Conceptual models of major ecosystems in Canada's Pacific Ocean

Sharon Jeffery, Patrick L. Thompson, Candice St. Germain, Cathryn Murray, Jocelyn Nelson, Beatrice Proudfoot, Selina Agbayani, Jessica Finney, Emily M. Rubidge, Norma Serra Sogas, Joy Wade, Sarah Dudas, and Carolyn K. Robb

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CONCEPTUAL MODELS OF MAJOR ECOSYSTEMS IN CANADA'S PACIFIC OCEAN

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Jeffery, S., Thompson, P.L., St. Germain, C., Murray, C., Nelson, J., Proudfoot, B., Agbayani, S., Finney, J., Rubidge, E.M., Serra Sogas, N., Wade, J., Dudas, S., Robb, C.K. 2023. Conceptual models of major ecosystems in Canada's Pacific Ocean. Can. Tech. Rep. Fish. Aquat. Sci. 3556: : ix + 228 p.

To aid **marine spatial planning** initiatives in Canada's Pacific Ocean, we developed a suite of conceptual models depicting the major ecosystems in our region. These range from the intertidal to the deep sea, including: High and low energy rocky shores, High and low energy soft shores, Rocky and soft bottom **subtidal**, Pelagic, Estuaries, Fjords, Hydrothermal vents, Seamounts, Bathyal plains, and Cold seeps. For each ecosystem, a series of four illustrations were developed. The first outlines the main ecological components of the ecosystem, including flora and fauna, and non-living components such as **whale falls**. The second outlines key ecological interactions, including predator-prey and competitive relationships. The third outlines the main environmental drivers (e.g., wave action, tides) influencing the species and their interactions. Finally, the fourth illustration outlines the main human activities impacting each ecosystem (e.g., fishing, agriculture). In order to illustrate the ecosystems there was a need to simplify their complexity; for example, full species lists and complete food webs were not outlined. To provide a general understanding of each ecosystem we included only the most important, representative, or iconic components. Together, the illustrations described here depict what is living and happening in each ecosystem, and can be used to inform **marine spatial planning** and as a tool to help non-scientists understand the ecosystems on our coast.

RÉSUMÉ

Jeffery, S., Thompson, P.L., St. Germain, C., Murray, C., Nelson, J., Proudfoot, B., Agbayani, S., Finney, J., Rubidge, E.M., Serra Sogas, N., Wade, J., Dudas, S., Robb, C.K. 2023. Conceptual models of major ecosystems in Canada's Pacific Ocean. Can. Tech. Rep. Fish. Aquat. Sci. 3556: ix + 228 p.

Pour faciliter les initiatives de planification spatiale marine menées dans la zone canadienne de l'océan Pacifique, nous avons établi une série de modèles conceptuels décrivant les principaux types d'écosystèmes de notre région. Ces écosystèmes, qui s'étendent de la zone intertidale à la haute mer, comprennent des rivages rocheux à faible et haute énergie, des rivages sablonneux à faible et haute énergie, des zones rocheuses subtidales, des zones subtidales à fond meuble, des zones pélagiques, des estuaires, des fjords, des cheminées hydrothermales, des monts sous-marins, des plaines bathyales et des suintements froids. Pour chaque écosystème, une série de quatre diagrammes illustrés a été mise au point. La première décrit les principales composantes écologiques de l'écosystème, comme la flore et la faune, ainsi que les composantes non vivantes, comme les carcasses de baleines. La deuxième présente les principales interactions écologiques entre ces composantes, y compris les relations prédateur-proie et les relations de concurrence. La troisième illustration présente les principaux facteurs environnementaux (p. ex., l'action des vagues, les marées) qui influencent les espèces et leurs interactions. Enfin, la quatrième illustration présente les principales activités humaines qui ont des répercussions sur chaque écosystème (p. ex., la pêche, les ports et l'agriculture). Il a fallu réduire la complexité des écosystèmes afin de les illustrer. Par exemple, des listes d'espèces complètes et des réseaux alimentaires détaillés ne pouvaient pas être clairement représentés dans les illustrations. Afin de permettre une compréhension générale de chaque écosystème nous avons inclus les éléments les plus importants, les plus représentatifs ou les plus emblématiques. Ensemble, les séries de représentations des écosystèmes décrites ici brossent un portrait de ce qui vit et de ce qui se passe dans chaque écosystème, et peuvent être utilisées pour orienter les exercices de planification spatiale marine ou pour aider les non-scientifiques à comprendre les écosystèmes de notre littoral.

1 INTRODUCTION

The Pacific Ocean along the coast of British Columbia (BC) is home to complex and biodiverse marine ecosystems, from estuaries and rocky shores, to offshore hydrothermal vents and seamounts. The services provided by these ecosystems support abundant marine species and habitats, underpin the cultures and economies of communities across this coast, and are key considerations in **marine spatial planning** (MSP) initiatives; the development and monitoring of **marine protected areas** (**MPA**s); cumulative impact mapping; and emergency response planning.

To inform these initiatives, we need to understand the major ecosystems in Canada's Pacific Ocean. Conceptual models are a representation of a system, such as an ecosystem, and can be used as a tool to help foster an understanding of the subject they represent. To help with planning initiatives, we developed a suite of thirteen conceptual models representing the major ecosystems within Canada's Pacific Ocean, from the British Columbia (BC) coastline to the boundary of the Canadian Pacific Exclusive Economic Zone (EEZ)(Figure 1).

Our conceptual models provide a general overview of the components and processes within each ecosystem. For each ecosystem, we created a series of four illustrations depicting: the main ecological components, key interactions between ecological components, main environmental drivers, and most common human activities including climate change **stressors**. The ecological components include representative species and habitats found within each ecosystem, with a focus on including Ecologically Significant Species (ESS) (DFO 2006a), and species of **conservation concern** (e.g., Gale et al. 2019), wherever possible. Key interactions between the ecological components (including predator-prey and competitive relationships) are depicted in the ecological interactions illustration, while environmental drivers that shape each ecosystem, such as wave action, **upwelling** and tides, are detailed in the environmental drivers illustration. In the fourth illustration, we describe human activities, including climate change drivers for each ecosystem.

In this report we outline:

1. Our process for creating these models;
2. A description of each ecosystem, including the ecological components, interactions, environmental drivers, and human activities;
3. Application of the models for MSP and other planning initiatives.

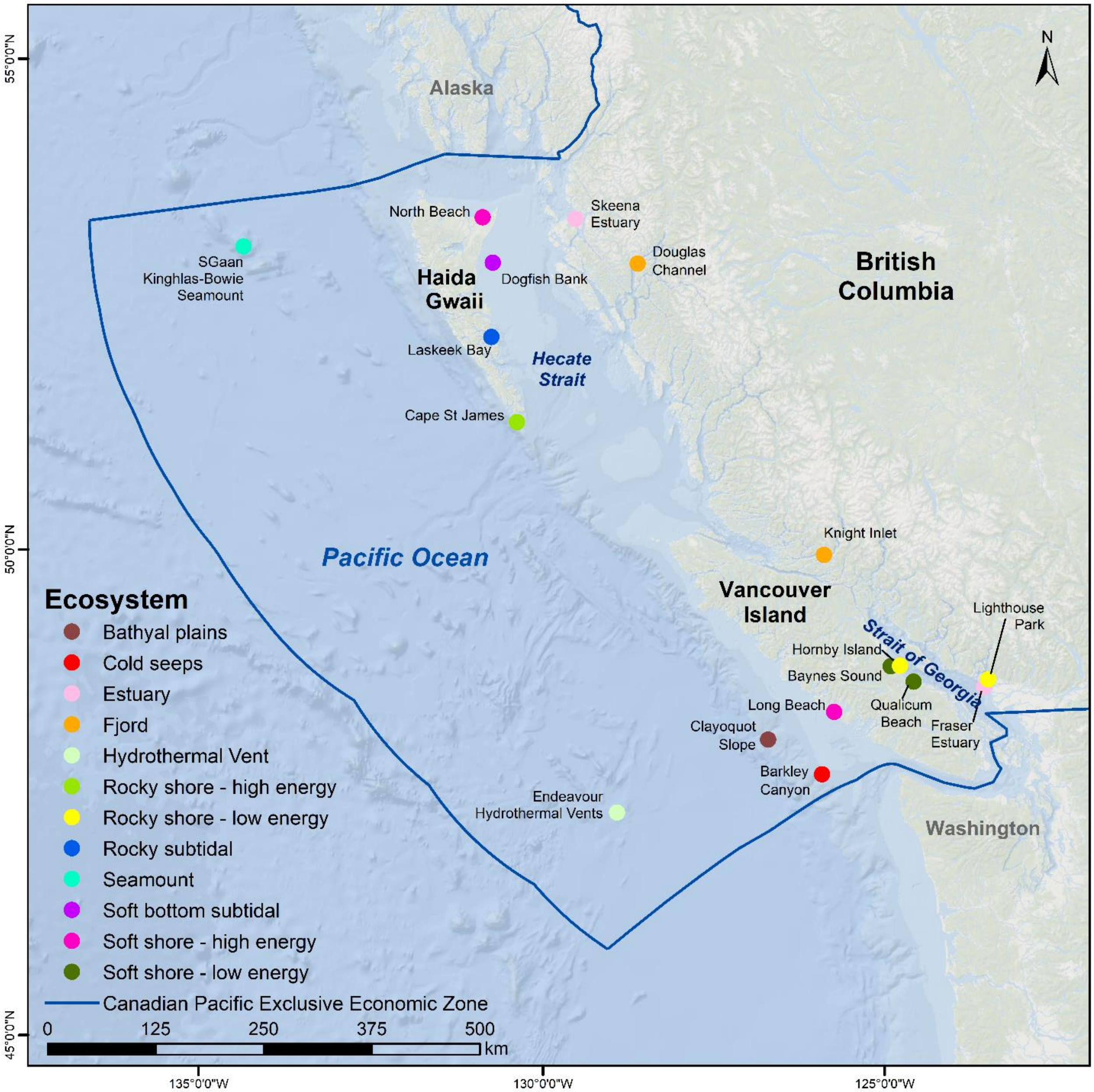

Figure 1. Map of BC showing the Canadian Pacific Exclusive Economic Zone, and locations used as examples for each ecosystem inTable 2.

