Summary of the Assessment

CRITERION			
A. Reduction in Geographic Distribution	**A1** Past 50 years	**A2** Future or any 50y period	**A3** Historical (1750)
	LC	DD	DD
B. Restricted Geo. Distribution	**B1** Extent of Occurrence	**B2** Area of Occupancy	**B3** # Threat-defined Locations < 5?
	LC	LC	LC
C. Environmental Degradation	**C1** Past 50 years (1970)	**C2** Future or any 50y period	**C3** Historical (1750)
	DD	LC	DD
D. Disruption of biotic processes	**D1** Past 50 years (1970)	**D2** Future or Any 50y period	**D3** Historical (1750)
	DD	LC	DD
E. Quantitative Risk analysis	NE		
OVERALL RISK CATEGORY	LC		

DD = Data Deficient; LC = Least Concern; NE = Not Evaluated

Overall, the status of the New Zealand mangrove ecosystem is assessed as **Least Concern (LC).**

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7. Appendices

1. List of Key Mangrove Species

List of plant species considered true mangroves according to the Red List of Threatened Species (RLTS) spatial data (IUCN, 2022). We included species whose range maps intersect with the boundary of the marine provinces/ecoregions described in the distribution section.

Class	Order	Family	Scientific name	RLTS category
Magnoliopsida	Lamiales	Acanthaceae	*Avicennia marina* subsp. *australasica*	LC

2. List of Associated Species

2.1 List of taxa associated with mangrove habitats in the Red List of Threatened Species (RLTS)

List of taxa that are associated with mangrove habitats in the Red List of Threatened Species (RLTS) database (IUCN, 2022). We included only species with entries for Habitat 1.7: "Forest - Subtropical/Tropical Mangrove Vegetation Above High Tide Level" or Habitat 12.7 for "Marine Intertidal - Mangrove Submerged Roots", and with suitability recorded as "Suitable", with "Major Importance" recorded as "Yes", and any value of seasonality except "Passage". We further filtered species with spatial point records in the GBIF (some species are excluded due to mismatch in taxonomic names, or lack of georeferenced records). The common names are those shown in the RLTS, except common names in brackets, which are from other sources.

Class	Order	Family	Scientific name	RLTS status	Common name	New Zealand status*
Aves	Charadriiformes	Scolopacidae	*Actitis hypoleucos*	LC	Common Sandpiper	Native Vagrant
Gastropoda	Pylopulmonata	Amphibolidae	*Amphibola crenata*	LC		
Actinopterygii	Tetraodontiformes	Tetraodontidae	*Arothron stellatus*	LC	Stellate Puffer	
Aves	Cuculiformes	Cuculidae	*Chrysococcyx lucidus (Chalcites lucidus)*	LC	Shining Bronze-cuckoo	Native Migrant Not Threatened
Aves	Charadriiformes	Charadriidae	*Charadrius mongolus*	LC	Lesser Sandplover	Native Vagrant/Straggler
Aves	Pelecaniformes	Ardeidae	*Egretta garzetta*	LC	Little Egret	Native Vagrant/Straggler
Aves	Pelecaniformes	Ardeidae	*Egretta novaehollandiae*	LC	White-faced Heron	Native Not Threatened
Aves	Pelecaniformes	Ardeidae	*Egretta sacra*	LC	Pacific Reef-egret	Native Nationally endangered
Aves	Passeriformes	Acanthizidae	*Gerygone igata*	LC	Grey Gerygone	Endemic Not Threatened
Actinopterygii	Gobiiformes	Eleotridae	*Gobiomorphus gobioides*	LC	Giant Bully	Endemic
Aves	Gruiformes	Rallidae	*Gallirallus philippensis (Hypotaenidia philippensis)*	LC	Buff-banded Rail	Native Declining
Aves	Suliformes	Phalacrocoracidae	*Microcarbo melanoleucos*	LC	Little Pied Cormorant	Native Relict
Aves	Charadriiformes	Scolopacidae	*Numenius phaeopus*	LC	Whimbrel	Migrant
Aves	Suliformes	Phalacrocoracidae	*Phalacrocorax sulcirostris*	LC	Little Black Cormorant	Native Increasing

