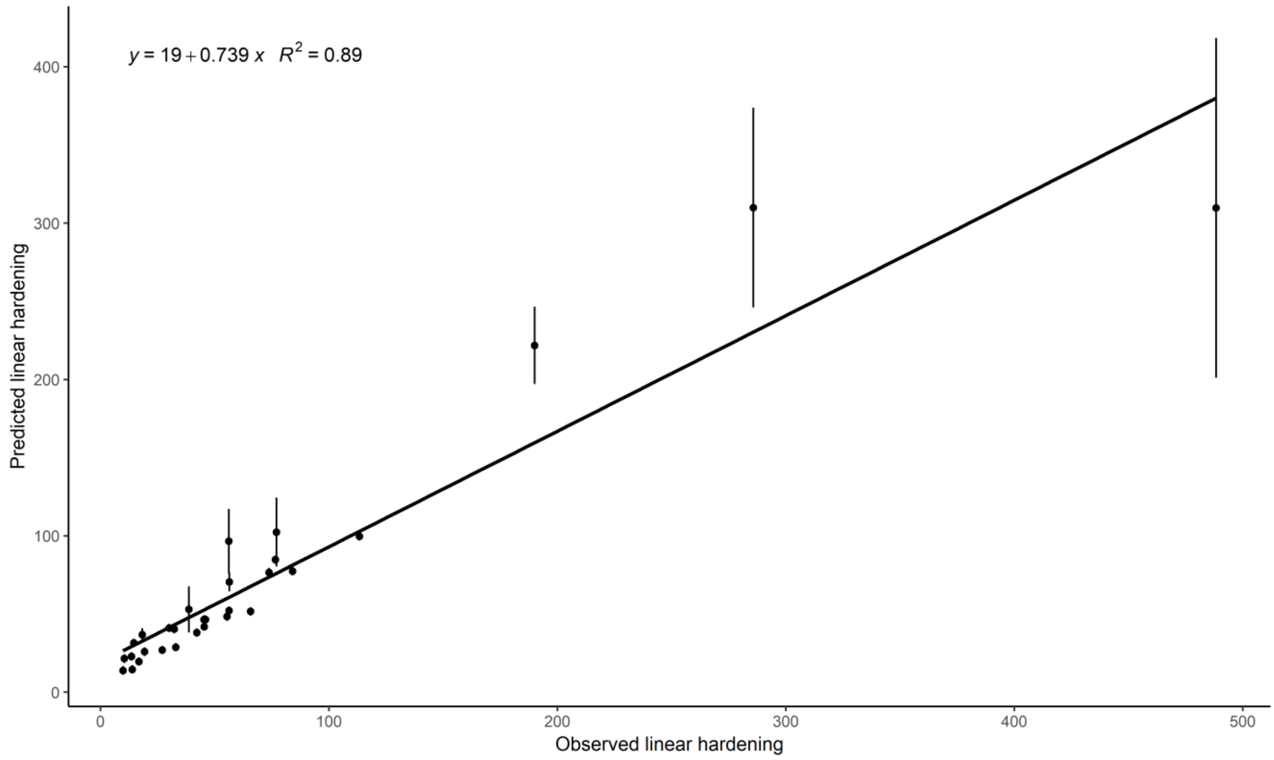
Supplementary Information: NATSUSTAIN-21039140A

