BRITISH COLUMBIA
COASTAL HABITAT REVIEW

Protecting Sensitive Coastal Ecosystems

Maryann Watson

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EXECUTIVE SUMMARY

This report reviews the trends, changes, and projections which have been studied in British Columbia's coastal habitats and species, with a focus on those under provincial jurisdiction. This review provides insight into the geographic areas or ecosystem features on the coast that are most at risk, the stressors putting them at risk, the activities which are directly impacting coastal ecosystems, and a discussion of the extent and gaps in protection of these features under provincial legislation.

Information gaps and baselines

While many scientific studies have tried to assess and quantify changes in key coastal ecosystems and species, British Columbia (BC) is largely lacking in long-term scientific data and monitoring that allow for these changes to be assessed against baselines. Studies that do track trends in coastal habitats, species, or indicators over time have limited spatial scale, often focusing on a small section of the coast. While this does give some insight into the response of coastal features over time, understanding trends across spatial and temporal scales, and levels of impact (human activity), will give a better understanding of the status and trends for vulnerable ecological features.

The monitoring programs that are being initiated as part of the Marine Planning Partnership (MaPP) process and the Marine Protected Area Network for BC's Northern Shelf Bioregion do hold promise for developing coordinated longer-term and broader scale information gathering in northern and central coast regions. However, this leaves gaps on large parts of the most heavily populated areas of the coast, particularly the Southern Strait of Georgia bioregion, where somewhat scattered, individual areas have received attention from different groups for data gathering or mapping. There is a need for coastwide coordination to identify the most significant issues and data gaps.

Vulnerable habitats on the coast

A variety of human activities on the coast are placing stress on habitats and their associated species. Stressors interact with coastal habitats in different ways and therefore have direct and indirect impacts to the species they support. Methods to quantify and map cumulative impacts from multiple human activities, including marine, coastal, and land-based activities, are developing and can provide measures of relative impact.

Cumulative impact studies show the highest impacted areas are within the Strait of Georgia on BC's south coast, and increasingly on the northern coast around Prince Rupert and the Skeena estuary with growing levels of human activity. Coastal land-based activities have some of the highest levels of impact on local scales, resulting in mudflats, salt marshes, beaches, and rocky intertidal areas being some of the most impacted habitats.

The numbers of species at risk within the Salish Sea is rising, and the province currently has no legislation for endangered and at-risk species, despite commitments to develop legislation in 2018.

Climate change

Of all the threats facing BC's coastline, climate change will have the most significant and pervasive impact over the next decades. Vulnerabilities of important coastal habitats to climate change have been highlighted both by studies focusing on individual features and species, and by coastwide analyses.

Kelp forests are showing changes in areas with rapid sea temperature changes. Sea level rise may outpace the ability of estuaries and their associated habitats, such as salt marshes and seagrass meadows to keep up, and ocean acidification threatens the very base of the coastal foodweb.

The areas with higher cumulative impacts from local human activity stressors may also be those most vulnerable to climate change impacts due to lowered resiliency, highlighting the importance and usefulness of proactive planning and protection measures for sensitive and key habitat areas. Additionally, the contributions of some key habitats and species to climate mitigation strategies, such as blue carbon, should be an important focus of coastal management.

Maintaining resilient coastlines

Multiple reviews of the impacts of climate change to BC's coastal marine ecosystems highlighted that strategic protection of important species and habitats to maintain biodiversity and ecosystem services is key to supporting climate adaptation for coastal ecosystems. Resiliency is supported through coordinated and systematic management planning and protection measures across vulnerable habitats. Systems or networks of protected areas that replicate representative features and species also serve to support resiliency and adaptation to environmental changes.

The implementation of marine planning and a marine protected area network on BC's northern shelf bioregion will contribute to conservation of key and vulnerable habitats on the less populated and less impacted regions of the coast, and can serve to drive coordinated monitoring over larger spatial and temporal scales than has been achieved before. However, this leaves a gap for the more vulnerable areas of the southern coast.

A coast-wide strategy is needed to encompass the ongoing processes, fill gaps in planning and management needs, and serve to connect and coordinate people along the coast in order to build our knowledge of BC's key habitats and species, their human and non-human stressors, and how they are responding and adapting to change.

CONTENTS

INTRODUCTION

> On the northwest coast, there is no graceful interval between the ocean and the trees; the forest simply takes over where the tide wrack ends, erupting full-blown from the shallow, bouldered earth.
>
> The boundary between the two is unstable and the sea will heave stones, logs, and even itself into the woods at every opportunity.
>
> \- John Vaillant, The Golden Spruce

British Columbia's (BC) coastline spans over 25 thousand kilometres and 7 degrees of latitude from the southern tip of Vancouver Island to the Alaska border, encompassing a complex array of ecosystems. British Columbia has the highest level of biological diversity in Canada, and this diversity extends into the waters along the coast.

As described in the quote above, on BC's coast the land and sea are intimately connected, creating a highly productive coastal environment. A growing number of studies have elucidated the interplay between coastal ecosystems at the marine-terrestrial boundary, including the ways in which marine species (including Pacific salmon, Pacific herring, shellfish, and seaweeds) contribute to the adjacent land and enhance the ecosystems productivity (spatial subsidies).

In exchange, ecosystems on the landward side of the coast also contribute to and support marine species, including by providing riverine spawning grounds, sediment supply to coastal sand ecosystems and tidal marshes, and woody debris structure to estuarine and intertidal habitat.

Similarly, land-based activities and coastal industry also have cascading impacts through the coastal environment, disrupting some of these connections and resulting in degradation of key habitats or species. Most human activities that impact marine habitats are based in coastal regions, on the continental shelf, or within watersheds near the ocean [1].

The goal of this report is to provide a review of the current scientific literature on BC's coastal habitats and species, and the stressors on these ecosystems in order to provide some answers to the following questions:

1) What trends, changes, and projections have been observed or studied for coastal ecosystems in BC, specifically those under provincial jurisdiction?

2) What geographic areas of BC or ecosystem features are most at risk and what stressors (or "pressures") are putting them at risk? What activities are directly impacting coastal ecosystems?

3) Which of these geographic areas or ecosystem features have protection designation under provincial legislation, which are lacking protection?

4) What gaps in protection remain for geographic areas or ecosystem features that are covered by a protection designation?

Wya Point, Ucluelet.
Photo: Mark Smith, Flickr Creative Commons

METHODS

In order to determine what trends, changes, and projections have been studied or observed for coastal ecosystems in BC, a suite of features to assess was chosen (coastal habitats, species, and status indicators), as has been done by other projects providing assessments of ecosystem status on the BC coast (e.g. Ocean Watch [2], British Columbia Marine Conservation Analysis (BC MCA) [3], and Ecological Conservation Priorities for the Northern Shelf Bioregion Marine Protected Area network planning [4], Okey et al. 2018 [5], and the Health of the Salish Sea Ecosystem Report [6]). Here, a subset of these was chosen to represent the range of coastal habitats, with a focus on coastal features and species under provincial jurisdiction.

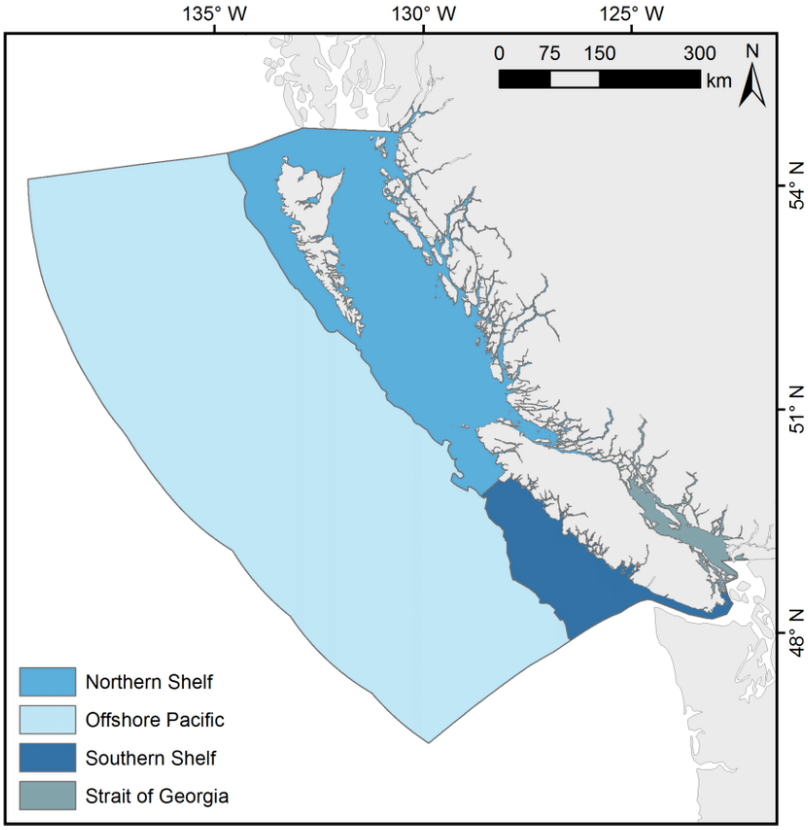
For each feature a search was conducted on Google Scholar and Web of Science databases for literature and reports published in the last 20 years (2000 – 2020), with a primary focus on studies conducted in British Columbia, as well as using other examples along the Northwest Pacific coast. Literature was also identified through key citations from the reviewed studies. Some literature from before 2000 has been included where it was informative and where more recent studies were not available.

For the available literature which met search criteria, abstracts were reviewed to determine whether the study assessed feature status, change in status, management or conservation recommendations. The studies chosen for further review were compiled in a database. Figures from some of the reviewed studies have been chosen to illustrate the distribution or nature of changes to coastal habitats and species, or key findings of important studies.

FEATURES

- Estuaries
- Seagrass
- Saltmarsh
- Coastal Sand Ecosystems
- Kelp
- Sea stars
- Shellfish
- Forage fish & Juvenile salmon
- Species at Risk
- Logging
- Invasive Species
- Acoustic Habitat
- Shoreline armouring
- Climate Change

To address the questions on vulnerabilities, and the degree of protection and gaps in protection for coastal habitats, provincial protection measures, and literature on these measures, were reviewed. The database of marine protected areas on the BC coast compiled by Robb et al. (2011; Supplementary Material) was used to review Provincial Parks, Ecological Reserves, Conservancies, and Wildlife Management Areas. Where available, Management Plans, Purpose Statements or Management Direction Statements were reviewed, or if these were not available the protected areas webpage was reviewed, for mention or inclusion of the features, habitats and species included in this report.



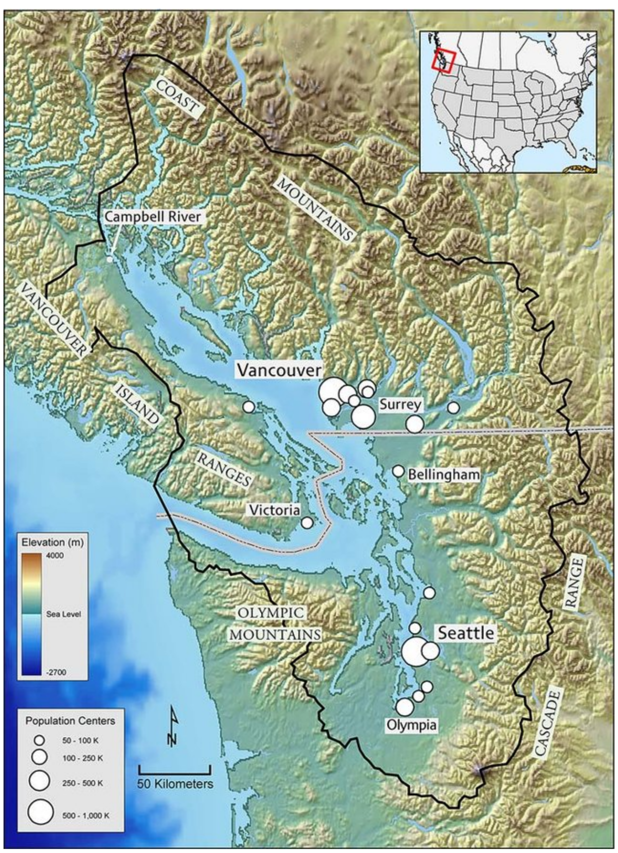


Figure 1. Maps of some of the Pacific marine regions referred to in this report.
TOP: Bioregions of the Pacific Region of Canada [7]. BOTTOM: Map outlining the boundaries of the Salish Sea which includes the international waters of the Juan de Fuca Strait, the Puget Sound Basin (United States) to the south, and the Strait of Georgia and the Georgia Basin (Canada) to the north [8].

ESTUARIES

- Estuaries are critical to the majority of coastal wildlife for at least some of their life cycle.
- The abundant estuaries on the coast are also often the focal points for development and economic activity which can degrade these habitat mosaics.

Some of the most prominent features of BC's coastline are the abundant rivers that flow into the ocean all along the coast. Where these rivers empty into the sea, they create estuaries; dynamic coastal habitats where fresh and saltwater mix. These estuaries are among the most productive ecosystems in the world with higher food availability than the surrounding marine and freshwater ecosystems.

There are over 442 estuaries along BC's coast occupying a total area of 745km^2. The four largest estuaries (the Fraser, Skeena, Nass, and Nicomekl/Serpentine) make up nearly two-thirds of this area (63%); and over a third (39%) of all estuarine area is found in the Vancouver Lower Mainland area.

An estimated 80% of all coastal wildlife use estuaries for all or some of their lifecycles, including over 50 species at risk [9]. Estuaries in BC are particularly important for many species of fish, including juvenile salmon, which use the transitional habitat in a key life-stage as they move from river environments into the ocean.

Estuaries are also among the most altered habitats in the world [10], facing threats from both landward and marine sides. In 2007 Ryder et al., under the Pacific Estuary Conservation Program (PECP; a coalition of government and non-government agencies with the goals of conserving important estuaries on BC's coast), identified, mapped and ranked 442 estuaries on the coast [11]. The estuaries were ranked according to their relative biological importance to waterbirds, and based on attributes such as estuary size, habitat rarity, herring spawn abundance, intertidal species rarity, and waterbird usage. At the time of the report, Ryder et al. (2007) found that 200 of the 422 estuaries assessed had been degraded through human impact of some kind (Figure 2), and noted that approximately 43% of BC's estuaries were threatened by coastal development, modification, and pollution.[1]

[1] The Nature Trust of British Columbia recently secured funding to implement a five-year project to improve estuary habitat, and examine sea level rise building on tools developed by the U.S. National Estuarine Research Reserve System. More at: https://www.naturetrust.bc.ca/our-projects/enhancing-bc-estuaries

Additionally, over a third (38%) of BC estuaries have economic tenures within their intertidal areas [12]. The largest estuary in BC, the Fraser River, is also one of the most productive salmon rivers on the coast, but has suffered significant habitat loss and degradation with uncertain implications for salmon [13]. Robb (2014) assessed the distribution of human activities threatening 376 estuaries in BC. Of the 16 threats evaluated, BC estuaries were impacted by 7.9 threats on average, with two estuaries within the Strait of Georgia region impacted by 15 of the 16 threats [14]. This analysis also found that the estuaries that were the most highly threatened also had the lowest average area within protected areas, and many were close to major urban centres [14]. The Pacific Salmon Explorer (a project of the Pacific Salmon Foundation), gathered baseline monitoring indicators for the Skeena Estuary, and identified that many proposed development projects for the estuary are concentrated in areas facing a high risk of degradation from cumulative pressures [15].

Estuaries are composed of a mosaic of coastal habitats including seagrass meadows, tidal saltmarshes, and mudflats. The pressures facing each of these unique habitats are discussed further in the next sections.