Aves	Suliformes	Phalacrocoracidae	*Phalacrocorax varius*	LC	Great Pied Cormorant	Native Recovering At Risk
Aves	Pelecaniformes	Threskiornithidae	*Platalea regia*	LC	Royal Spoonbill	Native
Aves	Charadriiformes	Charadriidae	*Pluvialis fulva*	LC	Pacific Golden Plover	Migrant
Aves	Passeriformes	Rhipiduridae	*Rhipidura fuliginosa*	LC	New Zealand Fantail	Endemic Widespread
Aves	Coraciiformes	Alcedinidae	*Todiramphus sanctus*	LC	Sacred Kingfisher	Native Common
Aves	Charadriiformes	Scolopacidae	*Tringa nebularia*	LC	Common Greenshank	Straggler
Aves	Charadriiformes	Scolopacidae	*Xenus cinereus*	LC	Terek Sandpiper	Straggler
Liliopsida	Alismatales	Zosteraceae	*Zostera muelleri*	LC	Species code: Zc	Replaced by mangroves
Aves	Passeriformes	Zosteropidae	*Zosterops lateralis*	LC	Silvereye	

*New Zealand status: Robertson, P Hyvönen, MJ Fraser and CR Pickard (2007).

2.2 List of bird species associated with mangrove and considered at risk within New Zealand

We also identified 11 bird species associated with mangroves that are considered at risk within New Zealand using the threat classification devised by Robertson *et al.* (2017). Only two are also included in the IUCN Red Data List. The white heron or eastern great egret (Kōtuku in Māori) is very rare in New Zealand and is culturally important although very common and with a wide distribution throughout Asia and Australia.

Class	Order	Family	Scientific name	Category	Common name
Aves	Charadriiformes	Laridae	*Sternula nereis*	Nationally critical	New Zealand fairy tern
Aves	Pelecaniformes	Ardeidae	*Ardea alba modesta*	Nationally critical	white heron
Aves	Pelecaniformes	Ardeidae	*Botaurus poiciloptilus*	Nationally endangered	Australasian bittern
Aves	Charadriiformes	Scolopacidae	*Calidris canutus rogersi*	Nationally vulnerable	Lesser knot
Aves	Charadriiformes	Laridae	*Hydroprogne caspia*	Nationally vulnerable	Caspian tern
Aves	Suliformes	Phalacrocoracidae	*Phalacrocorax varius*	At risk	Pied shag*
Aves	Passeriformes	Locustellidae	*Poodytes punctata vealeae*	At risk	North Island fernbird
Aves	Gruiformes	Rallidae	*Gallirallus philippensis assimilis*	At risk	Banded rail*
Aves	Charadriiformes	Haematopodidae	*Haematopus finschi*	At risk	New Zealand pied oystercatcher
Aves	Charadriiformes	Recurvirostridae	*Himantopus himantopus leucocephalus*	At risk	Pied stilt
Aves	Charadriiformes	Scolopacidae	*Limosa lapponica baueri*	At risk	Eastern bar-tailed godwit

*Also in the IUCN Red List

Data: (Bell & Blayney, 2017); Threat classification (Robertson *et al*., 2017).

3. National estimates of mangrove carbon storage

There is no definitive assessment of the total amount of carbon stored in New Zealand mangrove forests. We provide here estimates made by extrapolating recent allometric studies of mangrove total carbon in biomass.