Supplementary Box 1: Model diagnostics

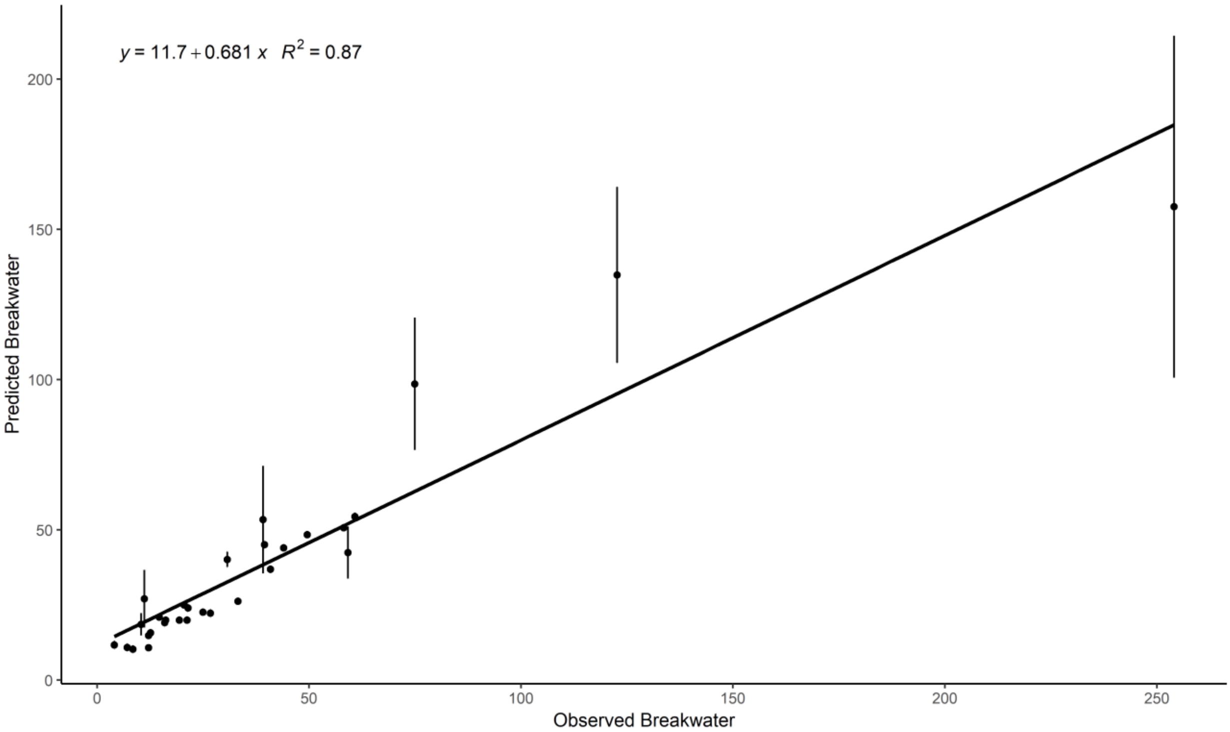
Random forest model statistics for coastal infrastructure extent in 30 global coastal locations. RMSE is the root mean squared error and values in brackets represent the range of the response variable for the model.

	% variation explained	RMSE (data range)	Obsvs. pred.
(a) Total infrastructure	54 %	39 km (478 km)	$R^2 = 0.89$
(b) Breakwalls	35 %	24.4 km (250 km)	$R^2 = 0.87$
(c) Pontoons	50.7 %	8.7 km (66 km)	$R^2 = 0.91$
(d) Wharves	54 %	7.3 km (75 km)	$R^2 = 0.92$
(e) Jetties	29.2 %	12.3 km (137 km)	$R^2 = 0.86$

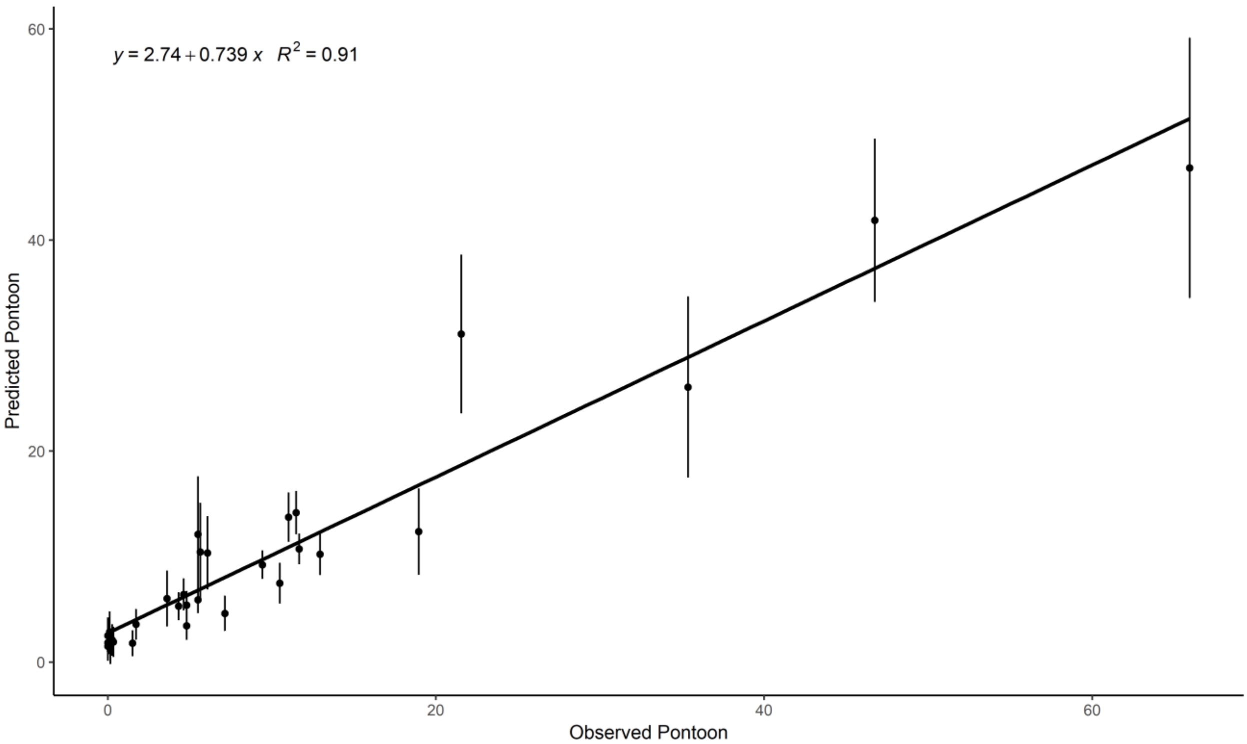
To estimate the prediction variances of the random forest models infinitesimal jack-knife techniques were used This technique works by omitting each observation (Leave-One-Out) and rerunning the estimate with the remaining data. Variances were square root transformed to provide a standard deviation for each data point. The prediction variables were observed to be larger as the observed hardening increased. This is potentially due to the low number of locations with extensive hardening available for the model.