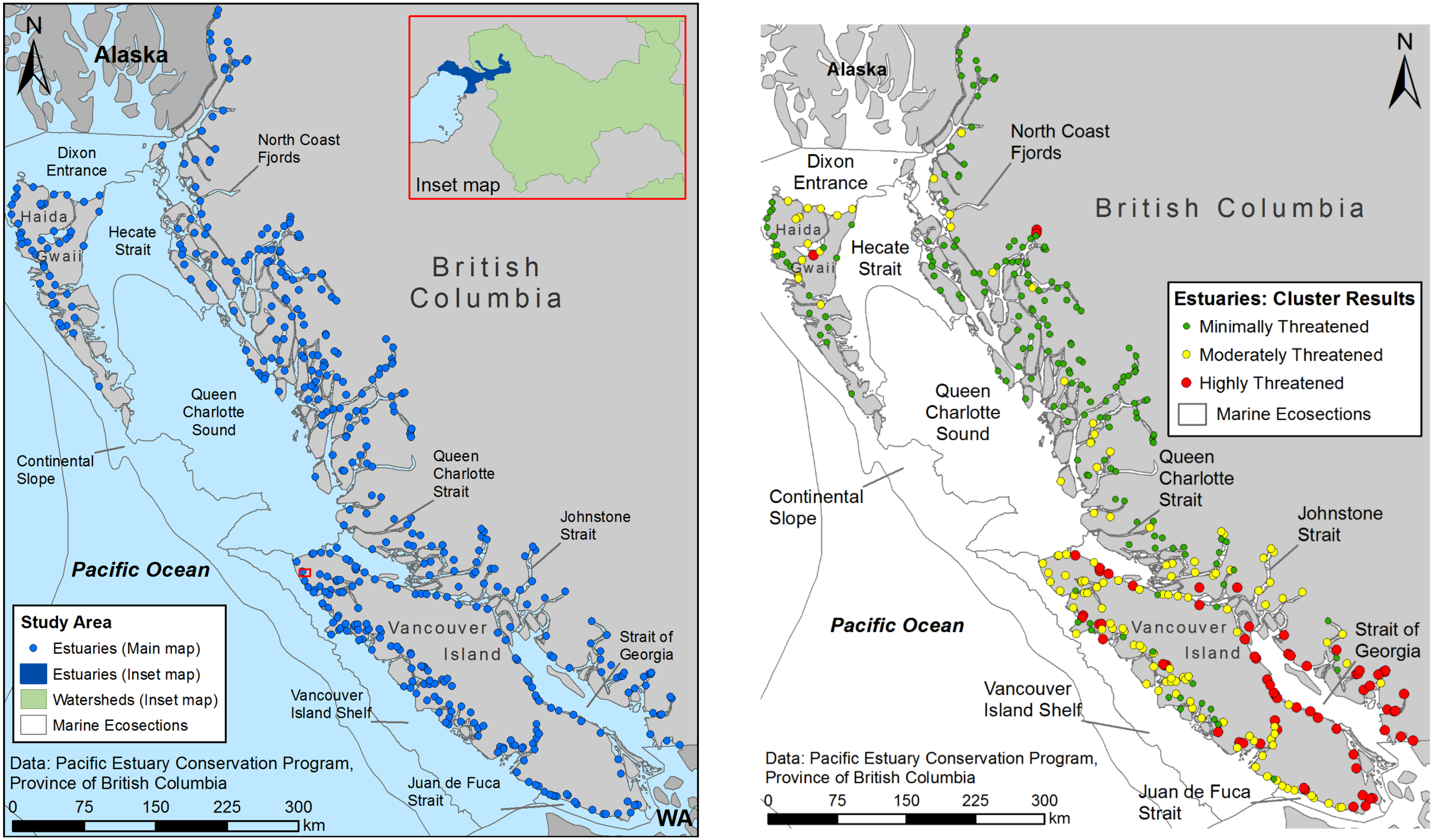


Figure 2. LEFT: Estuaries on the BC coast, inset map shows a typical estuary and watershed.
RIGHT: Estuary-watershed systems are shown classified based on the number of the 16 possible threats found within their bounds, From Robb (2014)[12].

SEAGRASS

- Seagrass meadows are key habitats for many coastal species, particularly for juvenile stages, however their extent and distribution has not been well surveyed in BC.
- These habitats are sensitive to human activity and damage, and local scale studies have documented dramatic losses which are reflective of global averages in seagrass declines.

Seagrasses, a marine vascular plant, occur across the globe in meadows within shallow tidal and subtidal environments, occupying only about 0.2% of the global ocean area. Seagrasses are among the most productive aquatic plants, and are efficient carbon sinks [16]. In BC, a seagrass species called eelgrass (*Zostera marina*) provides important coastal habitat and ecosystem services. Eelgrass meadows and saltmarsh occupy a combined 400km^2 of BC's coastal environment [17].

Eelgrass meadows are valuable habitat for many juvenile fishes including Pacific salmon, are important spawning areas for Pacific Herring [13,18], and are a key food source for many bird species. For example, migratory Brant geese moving along the Pacific flyway feed preferentially on intertidal or shallow eelgrass in their stopover sites including Boundary Bay and Parksville - Qualicum Beach in the Strait of Georgia [19].

Seagrass plants are highly sensitive to environmental changes, making them important indicators of marine ecosystems and coastal change. Due to their growth in proximity to shorelines, interaction with human uses is high. Worldwide, seagrass ecosystems are experiencing declines [20]. Human impacts in the coastal zone are recognized as the primary cause of seagrass loss, these impacts include nutrient loading or reductions in water clarity from residential and urban run-off and sewage, direct physical damage (e.g. from boating, anchoring), shoreline armouring altering nearshore hydrology and sediment dynamics, and activities related to coastal forest harvest (e.g. shading from log booms or smothering from woody debris) [21].

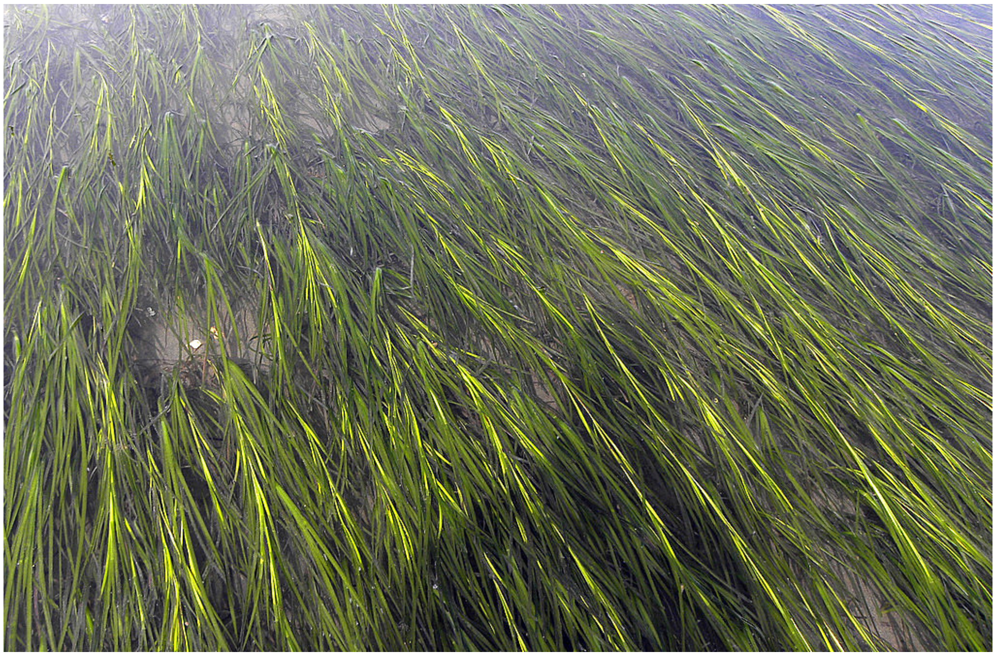
While several studies have focused on how coastal marine life uses eelgrass, meadows on the BC coast have not been well surveyed in order to observe long-term or coast wide trends. In fact, just over half of the estimated extent of North America's seagrass meadows have been mapped [22]. Only a couple studies in BC, and a few in the Salish Sea of Washington State have evaluated changes in eelgrass meadows over time. Several local-scale eelgrass mapping initiatives are ongoing, (e.g. Islands Trust Conservancy [23–25], Friends of Semiahmoo Bay [26,27], Mayne Island Conservancy [28], SeaChange Marine Conservation Society and Tsleil-Waututh Nation [29]). Coordination of these monitoring programs, and resources to ensure their continuation will help to reveal change over time and across monitoring locations.

The Howe Sound Ocean Watch Report (2017) rated the eelgrass meadows within Howe Sound as being in a 'Critical' state due to high local levels of threat from human activity such as docks, boat moorings, log booms and coastal erosion [30]. Recently, Nahirnick et al. (2020) tracked an average decline of 45% in the size of three eelgrass beds in the Salish Sea between 1932 and 2016 using aerial imagery. This decline is similar to global averages and projections of loss. The authors of this study note that the meadows assessed in their study are representative of areas of moderate human influence, so there is further need to expand studies to areas of both low and higher coastal development [21].

A coast-wide study of fish diversity in eelgrass found that meadows experiencing higher human impacts had more similar fish communities than those with lower levels of human influence, indicating that eelgrass communities react similarly to human disturbances across a broad spatial scale [31].

Multiple studies have investigated potential impacts from invasive species on eelgrass. Negative interactions between eelgrass and the non-native Pacific Oyster (*Crassostrea gigas*) have been documented [32,33]. Recent range expansion of the invasive European Green Crab (*Carcinus maenas*) is a growing threat to eelgrass meadows in BC [34]. An introduced eelgrass species (*Zostera japonica*) is considered invasive in some areas, but few negative interactions between the introduced species and native species have been documented. Because of this, little management action has been taken to mitigate its spread [19]. Additionally, an eelgrass wasting disease is present in meadows on the BC coast and is expected to increase in prevalence with warming ocean temperatures [35]. This disease resulted in a large-scale die-off of eelgrasses across the Atlantic in the 1930s [36].

Older studies document local losses of eelgrass beds resulting from coastal development activities such as dredging and construction. For example, a 30% loss in eelgrass coverage at Roberts Bank in the Strait of Georgia was reported between 1969 and 1984 as a result of impacts from construction of a causeway and coal-handling port [37]. In the Puget Sound region, dredging and filling for port development has resulted in similar losses of eelgrass meadows since the 1950s [38].



A seagrass meadow.
Photo: Susannah Anderson, Flickr Creative Commons

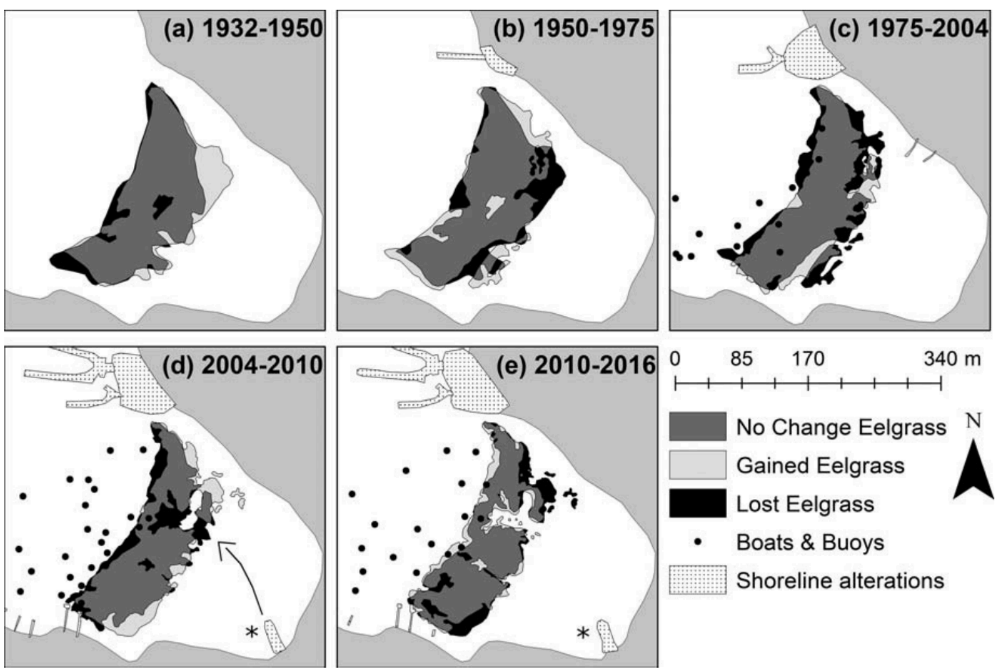


Figure 2. From Nahrinick et al. (2020), showing one of the study's three eelgrass meadows in the Southern Gulf Islands of British Columbia over decades. They say: "Eelgrass loss appears to be associated with the expansion of the ferry terminal in (c). Increased boat presence in (d) coincides with the recession of the deep eelgrass meadow edge. The installation of the boat launch in (d) in the SW corner at * also coincides with the large section of eelgrass loss in the middle of the meadow, which is along the trajectory of boats launched from the boat launch. Also in (d) eelgrass loss occurs at the SW corner of the meadow with the installation of two docks"[21].

SALT MARSH

> - Salt marshes are key components of estuaries, but are vulnerable to coastal development.
> - Significant losses of salt marsh habitat due to sea level rise resulting from climate change are projected, particularly where coastal infrastructure prevents marsh migration inland or disrupts sediment supplies.

Salt marshes are one of the most common and extensive intertidal habitats along coastlines in temperate regions [39]. Worldwide, salt marshes have experienced chronic pressures from rising human activity on coasts. In a study of 12 of the world's largest estuaries, Lotze et al. (2006) found a 67% loss of coastal wetlands during human history [10]. Brophy et al. (2019) mapped historical estuary extent on the west coast of the United States and used this to estimate that 85% of vegetated tidal wetland has been lost since European settlement, including estuary habitat within the Salish Sea [40].

Due to their low topography (often only changing a few meters in elevation over hundreds to thousands of meters of area) salt marsh habitat areas are often targeted for coastal development or land conversion. In 1994, the British Columbia/ Washington Marine Science Panel estimated extensive destruction of estuarine wetlands within the Salish Sea region, both in the Strait of Georgia and Puget Sound, including 96% loss in the north arm of the Fraser estuary and nearly 100% loss within the Puyallup area estuaries [41].

Sea level rise rates and changing sediment supply rates are some of the major drivers of salt marsh decline. Generally, tidal marshes have been able to keep pace with sea level rise rates through multiple feedbacks, including increased growth of vegetation which traps sediment and increases rates of marsh growth. In some cases, sea level rise causes salt marshes to move inland, replacing terrestrial coastline. However, coastal development and other infrastructure (e.g. dykes) may prevent this inland movement in some areas, causing 'coastal squeeze' and subsequent loss of salt marsh habitat. Many salt marshes are also heavily dependent on sediment delivery from rivers, but as human impacts to watersheds alter river dynamics, especially through the construction of dams and other water diversions, sediment delivery to many of these marshes declines.

Kirwan & Murray (2008) modeled responses of salt marshes in the Fraser River Delta to projected sea level rise scenarios to show that with slow sea level rise, these marshes may be able to maintain their characteristics and productivity. However, under more rapid sea level rise scenarios, the marsh areas declined and were unable to migrate landward due to dykes [42] (Figure 4). Similarly, Thorne et al. (2018) modeled sea level rise scenarios for salt marshes along the US Pacific coast and projected that under higher sea level rise scenarios, wetland and marsh habitats may decline by 83% in some estuaries by the year 2110 [43].

There has been little monitoring of changes to salt marsh habitat on the BC coast. Older estimates suggest that 70% to 83% of salt marshes in BC have been either lost or degraded [44], and marshes on the lower mainland of BC have declined by over 80%, from 2230ha historically to 380ha in 1978 [45].

Due to its importance and proximity to major centres, the Fraser River delta has been the focus of several studies. Balke (2017) compared air photos from 1979 to 2013 to show a large recession of the Sturgeon Bank marsh in the Fraser River delta, estimating that since 1979 the marsh has receded between 200-700m along its edge and that around 160ha of marsh area has been lost [46]. Atkins et al. (2016) also focused on the influence of people to the Sturgeon Bank marsh and concluded that reduced sediment delivery to the marsh over the last 150 years is contributing to marsh erosion [47]. Gailis (2020) used aerial photos from 1930 of the western portion of the Boundary Bay salt marsh compared to satellite photos from 2018 and found areas of marsh growth over that time, indicating that typical sedimentation processes are still allowing for expansion of the marsh, but notes that the extent and dynamics of the full extent of the marsh has not been examined, and that the elevation of the marsh has not been determined to assess resiliency to future sea level rise [48].