The studies show considerable variation in their findings with above-ground carbon ranging between 4 and 46 t ha^{-1} and total storage of 60 to 117 t ha^{-1} (Table 2). These variations likely reflect a combination of site hydrodynamic conditions, climate and latitude, tree density, nutrients, and stand age. Growth form is also important: a study of Auckland mangroves (Suyadi, *et al*., 2020) found that tall mangroves contain considerably more above-ground carbon (46.3 ± 0.9 t C ha^{-1}) than dwarf mangroves (24.9 ± 0.9 t C ha^{-1}). Different sized areas and rates of increase in area by the two forms observed in Auckland suggest that a more nuanced analysis is necessary other than broad mangrove area with which to calculate total New Zealand mangrove carbon storage (Suyadi, *et al*., 2020). With these caveats, the studies suggest New Zealand mangroves store a national carbon mass of between 2.8 and 3.4 million tonnes.

Biomass carbon (mean)	**Suyadi *et al.* (2020)**	**Tran *et al.* (2017)**	**Bulmer *et al.* (2016)**
Above-ground Carbon (t ha^{-1})	40.2 (Dwarf: 24.9 ± 0.9 Tall: 46.3 ± 0.9)	12-39	13.4 ± 1.6
Below-ground Carbon (t ha^{-1})		48-60	20.9 ± 1.9
Sediment Carbon (t ha^{-1})			81.4 ± 9.4
Total Carbon (t ha^{-1})		60-99	117.1 ± 16.8
Total New Zealand Carbon (Mt)*		2.8	3.4

*Extrapolations assume total mangrove area of 28,700 ha.

4. National estimates for subcriterion A1

To estimate the New Zealand mangrove ecosystem extent in 1970, we gathered reliable information on the mangrove area within the province around this period (Table b). We then estimated the mangrove area in 1970, assuming a linear relationship between mangrove extent and time, to determine the total mangrove area in the New Zealand province (Table a). We assumed that the percentage of mangrove extent within the province remained constant over time, as the percentages did not change between 1996 and 2020 (GMW v3.0 dataset). However, using mangrove area estimates from different sources can lead to uncertainty (Friess and Webb, 2014)[2] and there were no regional statistics or global studies available for this time period. Thus, the estimates for 1970 should be considered only indicative.

Table a. Estimated mangrove area by country in 1970 and 2020. Estimates for 2020* mangrove area are based on the Global Mangrove Watch Version 3 (GMW v3.0) dataset. The references used to calculate mangrove area in 1970 are listed below in Table b.**

Year	Country total 2020*	Within province 2020*	Country total 1970**	Within province 1970**
New Zealand GMW	290.3	290.3	287	287
LCDB v5/NCC	281.7	281.7	230	230
The New Zealand		**290.3**		**290.3**

[2] Friess, D. A. and Webb, E. L. (2014). Variability in mangrove change estimates and implications for the assessment of ecosystem service provision. *Global Ecology and Biogeography*, 23 (7). 715-725 doi:10.1111/geb.12140

Table b. List of selected studies considered to have reliable information on mangrove area for the New Zealand province.

Country	Year	Mangrove Area (Ha)	Reference
New Zealand	1971	28700 Alternative: 19830	Spalding, M.D., Blasco, F. and Field, C.D., eds. (1997). World Mangrove Atlas. The International Society for Mangrove Ecosystems, Okinawa, Japan. 178 pp.
	1980	19830	Nature Conservation Council. (1984). *Strategies for the management of mangrove forests in New Zealand. A discussion document prepared by a task Force of the Nature Conservation Council*. Wellington, Nature Conservation Council.
	1980	19830 - 23000	Hackwell, K.R. (1989). *New Zealand mangroves: State-of-the-art report.* Wellington, Nature Conservation Council.
	2018	28172	Manaaki Whenua Landcare Research. (2019). *LCDB v5.0—Land Cover Database version 5.0, Mainland, New Zealand* [dataset]. https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/
	2018	30048	Bunting *et al*., 2022 et *al*. GMW 3.0 [dataset]
	2020	29608	Bunting *et al*. 2022 *et al*. GMW 3.0 [dataset]