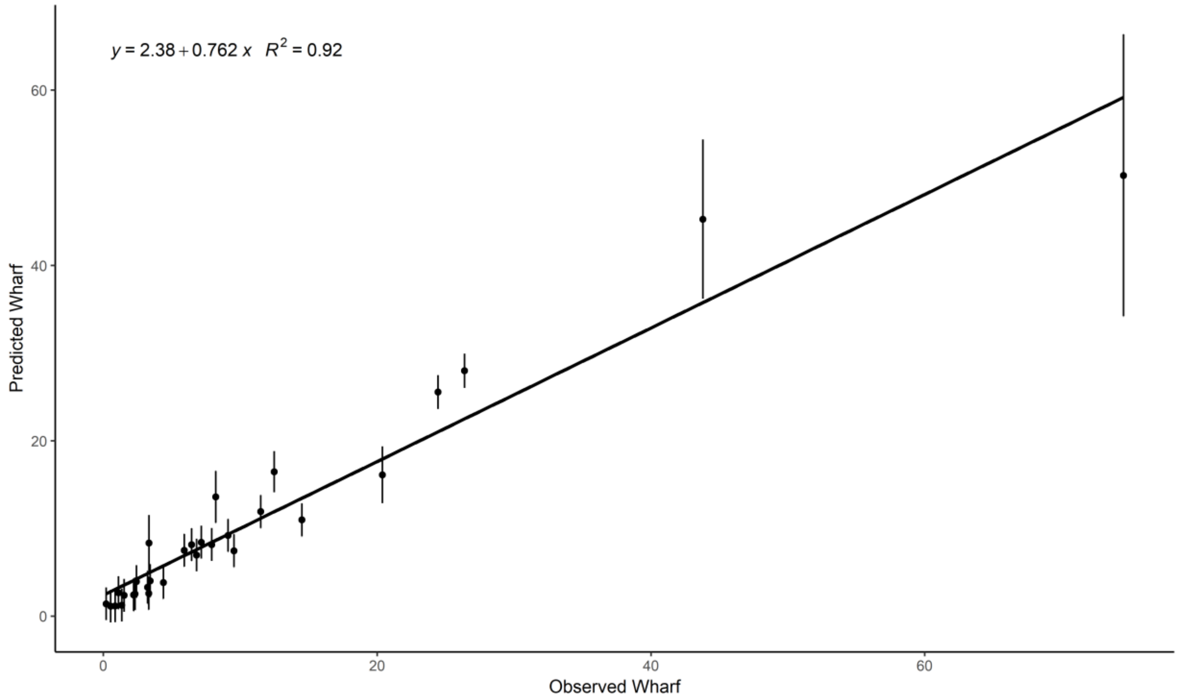
The observed total linear hardening vs predicted values from the Random Forest model. Standard deviations were generated using infinitesimal jackknife resampling methods.