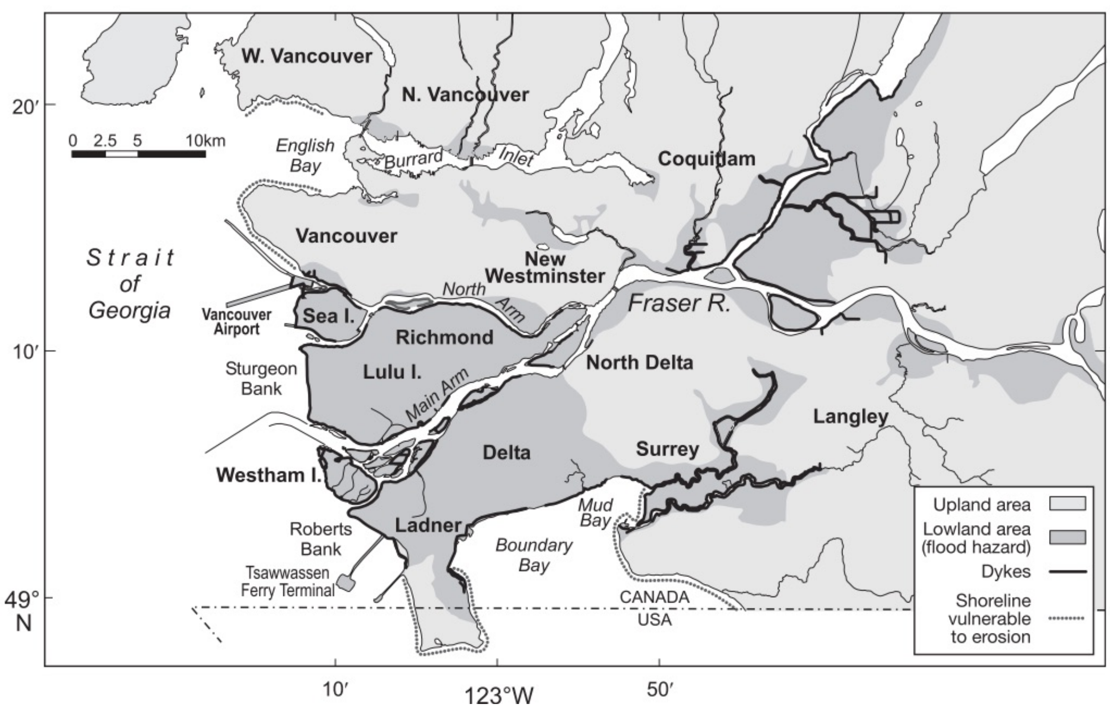


Figure 4. Sensitivity to sea level rise of the greater Vancouver and Fraser Delta region. Low-lying regions around estuaries and deltas are especially vulnerable to the projected increase of 0.65 m by 2100. Sea level rise will be exacerbated by local subsidence and the projected increase in storm intensity. From [49].

MUDFLAT

- Often overlooked as important intertidal habitat, mudflats support rich and productive microorganisms which are a key food source for estuarine life.
- Mudflat communities appear to be resilient and able to cover relatively quickly following disturbances.

Accumulation of fine-grained sediments within estuaries result in the formation of mudflats. These intertidal habitats have received less attention than other estuarine habitats like salt marshes or seagrass meadows, but are crucial components of estuary ecosystems. Mudflats provide important habitat for burrowing invertebrates, as well as being important foraging and nursery areas for fish, and stopover sites for birds.

Biofilm (a layer of organic and inorganic substances that grows on intertidal mudflats; Figure 5 [50]) has been found to be of great importance within estuary systems due to its productivity, key role in estuary foodwebs, and contribution to sediment stabilization. Biofilm growth is determined by tides, light, temperature, and availability of nutrients, in temperate regions biofilm growth reaches its peak in early summer. These films contribute up to half of the primary productivity in estuaries [51], and are now understood to be an important food source for many estuarine species, including invertebrates, fish and are particularly important for migratory birds.

The Pacific Flyway is a chain of stops, including many estuaries, along the west coast of North America used by millions of migrating shorebirds each year to feed and rebuild energy for their journey. It was recently documented that mudflat biofilms in the Fraser River Estuary (Figure 6) are key energy sources for migrating Western Sandpipers [52] and dunlin, accounting for as much as 59% of the birds' diet [53].

Threats and degradation of estuary and saltmarsh habitat also apply to mudflats, with primary threats being erosion of mudflat sediments, land conversion and urbanization, rising sea levels, and coastal squeeze [49]. Mudflat communities appear to be resilient and able to recover following disturbances. Mudflat communities on the North coast (Skeena River Estuary) show recovery from historical industrial activities (salmon cannery and pulp mill) [54], and biofilms are able to regenerate relatively rapidly following physical disturbances [50]. This evidence indicates that protection of mudflats from human impacts can support habitat recovery and resilience.

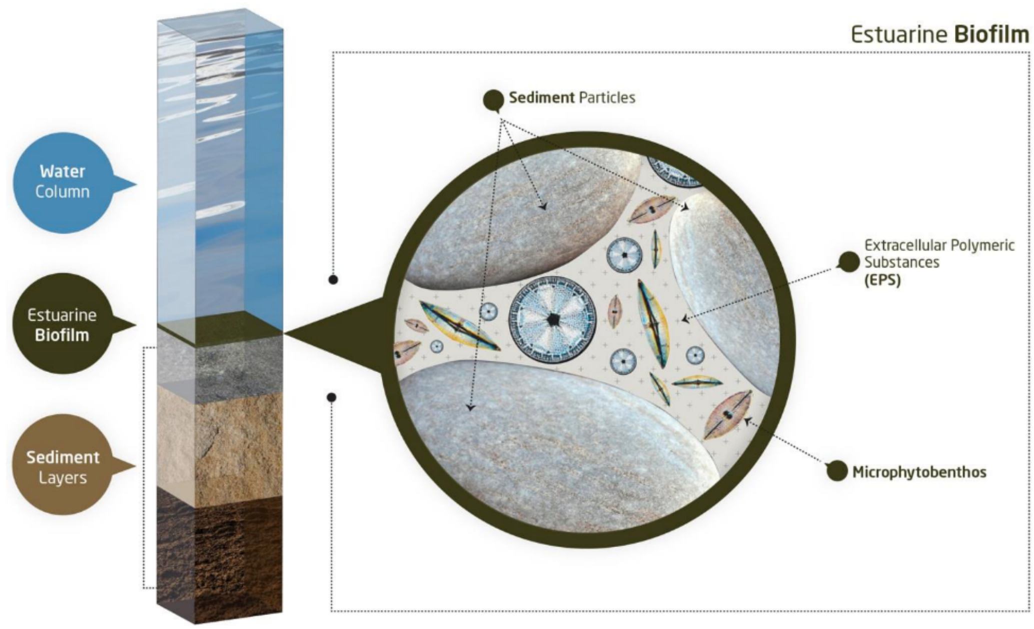


Figure 5. Schematic of microbial biofilm within intertidal sediments [50].

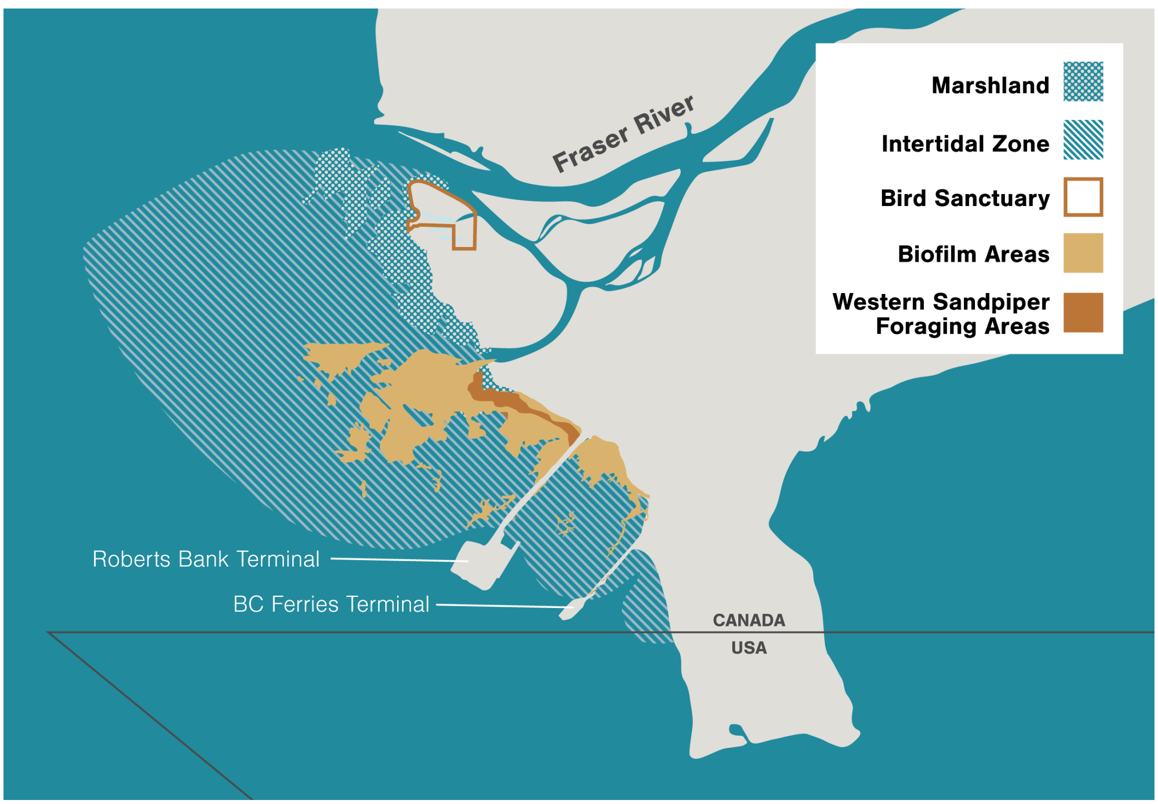


Figure 6. The location of Roberts Bank and the existing Deltaport terminal in the Fraser River delta. Western sandpipers that land at Roberts Bank feed on biofilm and prefer to stay within about 300 meters of the shore. From Hakai Magazine, illustration by Mark Garrison [55].

COASTAL SAND HABITAT

- British Columbia has a diversity of coastal sand habitats which provide important ecosystem services.
- Significant losses of these habitats have been noted in several areas from disrupted coastal sediment dynamics.

Coastal sand habitats are habitats where sand is the dominant substrate and encompass the terrestrial portion of beaches, spits, and dunes. In BC, the main sand ecosystems are eroding bluffs of sands paired with a depositional feature such as a spit or sand bar (e.g. Strait of Georgia; Point Grey Bluffs in Vancouver), large embayed beaches with a well-developed terrestrial backshore (e.g. West Coast Vancouver Island), and dune systems (e.g. Haida Gwaii).

These habitats occur over 940km of BC's coast, from southern Vancouver Island to the tip of Graham Island on Haida Gwaii. Around 125 coastal sand ecosystem sites are mapped in the province (see Figure 7), and support unique ecological communities, including nesting sites and stopover sites for resident and migratory birds. These formations also support other habitats, such as salt marsh communities on the leeward side of protective sand spits, and provide coastal protection from flooding and erosion during storms. As such, coastal dunes have been subject to stabilization efforts to enhance flood protection and wave erosion defence.

These habitats depend on the movement of sand from source areas such as bluffs and shallow subtidal sand bars to beaches and dunes. Reduction in this supply or disruptions to sand movement can erode the beach or dunes, including by invasive plant establishment, development of shoreline protection, or other structures such as groynes.

A comprehensive report on BC's coastal sand habitats was completed in 2011 for the Coastal Sand Ecosystems Recovery Team [56]. This report identifies seven primary threats to coastal sand ecosystems (in order of priority): invasive plants, disruption to coastal sediment transport, recreation, coastal development, climate change, invasive animals, and atmospheric nitrogen deposition.

There is little comprehensive and quantitative data on the trends of coastal sand habitat. Page et al. (2011) used aerial photos of six representative systems to assess changes and found evidence of significant changes since 1930 in each, from declines of nearly 80% of dunes on Goose Spit (Comox Bay) due to invasion of introduced species, to over 95% of Witty's Spit (Metchosin), to 129% increases of the sand spit on Clayoquot Island (Clayoquot Sound) [56]. Overall, the report finds that extensive declines, ranging from 10% to 95%, have occurred at most coastal sand ecosystem sites.

Invasive plants are a primary concern as they can rapidly reduce habitat biodiversity, and cause changes to sand movement. On Wickaninnish Beach (West Coast Vancouver Island) colonization of coastal dunes by an invasive grass has displaced native grass species and dense root systems have reduced sand supply, dramatically altering the dune [57]. Focused restoration efforts have been shown to be effective [58].

Apart from invasive plants, changing environmental conditions are resulting in a ‘greening’, or increasing in vegetation cover, of coastal dunes worldwide [59]. This increase in vegetation may increase the resilience of these structures to erosion from ocean storms, but could also alter coastal sediment movement processes.

Dunes on East Beach, Haida Gwaii.
Photo: Karen Noah, Flickr Creative Commons

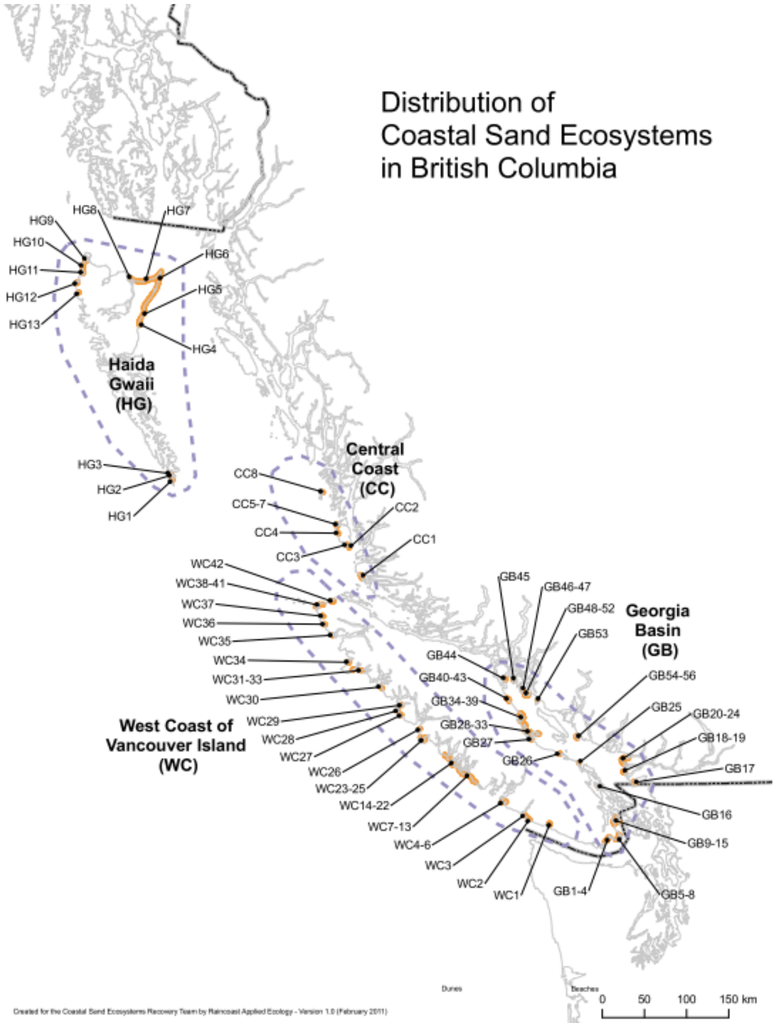


Figure 7. The distribution of coastal sand ecosystems in BC. Labels refer to site numbers within coastal regions (GB: Georgia Basin, WC: West Coast of Vancouver Island, CC: Central Coast, HG: Haida Gwaii). From Page et al. (2011) [56].

KELP

- Declines and changes in kelp beds have been noted in several areas of the BC coast.
- Warming ocean temperatures are the primary driving pressure of kelp change, but local factors also play large roles in kelp forest dynamics (such as proximity to populated areas, or the presence of sea otters).

Kelps (large brown macroalgae) are found along 25% of the world's coastlines in temperate and subpolar regions. Kelp form complex habitat structures and are highly productive, supporting and fuelling high levels of local biodiversity in coastal ecosystems. Kelp forests also provide habitat for juvenile salmon and forage fish [60].

Canopy-forming kelps (those that can be viewed at the surface, such as giant and bull kelp) have generally been better studied and surveyed due to the ability to survey using aerial photography or small vessels. Surveys documenting changes in kelp cover are limited on the BC coast, though monitoring through the Marine Planning Partnership focuses on changes in kelp distribution and abundance. Developing methods using high-resolution satellite to map kelp beds on the BC coast will improve the ability to survey large areas of the coast [61].