2 CREATION OF ECOSYSTEM CONCEPTUAL MODELS

2.1 Ecosystem selection

The first step in creating ecosystem conceptual models was to identify the major ecosystems in Canada's Pacific Ocean. To select these ecosystems, we reviewed conceptual models developed to support MSP in other jurisdictions (e.g., the coast of Washington State by Andrews et al. (2013), and within the Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site by

Martone et al. (2016)). These models focused on shallow, coastal ecosystems. For instance, model development in Washington State included the waters and habitats within the MSP planning boundary, which extends 35-55 nm offshore (Andrews et al. 2013). Similarly, conceptual models developed by Martone et al. (2016) were focused within the planning boundary of the National Marine Conservation Area Reserve (NMCAR), which extends around Haida Gwaii to approximately 5 nm offshore. Because the area represented by our models extends to the 200 nm limit of the Canadian Pacific EEZ (Figure 1), we expanded on the ecosystems chosen in these past projects to include ecosystems present in the larger geographic area encompassed by our project (e.g., fjord systems, offshore areas, etc.), including a suite of deeper ecosystems that have not been represented previously.

Previous work by Murray et al. (2015) in the Canadian Pacific Ocean classified habitats to support cumulative impact mapping. This work covered the same geographic area described here (i.e., the entire Canadian Pacific EEZ). While the scale of the cumulative impact mapping habitat classes developed by Murray et al. (2015) was smaller than the ecosystems developed in this project, the classes were useful to help inform our delineation of ecosystems.

The ecosystems for this project were informed by the previous work described above, and selected through a combination of expert knowledge and metrics around the prevalence and size of potential ecosystems. Expert guidance came from biologists with extensive experience working throughout BC marine waters, and thus considerable knowledge of the ecosystems present in the area, many of whom are members of the author team. For an ecosystem to be included in this project it had to be identified as a major ecosystem by our experts, relatively large, and relatively prevalent in our area. While many of the habitats and ecosystems are defined similarly between this project and those mentioned above, there are some differences in terminology, and in the depth ranges and energy levels included in each model. These differences are outlined in a comparison table (Table 1).

Table 1. Ecosystems of the conceptual models presented in this report (Canadian Pacific EEZ), compared with the classifications in other, similar processes: Washington State's marine spatial planning process (Andrews et al. 2013), Gwaii Haanas (Martone et al. 2016), and cumulative impact mapping in the Canadian Pacific (Murray et al. 2015).

Canadian Pacific EEZ **(this report)**	**Washington State MSP** **(Andrews et al. 2013)**	**Gwaii Haanas** **(Martone et al. 2016)**	**Cumulative Impact Mapping** **(Murray et al. 2015)**
Rocky shore - high energy	Rocky intertidal, outer coast	Rocky intertidal	Rocky intertidal
Rocky shore - low energy	N/A	Rocky intertidal	Rocky intertidal
Soft shore - high energy	Sandy beaches, outer coast	Sandy beach	Beach intertidal
Soft shore - low energy	N/A	Sandy beach	Beach intertidal, mudflats intertidal, seagrass, soft intertidal
Rocky subtidal	Kelp forests (including rocky reefs); Seafloor (above 60 m)	Rocky subtidal/kelp forest; Sea Floor/Benthic	Kelp, rocky reef, hard shelf (30 – 200 m)

Canadian Pacific EEZ (this report)	Washington State MSP (Andrews et al. 2013)	Gwaii Haanas (Martone et al. 2016)	Cumulative Impact Mapping (Murray et al. 2015)
Soft bottom subtidal	Seafloor (above 60 m)	Sea Floor/Benthic	Sponge reefs, soft shelf (30-200 m), subtidal areas include soft shallow substrates and seagrass
Pelagic	Pelagic zone	Pelagic	Shallow pelagic, deep pelagic
Estuary	Conceptual model not included in report but planned for large coastal estuaries (including eelgrass beds, sand and mudflats)	Estuarine	Soft intertidal, beach intertidal, mudflat intertidal, seagrass, shallow pelagic
Fjords	N/A	N/A	N/A
Hydrothermal Vents	N/A	N/A	N/A
Seamounts	N/A	N/A	Seamounts
Bathyal Plains	N/A	N/A	Deep
Cold Seeps	N/A	N/A	N/A

In total, thirteen ecosystems were identified (Table 2), and a conceptual model was built for each of them. For the purpose of this project we defined an ecosystem as a system with a specific geographic location that includes all living organisms (humans, plants, animals, micro-organisms), the physical, chemical, and climatic environment, and the processes that control the dynamics of the system (DFO 2007).

The process to identify the major ecosystems was a subjective one given that oceanographic and physical conditions do not have hard boundaries. The author team and experts had to make choices on the most representative way to delineate the ecosystems. These decisions can be illustrated in a couple of examples. First, one area of our coast that is often considered an ecosystem but that is not considered in our suite of ecosystems, is the continental slope. For the purpose of these models, the slope was not considered an ecosystem unto itself because it is comprised of many different substrates and features that are already described as ecosystems here. For instance, hydrothermal vents and cold seeps occur on the continental slope; rocky areas of the slope are similar in terms of species and environmental drivers to those found on seamounts; and soft substrate areas on the slope are comparable to the soft bottom **subtidal**, or **bathyal plains** (depending on the depth).

Another challenge was deciding what to consider as a habitat (smaller in geographic area), versus an ecosystem (larger geographic area comprised of multiple habitats). Examples of these choices were our decisions to include eelgrass as a habitat within estuaries and soft bottom ecosystems; sponge gardens within rocky **subtidal** and seamount ecosystems; and sponge reefs within soft bottom **subtidal** ecosystems. It is possible that a different set of experts may have chosen a slightly different suite of ecosystems. However, we believe that the information included in the conceptual models captures the major ecosystems on the BC coast and that, between them, all important habitats are depicted.

Beaches, or **intertidal** ecosystems, were referred to as 'shore' for the purpose of these models. Shores consisting of smaller substrate particles sizes like silt and sand are referred to as soft shores, whereas shores consisting of consolidated substrates like cobble, boulder and bedrock are referred to as rocky shores. In the models presented in this report, the rocky shore – high energy ecosystem consists of mainly immobile substrate like bedrock and large boulders because smaller substrates like cobble are moved around with wave action. Rocky shores with cobble substrate have a diminished number of species because of this scouring action, and the impacts of environmental drivers are different within them, thus they should be considered an ecosystem unto themselves. This type of rocky shore is less prevalent on our coast and is not included in our suite of ecosystems. On low energy beaches there is less wave action and so substrates as small as cobble remain largely immobile. For this reason, the rocky shore – low energy ecosystem includes beaches with smaller substrate sizes than that of the high energy one.

Another distinction used to define ecosystems was on-shelf versus off-shelf. These terms refer to the location of the ecosystems relative to the continental shelf break; on-shelf refers to ecosystems that occur on the continental shelf from the coastline to the shelf break (start of the continental slope) and off-shelf refers to the area below the shelf break. On-shelf ecosystems include rocky shore and soft shore ecosystems, rocky **subtidal**, soft bottom **subtidal**, estuaries, and fjords. Off-shelf ecosystems can be on the continental slope or below it and include hydrothermal vents, seamounts, **bathyal plains**, and cold seeps. The **pelagic** ecosystem is the only ecosystem that doesn't include a **benthic** area and so is tied to depth in the water column, rather than the shelf break. It can occur in water over both on-shelf and off-shelf areas.

Table 2. Description of the ecosystems included in the suite of conceptual models, including examples of where these ecosystems can be found on the Pacific coast of Canada.

Ecosystem	Description	Examples
Rocky shore – high energy	Intertidal areas with rock substrate that is largely immobile (e.g., large boulders, bedrock), and high wave exposure.	Rocky shores off Cape St James, Haida Gwaii
Rocky shore – low energy	Intertidal areas with rock substrate (e.g., cobble, boulder, bedrock) and low wave exposure.	Lighthouse Park, West Vancouver; rocky shores around the gulf islands
Soft shore – high energy	Intertidal areas with sand substrate and high wave exposure.	North Beach, Haida Gwaii; Long Beach, Vancouver Island
Soft shore – low energy	Intertidal areas with mud and sand substrates, and low wave exposure.	Spanish Bank, Vancouver; Qualicum Beach, Vancouver Island; Baynes Sound
Rocky subtidal	On-shelf subtidal areas from the low intertidal to the continental shelf break (~180 m depth) with rock substrate (cobble, boulder, bedrock). This ecosystem is generally more prevalent in shallow nearshore areas and is not defined by wave	Laskeek Bay kelp forests, Haida Gwaii

Ecosystem	Description	Examples
	exposure. Kelp forest habitat is included in this ecosystem, as are sponge gardens and coral aggregations at deeper depths.	
Soft bottom subtidal	On-shelf subtidal areas from the low intertidal to the continental shelf break (~180 m depth) with soft substrate such as silt and sand. These soft substrates are more prevalent at deeper depths and are sometimes interspersed with rocky outcroppings. Eelgrass habitat is found at shallower depths in this ecosystem, and sponge reefs can be found in deeper areas.	Dogfish Bank
Pelagic	Epipelagic portion of the water column that is not near the shore or the seafloor (0-200 m).	
Estuaries	Intertidal and subtidal areas where streams or rivers meet the ocean.	Fraser River estuary; Skeena River estuary
Fjords	Subtidal areas within coastal fjords. Usually inlets with steep sided mountains and a deep narrow waterway with vertical walls underwater, and a freshwater source at the head (intertidal habitats are captured within the two low energy shores above).	Knight Inlet; Douglas Channel
Hydrothermal vents	Subtidal benthic areas where hydrothermal fluids vent from cracks in the oceanic crust and drive **chemosynthetic** production.	Endeavour Hydrothermal Vents
Seamounts	Subtidal mountains with summit elevations exceeding 1,000 m above the surrounding seafloor, which are roughly circular or elliptical in shape.	SGaan Kinghlas-Bowie Seamount
Bathyal plains	Relatively flat subtidal areas within 1,000 and 4,000 m depth (the bathyal zone).	Clayoquot Slope
Cold seeps	Subtidal, benthic areas, usually occurring between 150 – 2,000 m depth, where reduced chemicals (e.g., hydrocarbons such as methane and hydrogen sulphide) seep from the ocean floor.	Barkley Canyon

2.2 Ecological components and interactions

2.2.1 Selection of ecological components and interactions

The ecological components chosen for each ecosystem represent the main species and habitats found within each ecosystem. The initial list of species and habitats drew upon the collective ecological knowledge of this team of authors and other reviewers to populate lists of representative species for each ecosystem. When populating these lists, consideration was given to the most iconic and influential species for each ecosystem, as well as those identified as important by previous planning efforts, including ecological **conservation** priorities for **marine protected area network** planning in the Northern Shelf Bioregion (Figure 2)(Gale et al. 2019). Species identified as ecological **conservation** priorities include those of **conservation concern** as assessed by global, national, and provincial authorities (e.g., species listed as threatened or endangered under the Government of Canada's Species at Risk Act), species identified as ecologically significant (ESS), and highly vulnerable species (those that are vulnerable to disturbance or slow to recover from impacts). ESS are those species that have high ecological importance and warrant special management measures, such as keystone and other highly influential predators, key forage species, nutrient importing and exporting species, and habitat-forming species (Rice 2006; DFO 2006a).