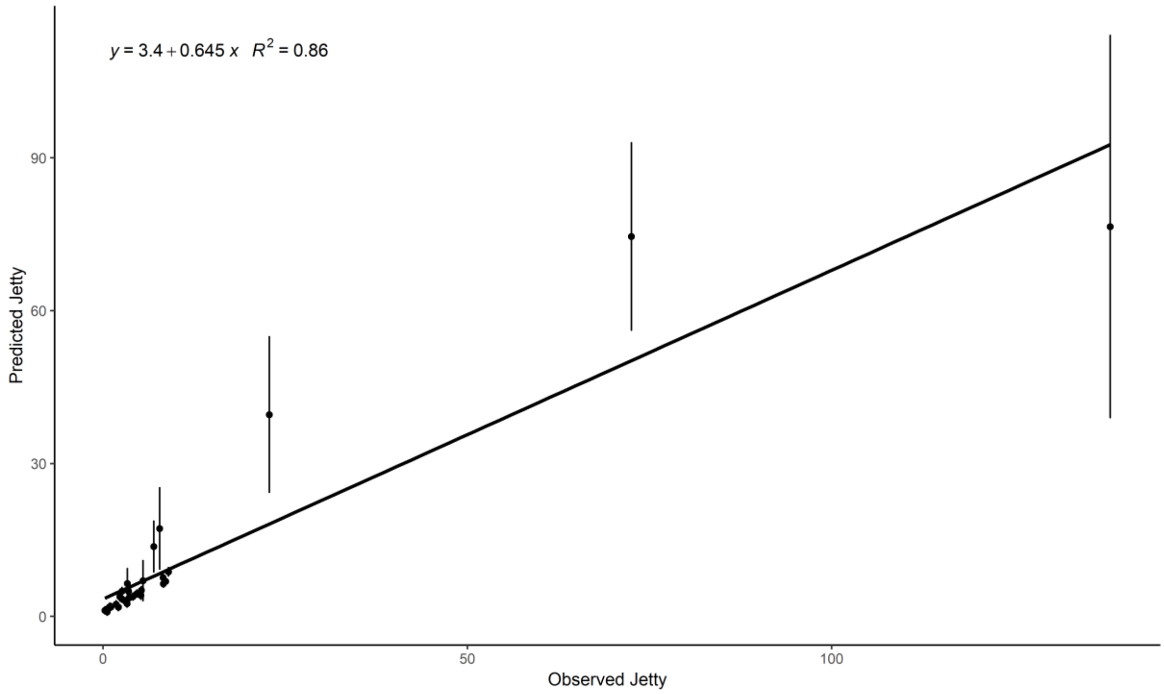
The observed breakwater length vs predicted values from the Random Forest model. Standard deviations were generated using infinitesimal jackknife resampling methods.



The observed pontoon length vs predicted values from the Random Forest model. Standard deviations were generated using infinitesimal jackknife resampling methods.

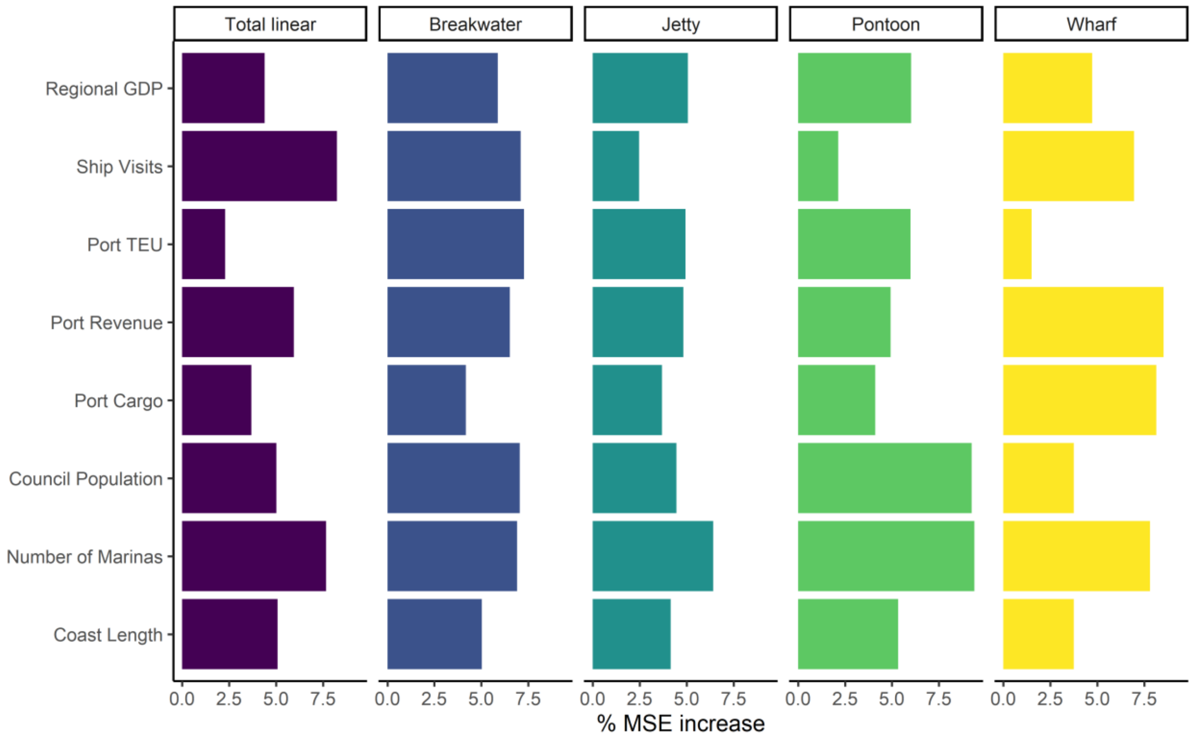


The observed wharf length vs predicted values from the Random Forest model. Standard deviations were generated using infinitesimal jackknife resampling methods.



