Measuring Coastal Vulnerability in Vancouver Under a Changing Climate

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Introduction

Coastal communities are increasingly exposed to sea-level rise, flooding, and erosion associated with climate change (Hinkel et al., 2014; Vousdoukas et al., 2020). Natural coastal habitats can help reduce these risks: salt marshes and wetlands attenuate waves and retain sediment, while eelgrass and kelp beds reduce nearshore wave energy and bed shear stress (Möller et al., 2014; Morris et al., 2020; Reidenbach & Thomas, 2018; Temmerman et al., 2013). Nature-based solutions are therefore increasingly considered in climate adaptation, although public awareness of coastal hazards and habitat-protection benefits varies among communities (Kim & Petrolia, 2013; Seddon et al., 2020).

Vancouver includes highly urbanized waterfronts, estuarine environments, beaches, tidal flats, forested shorelines, and marine habitats. Understanding the relative exposure of these shoreline types, and the extent to which adjacent habitats contribute to protection, is important for coastal planning and conservation.

This study used the InVEST Coastal Vulnerability model to assess relative exposure along Vancouver's shoreline under current conditions, a habitat-removal scenario, and a high-emissions sea-level-rise scenario. A community workshop was also used to compare public perceptions of coastal vulnerability with model outputs.

The objectives of the study were to:

1. Assess relative coastal vulnerability along the Vancouver shoreline.
2. Quantify the contribution of coastal habitats under current and future conditions.
3. Compare community perceptions of coastal vulnerability with model results.

Methodology

Study Area

The assessment covered Vancouver's marine shoreline from the Fraser River estuary in the south to Burrard Inlet in the north. The study area includes highly developed waterfronts, harbour infrastructure, beaches, tidal flats, estuarine habitats, and forested shorelines.

Habitat Mapping and Classification

Coastal habitat polygons were compiled from the Metro Vancouver Sensitive Ecosystem Inventory (SEI) mapping tool and associated 2020 update (Caslys Consulting Ltd., 2022; Metro Vancouver, n.d.). Mapped ecosystems were reclassified into model-relevant habitat groups, including wetlands, freshwater, tidal flats, mature and old forest, young forest/shrubland, grassland/herbaceous cover, open field/sparsely vegetated land, and bare/sparse land. Where SEI polygons contained multiple ecosystem components or broad riparian labels, SEI descriptions, satellite imagery, and available ground-truthing information were used to assign the dominant habitat type.

Table 1. Summary of SEI ecosystem reclassification for the model.

Original SEI Ecosystem Categories	***Ecosystem Categories after Re-classification***
Alpine	Alpine - Isolated Alpine - Moderately Connected Alpine - Well Connected

Estuarine	Bare / Sparse
Herbaceous	Grassland / Herbaceous - Isolated Grassland / Herbaceous - Moderately Connected Grassland / Herbaceous - Well Connected
Intertidal	Tidal Flat - Isolated Tidal Flat - Moderately Connected Tidal Flat - Well Connected
Mature Forest (SE)	Mature Forest - Isolated Mature Forest - Moderately Connected Mature Forest - Well Connected
Mature Forest (ME)	Merged with above category
Old Forest	Old Forest - Isolated Old Forest - Moderately Connected Old Forest - Well Connected
Riparian	Reclassified into separate categories based on SEI description
River Riparian	Reclassified into separate categories based on SEI description
Sparsely Vegetated	Open Field/Sparsely Vegetated
Woodland	Reclassified into different categories
Wetland	Wetland - Isolated Wetland - Moderately Connected Wetland - Well Connected
Freshwater	Freshwater - Isolated Freshwater - Moderately Connected Freshwater - Well Connected
Young Forest	Young Forest/Shrubland - Isolated Young Forest/Shrubland - Moderately Connected Young Forest/Shrubland - Well Connected
Old Field	Reclassified into different categories
Freshwater Reservoirs	Reclassified into different categories

Each polygon was also assigned a relative structural-connectivity class: isolated, moderately connected, or well connected. Connectivity was interpreted from patch area, the shortest edge-to-edge distance to nearby habitat of the same type, and the longest shared boundary with an adjacent habitat polygon. Larger patches, shorter separation distances, and longer shared boundaries were interpreted as indicators of stronger connectivity, consistent with standard landscape-metric approaches (McGarigal & Marks, 1995). The resulting composite classes, such as “Wetland - Well Connected” and “Young Forest/Shrubland - Isolated,” distinguish habitat composition from its broader landscape context. This was a structural-connectivity screen and did not estimate species-specific functional connectivity.

Habitat ranks and protection distances were assigned in the InVEST habitat table using the model guidance and literature on habitat-mediated wave attenuation and sediment stabilization (Arkema et al., 2013; Natural Capital Project, n.d.). Ranks range from 1 (very high protection) to 5 (no protection), and the protection distance defines the extent within which a habitat contributes to a shoreline point's habitat-protection score.

Scenario Development

Three scenarios were compared: (1) current conditions, using existing shoreline characteristics and habitat distribution; (2) habitat removal, in which habitat protection was removed to estimate the contribution of natural habitats; and (3) sea-level rise, using an SSP5-8.5 high-emissions pathway to examine changes in relative exposure under future conditions (IPCC, 2021).