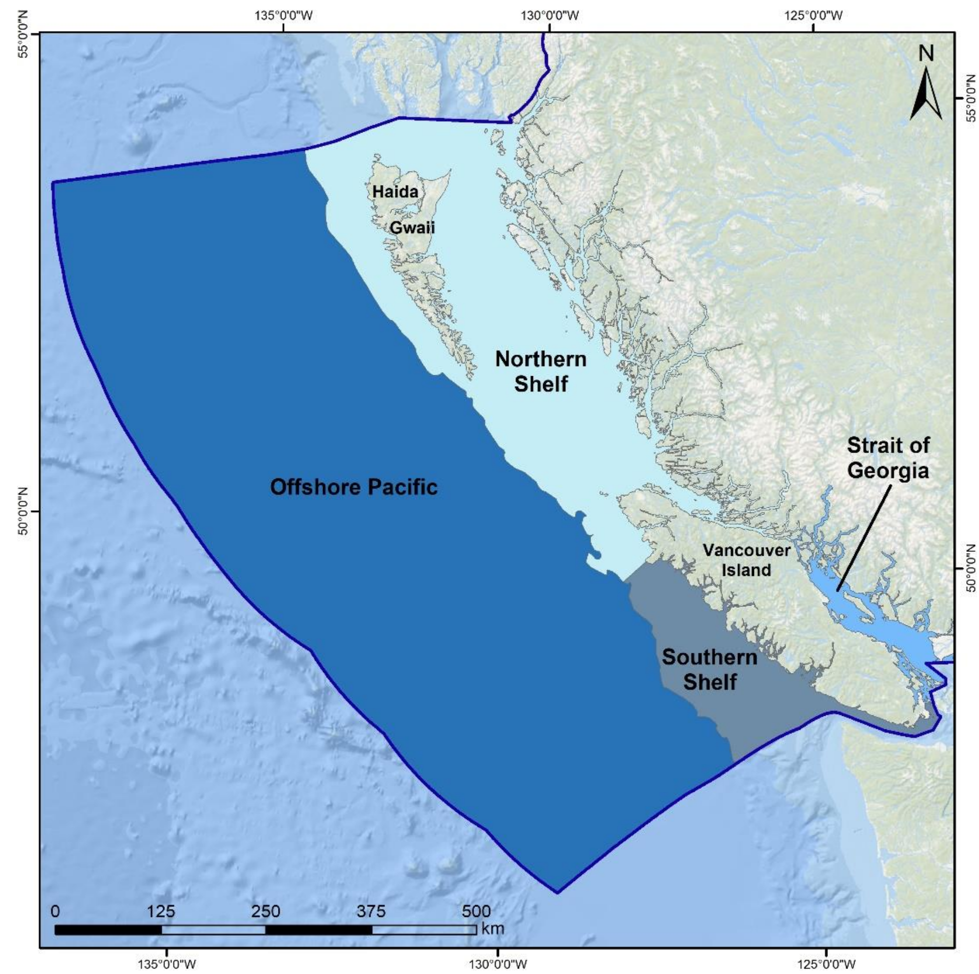

Figure 2. Map of the marine bioregions in Canada's Pacific Ocean.

For each species chosen as an ecological component, we conducted a literature review of technical reports, primary literature, field guides, and online species atlases (e.g., Fishbase) to confirm the species was an integral component of that ecosystem and to identify linkages between ecosystems. These results are shown in Appendix tables A2a and A2b.

It is important to note that the ecological components and interactions in the conceptual models do not include all species and interactions present in each ecosystem. Rather, the models include ecological components and interactions that are considered important, representative, or iconic for an ecosystem. For example, multiple species of mussels and barnacles inhabit rocky shore high energy ecosystems, but only the California mussel and gooseneck barnacle are included in the models as they are highly iconic species for that ecosystem. Also, to provide an accessible overview of the interactions within each ecosystem, full food webs are not described; a single species was often selected for inclusion that was representative of the role a functional group plays. For example, if multiple grazers were ecological components within an ecosystem, only one might be highlighted to showcase the interaction between grazers and algae (e.g., many grazers consume **macroalgae** in rocky shore high energy ecosystems, but only the purple sea urchin is depicted for the interaction).

In the model illustrations, arrows are included linking species with their food items. These arrows show the direction of energy flow within the ecosystem, such that prey items are linked to consumers with an outward facing arrow showing energy flowing from the prey species to the consumer.

The ecological components of an ecosystem can vary over space and time. For example, different populations and species of salmon utilize different estuaries along the coast at different times, and for varying lengths of time, as they transit between their natal streams and the ocean. Further, habitats are continuous and defined boundaries do not exist between ecosystems. As such, it is important to recognize that there is variability in the components for each ecosystem across the coast, particularly when considered at a finer spatial scale.

2.3 Environmental drivers

2.3.1 Environmental driver selection

Ecosystems are influenced by a suite of environmental drivers. Understanding these drivers can explain the composition and distribution of species and habitats, and their interactions. Environmental drivers include broad-scale oceanographic processes, such as **upwelling** that can influence productivity; long-term climate cycles that influence temperature and precipitation; variability stemming from up-stream sources, such as freshwater and sediment input; or more localized factors, such as sediment grain size.

The environmental drivers chosen for each ecosystem represent the main drivers influencing each ecosystem. The suite of drivers chosen for each ecosystem drew upon the collective ecological knowledge of this team of authors and other reviewers. In total, thirty-six drivers were chosen; some were specific to a single ecosystem, while others were more broadly applicable and occurred in a maximum of nine ecosystems.

The suite of environmental drivers included in each conceptual model is shown in Table 3.

Table 3. Environmental drivers included in each ecosystem.

Environmental drivers	Ecosystems												
	Rocky shore – high energy	Rocky shore – low energy	Soft shore – high energy	Soft shore – low energy	Rocky subtidal	Soft bottom subtidal	Pelagic	Estuary	Fjords	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Climate cycles	×	×	×	×	×	×	×	×	×				
Extreme temperature and UV light	×	×	×	×				×					
Tides	×	×	×	×				×					
Wind	×	×	×	×				×	×				
Wave energy	×		×		×								
Upwelling	×		×		×	×	×	×	×		×	×	
Tidal currents					×				×		×		
Along-shore currents	×		×										
Currents						×	×			×		×	×
Eddies						×	×				×		
Taylor column											×		
Freshwater plumes						×	×						
Freshwater input		×		×				×	×				
Sediment input								×					
Sedimentation					×				×	×			×
Sediment erosion/deposition			×	×									
Sediment grain size			×	×									
Salinity					×			×	×				
Water temperature					×	×	×						
Dissolved oxygen						×		×	×		×	×	×
pH											×		×
Light					×						×		
Pressure										×	×	×	×
Heat													×
Habitat variability										×			

	Ecosystems												
Environmental drivers	Rocky shore – high energy	Rocky shore – low energy	Soft shore – high energy	Soft shore – low energy	Rocky subtidal	Soft bottom subtidal	Pelagic	Estuary	Fjords	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Complex geomorphology					×						×		
Topographical features												×	
Physical isolation										×			×
Proximity											×		
Concentrated resources										×			
Nutrient limitation												×	
Volcanic activity											×		
Tectonic activity										×	×		×
Hydrothermal circulation										×			
Seeping gases													×
Light limitation										×		×	×
Microbes													×

2.3.2 Description of environmental drivers

Below is a description of each environmental driver selected for the ecosystem conceptual models in this report, and examples of how they interact with components of those ecosystems.

2.3.2.1 Climate cycles

Interactions between the ocean and the atmosphere cause climate cycles that occur on the order of years or decades. One such cycle is the Pacific Decadal Oscillation that cycles every 20-30 years causing warm and cool phases in the Pacific Ocean (Mantua 1999). A shorter but important climate cycle in the Canadian Pacific Ocean is the El Niño Southern Oscillation (ENSO), which causes El Niño and La Niña events. These events influence weather, which leads to variation in wind, waves, temperature, precipitation, and the strength of **upwelling** events. El Niño events bring warmer temperatures and less precipitation, while La Niña events result in cooler and wetter conditions (NRCAN 2019). Both events result in higher wave energy than neutral years (Barnard et al. 2015). **Upwelling** is weakened during El Niño events and strengthened during La Niña years (Jacox et al. 2015).

2.3.2.2 Extreme temperatures and UV light

Intertidal species exposed to air by low tides experience direct sunlight, rain and snow that can result in extreme temperatures and UV light exposure compared to species in **subtidal** ecosystems. When low tide events coincide with extremely hot or cold weather, or intense sunlight, temperature and UV-related stress can lead to high species mortality in **intertidal** areas (Hesketh and Harley 2023). The effects of extreme temperature and UV exposure will be more prevalent as the frequency, duration, and intensity of these extreme weather events increase with climate change (Hesketh and Harley 2023).

2.3.2.3 Tides

Tides create exposure gradients that influence temperature, salinity, and desiccation risk, with more extreme conditions experienced at higher elevations on the beach where organisms are exposed for longer periods. The gradient in environmental conditions caused by rising and falling tides influences the vertical distribution of species. For example, species that can tolerate prolonged periods of exposure can occupy a higher tidal zone where they are exposed to air for longer periods of time. Less tolerant species might occur only at lower elevations, or be restricted tide pools, rocky depressions, and crevices that retain water during low tide. This vertical distribution on a rocky shoreline is known as **zonation**.

2.3.2.4 Wind

Wind can cause increased desiccation stress for organisms exposed by low tide. Wind also alters the frequency, size, and energy of waves, and can mix surface water layers, reducing stratification. On a larger scale, it drives circulation patterns in the upper ocean layers (e.g., California current, **upwelling**) (Pickard and Emery 1961).

2.3.2.5 Wave energy

Wave energy caused by high winds, large swell, and storm surge exerts considerable forces in shallow marine areas where crashing waves can detach **macroalgae** holdfasts and dislodge **benthic** invertebrates.

2.3.2.6 Upwelling

Upwelling on the coast of BC brings cold, high salinity, nutrient-rich water from the deep onto the continental shelf, which increases the productivity of nearshore ecosystems (Peña et al. 2019). **Upwelling** is driven by along-shore winds, and primarily occurs in the summer when the predominant wind direction is from the north-east (Davis et al. 2014). Features of seafloor topography such as shelf-break canyons can also increase **upwelling** (Davis et al. 2014). Levels of **upwelling** are also influenced by El Niño and La Niña climate cycles (Jacox et al. 2015). **Upwelling** promotes **primary production** (Peña et al. 2019) and structures beach communities by influencing the availability of larvae and food supplies (Rodil et al. 2014). **Upwelling** is described in detail in Andrews et al. (2013).