The observed jetty length vs predicted values from the Random Forest model. Standard deviations were generated using infinitesimal jackknife resampling methods.

The relative importance for each of the variables was different for the hardening types. For example, for the total linear hardening, ship visits, number of marinas and port revenue were the three most important variables.



The relative importance of the variables in the random forest models for each of the hardening types (different colours). The importance is represented by the percent increase of mean square error (MSE) when they are removed. The higher the value the more important the variable was.

Supplementary Box 2: Linear distance and surface area calculations for coastal hardening

Artificial coastal infrastructure was categorised into 4 types: Breakwalls, Pontoons, Jetties, and Wharves.

1. Calculation of Linear Distance of coastal infrastructure (all locations)

Breakwall measurements were made by measuring the linear length of coastline they occupied in each model location. Wharves and Jetties extend away from the coast. Their extent was quantified as a linear measurement of the length of the structure (i.e. not by tracing each side). Marina pontoons are often configurated as main central walkways, with 'fingers' extending out to each side. The linear extent of marina pontoons was quantified by summing the length of the central walkway and the lengths of the fingers along the central walkway.

2. Calculation of Surface Area of coastal infrastructure (New Zealand locations only)

The surface area of artificial structures at each location was measured and calculated using the Linear Distances calculated as described above, depth data obtained from Land Information New Zealand (LINZ) Data Service bathymetric maps and, depending on structure type, specific measurements or assumptions.

Depth of breakwalls, wharves and jetties

When a mapped structure crossed multiple depths on the bathymetry chart, the average depth was calculated (this average was not weighted). The depth datum used was Mean Low Water Spring tides (MLWS).

Surface Area Calculations

Breakwalls:

- Surface Area = Linear Distance (m) * Depth MLWS (m)

Jetties:

Based on the authors' personal observations of coastal jetties around New Zealand and overseas, we assumed an average pile diameter of 0.5 m for all jetty piles, a distance of 7 m between successive rows of piles, and that each row consisted of 3 piles. The submerged surface area of jetties was calculated as:

- No. Piles = Linear Distance (m) / Pile Length Distribution (7) * Piles per Row (3)
- Surface Area = $2\pi r$ (~1.57) * Depth MLWS (m) * No. Piles

Wharves:

Based on the authors' personal observations of ports/commercial wharves around New Zealand and overseas, we assumed that all wharves consisted of wharf decks built upon an array of piles. We assumed an average pile diameter of 1 m, with a distance of 10 m between successive rows of piles, and that each row consisted of 1 pile for every 7 m of width. The submerged surface area of wharves was calculated as:

- No. Piles = Linear Distance (m) / Pile Length Distribution (10) * Width (m) / Pile Width Distribution (7)
- Surface Area = 2πr (~3.14) * Depth MLWS (m) * No. Piles

Pontoons:

Calculations were based on the authors' personal observations of recreational boating and marina facilities around New Zealand, plus additional Google Earth measurements obtained for three marinas. First, we assumed an average width of 1.5 m for all pontoons. In reality, the central walkway of a marina pontoon usually has a width of approx. 2 m, while its 'fingers' have widths of approx. 1 m. 'Intersections' between central walkway and successive fingers occur on average every 13.3 m. We assumed an average pontoon draft of 0.5 m. The submerged surface area of pontoons was calculated as:

- Surface Area = 2 * SUM[Linear Distance (m)] * Pontoon Depth (0.5 m) + SUM[Linear Distance (m)] * Pontoon Width (1.5 m)

Pontoon Piles:

Each 'intersection' of the central pontoon walkway with a perpendicular finger was associated with 3 pilings holding the pontoon in place. Pilings were assumed to have a diameter of 0.5 m.

- Surface Area = 2πr (~1.57) * AVERAGE[Depth MLWS (m)] * SUM[Linear Distance (m)] / Pile Length Distribution (13.3)

The surface area of the overall pontoon structures associated with a mapped location was the sum of the surface area of pontoons plus the surface area of all piles.

Supplementary Information Table 1. A – C: expected increases (transformed to ranks) in the domestic occurrence of marine NIS, derived from the coastal hardening vs. NIS occurrence regression equation for low, medium and high growth scenarios. Table rows are sorted in accordance with ranks in column B (bolded for ease). D: Rank contribution to total predicted domestic increase in coastal hardening. E: Regional marine biosecurity risk scores (transformed to ranks) calculated by Hatami et al. (2021)[1] based on modelled influx of ballast water and hull biofouling via international shipping.