Declines in kelp beds along areas of the BC coast and neighbouring Washington State coastlines have been recorded. Some larger scale mapping by the provincial government as part of a Kelp Inventory Program documented a 75% decline in some kelp beds on the BC Central Coast between 1993 and 2007 [62]. Declines of kelp bed extent over a 50km section of coastline in the Salish Sea between 2004 and 2017 was tracked using satellite images (Figure 8) [63]. The images used were limited in quality and the timescale of the study limits the ability to assess change within the perspective of ecosystem variation.

In a longer-term perspective from across the Salish Sea, Pfister et al. (2017) used 26 years of aerial censuses between 1989 and 2015 and to compare to surveys conducted in 1911 and 1912 along the coastline of Washington State [64]. They found that the kelp beds in the Strait of Juan de Fuca have been persistent for at least 100 years, although there is evidence of decreased abundance in the most easterly regions and hypothesized that this may be due to their proximity to urban centres. Other work in Puget Sound has assessed localized declines in kelp bed extent [65,66]. Recent surveys indicate that the current extent of bull kelp in Puget Sound is about 20% of its maximum historical extent [67]. In response to these observations, the Northwest Straits Commission completed a Puget Sound Kelp Conservation and Recovery Plan in May 2020 [68]. This plan contains a framework for research and management actions to protect and restore kelp in the region.

Harvest of kelp, and other algal species is also important for coastal First Nations on the North Pacific Coast. A study of small-scale kelp harvest on the Central BC coast documented minimal impacts from harvest to kelp forests and associated species on the Central BC coast [69]. However, they found that the wider-scale stresses of increasing sea temperature may have an important influence on recovery of kelp following harvest. Programs for monitoring kelp through the Marine Planning Partnership (MaPP) conducted by First Nations Guardians programs, the provincial government, and the Hakai Institute, are in their early years, and will help to fill the gaps in knowledge of kelp bed distribution, and to plan longer-term harvest management [70].

Kelps are sensitive to high temperatures and are expected to respond negatively to climate change induced sea temperature changes. Substantial losses in intertidal kelp diversity and persistence of more stress tolerant kelp species over several decades (comparing 1993/1995 and 2017/2018) on the West Coast of Vancouver Island suggest that sea temperature increases may be driving changes in kelp habitats across the BC coast [71]. Increasing temperatures have been documented to dramatically change kelp forests in California [72,73], particularly where other ecological stressors interact with temperature stress (such as loss of sea stars; see next section). Elevated sea temperatures also reduce the reproductive success of kelp species, particularly for species found in more northern and central areas of the Pacific coast [74].

Kelp forest dynamics on the BC coast are also changing with the return of sea otter populations. Watson & Estes (2011) documented these shifts on the West Coast of Vancouver Island, where sea otters preyed on and reduced abundances of sea urchins (which are kelp grazers; Figure 8), leading to the return of a kelp-dominated habitat [75]. Continued recovery of kelp habitat with sea otter populations increase is projected to contribute economically valuable services including supporting commercially valuable fish populations, carbon storage, and providing nutrients to the wider coastal ecosystem [76].

In the North Atlantic, marine heatwaves have been linked to declines in kelp forests, and heatwaves have been increasing in frequency and intensity [77]. Global reviews have been complied to evaluate trends in kelp at wider scales. Krumhansl et al. (2016) compiled kelp forest data from 34 ecoregions of the world where kelps grow (out of a total of 99 global ecoregions), and found declines in just over a third of these ecoregions [78]. Smale (2020) gathered results from studies that specifically looked at impacts to kelp from increased sea temperatures, and highlighted that different kelp species and regions will have variable tolerances and responses to warming ocean temperatures [79].

Giant Kelp (Macrocystis pyrifera)
Photo: California Sea Grant, Flickr Creative Commons

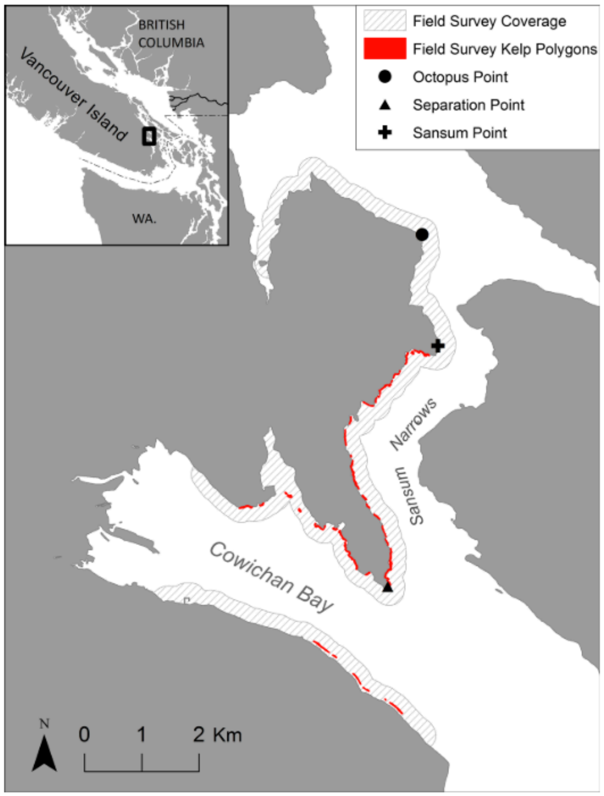


PLATE 1. Along rocky shores on the west coast of Vancouver Island, Canada, grazing by urchins (in this case primarily *Strongylocentrotus. franciscanus*) can create deforested landscapes such as pictured here. Photo credit: Lynn Lee.

Figure 8. LEFT: From Schroeder et al. (2019) showing the study area extent within Cowichan Bay and Sansum Narrows on the East Coast of Vancouver Island, British Columbia, Canada. Red areas indicate kelp beds surveyed by a kayak-based field survey in August 2016. Hatched lines indicate the total area covered by the kayak-based field survey in August 2016 [63].
RIGHT: From Watson & Estes (2011) without control of sea urchin populations by predators such as sea otters, grazing on kelp can result in dramatic declines in kelp forests and create these 'urchin barrens' [75].

SEA STARS

- Recent dramatic losses of key sea star species due to Sea Star Wasting Disease have had cascading impacts through intertidal and subtidal habitats along the coast.
- Higher temperatures have been linked to the severity of this disease outbreak, and though populations are recovering in areas of the coast, there are also continued recordings of disease.

Sea stars play important roles in many of BC's coastal ecosystems. The now widely used ecological term, keystone predator, originated from a study of the ochre sea star (*Pisaster orchraceus*), one of the most recognizable species on the Pacific northwest coast (see photo below), after experiments showed that its removal had cascading impacts on intertidal biodiversity [80].

Since 2013, over 20 species have been afflicted with Sea Star Wasting Disease (SSWD), which has caused massive die-offs in populations all along the North American Pacific coast, from Mexico to Alaska. Following the onset of a SSWD outbreak in 2013, substantial declines in abundance of several intertidal and sub-tidal sea stars, including the ochre star, and the sunflower star (*Pycnopodia helianthoides*), occurred all along the Pacific coast from Alaska to southern California. Shifts in abundances of these important predators has led to reorganization of entire ecosystems.

Schultz et al. (2016) documented the dramatic decline in numbers of the sunflower star in Howe Sound (89% average decline) and a concurrent four times increase in green sea urchins (which consume kelp), as well as an 80% reduction in kelp cover [81]. These findings suggest cascading effects from the removal of one of the largest predatory sea stars which consumes a variety of prey, including sea urchins.

The findings of Burt et al. (2018) showed that the sunflower star acts in concert with sea otters in kelp forest dynamics. By preying on smaller urchins while otters focus on larger individuals, the two predators work to maintain urchin populations and kelp forests. Following the decline in sunflower stars on the central coast of BC, even sites that had established sea otters experienced declines in kelp forest, and higher numbers of sea urchins [82].

Though this disease was known prior to the outbreak [83], the 2013-2015 SSWD event was distinct from previous events in its geographic extent, persistence, involvement of multiple species, and the extremely rapid progression from disease onset to death [84], and was the largest documented marine epizootic disease of a non-commercial species [85].

Higher seawater temperatures have been implicated as a driver of this outbreak, as the intensity of the outbreak was elevated in warmer-water southern regions relative to cooler northern areas [86], though multiple stressors are likely acting on these coastal species. The current status of sea star species varies by the species and location on the coast, though declines and signs of the disease are still being recorded (Figure 9)[2].

The ochre sea star (*Pisaster orchraceus).*
Photo: Royce Bair, Flickr Creative Commons

Figure 9. All observed sites of Sea Star Wasting Disease since January 2013. Grey pins indicate data collected between 2013-2018, and orange are observations since that time, for multiple sea star species. From the Multi-Agency Rocky Intertidal Network (MARINe) [87].

SHELLFISH

- Shellfish (bivalves) are key components of many intertidal and subtidal habitats in BC. From rocky shorelines to mudflats, shellfish modify and shape their ecosystems.
- Several important aspects of coastal health pertain to shellfish, including invasive species, species at risk, water quality, and microplastics. These factors are also tied to both commercial and recreational wild harvest, and to aquaculture.

Shellfish is a broad term used to encompass both shelled molluscs (e.g. oyster, clam) and crustaceans (e.g. crabs or shrimp). Here, the focus is on bivalves, which in BC consist of clams, oysters, mussels, and scallops.

Shellfish are important ecosystem engineers; by modifying their physical environments, they influence the other organisms within that system. This is especially true for those that form dense beds, like mussels, or reefs, like oysters, but also for those that live within soft-sediment habitats (such as clams living in sand or mud) where their shells create hard habitat for species, allowing more types of species to be present.

As filter-feeders, shellfish are sensitive to water quality, and are therefore good indicators of changes to coastal ecosystems (e.g. microplastics [88], harmful algal blooms [89], and other pollutants [90]). Shellfish are also sensitive to climate change, particularly changes in ocean acidity due to their shells [91,92]. This will be a growing challenge for shellfish populations and shellfish aquaculture in Canada and worldwide [93].

Shellfish harvesting, including First Nations, recreational, and commercial wild harvest, is an important aspect of coastal BC's culture. Shellfish harvesting is one of ten indicators used for the Health of the Salish Sea Report (a joint initiative between the United States' Environmental Protection Agency and Environment and Climate Change Canada) to assess the health of the Salish Sea ecosystem. The 2018 report notes that there has been an overall increase in the number of acres of shellfish beds where harvest is prohibited or restricted, continuing on a trend that has been noted in previous assessments [94]. In the Georgia Basin, the area of tidal lands closed to shellfish harvesting has steadily increased by 45% since 1989, and has almost tripled in the Puget Sound region. This trend is due in part to increased water quality monitoring, changes in closure classifications and mapping methods. However, primary drivers of closures are from pollution sources, such as runoff from urban areas and farms, sewage inputs and septic wastes [95].

Long-term closures in some areas have impacted local First Nations' access to harvest sites, for example Burrard Inlet has been closed to shellfish harvest since the 1970s due to contamination concerns, though some sites within the inlet have been opened more recently for limited food, social and ceremonial harvest. The Tsleil-Waututh Nation is seeking to restore harvest within the Inlet [96].

Past intensive harvest has caused significant declines in native bivalve species; the Olympia Oyster (*Ostrea conchapila*) is listed as Special Concern under the Canadian Species at Risk Act (SARA), and the Northern Abalone (*Haliotis kamtschatkana*) is listed as Endangered [97,98]. Introduced bivalves may also increasingly be competing with native species [99].

Shellfish aquaculture is an expanding industry in coastal BC; shellfish aquaculture covers over 3700ha of the province's coastline (Figure 10). Shellfish aquaculture is primarily focused on non-native species to BC, the Pacific oyster (*Crassostrea gigas*) and the Manila clam (*Tapes philippinarim*). Currently, shellfish culture operations are concentrated on the southern BC coast, with increasing interest in expansion to the central and north coast [100].

There are several different methods of culture (including on-bottom culture, suspended culture, and in-sediment culture) which have differing interactions with the coastal environment. Depending on the concentration of aquaculture sites and method of culture used, shellfish aquaculture may have both positive and negative interactions with coastal ecosystems [101]. Shellfish aquaculture on the BC coast interacts with and occurs in the same spaces as many other coastal industries, and ecological communities

Microplastics taken up by shellfish are an emerging and rapidly growing area of study [88,102]. Several recent studies have investigated potential links between plastic aquaculture equipment and microplastic concentrations within bivalves, however while plastics used in aquaculture do represent a source of microplastics, results from these studies do not indicate that aquaculture sites are a major contributor of microplastics in the ocean over other sources [88,103].

Oyster bed on Vancouver Island.

Photo: Christopher Porter, Flickr Creative Commons

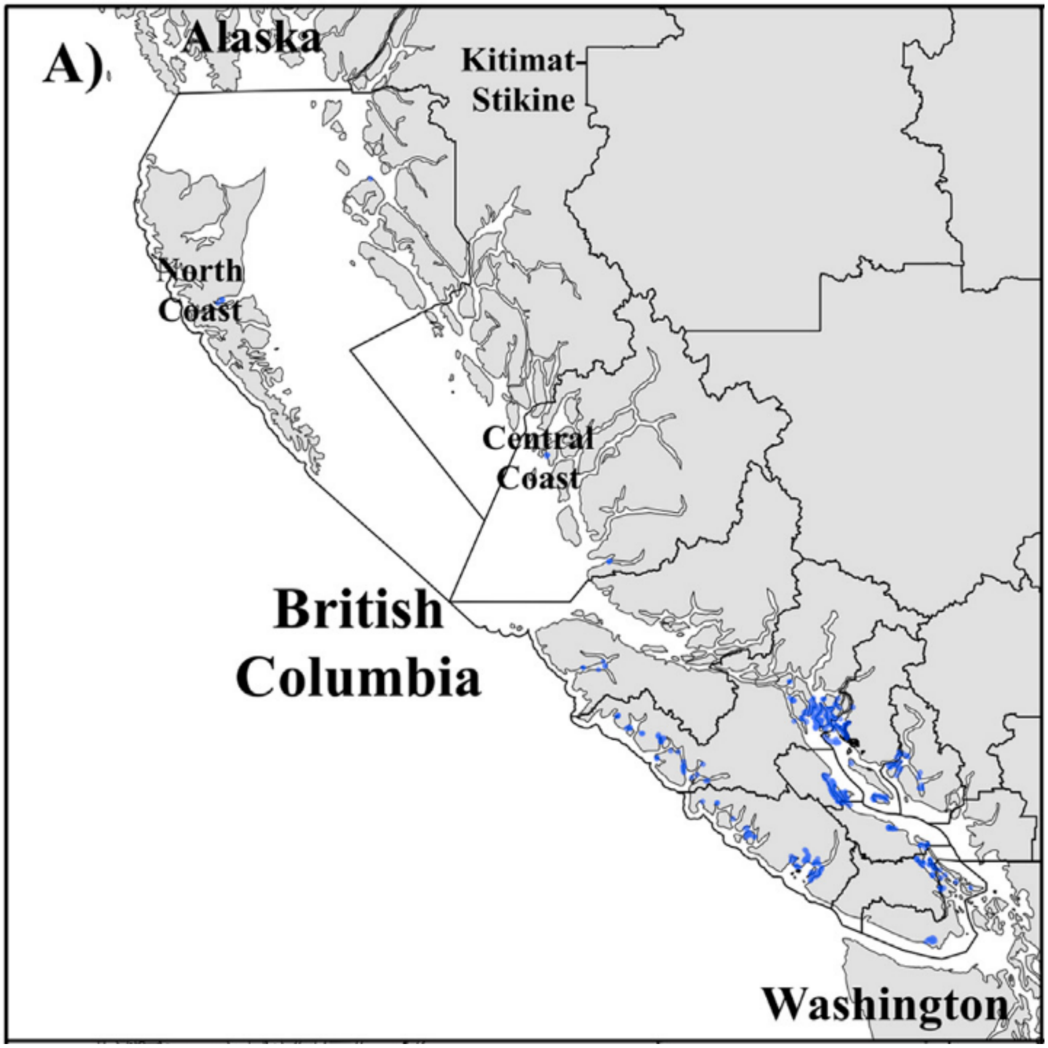


Figure 10. The location current beach and deep water shellfish aquaculture tenures (blue dots) on the BC coast, From Holden et al. (2019) [100].