2.3.2.7 Tidal currents

Tidal currents are generated as tides ebb and flood, and are amplified in areas of geographic constriction, such as narrow passages and over **glacial sills** (Rubidge et al. 2020). Areas of high tidal current can create high mixing and local **upwelling**, where strong tides regularly bring deeper water to the surface, leading to increased productivity. Water motion created by tidal currents supplies food particles, nutrients, and oxygen, and reduces boundary layers around **benthic** organisms, improving nutrient and gas exchange, and contributing to higher species diversity in areas with high tidal currents (Elahi et al. 2014). Tidal currents also reduce levels of sedimentation, which improves invertebrate **recruitment** (Baynes & Szmant 1998).

2.3.2.8 Along-shore currents

Along-shore currents are created by coastal winds and influenced by climate cycles. These currents transport nutrients and larvae along the coastline, creating ecological and genetic connectivity between regions (Kelly and Palumbi 2010; Peña et al. 2019). They flow over the continental shelf to the north in winter and to the south in summer (Freeland et al. 1984).

2.3.2.9 Currents

Currents in the deep sea are different from those in surface layers that are largely wind driven (National Geographic 2022) and are caused by large masses of water moving slowly around the globe along the deep seafloor in a 1,000 year cycle, starting in the North Atlantic, passing through the Antarctic, before reaching the Pacific in what is termed the “global conveyor belt” (Broeker 1991).

2.3.2.10 Eddies

Eddies are formed through interactions between larger scale currents, and seafloor topography or shoreline morphology. As currents meet headlands or submarine canyons, they change the pattern of flow and cause local **upwelling**. In doing so, eddies influence nutrient levels, salinity, and temperature where they form. A major eddy in the Canadian Pacific Ocean is the Juan de Fuca Eddy off southern Vancouver Island that forms in spring bringing low sea surface temperatures, high nutrients, and increased primary productivity (Andrews et al. 2013).

2.3.2.11 Taylor columns

Taylor columns are currents that circulate around relatively shallow seamount summits (Ma et al. 2021). They form as surface current flow gets deflected by the seamount summit forming a localized eddy (Roden 1991). These oceanographic features cause **upwelling** and enhance primary productivity at the seamount summit (Ma et al 2021).

2.3.2.12 Freshwater plumes

Freshwater plumes are low salinity layers of water at the ocean surface caused by the flow of freshwater from rivers into the ocean. Freshwater from rivers is buoyant and intrudes on coastal currents (akin to headlands creating eddies), creating mixing (Hodgins et al. 1994). These plumes also transport sediment, nutrients, and particulate organic matter, which together fuel productivity (Andrews et al. 2013). Where freshwater plumes meet ocean surface waters, zooplankton biomass can be high, creating valuable foraging grounds for juvenile fishes such as salmon (Morgan et al. 2005). The Fraser River plume is a major freshwater plume feature in the Canadian Pacific Ocean (Hodgins et al. 1994).

2.3.2.13 Freshwater input

Freshwater input from rivers, streams and terrestrial run-off creates temperature and salinity gradients, and reduces water clarity due to sediment suspended in the run-off. The degree of freshwater mixing can be variable depending on the amount of water motion, and the amount of run-off (Thomson 1981). The proximity to, and amount of, freshwater input can influence species composition and distribution. Freshwater input also delivers finer sediment, silt, and terrestrial debris (e.g., sticks, leaves) on beaches, particularly in winter when rain and storm events are more prevalent.

2.3.2.14 Sediment input and Sedimentation

Freshwater flow also results in sediment input comprised of fine sand, silt, and clay particles to estuary ecosystems (Dashtgard et al. 2012), causing highly turbid conditions during periods of high river flow and leads to sedimentation. Sources of sedimentation include river outflows and resuspension of nearby soft substrates. Sedimentation is generally lower in areas with greater tidal currents, and areas with more vertical relief (Rosman et al. 2010). In offshore ecosystems sedimentation originates from sources on the continental shelf.

2.3.2.15 Sediment erosion and deposition

Sediment erosion and deposition refers to the removal of sediment from one area, and the deposition of it in another. Erosion and deposition are facilitated by waves and currents.

2.3.2.16 Sediment grain size

Sediment grain size refers to the average size of grains of sediment. There are three main types of sediment: sand, silt, and clay, which decrease in grain size from sand (most coarse) to clay (most fine). The sediment grain size in ecosystems has many physical and ecological implications. Finer particles like silt and clay are not commonly found in high energy ecosystems as they are too easily resuspended with wave action and so do not accumulate on the seafloor.

2.3.2.17 Salinity

Salinity refers to the concentration of dissolved salt in water. Many chemicals make up the salts in seawater, but sodium chloride is the main one. Salinity is measured in units of parts per thousand (ppt). It is reduced in areas with freshwater inputs and is generally lower in coastal areas where freshwater sources are more prevalent. For instance, in the Strait of Georgia where the Fraser River influence is high, surface salinity ranges from 15 to 28 ppt (Iwabuchi 2011). Surface salinity on the west coast of Vancouver Island where freshwater influences are few is higher and much less variable over time (ranging from 27 to 31 ppt) (Iwabuchi 2011). Areas with low salinity (<24 ppt) are referred to as brackish.

Salinity also increases with depth. It is impacted by the level of **upwelling** with high salinities experienced during periods of stronger **upwelling** (Pickard and McLeod 1952).

2.3.2.18 Temperature

Water temperature varies seasonally and interannually due to climate cycles. Temperature also varies spatially due to factors such as proximity to river outflows and currents. **Upwelling** also influences water temperature by bringing colder waters to the surface from the deep. Water temperature is closely linked to depth, with temperatures decreasing from the surface to around four degrees Celsius in the deepest areas on the continental shelf (Peña et al. 2019). The metabolic rate of organisms is strongly influenced by temperature (Brown et al. 2004), which influences all aspects of biology. Other biological impacts of temperature include influencing how quickly organic matter is broken down, **recruitment** rates, species ranges, and the duration of **planktonic** larval dispersal (O'Connor et al. 2007).

2.3.2.19 Dissolved oxygen

Dissolved oxygen concentration refers to the amount of oxygen that is dissolved in water. Dissolved oxygen decreases with depth, and is influenced by water temperature, with warmer water able to hold less oxygen than cooler water. Low oxygen can be stressful to many species and thus oxygen concentrations can influence species distributions.

The **oxygen minimum zone** (**OMZ**) is an area of the ocean where the lowest dissolved oxygen concentrations occur. In the Northeast Pacific this zone occurs at approximately ~480 – 1,700 m (Ross et al. 2020). Oxygen concentrations are high in surface waters due to production from photosynthesis and being dissolved from the atmosphere. From the surface dissolved oxygen concentration declines with depth to the **OMZ** where it reaches a minimum. Below the **OMZ**, dissolved oxygen often increases due to its increased solubility under the low temperature and high pressure conditions.

2.3.2.20 pH

pH in the ocean refers to the acidity of seawater. It is measured on a log scale ranging from 0-14; the higher the acidity the lower the pH. pH is strongly influenced by carbon dioxide in the atmosphere, which lowers pH as it is absorbed. Generally, pH decreases with increased depth and water temperature (U of California 2023). pH in shallow areas in the Canadian Pacific Ocean is 7.6 – 7.8, which is lower than the global average (Marliave and Borden 2020).

2.3.2.21 Light

Light penetration decreases with water depth and is affected by factors such as water clarity and colour, sunlight intensity, and the surface conditions of the water. Light is necessary for the growth of algae, including phytoplankton, and is the basis for **primary production** in most ecosystems. Light penetrates the water column to a depth of about 200 m; a region known as the epi-pelagic, or **photic zone** (Turner 2015). Below this depth, there is not enough light to support plant growth and **primary production** relies on material transported from the **photic zone**, or **chemosynthetic** pathways (Levin et al. 2016).

2.3.2.22 Pressure

Pressure increases with depth; for every 10 m of depth the pressure increases by one atmosphere. The impacts of pressure on organisms are less for those without air filled spaces like swim bladders. It is for this reason that in deep ecosystems (e.g., hydrothermal vents, **bathyal plains**) species are more likely to have cartilaginous or fluid-filled body structures without compressible air spaces.

2.3.2.23 Heat

Heat within the seafloor influences gas formation in cold seeps. At low temperature and high pressure conditions fluids moving through the substrate freeze into methane hydrate, but if temperatures increase hydrates can melt and release methane into the sediment where it can migrate into the water column.

2.3.2.24 Habitat variability

Habitat variability is created by widely different environmental conditions within relatively small areas (e.g., drastically different temperatures occurring around hydrothermal vent fields), and leads to a mosaic of habitat types.

2.3.2.25 Complex geomorphology

Complex geomorphology refers to the rugosity of the seafloor; smooth rocky substrates have lower habitat complexity than rocky seafloors with cracks and crevices. Complexity can also occur at a larger scale and refer to seafloor topographical features such as pinnacles, plateaus, terraced flanks, cones, and craters that create numerous habitat types. Complexity at all scales leads to a greater diversity of **benthic** habitats.

2.3.2.26 Topographical features

Topographical features on the seafloor refers to hills, ridges, troughs, valleys, basins, and gaps (Manson 2009). These features often contain more hard substrate than areas without these features.

2.3.2.27 Physical isolation

Physical isolation refers to the physical separation of ecosystems in space. For ecosystems such as cold seeps and hydrothermal vents, large distances separate the ecosystems, restricting connectivity between them and creating a high rate of endemism (Ramirez-Llodra et al. 2007).

2.3.2.28 Proximity

Proximity refers to the distance between ecosystems. This distance influences the level of connectivity between ecosystems and influences the species composition. For instance, seamounts that are in close proximity to one another have more species in common than do seamounts that are far apart.

2.3.2.29 Concentrated resources

Concentrated resources refers to the concentration of resources at point sources, with sharp gradients in resource abundance away from the sources. For example, chemicals used for **chemosynthesis** on sulphide structures in hydrothermal vents are concentrated in small areas at their source.

2.3.2.30 Nutrient limitation

Nutrient limitation occurs in ecosystems with low to no primary productivity, such as **bathyal plains** that rely on importation of nutrients from other ecosystems.

2.3.2.31 Tectonic and volcanic activity

Tectonic and volcanic activity are common in regions where the edges of continental plates that comprise the earth's crust are in contact. The Northeast Pacific Ocean along the coast of BC is a subduction zone where oceanic plates are converging, which can cause magma beneath the crust to rise, leading to the creation of seamount structures.