Coastal Vulnerability Modelling

The Coastal Vulnerability model in the InVEST software suite was used to calculate relative exposure at shoreline points placed at 100 m intervals (Natural Capital Project, 2025.). Inputs included shoreline geomorphology, relief, natural habitat protection, sea-level change, wind exposure, wave exposure, and surge potential. Geomorphology data was retrieved from the Benthic Marine Ecounits dataset from the Coastal Resource Information Management System (CRIMS), which describes nearshore and seabed conditions using variables including depth, slope, relief, exposure, currents, and substrate (Government of British Columbia, 2024). Bathymetry was obtained from Canadian Hydrographic Service NONNA data (Fisheries and Oceans Canada, 2026). Wind and wave conditions were derived from NOAA WAVEWATCH III data (National Oceanic and Atmospheric Administration, National Centers for Environmental Prediction [NOAA NCEP], 2012). Elevation data were obtained from the provincial Terrain Resource Information Management dataset and the Canadian Digital Elevation Data dataset (Natural Resources Canada, n.d.; Province of British Columbia, 2026).

Each variable was expressed as a relative rank from 1 (very low exposure) to 5 (very high exposure). The final Exposure Index (EI) was calculated as the geometric mean of the included variable ranks:

$$EI = (\Pi\ Ri)^{\wedge}(1/n)$$

where Ri is the rank for each variable and n is the number of variables. The model reports relative exposure within the study area; it does not predict absolute flood depth, erosion rate, or shoreline position. Habitat role was calculated as EI without habitats minus baseline EI. Higher values indicate locations where mapped habitats made a larger relative contribution to reducing exposure.

Community Engagement

A community workshop held in January 2026 examined public perceptions of coastal vulnerability. The session was designed as an interactive mapping event, where participants were asked to identify areas they perceived as most and least vulnerable along the Vancouver shoreline.

Participants marked locations they considered vulnerable on printed maps and discussed perceived drivers, habitat functions, and adaptation priorities. Responses were summarized qualitatively and compared with model results to identify areas of agreement and divergence.

Results

Coastal Vulnerability Under Current Conditions

The model identified substantial spatial variation in relative exposure across Vancouver's shoreline. Shorelines with extensive wetlands, tidal habitats, forests, eelgrass, or kelp generally had lower EI scores, particularly along parts of the Fraser River estuary, Stanley Park, and the North Shore. Higher EI scores occurred where habitat cover was limited or shorelines were more exposed to waves. Engineered infrastructure reduced exposure in some urban settings, but those locations generally had limited habitat-based protection. Geomorphology plaus an important role in defining shoreline vulnerability. Comparison of the baseline scenario and when geomorphology was taken out of the equation indicated that geomorphology substantially influenced modeled coastal exposure. Without geomorphology, much of Vancouver's shoreline would have been classified as relatively more exposed, particularly along developed waterfronts and low-relief shoreline segments. The baseline results showed that engineered features, such as seawalls and other shoreline-protection structures, reduced relative exposure at some urban locations. This does not mean these shorelines are free from coastal risk; rather, it indicates that their existing physical form and engineered protection lower modeled exposure relative to unprotected or unconsolidated shoreline types. The comparison highlights that Vancouver's coastal vulnerability is shaped by both natural habitat protection and shoreline geomorphology, including the moderating influence of human-made structures.

Contribution of Coastal Habitats to Shoreline Protection

The habitat-removal scenario increased EI across much of the study area, showing that natural habitats contributed to lower relative exposure. The largest increases occurred along habitat-rich shorelines, notably in the Fraser River estuary and in areas with wetland and coastal forest cover (Figure 1). These results identify locations where habitat conservation or restoration may provide the greatest contribution to coastal resilience. Under baseline conditions, the average EI across Vancouver's shoreline was 2.42 with mapped coastal habitats included. In the habitat-removal scenario, the average EI increased to 2.88. The difference of 0.46 represents the average Habitat Role.