The exact area of mangroves in New Zealand is still unclear, although estimates can be made and the trends over time are in general agreement. The lack of clarity results from the different analyses and interpretation of remote-sensing data. The earliest comprehensive New Zealand inventory was undertaken by the NCC in 1984 using aerial photographs with most (94% of the total mangrove area) taken in a five year-period between 1979 and 1982. Around 3% by area were taken a decade earlier, in 1970 and 1971. These studies identified a total of 19,342.92 ha under mangroves. Subsequent, more detailed mapping of two harbours containing 19% of the total area of mangroves found 20% more mangroves than initially recorded. Applying this increase to the rest of the NCC dataset suggests a total closer to 23,000 ha (Hackwell, 1989). Mangroves had been undergoing a decline from the 1920s until legislative change protected them from 1977. The NCC's 1984 Atlas and revised data therefore suggest a minimum area of between 19,340 and 23,000 ha covered by New Zealand mangroves in historical times. Spalding *et al*. (1997) calculated the area under mangroves by digitizing 1:50,000 (1979-85) and 1:63,360 (1968-85) topographic maps to give an area of 287 km^2. Their source data were aerial photographs undertaken between 1960 and 1982. However, they also provide a lower area of 194 km^2, an area that had been proposed by one of the authors of the NCC (1984) atlas.

Bunting *et al*. (2022) have generated the GMW 3.0 time-series database for the area under mangroves in New Zealand from 1996 to 2020. The New Zealand government science agency Landcare Research has also generated a landcover five-yearly time-series database (LCDB v.5) using the same satellite imagery that includes mangrove cover from 1996 to 2018. The LCDB v.5 values range from 3 to 6 per cent less than those of the GMW 3.0 estimates, with the divergence increasing over time (Figure S1). The LCDB v.5 estimate for 2018 is 28,172 ha and for GMW 3.0 it is 30,048 ha.

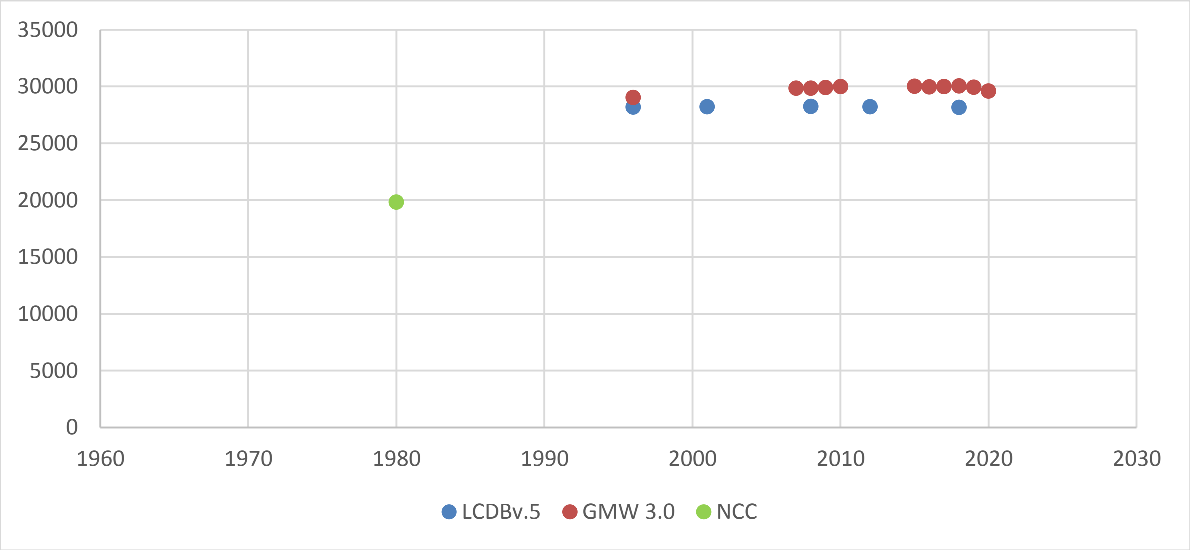

Figure S1. Estimates of the area of mangroves in New Zealand.