2.3.2.32 Hydrothermal circulation

Hydrothermal circulation in hydrothermal vents is achieved through down-drafting of seawater into the flanks of spreading ridges and transport through the crust near shallow magma chambers. Here the seawater is chemically altered by intense temperature and pressure, the dissolution of subsurface rocks, and the subsurface microbial community, before it vents out through cracks in the basalt of the ridge valley floor or through sediment overlying the seafloor.

2.3.2.33 Seeping gasses

Seeping gasses occur in cold seep ecosystems there they form carbonate deposits and support **chemosynthetic** communities. Microbial processes can cause the precipitation of carbonate into nodules, boulders, and carbonate pavements on the seafloor over hundreds of years (Luff et al 2004). When cold seeps are active for long periods of time, seafloor carbonates can form prominent mounds that add rugose topography to an otherwise smooth, sedimented seafloor.

2.3.2.34 Light limitation

Light limitation occurs with depth; below 200 m, the lower boundary of the **photic zone**, there is not enough light to support photosynthesis. At these depths, ecosystems must rely on energy imported from the **photic zone**, or on other energy pathways (e.g., chemosythetic production in hydrothermal vents).

2.4 Human activities

2.4.1 *Human activity selection*

The ecosystems of the Canadian Pacific Ocean support, and are affected by, a range of human activities from fishing and shipping to aquaculture and forestry. Human activities affecting marine habitats in the Pacific region can be categorized into three general types: marine, coastal, and land-based. Marine activities occur in the ocean (e.g., shipping, fishing, disposal at sea), coastal activities occur at the interface between land and sea (e.g., ports, aquaculture, log booms), and land-based activities occur within watersheds that flow into the sea. These human activities produce a range of **stressors**, which can include any physical, chemical, or biological stimulus that has the potential to change ecosystem components, habitats, or ecosystems (O et al 2015). **Stressors** from land-based activities are largely carried downstream with freshwater systems, entering the ocean via estuaries.

Cumulative impact mapping uses high quality spatial data to look at the extent and overlap of ecosystems and anthropogenic activities to assess ecosystem impacts. In 2015, Murray et al. created a cumulative impacts mapping model for the Canadian Pacific Ocean (described in more detail in section 4.1.2). The human activities included in the ecosystem conceptual models in this report were identified primarily from this past work; those activities with the highest impact scores for each of the corresponding marine ecosystems were chosen for the models. The habitat classes used for the cumulative impacts mapping aligned closely with ecosystems included in the conceptual models. However, this alignment was not perfect. Therefore, for some ecosystems the activities identified by the cumulative impacts mapping model were supplemented with those identified by regional habitat and activity experts as being prevalent in an ecosystem.

In total, sixteen human activities were included in the ecosystem conceptual models (Table 4). As a class of **stressors** caused by anthropogenic climate change, climate change **stressors** have been considered under the human activities section of the conceptual models (Table 5).

Table 4. Human activities included for each ecosystem conceptual model based on the highest impact scores from cumulative impact mapping for marine and coastal ecosystems in the Pacific Region (◈; Murray et al. 2015), and expert opinion (✱). Climate change icons are listed separately in Table 5.

		Ecosystems												
	Human Activities	**Rocky shore-high energy**	**Rocky shore-low energy**	**Soft shore- high energy**	**Soft shore- low energy**	**Rocky subtidal**	**Soft bottom subtidal**	**Pelagic**	**Estuary**	**Fjords-subtidal**	**Hydrothermal vents**	**Seamounts**	**Bathyal plains**	**Cold Seeps**
Marine	Commercial fishing	◈		◈	◈	◈	◈	◈	◈	✱		◈	✱	✱
	Disposal at Sea						◈							
	Marine Debris						✱				✱	✱	✱	✱
	Scientific Activities										✱	✱	✱	✱
	Shipping	◈	✱				✱	◈		✱				✱
	Recreational boating					◈	◈	◈	◈					
	Recreational fishing	◈		◈	◈	◈	◈		◈					
	Submarine Cables												✱	

	Human Activities	Ecosystems: Rocky shore-high energy	Rocky shore-low energy	Soft shore- high energy	Soft shore- low energy	Rocky subtidal	Soft bottom subtidal	Pelagic	Estuary	Fjords-subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold Seeps
Coastal	Aquaculture				◈		◈		◈					
	Industry				◈				◈					
	Ports		◈				◈		✱					
	Communities (coastal or coastal and non-coastal)	◈	◈	◈	◈	◈	◈	◈	◈	✱				
Land-based	Agriculture							◈	✱					
	Forestry roads and cutblocks				◈		◈		◈	✱				
	Pulp and paper mills		◈						◈	✱				
	Mining				◈				◈	✱				
	Paved roads				◈		◈		◈					

Table 5. Climate change stressors anticipated to impact marine ecosystems in the Pacific region based on cumulative impact mapping (◈; Murray et al. 2015) and expert opinion (✱).

Climate Change Stressor	Rocky shore – high energy	Rocky shore – low energy	Soft shore – high energy	Soft shore – low energy	Rocky subtidal	Soft bottom – subtidal	Pelagic	Estuary	Fjords – subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
UV radiation	◈	◈	◈	◈	◈	◈	◈	◈	✱				
Ocean acidification	◈	◈	◈	◈	◈	◈	◈	◈		✱	◈	◈	✱
Increased sea temperature	◈	◈	◈	◈	◈	◈	◈	◈	✱		✱	✱	✱
Sea level rise	✱	✱	✱	✱	✱			✱	✱				
Dissolved oxygen loss							✱	✱	✱	✱	✱	✱	✱

2.4.2 Description of human activities (other than climate change)

Below is a description of the human activities selected for the ecosystem conceptual models in this report, and examples of how they impact the components, interactions, and environmental drivers in these ecosystems.

2.4.2.1 Marine activities

Marine activities are those that occur fully in, or on, the ocean. These include fishing, disposal, debris, scientific activities, shipping, boating, and submarine cables.

2.4.2.1.1 Commercial fishing

Commercial fishing is an important economic sector in the Pacific Region, supporting diverse communities and regional and international trade. Gear used to harvest commercially targeted fish species include hook and line, longline, troll, trap, dive fishing, bottom and mid-water trawl, seine, and gillnet (Table 6; Murray et al. 2015).

Table 6. Commercial fishing gear with highest impact on each of the marine and coastal habitats in the Pacific Region, based on Murray et al. (2015) and expert opinion.

		Habitats												
Human Activities		**Rocky shore-high energy**	**Rocky shore-low energy**	**Soft shore-high energy**	**Soft shore-low energy**	**Rocky subtidal**	**Soft bottom subtidal**	**Pelagic**	**Estuary**	**Fjords**	**Hydrothermal vents**	**Seamounts**	**Bathyal plains**	**Cold Seeps**
Commercial fishing	Hook and line	×		×	×	×	×	×	×				×	
	Longline												x	
	Troll			×				×	×					
	Trap			×			×						×	
	Dive fishing			×										
	Bottom trawl						×							
	Mid-water Trawl							×						
	Seine							×	×					
	Gillnet							×	×					

2.4.2.1.1.1 Hook and line fishing

Hook-and-line fishing gears are those that use hooks (one or multiple, baited or unbaited) and lines to catch fish. Species typically caught using hook and line gear include rockfishes, salmon, lingcod, dogfish, halibut, and sablefish (BCMCA 2011). Handlines (including jigging) are considered to have a low level of bycatch, but they can damage corals and sponges if they come into contact with the seafloor (Fuller et al. 2008).

Generally, **stressors** associated with hook and line commercial fishing include bycatch, direct capture, and **stressors** associated with the use of small vessels including contaminants, invasive species, nutrient input, and oil spills (Murray et al., 2016).

2.4.2.1.1.2 Longline fishing

Longline fishing is accomplished by setting a long line with baited hooks attached at regular intervals. Longlines can be set near the surface (**pelagic**), or on the sea bottom (demersal). Both types of longlines are held in position by anchors at each end, and buoys or floats at the surface (DFO 2010a).

The use of demersal longline gear can degrade marine habitats by displacing or removing habitat-forming organisms such as corals and sponges. Loss of demersal and **pelagic** gear can have a direct impact on habitats and associated species by smothering **benthic** organisms, or via entanglement, particularly of marine mammals. The majority of bycatch for longline fisheries is seabirds, marine mammals, elasmobranchs (sharks, rays and skates), and invertebrates (e.g., seastars, stone crabs, corals and sponges) (DFO 2010a).

2.4.2.1.1.3 Troll fishing

Troller fishing vessels use two main poles, each about the length of the vessel, set amidship. Each pole has six to eight fishing lines with up to 80 lures attached to each line, and the lines are dragged slowly through the water. After a period of time, the lines are hauled in and the fish are removed from the hooks (BCMCA 2011). Troll gear is considered to have a low level of bycatch, but can damage corals and sponges if gear comes into contact with the seafloor (Fuller et al. 2008).

2.4.2.1.1.4 Trap fishing

Traps are frames covered with webbing that form an enclosure, the design and material of which vary depending on the targeted species. Traps can be set on single lines, or on ground lines containing multiple traps (BCMCA 2011). Traps can be used in a wide range of ecosystems and depths, and deployed from small inshore boats or large offshore vessels.

Traps can impact **biogenic structures** (i.e. corals and sponges) through crushing and entanglement. The severity of the potential impact will depend on the type of seafloor substrate, size and weight of the trap, retrieval methods, use of weights or anchors, and deployment times (DFO 2010a). Entanglement is one of the main impacts to marine species from trap fishing. There are reports of whale, turtle, and shark entanglements. Bycatch in traps also occurs, although the survival rate of caught non-air breathing species is assumed high with proper handling. Lost gear can continue to capture fish and invertebrates for many years, although this can be mitigated with improved fishing practices and the use of degradable materials (DFO 2010a).

2.4.2.1.1.5 Dive fishing

The species harvested by commercial divers are geoduck clam, sea cucumbers, and green and red sea urchins. Geoducks are commercially harvested by divers using high-pressure water delivered through a nozzle about the size of a garden hose, known as a “stinger”. This tool loosens the substrate around the clam allowing the harvesters to grasp the neck and lift the clams out live (BCMCA 2011). Sea cucumbers and sea urchins are hand-picked (BCMCA 2011).

There are no known bycatch concerns from dive fishing and minimal effects on ecosystems. However, hydraulic tools used for the geoduck fishery can disturb sediments and potentially damage kelp, eelgrass, and invertebrates living on the seafloor in areas that are fished (Fuller et al. 2008).