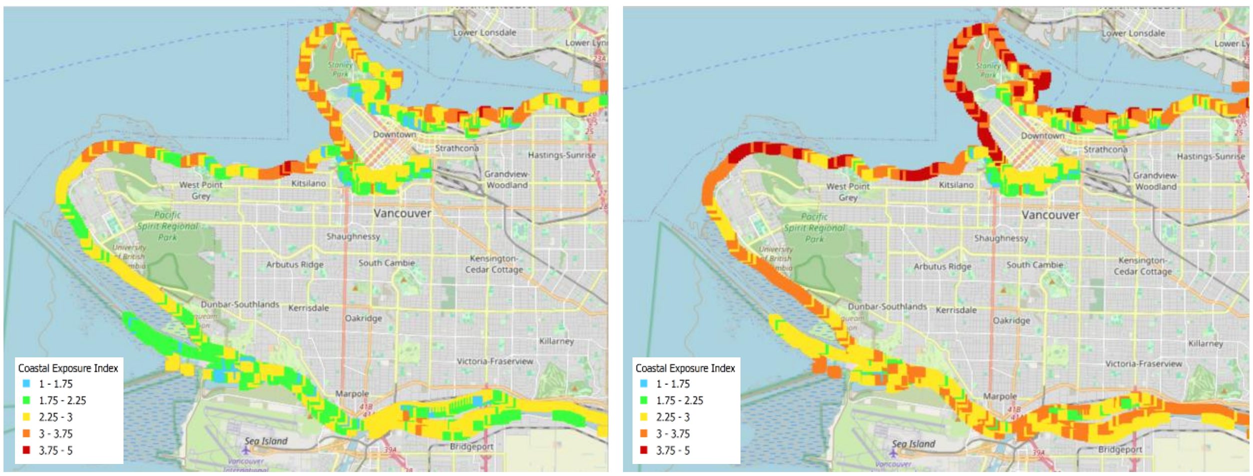

Figure 1. Baseline relative exposure (left) and exposure under the habitat-removal scenario (right).

Sea-Level Rise Scenario

Under the sea-level-rise scenario, more than 60 km of shoreline increased in vulnerability class relative to current conditions. The greatest increases were concentrated in the southern study area, including the Fraser River delta. Habitats continued to reduce relative exposure, but their average protective value declined from 0.532 under current conditions to 0.481 under the sea-level-rise scenario, a reduction of approximately 13%.

Approximately 43 km of shoreline, mainly in Burrard Inlet and along parts of the North Shore, showed a lower relative vulnerability class in the future scenario (Figure 2). This result does not indicate less sea-level rise at those locations. Rather, it reflects relative changes in modeled exposure caused by local geomorphology and the combined influence of all input variables.

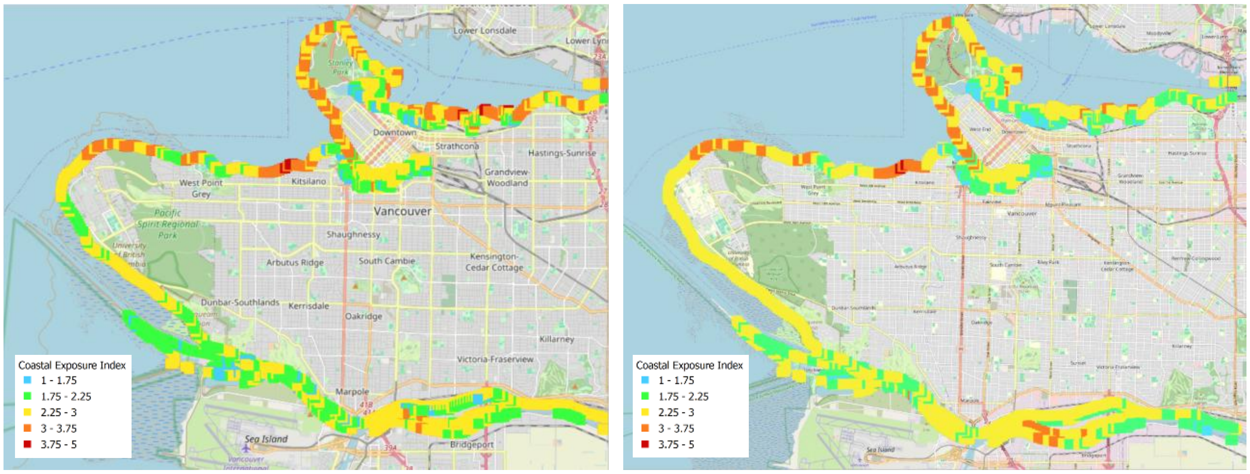

Figure 2. Baseline relative exposure (left) and relative exposure under the sea-level-rise scenario (right).

Discussion

Vancouver's shoreline resilience can be strengthened by maintaining connected mosaics of wetlands, salt marshes, and shore-fringing forest. Wetlands and salt marshes attenuate waves, slow water movement, and promote sediment retention, helping to limit erosion and flooding during high-water events (Möller et al., 2014; Temmerman et al., 2013). Where mature forest is directly connected to the shore and sufficiently wide, it can provide a landward buffer and help stabilize soils; however, its protective contribution is site-specific and should not be considered equivalent to that of intertidal marsh vegetation (Arkema et al., 2013).

The results provide a spatial basis for prioritizing conservation, restoration, and adaptation investments according to relative exposure and habitat contribution. They should be interpreted as a planning-scale screening assessment, with site-specific design or regulatory decisions supported by local bathymetric, hydrodynamic, engineering, and ecological studies.

Community Perceptions of Coastal Vulnerability

Participants commonly associated vulnerability with visible waterfront infrastructure, developed shorelines, and places with previous flooding or erosion. Their responses generally aligned with modeled exposure in low-lying coastal areas and the Fraser River estuary. However, the protective role of coastal habitats was less consistently recognized. Participants often emphasized elevation or development intensity while giving less attention to the combined influence of habitat, wave exposure, and geomorphology. This supports the use of map-based engagement to communicate how natural and engineered features jointly influence coastal exposure.

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