Location[1]	**A:** Expected increase in NIS 2043_LOW[2]	**B:** Expected increase in NIS 2043_MED[2]	**C:** Expected increase in NIS 2043_HI[2]	**D:** Contribution to total NZ increase in CH (2043)[3]	**E:** National biosecurity risk ranking[4]
Tauranga	1	**1**	1	3	1
Auckland	2	**2**	2	2	2
Lyttelton	7	**3**	3	1	3
Napier	3	**4**	4	5	4
Picton	4	**5**	5	11	14
New Plymouth	5	**6**	6	4	5
Bluff	6	**7**	7	8	13
Nelson	8	**8**	8	6	7
Dunedin	9	**9**	9	9	8
Opua	10	**10**	10	7	
Wellington	11	**11**	11	12	6
Whangarei	12	**12**	12	14	9
(Taharoa)					10
(Gisborne)					11
(Timaru)					12
Greymouth				10	
Westport				13	

[1] Locations in parentheses were not included in our coastal hardening model.

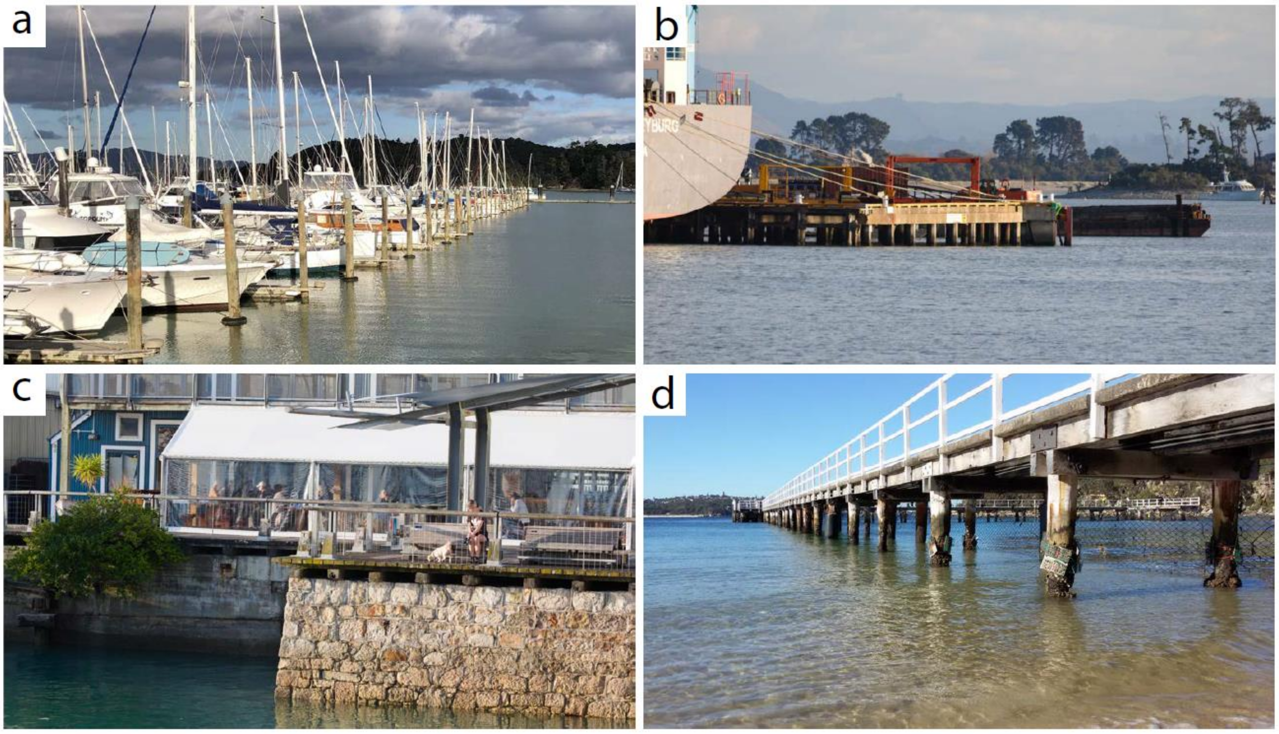
[2] Locations corresponding to empty cells were not included in our coastal hardening model or the risk models by Hatami et al (2021).

[3] Locations corresponding to empty cells were not included in our coastal hardening model.