2.4.2.1.1.6 Trawl fishing (bottom and mid-water)

Two types of trawl gear are used on the Pacific coast. The first is a large bag-shaped net either pulled along the ocean floor (bottom trawl) or through the water column (mid-water trawl). The trawl net is made of synthetic materials and kept open during trawling by water pressure on two “otter doors” made of iron-clad wood or metal (BCMCA 2011). The second type of trawl is called a “beam trawl”. The beam (or pole) is held horizontally across the mouth to keep the net open during trawling (DFO 2010a).

Bottom trawl gear can damage structural biota and habitat complexity. The impacts of bottom trawl gear are greater on sandy and muddy bottoms, and in low energy areas (i.e., with low natural wave or current disturbances). Sedimentation increases in areas where bottom trawl gear is used, albeit temporarily, as the net is dragged through the substrate (DFO 2006b). While not intended, when mid-water trawl gear contacts the seafloor, **biogenic structures** (e.g., glass sponge reefs), **epifauna**, and **infauna** may be damaged, and sediment re-suspended (DFO 2010a).

2.4.2.1.1.7 Seine fishing

Fishing by purse seine involves setting a net over the stern of the vessel with one end secured to a small boat or skiff, which moves from the main vessel to encircle a school of fish before drawing together the bottom of the net under the fish. Once the net is pursed, the fish can be brought aboard the vessel by means of a hydraulic pump or by dip-netting the fish from the water (DFO 2010a; BCMCA 2011).

Only in rare situations does seine gear encounter the sea floor and risk damaging **biogenic structures** (such as corals, sponges, and plants) and suspending sediment. Kelp habitat may be especially sensitive to encounters with rings and netting from seines (DFO 2010a). Non-target species captured by purse seining, although rare, may include sharks, some groundfish, squid, and some **benthic** invertebrates (DFO 2010a).

2.4.2.1.1.8 Gillnet fishing

Gillnets are panels of netting suspended by a line of floats at the top of the panel and held open by weights at the bottom. Fish are caught when they swim into the net and become entangled in the mesh by their gills (DFO 2010a). Gillnets for salmon fishing are suspended in the water (surface gillnets), while herring gillnets are anchored to the ocean floor (demersal gillnets), and are shorter with a smaller mesh than salmon gillnets (DFO 2010a).

The weights on demersal gillnets can crush **benthic** species, damage bottom features, and re-suspend sediments when deployed or retrieved. Lost gear can become entangled in **biogenic habitat**, or cause fouling of substrate or **benthic** organisms (DFO 2010a). Gillnets are known to capture several species of sharks and non-targeted species, including invertebrates and sea turtles, plus there are recorded interactions between gillnets and marine mammals and seabirds (DFO 2010a).

2.4.2.1.2 Disposal at sea

Disposal at sea is the deposition of dredged sedimentary waste in oceanic locations designated under permits. In Canada, the disposal of any substance into the sea is not allowed unless a permit is issued by the Environment and Climate Change Canada (ECCC) Disposal at Sea Program. Disposal at sea is considered acceptable for the disposal of non-hazardous substances from dredging operations to improve navigation (Government of Canada 2017).

Disposal of dredge materials at sea can increase water turbidity and cause changes to the sea floor. Contaminants present in dredged sediments can enter the water column and the food web causing negative effects to ecosystems (Bruce et al. 2021).

2.4.2.1.3 Marine debris

Marine debris is “any persistent, manufactured, or processed solid material discarded, disposed of, or abandoned in the marine environment, including all materials discarded at sea, on the shore, or brought indirectly to the sea by rivers, sewage, storm water, waves or winds” (PNUMA 2009). Marine debris can vary in composition, density, and shape, which affects whether it resides near the water’s surface, suspended in the water column, or near or on the sea floor (NOAA Marine Debris Program 2016; Cole et al. 2011). Plastic is the most common material present as marine debris, 80% of which comes from land sources (Cole et al. 2011).

Coastal ecosystems receive plastic litter from terrestrial and marine sources, with higher concentrations in areas near urban centers, tourism sites, river outflows, and where there are favourable shore currents. The accumulation of marine debris can change the physical and chemical composition of marine ecosystems and organisms. Marine life can become entangled in marine debris and drown, suffocate, or have decreased ability to catch food. Marine debris can also be ingested by marine organisms, which can lead to starvation and the intake of toxins from plastic debris (Gall and Thompson 2015). Marine debris can also act as a vector for invasive species, and discarded or abandoned fishing gear (ghost gear) can damage deep water species such as corals (Ramirez-Llodra et al. 2011).

2.4.2.1.4 Scientific activities

Incidental or intentional ecosystem damage can be caused by scientific experiments or surveys. Activities for scientific research can include collection of organisms, deployment of scientific instrument, and the use of remotely operated vehicles (ROVs). Hand picking or collecting by SCUBA or ROV removes organisms directly from the ecosystem. Sampling equipment such as trawls and grabs can disturb the seafloor, although typically at a scale and magnitude lower than commercial activities. Modern submersibles, ROVs, and other scientific tools introduce light, and may leave behind ballast weights or site markers (Ramirez-Llodra et al. 2011).

2.4.2.1.5 Shipping

The transport of goods and products by shipping facilitates international and domestic trade. The majority of large commercial vessels travelling through Canada's Pacific EEZ transit through the Strait of Juan de Fuca heading to BC and Washington State ports. The Inside Passage, a coastal route that connects southeast Alaska with Washington State through BC, is an important route for tugs, cruise ships, and smaller cargo vessels, offering protection from weather and rough seas (Clear Seas 2020). Most of the cargo moved via marine shipping is related to forest products, iron ore, wheat, and crude oil. Tugs make up a large proportion of the coastal shipping traffic, transporting raw materials and finished goods to support sectors such as sawmills and pulp mills. Tugs and barges also connect remote communities by transporting essential goods and services (Council of Canadian Academies 2017).

Shipping is a complex activity. Described in detail in Hannah et al. (2020), the action of anchoring and mooring can cause sediment disturbance, acoustic disturbance, and the introduction of invasive species with impacts on **benthic** communities and sensitive, habitat-forming species such as sponges and corals. A vessel at rest (at anchor or at berth) can cause obstruction, light and noise disturbance, and the introduction of invasive species. Accidental grounding or sinking of a vessel can cause substrate disturbance, noise disturbance, release of contaminants, and the introduction of debris and invasive species. While the vessel is moving (movement underway), it can cause sediment disturbance in shallow areas, light and noise disturbance, vessel strikes, water displacement in the form of wakes and waves, and the introduction of invasive species. Discharge can occur accidentally or as part of the ship's normal operation, and may release oils, contaminants, nutrients, or air pollution. Shipping is a well-known vector of invasive species around the world, and is responsible for many new species introductions along the Pacific coast of North America (Hannah et al. 2020). The consequences of shipping **stressors** to coastal and marine environments include habitat and **biodiversity** loss, species behavioural changes, eutrophication, and pollution.

2.4.2.1.6 Recreational boating

Recreational (or pleasure) boating is a popular activity in Canada's Pacific EEZ. It tends to be concentrated near population centres where facilities such as marinas, public docks, boat launches, and fueling and repair stations are available. In addition to navigating by motorboat or sailboat, recreational boaters can engage in other activities such as fishing, kayaking, swimming, SCUBA diving, sightseeing, or wildlife viewing. Marine recreational activities are concentrated during the summer months when weather and sea conditions are most favourable (BCMCA 2011).

Similar **stressors** exist for recreational boating as for shipping, and vary depending on the activity they are engaged in (Byrnes and Dunn 2020; Carreño and Lloret 2021). Anchoring of recreational vessels can disturb sensitive **benthic** habitats, such as eelgrass beds in soft shore and estuary ecosystems, which often lack dedicated mooring zones (Carreño and Lloret 2021). Moving recreational vessels can cause direct and indirect physical impacts through collisions, altering water turbidity, causing shoreline erosion affecting nearshore habitats (Whitfield and Becker 2014), or by increasing the noise levels (above and under water), which affects many marine species, including fishes (Whitfield and Becker 2014), coastal birds (Lyons and De Oliviera Menezes 2020), marine mammals (Erbe et al. 2019; Schoeman et al. 2020), and sea turtles (Work et al. 2010). Recreational vessel operations are a source of pollution to coastal and marine habitats, from accidental and operational oil discharges, engine exhaust emissions, use of antifouling paints, and litter (Whitfield and Becker 2014; Carreño and Lloret 2021). Aquatic invasive species can be introduced and spread by recreational vessel activities, which in turn can cause ecological and economic impacts (Simard et al. 2017).

2.4.2.1.7 Recreational fishing

Recreational fishing has a similar list of **stressors** as commercial fisheries, but recreational fishing **stressors** are considered more spatially restricted and often less intense. Motorized vessels engaged in recreational fishing can cause localised degradation of habitats, particularly in shallow waters with **seagrass** beds. Noise from recreational fishing vessels can also affect fish and other species including marine mammals. Waves from recreational fishing vessels can cause shoreline erosion and resuspend sediments (Cooke and Cowx 2006).

One of the dominant impacts of recreational fishing is the loss of gear (lines and wires, leaders, lead sinkers, and hooks) (Chiappone et al. 2004). Lost gear can become entangled with marine species such as birds, marine mammals, turtles, corals, and sponges, and often continue fishing as ghost gear. Anglers fishing from shore can disturb wildlife and nesting sites, and modify coastal vegetation to gain access to fishing sites (Cooke and Cowx 2006).

2.4.2.1.8 Submarine cables

Submarine cables are used for telecommunications and to connect islands, underwater observatories, and marine renewable energy installations to electricity infrastructure. Submarine cables produce electromagnetic fields that can interact with marine species that use electrosense to detect prey and navigate, such as sharks, rays, mammals, turtles, molluscs, and crustaceans (Taormina et al. 2018). The installation, maintenance, and decommissioning of submarine cables can cause damage or loss of **benthic** habitats, noise, chemical pollution, increased risk of entanglement, and the creation of artificial reefs (Jurdana et al. 2014; Taormina et al. 2018). Cable repairs and removal can cause damage to the seabed and resuspend sediment, particularly when cables are buried (Jurdana et al. 2014). These cables are often buried in the seabed to reduce the risk of damage by human activities like trawl fishing or anchoring. However, cables on rocky bottoms are laid on the seabed.

2.4.2.2 Coastal and land activities

Coastal activities are those occurring within the general interface between land and sea, while land activities take place further inland in watersheds that connect to the sea. Coastal activities can have an impact on marine ecosystems directly or via overland flow due to proximity. Land activities occurring in the watersheds may impact marine environments through **stressors** transported downstream to the ocean.