FORAGE FISH & JUVENILE SALMON

- Many species of forage fish and Pacific salmon rely on nearshore coastal habitats to carry out critical stages of their life cycles, from juvenile nursery habitat, staging habitat, and spawning habitat.
- Impacts to fish populations are species-specific, and for forage fish much is still unknown regarding habitat use and preferences, though shoreline modification may hinder efforts to map and assess key spawning areas.
- Degradation of estuary habitats is most harmful to salmon populations as estuaries are key transitional zones in their movements between freshwater and saltwater.

The life histories of Pacific salmon species, and multiple species of forage fish in BC are shaped by their use of both coastal, and for some species, riverine, habitats and of open ocean ecosystems. Forage fishes are small-bodied fish species that feed on plankton and are eaten by many marine predators forming a critical energy link in marine foodwebs. In BC, these include Pacific herring, eulachon and Pacific Sand Lance, as well as Longfin Smelt, Surf Smelt, Northern Anchovy, and Pacific Sardine. Forage fishes have been the dominant fish species, in terms of biomass and abundance, in some regions for thousands of years, such as Pacific herring in the Strait of Georgia [104].

Because of this reliance on coastal habitats for at least part of their lifecycles, these fish populations are an indicator of the status of nearshore systems. Additionally, due to their importance within the foodweb, impacts to these fish species can have greater effects throughout the coastal and ocean ecosystems.

It is often very complex to disentangle and prioritize the pressures on these populations within both their marine, coastal and freshwater habitats (e.g. [105]). However, survival of juvenile fishes in coastal habitats during early life stages is a key factor for many species such as salmon and eulachon, and availability of preferential spawning habitats is critical for beach spawning fishes (such as capelin, surf smelt, and Pacific sand lance). Multiple diverse human activities in coastal fish habitat impact fish at multiple scales, from individual, physiological effects (e.g. pollutants) to population level (e.g. changes to spawning habitat use; Figure 11)

FORAGE FISH

Localized declines in both surf smelt and Pacific herring have been noted within Puget Sound [106]. Population-level depletion of Pacific herring within fisheries regions of BC have led to the closure of fisheries around Haida Gwaii, the Central

Coast, the West Coast of Vancouver Island, and the Prince Rupert region [107], while herring populations in the Strait of Georgia have fluctuated [108].

Pacific herring use nearshore (intertidal and subtidal) areas to spawn each spring, laying adhesive eggs onto surfaces (e.g. seaweeds, seagrass, woody debris). Therefore, a number of habitat changes and pressures have the potential to impact herring spawning sites. Additionally, structures may also harm herring spawns; creosote, used to treat structures like dock pilings, has been shown to greatly reduce hatching rates of eggs laid on treated wood, and result in physical deformities in hatched fish [109]. There have been some community-based initiatives to wrap dock pilings in other material, such as on Mayne Island, Squamish Harbour and False Creek [110].

Surveys and estimates of herring spawning sites on the BC coast have been recorded since 1928, and show that around 19% or more of the coast has been used for spawning at least once during the last 75 years. However, a far smaller area (1-2%) is used for repetitive spawning over a number of years [111].

Eulachon, like Pacific salmon, hatch in fresh water and spend most of their adult lives in the sea, and return to fresh water to spawn and die (this life history is termed 'anadromous'). Eulachon are "of special concern" in BC under the Species at Risk Act due to recent declines in population and spawn returns. In 2011, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed three management units of eulachon: the Fraser and Central Pacific units were assessed as Endangered, and the Nass/Skeena unit was re-assessed in 2013 as being of Special Concern [112]. These fish face threats in both freshwater and marine environments at coastwide and localized scales [105,113].

Pacific Sand Lance bury themselves within sandy substrates at night, for resting periods during the day, to evade predators, and they are even able to remain buried in sand during low tides. Sand lance have strong preferences for specific sediment types (i.e. grain size) [114], and so changes to these preferred sites result in habitat loss.

Baseline data is lacking to track changes to spawning and nearshore sediment habitat for many of these forage fish species [115], though loss of critical spawning habitat and exposure to pollutants early life-history stages in areas of high human impact are areas of focus for protection of forage fish habitat [106,115,116]. Shoreline modifications to beach habitat disrupt processes and conditions that support fish spawning and egg development, including changes to temperature and moisture [117], as discussed further in the section on shoreline armouring. Ongoing mapping projects, primarily community organized and undertaken, are surveying forage fish habitat in some regions of southern BC. These initiatives will aid in monitoring changes to habitat and use by spawning fish (e.g. [118,119]).

Pacific herring eggs on intertidal seaweeds near Qualicum, Vancouver Island.
Photo: Maryann Watson

JUVENILE SALMON

Pacific salmon have received much attention and study. Depending on the species, juvenile Pacific salmon may spend between weeks and months in coastal habitats, using estuaries as staging and transitional zones before moving out into the marine environment. As adults, salmon return to these coastal habitats in their journey to their freshwater spawning grounds.

Salmon populations all along the BC coast are declining, though declines in southern coast populations are generally more dramatic than those on the northern coast [120]. However, many populations on the northern coast, particularly within the Skeena and Nass Rivers are also in decline and need of recovery action, while the majority of populations on the Central Coast (70%) lack sufficient data to be assessed [15]. Climate change impacts and habitat changes are two of the primary factors driving salmon population declines [120]. Threats to salmon habitat are also indicative of those faced by other anadromous, and migratory fish which use nearshore habitats; habitat loss and degradation from logging activities, human-introduced barriers or alteration to freshwater flow, development in habitat, and aquaculture in migration routes [121,122].

The condition of transitional habitats, especially estuaries and eelgrass habitat, are particularly important for juvenile Pacific salmon [13,122]. Hodgson et al. (2020) reviewed studies worldwide on impacts to juvenile salmon within estuaries and found evidence that 24 activities and 14 stressors resulting from these activities impact juvenile salmon in estuaries. Stressors include pollutants, sea lice, loss of habitat connectivity, changes in flow, and higher temperatures (Figure 11) [122]. Coastal industries may also impact juvenile salmon habitat and migration corridors, leading to changes in their survival rates. Several studies have also shown potential roles of open net-pen salmon farms in transmitting sea lice parasites to wild juvenile salmon and to Pacific herring [123,124].

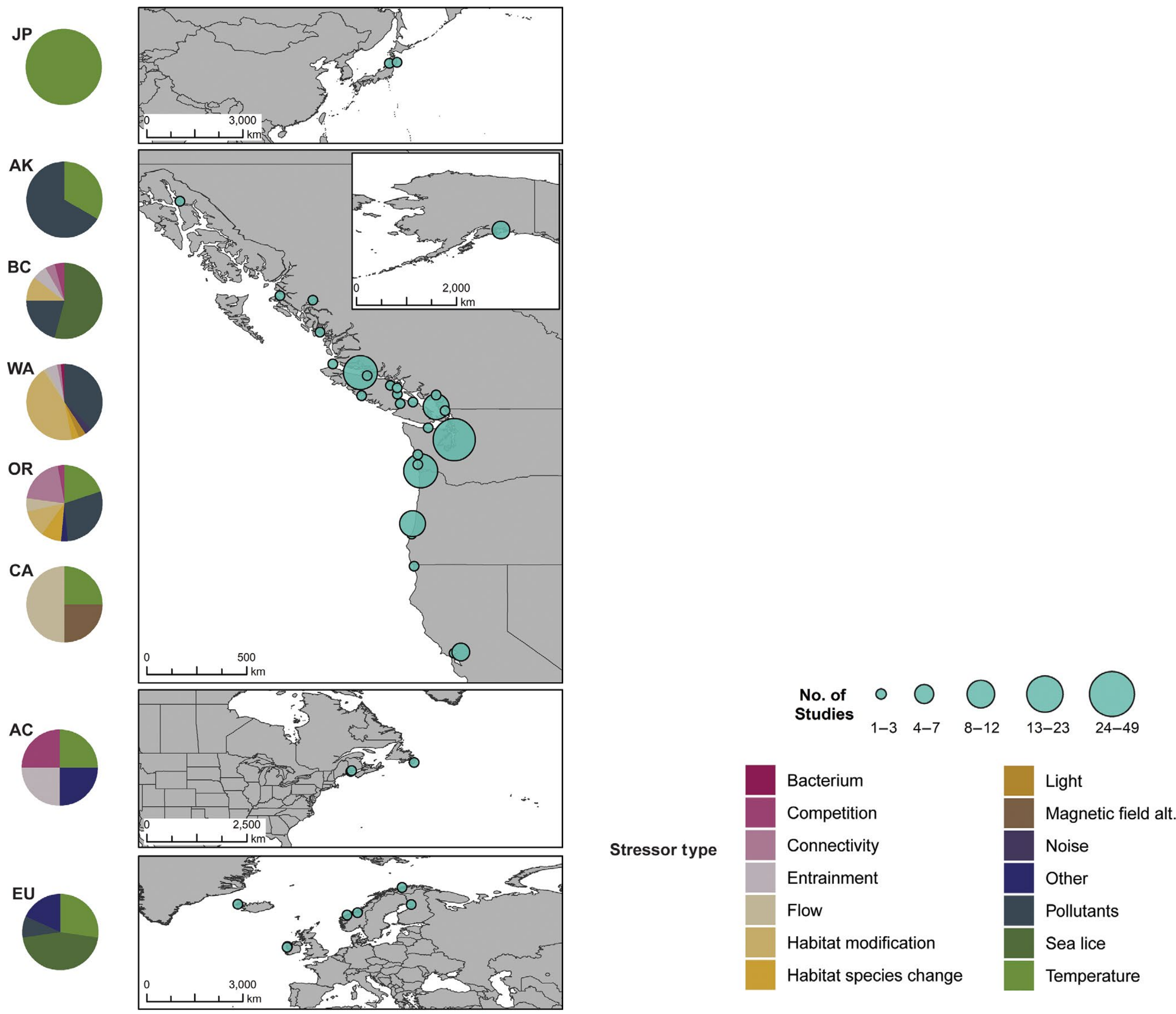


Figure 11. Studies on human activities and stressors from these activities on juvenile salmon in estuaries, as reviewed by Hodgson et al. (2020). Pie charts show 14 identified stressors by region. Size of blue circles shows numbers and locations of studies included in review. JP: Japan, AK: Alaska, BC: British Columbia, WA: Washington, OR: Oregon, CA: California, AC: Atlantic Coast, EU: Europe.

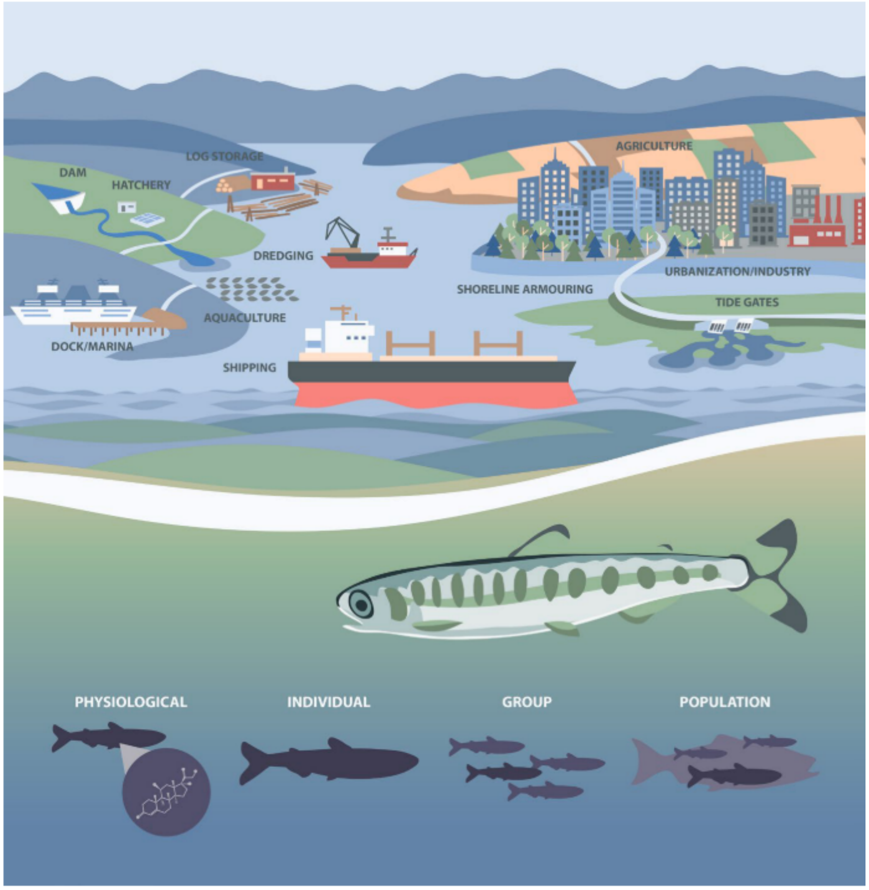


Figure 12. Graphic depicting the multiple activities that occur in estuaries and the biological scales at which impacts from these activities are measured for salmon. From Hodgson et al. 2019 [122].

SPECIES AT RISK

- The numbers of marine species at risk are rising, and there has only been reporting of these numbers within the Salish Sea region.
- Despite commitments to develop Provincial species at risk legislation in 2018, the process has been stalled. Protections for marine species at risk in Canada may be left in regulatory gaps.

Marine Species at Risk are one of ten indicators used for the Health of the Salish Sea Report (a joint initiative between the United States' Environmental Protection Agency and Environment and Climate Change Canada) for species which depend on the Salish Sea marine ecosystem for some or all of their life history [94].

The most recent reporting on this indicator by Zier & Gaydos (2016) found that, as of 2015, 125 native species, sub-species or 'ecologically significant units' (such as management units, or Designatable Units) that depend on the Salish Sea marine ecosystem were listed as species of concern by one or more of the four jurisdictions in the Salish Sea: the province of British Columbia, the state of Washington, the Canadian federal government, and the United States federal government) [125]. Between 2013 and 2015, 12 new species were added to the indicator list [125]. Between 2002 and 2013, the number of species of concern in the Salish Sea has nearly doubled from 60 to 119 [126] (Figure 13 & 14). Some of these listings are due to increased understanding of species' use of the Salish Sea marine ecosystem, but are also due to declining populations. These increases in the numbers of species of concern suggest that recovery efforts are being outpaced by declines.

Johannessen and McCarter (2010) list 12 marine species that occur within the Strait of Georgia that have received designation by the Committee on the Status of Endangered Wildlife In Canada (COSEWIC; Figure 15 [104]). It is important to note, however, that biases in listing of marine species under the Species at Risk Act (SARA) have been observed, particularly those of commercial interest [127–129]. Additionally, although the provincial government committed to creating species at risk legislation in 2018 [130,131], the process has stalled and the government appears to have backtracked on this goal [132], meaning there remains a gap in legal protection for coastal species at risk on provincial or private lands.

	British Columbia	Washington State	CANADA	U.S.A.	TOTAL
INVERTEBRATES	2	2	5	0	**5**
FISHES	7	22	30	12	**43**
REPTILES	1	2	2	2	**2**
BIRDS	48	15	26	1	**59**
MAMMALS	13	10	16	5	**16**
TOTAL	**71**	**51**	**79**	**20**	**125**

Figure 13. Table showing species of concern in the Salish Sea in 2015 by taxonomic grouping and listing jurisdiction. From Zier & Gaydos (2016) [125].

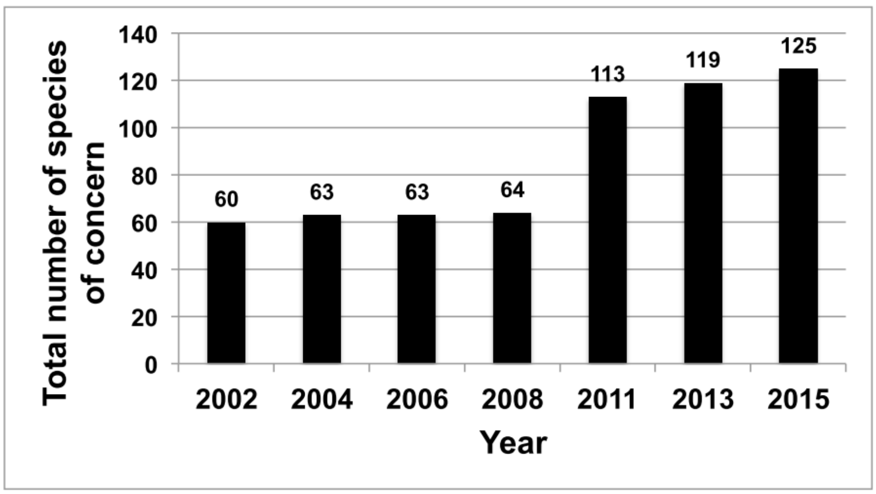


Figure 14. Number of species of concern within the Salish Sea from 2002 - 2015. From Zier & Gaydos (2016) [125].