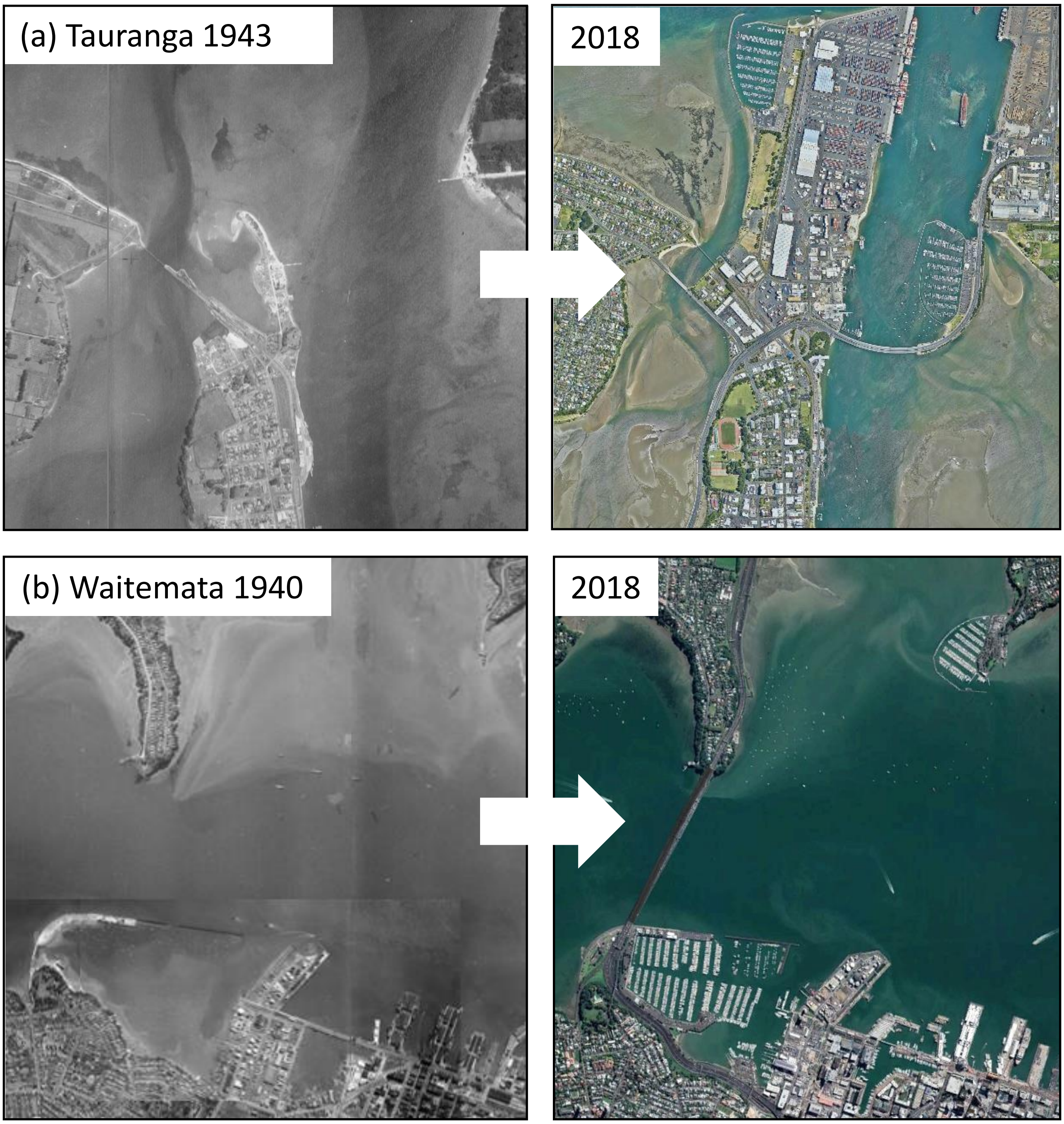
[4] Locations corresponding to empty cells were not included in the risk models by Hatami et al (2021).

Supplementary Information Table 2: Coastline and infrastructure types digitised at 30 international urban centres.