2.4.2.2.1 Aquaculture

There are three main types of aquaculture in Pacific Canada: finfish, shellfish, and aquatic plants, which occur in multiple ecosystems. Most finfish aquaculture facilities are located around the northern and western coasts of Vancouver Island (DFO 2020a). Finfish are farmed in open net cages suspended in the ocean, usually in sheltered areas like bays, and there are no barriers between the farmed fish and the surrounding ocean other than the net (Georgia Strait Alliance 2003).

Shellfish farming in BC includes oysters, scallops, mussels, and clams, and may occur as raft systems, longline systems, or beach or **epibenthic intertidal** systems where the shellfish are exposed to the air during low tide. Raft systems are securely anchored to withstand severe weather and currents, and are often used in deep water for rearing oysters, clams, and mussels on trays. Longline systems are anchored on both ends with floats and culture systems attached to the line between them. **Intertidal** farming may be on or near the substrate, which is first cleared for planting and often protected by a mesh covering to prevent **predation**, and involves systems that are exposed to air at low tide (BC Shellfish Growers Association n.d.: a,b).

Aquatic plants, such as local kelp species, are grown on ropes tensioned between anchors on the seafloor and floats. These do not require the addition of fresh water, fertilizers, or pesticides (Cascadia Seaweed n.d.). Species may be grown in monoculture, or in integrated multi-trophic aquaculture, which could help alleviate some of the **stressors** from the culture of animals, such as finfish (Stévant et al. 2017).

There are several **stressors** from shellfish and finfish aquaculture activities (Murray et al. 2016; Barrett et al. 2019). Escaped finfish and shellfish may interact with wild species and ecosystems through direct **competition** over resources and reproduction, disease and parasite transfer, and altering water quality (DFO 2010b). Finfish and bivalve aquaculture can also modify nutrient dynamics. Bivalve aquaculture contributes to the removal of seston (suspended particular matter), and release of organic matter and nutrients to the water column, which may alter nearby **pelagic ecosystems**. In finfish farms, nutrients are released through fish feces and food waste, which in large accumulations can smother **benthic** organisms or alter **benthic** habitats (DFO 2010b; DFO 2020a).

The presence of structures used in aquaculture can have a direct effect on the seafloor; attract a variety of organisms that may affect both the water column and **benthic** environments; and create habitat for species that live on hard surfaces. Debris from aquaculture structures (e.g., nets) can trap or entangle wildlife (DFO 2010b). Additionally, there are **stressors** from associated boat traffic including accidental inputs of litter and fuel spills (DFO 2010b). Chemicals can also be introduced into the marine environment from aquaculture sites when treating fish for bacterial and parasite infections, and mussels for biofouling. Acoustic harassment devices (AHDs), which produce intense sounds to discourage **predatory** animals from approaching, may cause long term effects on the hearing of marine mammals such as seals. Artificial light, used to improve fish productivity and growth, could have an effect on species attracted to the light (DFO 2010b).

2.4.2.2.2 Industrial tenures

Industry facilities are tenured Crown land locations where heavy and light industrial activities occur (BCMCA 2011). Uses include a wide array of industries including storage, processing, refinement and transportation of natural resources, truck terminals, machine shops, factories, plants, and mills. Industrial facilities may occur along the coast or further inland in the watershed. **Stressors** associated with industrial facilities include contaminated wastewater, sedimentation, noise, and/or debris (Ban et al. 2010). **Stressors** from industrial facilities may enter the marine environment directly or be transported downstream to marine habitats, and as such may impact a wide variety of ecosystems and species. When occurring on the coast, modifications to the shore may result in changes to water flow, sedimentation, shading, and nearshore bathymetry, but depends on site-specific characteristics including shoreline shape and bathymetry, the orientation of shore to waves and prevailing winds, and sources of sediment, flora, fauna, and freshwater input (Dethier et al. 2016).

2.4.2.2.3 Ports and Marinas

Ports are the central hubs of the shipping industry, facilitating transfer between shore and large shipping vessels of cargo and materials, and people from cruise ships or ferries. Ports have physical infrastructure to support shipping activities, in the form of breakwalls, wharves, piers, and jetties. The Port of Vancouver is Canada's largest port, with 27 marine cargo terminals handling over 147 million tonnes of cargo (Vancouver Fraser Port Authority 2023).

In BC there are over 200 marinas, yacht clubs, and Small Craft Harbours (AHOY British Columbia 2023). Marinas and yacht clubs are designed to handle recreational vessels, including sailboats and motorboats. Marinas can host additional uses such as gas and fuel docks, launching ramps, boathouses, restaurants, and shops. Small Craft Harbours are run by DFO to mainly support the fishing and aquaculture industry, although some are also used by recreational boaters (DFO 2021a).

Stressors associated with ports include changes in water flow, contaminants, habitat disturbance, noise, nutrient input, oil spills, and invasive species (Murray et al. 2016). Also, modifications of the shoreline may result in changes to water flow, sedimentation, shading, and nearshore bathymetry, but depends on site-specific characteristics including shoreline shape and bathymetry, the orientation of shore to waves and prevailing winds, and sources of sediment, flora, fauna, and freshwater input (Dethier et al. 2016). **Stressors** from marinas are similar to ports, but often with lower magnitude and intensity.

Dredging, an activity often associated with ports and marinas, removes accumulated sediment to keep waterways clear for navigation. Dredging can cause negative impacts, including the removal of both species and habitats from the dredged site, alteration of the sea bottom topography and hydrography, alteration of sediment composition, and local increase of turbidity due to sediment resuspension (OSPAR 2004).

2.4.2.2.4 Communities and Human Settlements

Communities include populated places such as cities, towns, and other residential areas along the coast and in watersheds. Impermeable surfaces associated with urban development within communities can increase overland water flow into streams and sewage systems carrying contaminants, debris, nutrients, and sediment into nearby marine habitats (Murray et al. 2016). Larger cities with bigger populations tend to be associated with more extensive areas of impermeable surfaces and more sources of contaminants, debris, and other **stressors** compared to smaller rural communities. Human settlements may also cause shoreline modification, which can result in changes to water flow, sedimentation, shading, and nearshore bathymetry, but depends on site-specific characteristics including shoreline shape and bathymetry, the orientation of shore to waves and prevailing winds, and sources of sediment, flora, fauna, and freshwater input (Dethier et al. 2016).

2.4.2.2.5 Agriculture

Agricultural areas include livestock production, crops farmed in fields, greenhouse crops, nursery products, and other specialty crops. Agriculture can result in nitrogen accumulation in soils and water, and increased erosion of soils leading to increased sedimentation of streams and waterways near agriculture areas (Murray et al. 2016). Fertilisers and pesticides applied to crops and wastes from livestock may end up in the ocean through streams, rivers, ground water, and atmospheric deposition, and may cause shifts in species composition, algal production, water clarity, oxygen availability, and **plankton** blooms (Smith et al. 1999).

2.4.2.2.6 Forestry roads and cutblocks

Forestry activities include forest harvesting, log handling, and road creation. Forest harvesting involves the removal of large trees via the use of heavy machinery, and the transportation of harvested logs along forest resource roads in large trucks. Cutblocks are areas of Crown or private land with defined boundaries in which timber has been harvested by clearcut (Government of British Columbia 2022). **Stressors** associated with forestry activities increased sediment input into aquatic environments due to erosion from exposed and disturbed soils.

Water-based log handling is a cost-effective alternative to land-based transportation of logs through remote and mountainous areas of BC (White 2001). Harvested logs are stored and transported as flat rafts known as log booms. Water-based log handling takes place in many coastal areas including large rivers, estuaries, and small ports. **Stressors** associated with water-based log handling and log booms include sedimentation, habitat disturbance, smothering of **benthic** organisms by woody debris, shading, and debris accumulation (White 2001; Ban et al. 2010).

Resource roads, including forestry roads, are gravel or dirt roads built for industrial purposes to access natural resources in remote areas. Resource roads are maintained by forest and mining industries under road use permits. Resource roads are often used by the general public to access rural communities and recreational opportunities (Government of British Columbia 2021.). These unpaved roads can be prone to increased erosion, particularly those situated on steep slopes and actively used by large logging trucks and mining equipment. Resource roads can be a source of higher sedimentation levels in waterways and marine ecosystems compared to paved roads.

2.4.2.2.7 Paved Roads

Paved roads are a network of streets, highways, public ways, or easements that are covered in concrete, asphaltic concrete, fresh or recycled asphalt, or rubberized asphalt (Law Insider 2023). These surfaces are impermeable, and they increase overland flow and carry contaminants, debris, nutrient input, and sedimentation to marine habitats.

2.4.2.2.8 Pulp and paper mills

Pulp and paper mills process residual timber materials (residual chips, shavings, sawdust, and hog fuel) and convert them into high-value pulp and paper products. These processes use chemicals that can be lethal to aquatic life in high concentrations (Office of Legislative Counsel. Ministry of Attorney General 2018). Mill effluents can reduce oxygen supply and increase the amount of suspended solids in marine waters (Ban et al. 2010). When mills occur on the coast and modify the shoreline, the modifications may cause changes to water flow, sedimentation, shading, and nearshore bathymetry, but depends on site-specific characteristics including shoreline shape and bathymetry, the orientation of shore to waves and prevailing winds, and sources of sediment, flora, fauna, and freshwater input (Dethier et al. 2016).

2.4.2.2.9 Mining

Mining activities include mineral extraction and quarries. Quarries extract sand, gravel, construction aggregate, construction stone, and dimension/decorative stone via blasting of rock. A quarry operation may also include material sorting, crushing, stockpiling, washing, transfer of materials onto barges, and operations of temporary portable asphalt plants (Government of British Columbia n.d.). **Stressors** from mining include acid drainage, metal leaching, release of processing chemicals, and increased erosion and sedimentation (Murray et al. 2016).

2.4.3 Description of climate change stressors

While there are many **stressors** associated with global climate change (Halpern et al. 2008), we considered five main **stressors** in the development of these conceptual models: change in UV radiation, ocean acidification, increased temperature, sea level rise, and dissolved oxygen loss (Table 5). We included these climate change **stressors** because they are relatively well studied and have large effects on the species and processes within marine ecosystems (Harley et al. 2006), including varying levels of physical and chemical changes (Murdock et al. 2007). The nature of how each climate change **stressor** impacts species and processes differs from ecosystem to ecosystem (Ainsworth et al. 2011).

Climate cycles like El Niño and La Niña, accentuate the impacts of climate change stressors and are discussed in the environmental drivers section for individual ecosystems. Other aspects of climate change that are not considered in the conceptual models include increased frequency of extreme weather events; changes in the timing, duration, and frequency of coastal **upwelling** events; changes to rainfall patterns; and changes to wind patterns. Many of these drivers will also impact the ecosystems in these models, and are often connected to the larger, global drivers that we have included.