Grouping	Common name	Species	Legal listing under SARA	COSEWIC status
Invertebrate	Northern abalone	*Haliotis kamtschatkana*	yes	Endangered
Invertebrate	Olympia oyster	*Ostrea conchaphila*	yes	Special Concern
Fish	Bluntnose Sixgill Shark	*Hexanchus griseus*	no	Special Concern
Fish	Chinook salmon (interior BC spawners)	*Oncorhynchus tshawytscha*	no	Threatened
Fish	Coho salmon (interior B.C. spawners)	*Oncorhynchus kisutch*	no	Endangered
Fish	Green sturgeon	*Acipenser medirostris*	yes	Special Concern
Fish	Sockeye salmon (Cultus and Sakinaw Lakes)	*Oncorhynchus nerka*	no	Endangered
Mammal	Steller Sea Lion	*Eumetopias jubatus*	yes	Special Concern
Mammal	Harbour porpoise	*Phocoena phocoena*	yes	Special Concern
Mammal	Humpback whale	*Megaptera novaeangliae*	yes	Threatened
Mammal	Killer whale, northern resident	*Orcinus orca*	yes	Threatened
Mammal	Killer whale, southern resident	*Orcinus orca*	yes	Endangered

Figure 15. Marine invertebrates, fishes, and mammals found in the Strait of Georgia that have been listed by COSEWIC. Some have also received designation under the Species at Risk Act (SARA). From Johannessen and Carter (2010) [104].

PRESSURES

LOGGING

- Past marine-based logging activities (such as log booms or rafts) in estuaries and shallow coastal waters have legacy impacts on marine habitats.
- Management practices and marine planning are working to mitigate these impacts.

Commercial logging has been one of the primary industries, along with commercial fisheries, supporting BC's coastal economies over the last century. Over much of the BC coast, terrain and accessibility needs have meant that transportation of logs has been principally marine-based.

The transportation of logs between harvest or collection points to storage and processing points may have multiple interactions with coastal habitats. The effects of these practices on estuary habitats has been documented [133] and reviewed [134]. Many of these studies were performed decades ago but some of the documented impacts to estuaries in BC include sediment build-up, toxins leached from wood, physical damage from grounding of log rafts, shading of seagrass meadows, and buildup of decomposing bark and woody debris creating anerobic habitats [134–136].

There have been improvements to operations to minimize these impacts, and reduced forestry operations in some areas of the coast have decreased disturbances in these areas, though concerns remain [137]. As such, management issues, objectives and strategies for 'Logging-Related Marine Activities' remain key components of the Central Coast, North Coast, and Haida Gwaii Marine Planning Partnership Plans [135,137,138].

Log boom near Squamish.

Photo: Ruth Hartnup, *Flickr Creative Commons*.

INVASIVE SPECIES

- The numbers of introduced and invasive species on the BC coast is rising. Aquaculture and shipping are the primary vectors of introduction of non-native species.
- Many of these invasive species are intertidal, and may establish and spread more easily in areas of higher human activity.

Introductions of non-native, or alien, species to coastal ecosystems is increasing globally [139]. Once established, introduced non-native species may become invasive if they establish to a point that transforms marine habitats and threatens biodiversity through competition with local species.

The introduction of non-native species, both invasive and non-invasive, has led to their spread through BC's coastline [140,141]. Studies showing risk of further spread for more recent invaders (e.g. Green crab, tunicate) highlight opportunities for coordinated response and management [140,142–144].

On the BC coast, over 89 non-native species have been recorded [49,140,145], which have been introduced, both intentionally and unintentionally, through aquaculture [140], as well as through shipping [141]. Recreational boats may be also responsible for the spread of invasive species over the BC coast following their introduction (Figure 16) [141,146]. The Strait of Georgia region has the highest level of non-native species on the coast with almost three times as many non-native species as other areas, and the number of non-native species has increased by 40 times over the last 100 years [49,104]. Most of these are mollusc species, but crustaceans, algaes and plants, as well as worms have also been introduced. Over a third of these are intertidal species [145].

Invasive species may establish more easily in areas of higher human activity because shoreline modification and the introduction of artificial structures into coastal environments may favour non-native species over native ones [141]. Additionally, rising temperatures may facilitate further dispersal of non-native species along the BC coastline [140].

BIVALVES

Pacific oysters (*Crassostrea gigas*) were imported to BC for culture around 1913, along with a number of associated species, and have been the dominant vector for the introduction of many other species [145]. Pacific oysters are highly successful, and have been introduced to over 66 countries and have established self-sustaining populations in 17 countries [147]. Populations have established throughout the Strait of Georgia and the west coast of Vancouver Island, and there are reports of establishment on Haida Gwaii [148]. Increased growth of oysters along the coast may displace local species and change habitat diversity patterns. Pacific oysters may be impacting eelgrass at local scales; eelgrass has been found to be absent on the seaward side of Pacific oyster beds around Cortes Island [33], reducing the diversity of species using those areas [32]. These patterns may be due to the altering of waterflow, inputs of sulphide to the water, or production of faeces and pseudofaeces (expulsion of particles that cannot be used as food) adding organic matter to the sediment and altering sediment properties [32].

SEAWEEDS

A number of non-native seaweeds have become invasive on the BC coast [149,150]. In some areas, these populations have become so successful that commercial harvest quotas for beach-cast seaweed have been developed [143].

EUROPEAN GREEN CRAB

One of the most recent invasive species to arrive on the BC coast, the European Green Crab (*Carcinus maenas*), has invaded temperate coastal habitats around the world. These crabs prey on native species including clams, oysters, and other crab species, and are ecosystem engineers in that they have been documented to transform eelgrass meadows into mudflats as a result of their feeding behaviours [34].

Green crab invasion on Canada's Atlantic coast has had many negative impacts to habitats. The species was unintentionally introduced to the west coast of North America in the 1980s within San Fransisco Bay, and ocean currents carried larvae northwards. Crab populations have expanded along the west coast of Vancouver island and to some areas of BC's central coast, but for many years it was thought that cooler water temperatures limited their establishment in many areas of coastal BC. However, this may be changing with rising sea temperatures. The Green crab was first documented in the inner Salish Sea in 2016 [144], and may have higher impact in areas of the coast where habitats are already under pressure from higher levels of human activity [34].

SPARTINA

Spartina (cordgrass, *Spartina* spp.) grows in coastal habitats such as intertidal mud flats, estuaries, and salt marshes. There are several invasive species of *Spartina* found globally, five of which are invading coastal areas in the Pacific Northwest of North America (Oregon, Washington, British Columbia [151]). The grass grows in dense stands, converting mudflats into meadows, and altering patterns of sediment circulation and water drainage [152]. *Spartina* was first found in BC in 2003, and still has a fairly limited distribution on the coast (less than 22ha; [152]) within the Fraser River Delta (Boundary Bay, Roberts Bank, and Burrard Inlet) on the southern mainland, the east coast of Vancouver Island (in Baynes Sound and Comox Harbour), and in the Northern Gulf Islands (on Denman, Hornby, Sandy Island) [153]. There is significant threat of *Spartina* spreading along the coastline as has occurred along the west coast of the United States[153], as dispersal can occur by ocean currents and large areas of the BC coast have been determined to be suitable habitat for *Spartina* [154].

Cordgrass (Spartina) colonizing a mudflat.
Photo: Akuppa John Wigham, Flickr Creative Commons

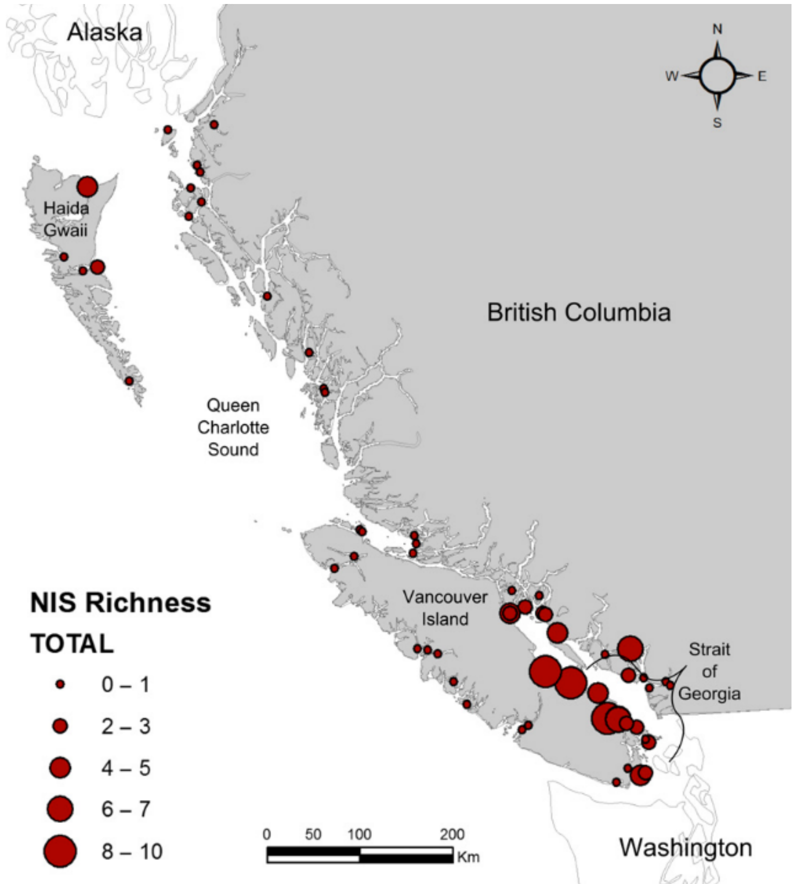


Figure 16. The richness of introduced species (here termed non-indigenous species; NIS) within marine fouling communities at each sampling sites. Marine fouling communities are those found on artificial surfaces like the sides of docks, marinas, harbours, and boats. Size of the circles corresponds to the number of non-native species at that site. From [141].

SHORELINE ARMOURING

- Disruption of shoreline physical structure and sediment dynamics has led to loss of important habitats such as seagrasses and spawning beaches.
- Armoured shorelines will also weaken coastal adaptation to sea level rise, preventing landward migration of habitats.

“Armouring a shoreline involves putting a static structure into a dynamic environment, where impacts and interactions are diverse and unpredictable” [155]. Shoreline armouring includes a variety of measures to stabilize coastal sediments, banks, and bluffs that would otherwise erode and compromise coastal infrastructure. It is one of the most widespread forms of coastal development, both on the south coast of BC in the Salish Sea, and worldwide [156].

These structures, placed at the interface of marine and terrestrial environments can disrupt processes in both systems. For example, Heerhartz et al. (2014) evaluated the changes in armoured beaches, particularly the accumulation of seaweed wrack (an important nutrient exchange from marine to terrestrial coastal habitats), and found that armouring altered beach structure and reduced the beach space available for accumulation [157]. Aside from beach habitat, armouring is also a contributor to change within other estuarine habitats [14,158], and as discussed in the forage fish section, can alter physical properties of important spawning habitat.

The impacts to coastal habitats from shoreline armouring are diverse, and depend on the environmental context in which the armouring is placed (e.g. sediment dynamics, wave energy and exposure), and changes to the coastal environment as a result of armouring occur over different time scales. For example, changes to seaweed wrack accumulation on shorelines occurs relatively quickly (days), while changes to the beach profile and grain sizes occur over longer periods (seasons to years; [156]).

Beach sediments are maintained by drift cells, sections of shorelines with source and deposition areas of sediments. Identification and classification of shorelines into drift cells can help to assess where degradation and disruption of shoreline processes are occurring, and may be indicative of habitat use for some species of forage fishes [159]. Shoreline armouring structures can contribute to disruption of drift cells, and continued monitoring of drift cells and fish habitat use may give insights into how to best protect and manage important fish habitat areas and the processes which maintain them.

The development of shoreline armouring is likely to increase with sea level rise and other climate change-related coastal impacts (e.g. increased storm frequency and severity) [158].

The seawall in Stanley Park, Vancouver.
Photo: Stanley Park Seawall, Flickr Creative Commons

ACOUSTIC HABITAT

- All types of marine life depend on sounds in their environment for important functions, from feeding, navigating, and reproduction.
- Human activities on the coast input noise into the marine environment that interferes with biologically important sound.

Marine life both produces, and responds to, sounds in their environment. All of the sounds present at a particular location together make up a 'soundscape'. When a soundscape is examined from the perspective of the animals that use and experience it, it is their 'acoustic habitat'.

Soundscapes have been shown to be important for many species from marine mammals to invertebrates. Many species of fish in BC's waters have now been shown to produce sounds [160], including Pink and Chum salmon, and Pacific Herring. It is believed that many more fish species produce sounds but have not yet been recorded.

Each coastal habitat has a unique soundscapes, and degraded habitats have different soundscapes than healthy ones. Sounds emitted from habitats, such as oyster reefs, are acoustic signals to planktonic marine life – larval oysters and fishes have been shown to respond to sounds emitted by environments as a signal for settlement [e.g. 160].

Like many regions of the world's oceans, BC's coastal environment is becoming noisier from human activities, including shipping, other boat traffic, and coastal development. As these rising noise levels impede the ability of marine life to communicate and respond to the soundscape of their environment, their acoustic habitat is degraded. International standards for measuring and mitigating noise levels have been developed, for example the European Union Marine Strategy Framework Directive (2008/56/EC) suggests that the annual average ambient noise level should not exceed 100dB, though shipping noise in some areas of the BC coast exceeds this (Figure 17) [162].

Studies of species- and population-specific loss of acoustic habitat has been explored for cetaceans on the BC Coast [163], and increasing knowledge of other species' interactions with underwater sounds and human-generated noise provides evidence that degradation of acoustic habitat is occurring in many coastal habitats (e.g. [164]).

Additionally, some noise sources can cause direct physical injury to marine life. Laboratory-based studies have shown barotrauma injuries to juvenile Pacific salmon from pile driving sounds [165,166]. Pile-driving activities occur during construction of coastal infrastructure, such as docks or marine terminals (e.g. ferry, other vessel traffic).

Successful noise management initiatives have been trialled within critical habitat of Southern Resident Killer Whales in the Salish Sea [167]. The ECHO Program vessel slowdown initiative, ongoing seasonally since 2017, is a voluntary request to vessels to reduce their speeds when transiting Haro Strait to 15 knots or less for vehicle carriers, passenger ships and container ships, and 12.5 knots or less for bulk ships, tankers, Washington State Ferries and government ships. Participation has been increasing over the years, and has led to a successful reduction in noise intensities in the area. Implementation of these types of measures in other areas of the coast, or further protections for quiet areas of the coast from noise inputs are opportunities to expand noise management for the wide range of coastal species which rely on acoustic habitat [168].

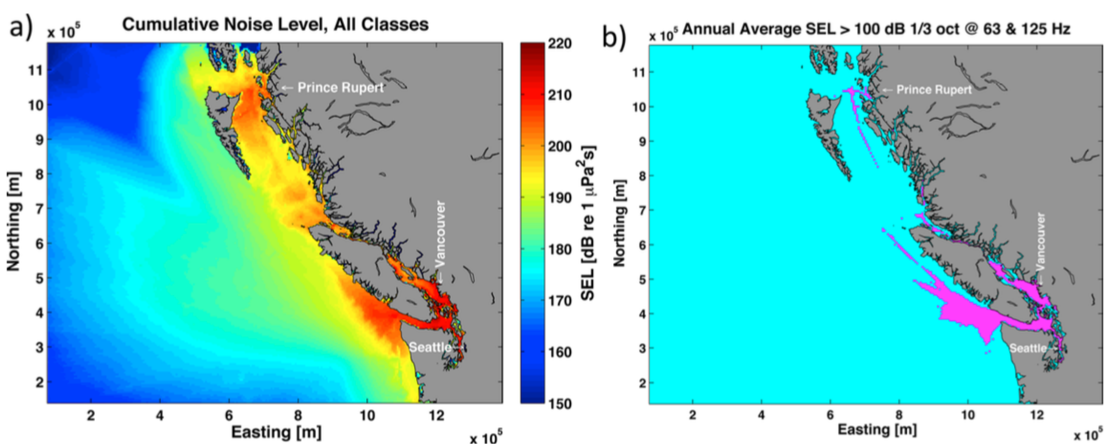


Figure 17. Mapping cumulative noise from shipping along the BC coast to inform marine spatial planning. a) Cumulative sound exposure levels from vessel traffic between January and December 2008. b) Areas where the estimated average sound pressure levels exceed the EU Marine Strategy Framework Directive of 100dB. From Erbe et al. 2012 [162].