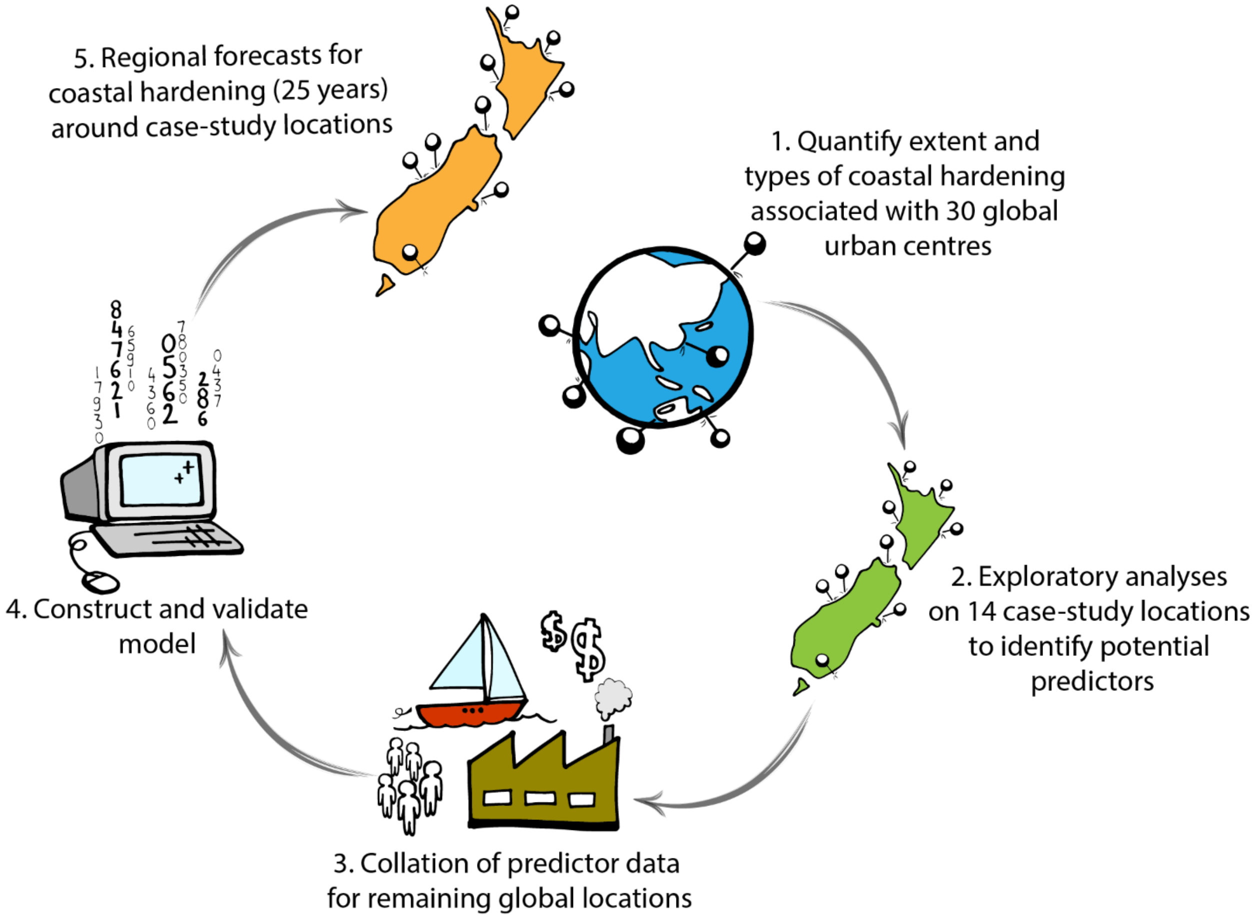
Type	Definition
Natural	Sections of coast that have not been structurally changed. E.g. beaches, rocky reefs, mud flats, mangroves. Unit: length (km).
Breakwall	Engineered sections of coast such as sea walls, breakwaters, groynes and launching ramps. Constructed from rip-rap boulders, concrete or stone. Unit: length (km).
Wharf	Large commercial wharves, quays and piers. Usually constructed from arrays of pilings with occasional sheet metal or concrete facades. Unit: length (km), calculated as perimeter length for large wharves protruding from shore.
Jetty	Small to medium-sized wharves (e.g. privately-owned mooring facilities). Usually constructed from wood or concrete pilings. Bridges, comprising fewer pilings than wharves, were also included in this category. Unit: length (km).
Pontoon	Floating docks / vessel berths. Common in marinas, sometimes attached to coastal jetties. Commonly constructed from polystyrene filled concrete or polyethylene blocks, moored by pilings. Unit: length (km). Pontoons are designed with 50-year service lives and consented as permanent structures.



Supplementary Information Figure 1: Common coastal infrastructure types associated with urban centres around the world and mapped in this study. (a) floating marinas feature extensive pontoon surfaces that offer berthing space to hundreds of recreational and small commercial vessels. (b) commercial shipping wharves are often supported by large piles and concrete backing structures. (c Seawalls are used to stabilize developed coastlines or provide protection for port and marina facilities. (d) Jetties are used for berthing of small commercial and passenger vessels.



Supplementary Information Figure 2: Historical changes in coastal infrastructure, illustrated using New Zealand (1940s – 2018) as an example. The predominantly sandy beach, rocky reef and mangrove shores of many of the country's largest estuaries have been replaced by shipping (wharves, seawalls, reclamation), boating (floating marinas, groynes) and civic (bridges, coastal roads) infrastructure. Examples here are for the coastal harbours associated with the cities of Tauranga (a) and Auckland (Waitemata Harbour, b).



Supplementary Information Figure 3: Stages of development for a model to predict regional rates of coastal hardening.

References for Supplementary Information

1 Hatami, R. *et al.* Improving New Zealand's marine biosecurity surveillance programme. Biosecurity New Zealand Technical Paper No: 2021/01. (Wellington, 2021).