CLIMATE CHANGE

- Stressors on coastal habitats and species due to climate change impacts are pervasive and compound in areas of high human impact.
- Protecting key habitats from human impacts supports resiliency and adaption to climate change, and should incorporate accounting for the benefits of carbon sequestration by vegetated coastal habitats (blue carbon).

The diverse pressures resulting from climate change within marine environments, including increasing sea temperatures, ocean acidification, and increased ultraviolet radiation levels (which in turn influence several oceanographic processes, such as changes in upwelling of deeper water layers, rising sea levels, increased storm frequency, changed precipitation patterns which influence coastal salinity levels and runoff from land), will drive a multitude of responses within coastal ecosystems [169].

Responses to climate change within coastal ecosystems will be shaped by impacts to, and responses of, key species and habitats. In BC, these include those features reviewed within this report: kelps, eelgrass, keystone predators (such as the purple sea star, *Pisaster ochraceus*), forage fishes, as well as salmon, invertebrates, and plankton [170].

Local and regional influences will shape how species and habitats respond along the coast. For example, decades of daily sampling at lighthouse stations along BC's coastline indicate that the Strait of Georgia has showed a higher rate of sea surface temperature increase than the global average, and is also higher than the northern BC coast [171].

All of the species, habitats, and other pressures reviewed in this report are, and will continue to be, affected by climate change influences. Multiple reviews of the impacts of climate change to BC's coastal marine ecosystems highlighted that strategic protection of key species and habitats, and protection of biodiversity and ecosystem services are critical to support climate adaptation [170,172]. Additionally, the development of coordinated scientific monitoring for marine ecosystems is necessary to detect, understand, and respond to changes [172].

BLUE CARBON

Blue carbon is carbon that has been sequestered and stored by coastal and marine ecosystems. Many marine ecosystems and their species play important roles in carbon cycling. Globally, marine ecosystems (primarily vegetated coastal ecosystems like mangrove forests, seagrass beds, and salt marshes) have been estimated to sequester carbon at rates 35 times higher than tropical rainforests despite having a much smaller areal extent [173].

The soils of salt marshes are an important contributor to carbon storage, though their storage rates have not been well studied in BC or the rest of the Pacific coast of North America. Recently, carbon accumulation rates were assessed within part of the Boundary Bay salt marsh in Delta [48] and for salt marsh areas within Clayoquot Sound [174]. Studies of eelgrass meadow carbon sequestration in BC suggest that although eelgrass in temperate regions sequesters carbon at a lower rate than species in tropical regions, these habitats still provide important carbon storage relative to other, non-vegetated coastal habitats [16,22,175,176].

Kelp and other macroalgaes have also been identified as a major contributor to carbon sequestration in coastal environments due to their rapid growth and production of large amounts of detritus that can be sequestered in sediments [177,178]. Though estimates of rates and production have been conducted, these have not yet been performed specifically for conditions and species on the BC coast. A recent study of Australia's vegetated coastal habitats found that kelp made large contributions to carbon storage and sequestration, and that potential changes to kelp forest area would have important impacts to carbon accounting strategies in the decades ahead [179].

The BC Parks Conservation Policy for Ecological Reserves, Parks, Conservancies, Protected Areas and Recreation Areas (2014) includes considerations of climate change within the provincial protected areas system, but does not include management of carbon sinks or sources [180]. Recognizing and understanding the value of these vegetated coastal ecosystems for blue carbon is important in order to support and plan for their protection and restoration.

VULNERABILITY & PROTECTION OF FEATURES

VULNERABILITY

Human activities, pressures, and threats interact with coastal habitats and species in different ways and at various scales as reviewed in the sections above. Changes to habitats may also have run-on impacts to the species they support in ways we do not yet understand.

Different habitat types are also differentially impacted by various pressures across spatial scales, particularly due to concentrations of human activities. The response of species or ecosystems to multiple pressures is difficult to elucidate and understand. Where coastal habitats are impacted by both marine-based and land-based activities, the importance of understanding the cumulative impacts of multiple stressors is compounded [181]. Recent developments in cumulative impact mapping for the BC coast have collected information on land-, coastal-, and marine-based activities and stressors in order to map impacts onto marine habitats [182–185]. These studies have shown that growing levels of human activity are resulting in the highest impacted areas being within the Strait of Georgia on the south coast, and also increasingly the northern coast around Prince Rupert and the Skeena estuary (Figure 17) [184]. Coastal, and land-based activities have high levels of impact within a localized area, resulting in intertidal areas (mudflats, salt marshes, beaches, rocky intertidal areas and reefs, and seagrasses) being some of the highest impacted habitats [1,183,184,186]. These studies have also highlighted that the areas with high levels of local stress are the most vulnerable to climate change stressors [185].

These studies indicate the need for management actions that will bolster the resilience of the most vulnerable areas and habitats on the coast. Though coastal planning has taken place for some areas or habitats in BC, there is a need for coordination of planning and management efforts across the coast that takes into account the spatial scale of cumulative effects, encompasses the full scope of pressures on these systems, and can utilize appropriate regulatory measures to mitigate these pressures. Ecological resilience is also supported through replication of representative features and species across a protected area system, or network [187]. Protected areas can also serve as a reference for monitoring change, biological responses, and relative impact of human activity.

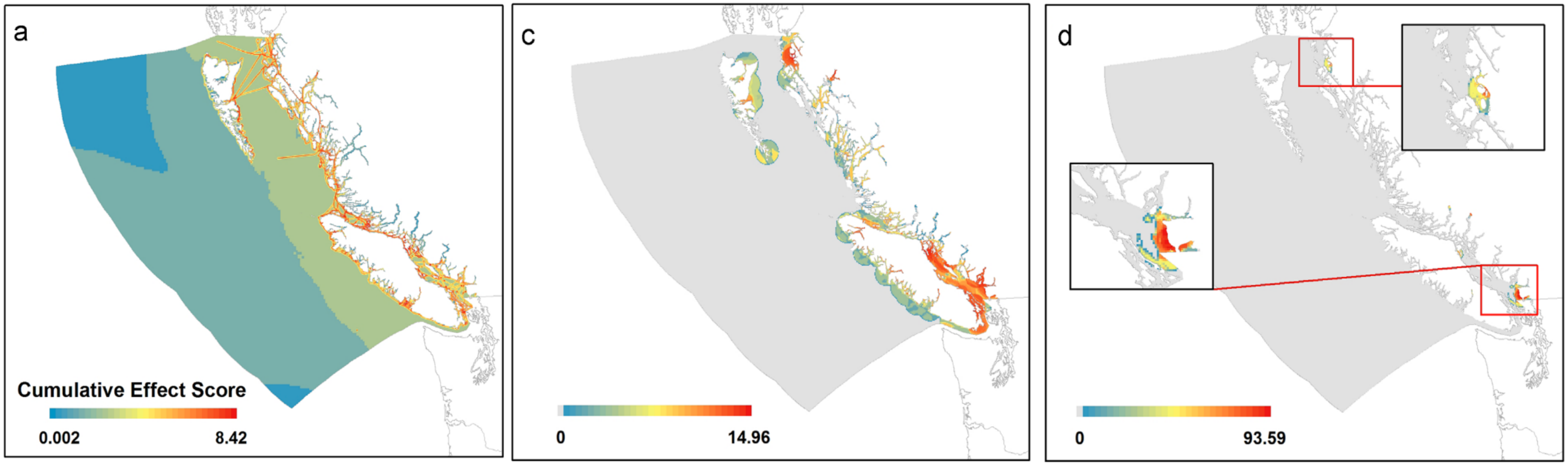


Figure 17. Cumulative effects score by activity class (a) marine, (c) coastal, and (d) land. Note that the colours are the same but the values differ across the panel. From Clarke Murray et al. 2015 [145] .

Human activities included in analysis:

(a) Marine	(c) Coastal	(d) Land
Aquaculture: finfish Aquaculture: shellfish Disposal at sea (Ocean dumping, marine debris) Recreational boat routes Shipping: commercial, cruise	Human settlements (coastal) Industrial tenures (coastal) Log booms Marinas Ports Pulp and paper mills Recreational fishing lodges	Agriculture Human settlements Forestry cutblocks Forest service roads Industrial tenures Mining Paved roads Pipelines

PROVINCIAL PROTECTION & MANAGEMENT

BC has had multiple protected area policies which recognize the need for representative biodiversity protection [e.g. 152,160,161], ecosystem based management, and the conservation of ecological integrity within provincial parks and protected areas. Provincial protected area designations cover over 2500km^2 of the BC coast within the 11 recognized marine ecosections, under various legislation, including as Parks, Ecological Reserves, Conservancies, and Wildlife Management Areas (Figure 18).

Agency: British Columbia Ministry of Environment (Provincial)
Goal 1: Representativeness
To protect viable, representative examples of the natural diversity of the province, representative of the major marine ecosystems, the characteristic habitats, communities and cultural heritage values of each marine ecosection
Goal 2: Special features
To protect the special natural, cultural heritage and recreational features of the province, including rare and endangered species and critical habitat, outstanding or unique botanical, zoological, geological and paleontological features, outstanding or fragile cultural heritage features and outstanding recreational features.
Legislation: Ecological Reserve Act; Protected Areas of British Columbia Act; Park Act; Wildlife Act; Land Act; Environment and Land Use Act

Designation	Number	Area (km^2)
Ecological Reserve (ER)	20	513
Protected Area (PA)	2	< 1
Provincial Park (PP)	93	688
Wildlife Management Area (WMA)	6	216
Conservancy (CON)	28	1082
Recreation area (RA)	1	< 1

Figure 18. BC's provincial legislative tools, designations and associated goals for protected areas, from Robb et al. 2011 [190].

British Columbia's Protected Area Strategy (1993) outlines two goals:

1) To protect viable, representative examples of the natural diversity of the province, representative of the major terrestrial, marine and freshwater ecosystems, the characteristic habitats, hydrology and landforms, and the characteristic backcountry recreational and cultural heritage values of each ecosection.

2) To protect the special natural, cultural heritage and recreational features of the province, including rare and endangered species and critical habitats, outstanding or unique botanical, zoological, geological and paleontological features, outstanding or fragile cultural heritage features, and outstanding outdoor recreational features such as trails [188].

Similarly, goal 1 of the Canada-British Columbia Marine Protected Area Network is "to protect and maintain marine biodiversity, ecological representation and special natural features" [191].

To assess how the features reviewed in this report are represented within the provincial protected areas system, the Management Plans, Purpose Statements, or Management Direction Statements, and webpages of provincial protected areas (as listed by Robb et al. 2011 [190]).

This list included 144 Parks, Ecological Reserves, and Conservancies, 1 Municipal Park (Whytecliff Park), and 6 Wildlife Management Areas. Of these, 36 had Management Plans available, and 68 had a Purpose Statement or a Management Direction Statement available. Though management plans are not a legal requirement for parks, there is an established management planning process, and they are described by BC parks as key tools for the protection of the features and values within a protected areas, and to define the protected area's role within the provincial protected areas system [189].

Salmon, shellfish, species at risk, and estuaries were the most common features mentioned as being included in protected areas (Table 1). None of the protected area descriptions included the extent of the features included. Absence of mentions does not indicate that these features are not present within protected areas, but do suggest that the presence or extent of these features have not always been assessed or included within protected area or management planning. Knowledge of the location and distribution of important coastal habitats and features such as these are a key part of achieving representation goals beyond areal representation goals.

Marine protection representation goals for ecosections have been reported on within some Purpose Statements, Management Plans, and within past provincial updates (e.g. Figure 19), however many of the Management Plans or Purpose Statements were produced in the early 2000s, and more recent updates on ecosection representation in the provincial marine protected area system are either unavailable or have not been conducted. These goals for representation of ecosections appear to be primarily area-based, and not focused on coverage or inclusion of particular habitats or species. Protected areas along the BC coast have been established mostly on a site-by-site basis, are a range of sizes with differing objectives and restrictions [192].

Table 1. Mentions of features reviewed in this report within Management Plans, Purpose Statements, Management Direction Statements, or on the protected areas webpage if plans or statements not available.

Feature	# Protected Areas which mentioned feature
Coastal Sand Habitat	16
Eelgrass	12
Estuary	32
Forage Fish	17
Kelp	17
Mudflat	7
Salmon	39
Salt marsh	10
Sea Stars	10
Shellfish	38
Species at risk	38

The conservation of ecological integrity is one of the key aims of the provincial protected areas system. Goal 1 of the BC Parks Program Plan (2007-2012) was that "BC Parks is recognized for its leadership in the proactive stewardship of ecological and cultural integrity" [193]. The 2014 BC Parks Conservation Policy for Ecological Reserves, Parks, Conservancies, Protected Areas, and Recreation Areas states that, "when required to achieve the objectives of a protected area management plan, marine plans may be prepared to guide actions and will reflect, above all else, the primary importance of ecological processes and the maintenance of ecological integrity"[180]. BC Parks defines ecological integrity to be "when an area or network of areas supports natural ecosystem composition, structure and function, and a capacity for self-renewal"[194]. The Federal Oceans Act has recently been amended to include the conservation and maintenance of ecological integrity as a reason for designating a federal marine protected area and defines ecological integrity as "a condition in which (a) the structure, composition and function of ecosystems are undisturbed by any human activity; (b) natural ecological processes are intact and self-sustaining; (c) ecosystems evolve naturally; and (d) an ecosystem's capacity for self-renewal and its biodiversity are maintained" [195].

Though BC Parks notes that as objectives of provincial parks and protected areas range from recreation to wilderness conservation, objectives for ecological integrity will not be implemented in the same ways across protected areas [194]. However, a report from the BC Auditor General in 2010 concluded that the parks and protected areas system have not been designed to ensure ecological integrity, and that little action has been taken to ensure the conservation of ecological integrity across terrestrial and marine areas [196]. One of the weaknesses found in this report was that the size of many parks and ecological reserves is too small to maintain ecological integrity.

Provincially protected areas that include marine components tend to be small. Robb et al. (2015) found that marine protected areas on the BC coast encompass an average of 74km^2 of marine area, though 75% of these areas were smaller than 10km^2 each [192]. Additionally, many of these areas allow extractive activities despite management objectives intending to prohibit them, and many lack management plans [190,192]. Over half of these protected areas encompass predominantly terrestrial areas with smaller marine areas, while only a few encompass solely marine areas [190]. Management objectives for these areas may be set for the terrestrial component, and not implemented within the marine areas.

Activities within parks require permits, and for most areas, the activities must be "necessary to preserve or maintain the recreational values of the park involved"[197]. Access to ecological reserves is only allowed for "ecological scientific research or educational purposes" [198]. In Wildlife Management Areas the regional manager must grant permission for any activities that use land or resources, and "limited or modified resource based activities" may be allowed in WMAs [199]. The Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) now administers WMAs.

Coastal planning was undertaken for eight areas around northern Vancouver Island in the early 2000s, including for some smaller coastal and estuarine areas, such as Baynes Sound [200] and Cortes Island [201]. The planning was intended to guide decision making around a number of specific activities in those areas (such as shellfish aquaculture). For the most part the plans were not legally implemented, have not been updated since their creation [202], and a reorganization of aquaculture regulatory responsibility between the provincial and federal governments in 2009 [203], means that many of these plans are outdated.

Management and protection of some coastal areas has also been undertaken by privately-led initiatives, such as by the Nature Trust of BC [204], The Land Conservancy [205], or the Habitat Conservation Trust Foundation [206], which acquire privately owned land area for conservation purposes. These are often managed in partnership with other organizations, communities, or governments [207].

Around the same time period, the province also supported the development of estuary management plans in several locations [208]. For some of these locations, management frameworks were implemented through a provincial cabinet order, or a Memorandum of Understanding [209], but none have been fully implemented in regulations.

Many First Nations have developed marine use or fisheries plans for their territories [210–212]. For Nations on the north coast, some of these plans have been collaboratively included within marine planning processes (see discussion of Marine Planning Partnership below). However, in other areas, there is a need for updated provincial planning that supports these marine plans.

The recent Northern Shelf Bioregion (NSB) Marine Protected Area network planning is the first systematic MPA protection planning that has been undertaken in Canada. The proposed network scenarios are working toward meeting goals for representation of ecosections and goals for inclusion of priority species [213]. Concurrently, implementation of the Marine Planning Partnership plans (2015) for the NSB is being undertaken, and includes the production of new management plans for the Protection Management Zones (PMZ) that were identified through planning processes, development of indicators and monitoring for these areas, and development of projects (e.g. marine spill planning) [214].

The MaPP process compiled spatial data for the northern shelf bioregion from over 250 data layers to inform planning, these included administrative boundaries, species, habitats, and marine uses [214]. These were provided for public viewing on the web-based planning tool SeaSketch [215]. As part of the MPA network planning process for the northern shelf bioregion, a Conservation Gaps Analysis was undertaken, which included a review of the existing marine protected areas within the bioregion to evaluate the degree to which each protected area meets ecological objectives for the network. As both these processes move forward, this spatial data will be essential to implementation of marine protected areas and management zones, as well as providing some baseline information on the features by which monitoring can occur.

Conducting similar systematic planning for species and habitats within southern BC (including the Strait of Georgia and West Coast of Vancouver Island regions), may be even more important due to higher vulnerability from concentration of human impacts and cumulative effects, especially within the Strait of Georgia. Extensive habitat loss has occurred in some critical habitat areas, such as the Fraser River Estuary, placing these areas at tipping points from compounded pressures of ongoing human activities and climate change impacts.

In BC, coastal planning initiatives have been primarily undertaken at smaller and local-scales (e.g. at the scale of a single-estuary or within a limited coastal area) without an overarching direction or strategy to coordinate planning along the coast, and to date there has been little to no regulatory support to implement such planning. These management gaps are highlighted when contrasted with jurisdictions that have introduced coastal zone management programs and legislation, including those which have requirements for development of local-scale management plans across a large-scale coastline,[2] large-scale marine spatial plans that have legal backing,[3] or specific strategies for climate change impacts to coastal areas.[4]

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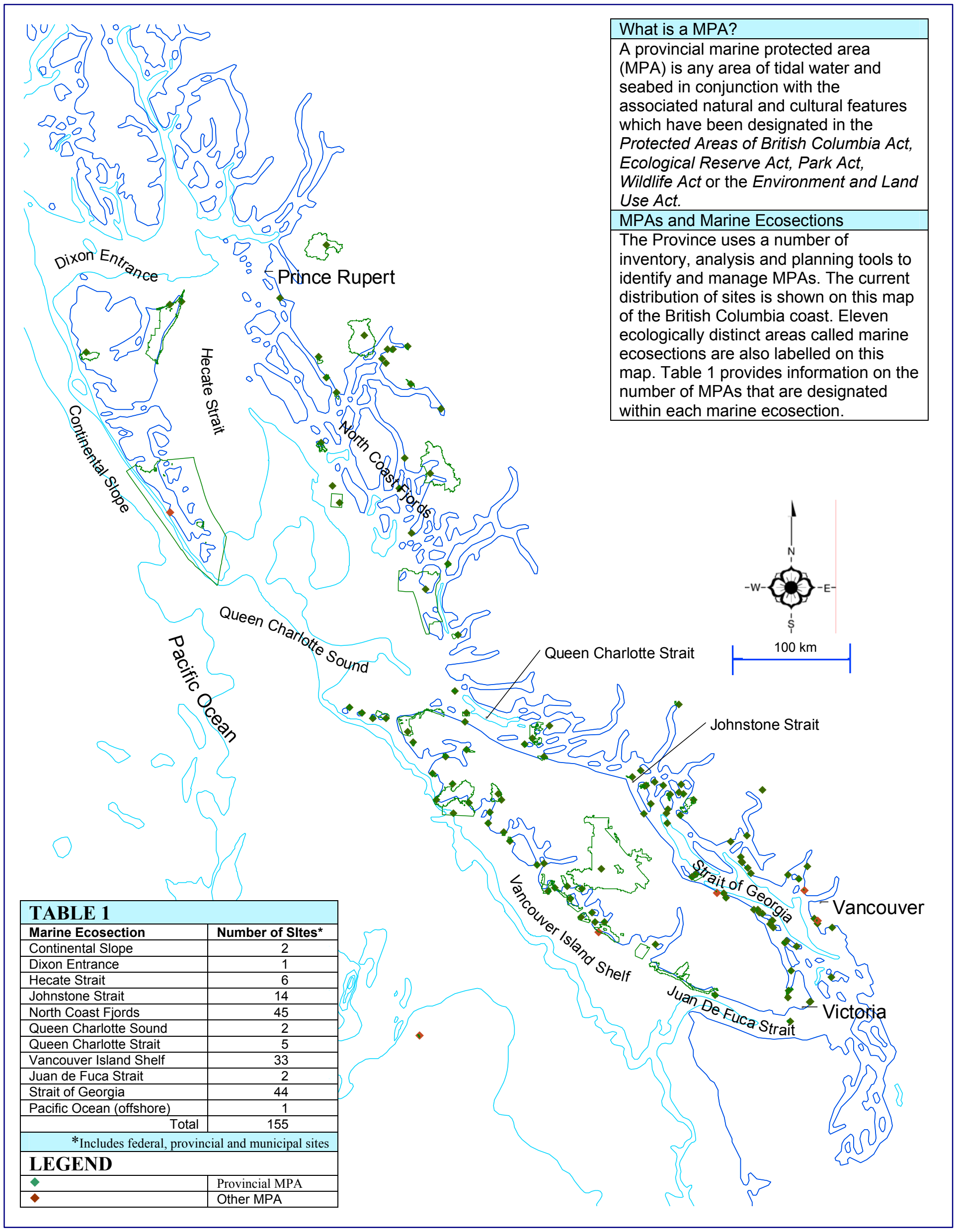
[2] The state of California's *Coastal Act* requires local governments to develop local coastal programs (LCPs) that then are approved and must be complied with by all public agencies [228].

[3] Washington State's Marine Spatial Plan for Washington's Pacific Coast has legal backing from the *Washington Marine Waters Planning and Management Act*, requiring state decisions to be consistent with the approved marine spatial plan [229]. Scotland's *Marine (Scotland) Act 2010* requires both the development of a national marine plan and regional marine plans, which must be accounted for in decision-making.

[4] The province of Nova Scotia recently introduced a *Coastal Protection Act* that includes important principles for regulating and managing the coastal environment, including recognition of the contribution of coastal development to erosion and preventing natural adaptation of habitats to sea level rise, and recognition that protecting coastal ecosystems will allow for natural adaptation and conserve ecological functioning [230].



Marine Ecosection	Number of Sites*
Continental Slope	2
Dixon Entrance	1
Hecate Strait	6
Johnstone Strait	14
North Coast Fjords	45
Queen Charlotte Sound	2
Queen Charlotte Strait	5
Vancouver Island Shelf	33
Juan de Fuca Strait	2
Strait of Georgia	44
Pacific Ocean (offshore)	1
Total	155

*Includes federal, provincial and municipal sites

Figure 19. Provincial and other Marine Protected Areas in British Columbia in 2007, with numbers of sites per ecosection [216].

RESTORATION

Globally, active restoration of marine and coastal habitats has contributed to the recovery and management of degraded areas and species [217]. Though restoration projects rarely achieve the same productivity or biodiversity as the original habitat, and monitoring of restoration sites required to assess success is often not carried out over the long-term.

Canada's *Fisheries Act* protects fish habitat from 'harmful alteration, disruption or destruction', and regulates activities proposed within fish habitat guided by the No Net Loss of ecological function principle. Under this principle, habitat compensation projects (i.e. habitat restoration or creation) may be required for projects within fish habitat. Compensation projects have not yet proven to be widely successful. A study of 16 freshwater habitat compensation projects by Quigley and Harper (2006), found that only a quarter of these projects achieved no net loss [218]. Similarly, an assessment of 71 wetland compensation sites in the Lower Fraser River in 2015 found only one-third of these sites to be considered successful [219].

In Washington State, the *Shoreline Management Act* also incorporates the principle of no net loss of ecological function, and requires compensation if development in the nearshore impacts eelgrass habitat [220].

Eelgrass restoration through transplant of shoots has had some success in BC [136], and several projects are led by community groups (e.g. the Squamish River Watershed Society [221]). Restoration projects require sustained investment and planning to ensure successful contribution to coastal ecosystems.

MAPPING

Knowledge of the locations and extent of habitats is crucial to management of human activities that impact them and to understand changes in these features. Many localized and regional mapping efforts have been undertaken on the BC coast. Some examples of these are:

- The Marine Ecosystem Reference Guide (MERG), developed by West Coast Aquatic, gathered information concerning local environments and natural resources, economies, social systems and different uses and activities in the Barkley and Clayoquot Sound regions in 2018 [222]. The Guide was originally intended to be a marine spatial plan resulting from the production of a Coastal Strategy for the West Coast of Vancouver Island in 2012 [223], but evolved into a decision-support tool for the region.

- The Islands Trust Conservancy, partnered with several organizations including the SeaChange Marine Conservation Society and individual island conservancies such as the Mayne Island Conservancy, funded a three-year mapping project of the of the eelgrass beds in the waters surrounding Canada's islands in the Salish Sea. This project, along with other mapping layers (including forage fish observations), and administrative features, have been put together on an interactive map tool [224] (Figure 20).

- The Discovery Islands Ecosystem Mapping project, led by the Surge Narrows Community Association, began in 2012 to map the Discovery Islands watersheds basin, and sensitive ecosystems. The project is primarily focused on land-based mapping but includes mapping of estuaries and intertidal areas. This community-based mapping project supports community involvement and land use decisions [225].

- The David Suzuki Foundation and Ocean Wise headed a mapping project in Atl'ḵa7tsem/Howe Sound, completed in 2019, which produced an online interactive map as well as modelling analyses of conservation and marine biodiversity hot spots for protection and management [226] (Figure 20).

- Ducks Unlimited Canada has led mapping of 442 coastal estuaries on the BC coast with the goal of restoring and conserving estuary and coastal wetland habitat [227].

- The British Columbia Marine Conservation Analysis (BCMCA; 2006–2013) online atlas provides spatial data for many features. The Atlas was developed to collaboratively identify marine areas of high conservation value and areas important to human use in Canada's Pacific Ocean. These data layers were one of the primary tools used in the MaPP process [214]. Though, for many layers, the Atlas notes that survey efforts are not consistent across all areas of the coast and some species tend to be under-represented by some survey methods. Additionally, some of data for certain areas may be outdated. For example, eelgrass mapping included in this Atlas has been conducted over many decades, from the 1890s to 2000s.

These projects, as well as many others, are contributing to building our knowledge of the coastal habitats along the BC coast, and can be used to make management and protection decisions, as well as to understand how these features may change in the future. However, these mapping efforts have been undertaken by various non-government organizations, communities and volunteers, and the data exists in multiple different repositories, making it challenging to identify where data gaps exist and to examine regional-scale impacts and changes.

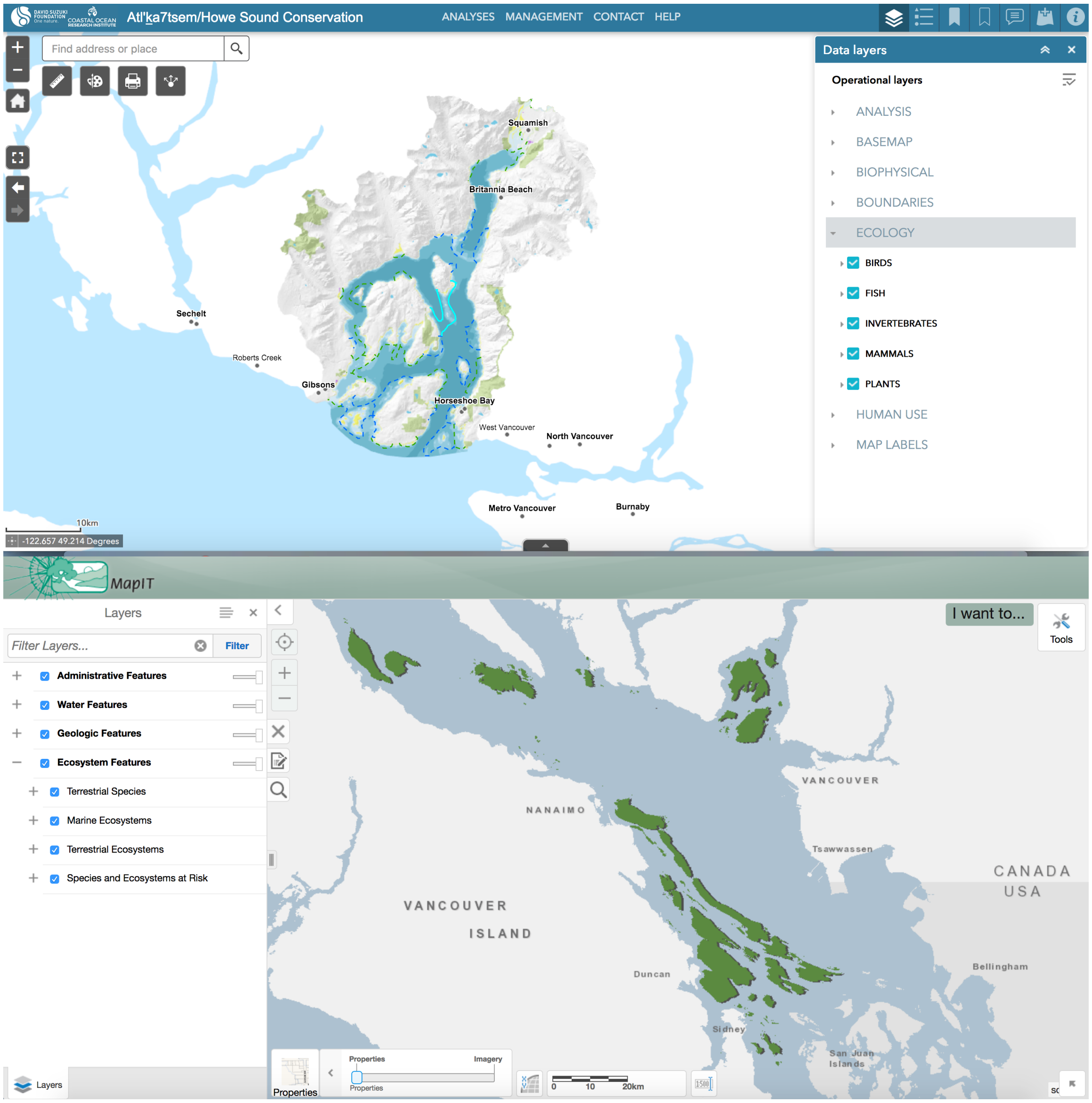


Figure 20. Screenshots from the online interactive mapping platforms discussed here. TOP: The David Suzuki Foundation's Atl'ka7tsem/Howe Sound marine conservation map [226], BOTTOM: The Islands Trust Conservancy's MapIT Shoreline Application: Salish Sea marine habitats [224].

CONCLUSION

BC's coastline is vast and diverse, and supports coastal communities socially, culturally, and economically. More than 75% of the province's growing population of over five million lives within 50 km of the coast.

Decades of increasing industrial activity have led to increased impacts and stresses on coastal ecosystems that make it difficult to understand baseline conditions and to assess cumulative impacts. However, changes in condition and population status in those species and habitats that have been studied are raising concerns regarding the long-term outlook for the coast.

Multiple processes and initiatives along the coast are responding to these concerns and acting to monitor, plan, manage, and protect these valuable habitats and species. Many of these are locally based initiatives, collaborations of wider communities or institutions (e.g. Hakai Institute), and First Nations led (e.g. the Central Coast Indigenous Resource Alliance; CCIRA).

The implementation of marine planning and a marine protected area network on BC's northern coast will contribute to conservation of key and vulnerable habitats on the less populated regions of the coast, in areas of lower cumulative impact from human activities, and can serve to drive coordinated monitoring over larger spatial and temporal scales than has been achieved before. However, this leaves a gap for the more vulnerable areas of the southern coast, where some planning, monitoring and mapping efforts have occurred sporadically but are in need of updating and regulatory support.

A coast-wide strategy is needed that:

- supports ongoing processes,
- fills gaps in planning and management needs,
- serves to connect and coordinate people along the coast
- implement management strategies,
- builds our knowledge of key habitats, species, and human and non-human stressors impacting the coast, and
- detects responses and facilitates adaptations to changes.

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