The five main climate change **stressors** included in the ecosystem conceptual models are described in more detail below, including a description of the processes behind each of them, as well as examples of how they impact our ecosystems.

2.4.3.1 UV radiation

Changes in the amount of UV radiation is a concern to many ecosystems and is most significant in shallow **benthic** and **intertidal** ecosystems (Okey et al. 2012) (refer to Table 5 for a full list). Increased UV radiation results from ozone layer depletion (Whitehead et al. 2009; Hader et al. 2011) and has long been recognized as a factor affecting both marine and terrestrial organisms mainly through changes to carbon and nitrogen cycling (Zepp et al. 1995; Whitehead et al. 2009). Though the Montreal Protocol was effective at reducing the production of ozone-depleting substances, increased stratospheric water and greenhouse gases due to climate change may cause a large loss of Arctic ozone by the end of the century (von der Gathen et al. 2021). Climate change may also cause cold Arctic winters to become colder, which would contribute to ozone loss the following spring (Wohltmann et al. 2020; Barnes et al. 2022). Between latitudes 60° S and 60° N, a continued trend of decreasing ozone in the lower stratosphere has been observed since 1998 though the cause is not clear (Ball et al. 2018).

Increased UV radiation impacts marine ecosystems in several ways; direct impacts can be both positive and negative. For **macroalgae** species that occur at depth and may be light limited, increased radiation can increase growth, whereas for species that grow near the surface and are not generally light limited, increased UV exposure can supress growth (Swanson & Fox 2007), or cause tissue damage (Poulson et al. 2011).

An indirect effect of increased radiation is the degradation it causes to coloured dissolved organic matter. This degradation allows more light to penetrate the water, which affects many shallow water processes, including biological availability of iron, copper, and trace metals with both positive and negative consequences for phytoplankton (Zepp et al. 2007).

Increased UV radiation is also anticipated to interact with other climate induced changes such as increased stratification of the water column, which will serve to intensify the effects of increased radiation on organisms and processes occurring near the surface.

Climate change will have many impacts, which complicates projecting future trends in UV light. UV light penetration will be affected by projected increases in cloud cover, smoke from wildfires, dust, and pollution, which will decrease UV penetration both through air and water (Smithsonian n.d.:a). Additionally, the depth of the mixed layer of surface waters has been deepening in some areas due to intensified surface winds caused by climate change, reducing the overall amount of UV exposure to organisms in the mixed layer (Barnes et al. 2022). This varies regionally due to the variety of factors that climate change affects. Warming water and increased freshwater input into the ocean will decrease the mixed layer, but surface cooling and stronger winds increase the mixed layer depth (Williamson et al. 2019).

2.4.3.2 Ocean acidification

Ocean acidification is a concern to many ecosystems (refer to Table 5 for a full list). The oceans are incredibly adept at absorbing carbon dioxide from the atmosphere and have absorbed a significant amount of anthropogenic carbon dioxide to date (Sabine et al. 2004). This has resulted in a reduction in ocean pH, creating more acidic conditions and causing a shift in the balance of dissolved organic carbon ions, such that calcium carbonate has become less available compared to bicarbonate. The saturation state of calcium carbonate is important to organisms; it refers to the concentration of carbonate in seawater compared to maximum concentration the water could hold (saturation). As the concentration of carbonate decreases with climate change, the saturation state decreases. The biological implication of an unsaturated state is that it becomes more difficult for organisms to build and maintain carbonate structures.

Calcium carbonate occurs in different forms in the marine environment: calcite and aragonite. The concentration at which aragonite is saturated in seawater is higher than that for calcite, meaning that aragonite is more soluble than calcite, and therefore more likely to dissolve under ocean acidification conditions. Because of this, animals and plants that form structures using aragonite are more at risk from acidification.

The maximum carbonate concentration that seawater can hold increases with pressure, so the saturation state naturally decreases with depth. Surface waters are generally in a saturated state, but the effect of pressure is such that deep ocean waters are mostly undersaturated with respect to aragonite and, at great depths, also undersaturated with respect to calcite. As the concentration of calcium carbonate in seawater decreases with ocean acidification, the depth at which waters become undersaturated is getting shallower. In BC, the saturation depth for calcium carbonate is projected to rise by 100 m by 2055 (Holdsworth et al. 2021), meaning that the depth range over which water is saturated will be considerably smaller with time. For organisms that are not mobile, this will place an increasing number in undesirable conditions over time, as the saturation depths becomes shallower and exposes more of the seafloor to unsaturated conditions.

Northeast Pacific Ocean surface waters are among the most acidic on earth, even without the compounding effects of climate change (DFO 2008). This is due to the fact that water **upwelling** in this region has travelled along the deep seafloor with ocean currents for many centuries (Thomson et al. 1981). As water travels, the effects of respiration increase carbon dioxide levels, leading to decreased pH. As a result, aragonite and calcite concentrations in the Northeast Pacific Ocean are naturally very low, making the region more vulnerable to the effects of ocean acidification (Haigh et al. 2015).

With decreasing carbonate concentrations, species that form structures from calcium carbonate (e.g., corals, molluscs, coccolithophore phytoplankton, coralline algae, etc.) are expected to build weaker skeletons (similar to osteoporosis in humans), and/or experience slower growth rates (Guinotte et al. 2006). They may also experience higher rates of mortality, and increased vulnerability to diseases (Green et al. 2013). Species may be able to compensate for the carbonate undersaturation physiologically by upregulating calcification, but this process comes at a metabolic cost (Gazeau et al. 2013). It is highly likely that ocean acidification will have impacts on marine food webs and fisheries in the region (Haigh et al. 2015).

Other implications of decreasing ocean pH include increased noise propagation through water (Joseph & Chiu 2010), and an increased metabolic demand on organisms to maintain the required pH within cells (Liao et al. 2019).

The impacts of ocean acidification will be highly dependent on location and may be mitigated to a certain extent by the presence of organisms such as **macroalgae** and eelgrass that can create refuge areas from acidification due to the uptake of carbon dioxide from the water with photosynthesis (Edworthy et al. 2023). The potential for creating refuge areas is dependent on photosynthetic rates and biomass and may only occur during summer months when there is enough light to allow high photosynthetic rates (Edworthy et al. 2023).

2.4.3.3 Increased seawater temperature

Increased seawater temperature was identified as a concern for all marine ecosystems in BC except hydrothermal vents (refer to Table 5 for a full list). Seafloor temperatures in deep areas off the continental shelf are projected to be relatively stable. Projections for seafloor temperatures on the continental shelf are variable; no change is projected for some (e.g., Scott Islands on northern Vancouver Island), increases of 1-2 degrees are projected for most, and >2 degrees are projected for others (e.g., North beach, Haida Gwaii) (Friesen et al. 2021). Surface temperatures are projected to increase 2-3 degrees by 2070 (Friesen et al. 2021).

This increase in sea temperature will be exacerbated with incidences of marine heatwaves that create environments of persistent extremely warm temperatures (Cheung and Frolicher 2020). The Northeast Pacific region's first recorded marine heat wave, often referred to as the "Blob", impacted the Northeast Pacific Ocean from Alaska to California from 2013 to 2015, and resulted in sea surface temperature anomalies in excess of 6^{o}C (Cheung and Frolicher 2020). There have been shifts in the distribution, and decreases in biomass, for many commercial species as a result of this marine heat wave (Cheung and Frolicher 2020).

Increased water temperatures can have many direct and indirect impacts on marine organisms. Some examples include altered reproductive timing and reduced offspring survival for Bull Kelp (Korabik et al. 2023); increased susceptibility to diseases such as eelgrass wasting disease (Groner et al. 2021); and changes to the groundfish community structure and depth occurrences as some species shift to deeper water to escape temperature increases, resulting in reduced diversity and biomass at some depths (Thompson et al. 2023).

2.4.3.4 Sea level rise

Sea level rise is a concern in most coastal ecosystems in BC (refer to Table 5 for a full list). Sea level is rising currently, and will continue to do so for millennia because of changes in ocean volume due to melting of glaciers, ice caps, etc., and the expansion of water with increasing surface temperatures (Nerem et al. 2006; Oppenheimer et al. 2019).

Expected sea level rise rates range from -1 to +2 mm/yr on the south coast of BC, to -1 to +6mm/yr on the north coast (Thomson and Crawford 1997). Rising ocean levels will impact ecosystems in many ways. Firstly, higher ocean levels will place **benthic** organisms in deeper water, for which they may not be adapted. For example, as light availability decreases with depth, eelgrass living at its depth limit will be light limited as sea levels rise (Han and Liu 2014). With time, it can shift its distribution shallower, but only if suitable habitat is available.

Sea level rise is also linked to increased erosion on soft shores (Leatherman et al. 2011). The link between sea level rise and erosion is multidisciplinary and not well understood, however, one theory is that higher sea levels allow waves to reach previously inaccessible stores of sand, which are transported offshore (Leatherman et al. 2011).

Sea level rise also places coastal infrastructure such as houses, ports, industrial tenures, and coastal roads at risk of inundation (Malik and Abdalla 2016).

2.4.3.5 Dissolved oxygen loss

Dissolved oxygen loss is of concern to many BC marine ecosystems including **bathyal plains**, cold seeps, seamounts, fjords, and estuaries (refer to Table 5 for a full list).

Dissolved oxygen levels in the upper 3,000 m of the water column in the Northeast Pacific have declined by 15%. Throughout coastal BC declines in dissolved oxygen are seen at all depths below the mixed surface layer, with the greatest decline at 200-300 m depth (Cummins and Haigh 2010). Additionally, under climate change conditions, the **OMZ** (see section 2.3.2.19) has expanded by extending into deeper waters (Ross et al. 2020).

This reduction in dissolved oxygen and expansion of the **OMZ** with climate change is expected to impact deeper communities. For instance, oxygen levels within the **OMZ** are considered lethal and thus areas on seamounts in this zone would not be suitable habitat for many fishes and crustaceans (Chu & Gale 2017). Species may respond to reduced oxygen levels by relocating if they are mobile, but for **sessile** species the changes may be lethal. Cold water corals and sponges on seamounts in the Canadian Pacific EEZ inhabit areas considered oxygen deficient (Chu et al. 2019), and oxygen concentration in these areas are declining such that they may become fatal to even these highly tolerant species (Ross et al. 2020).

2.5 How to read this report

The intent of this report is to provide a general picture of each ecosystem to inform **marine spatial planning** exercises, and to help non-scientists understand the ecosystems on our coast. Many ecosystems face similar drivers and activities, and this is reflected by similar content in each of the related sections of those ecosystems, which are designed to be read as standalone sections if desired.

Section 3 describes our current knowledge of the ecosystems in Pacific Canada that are depicted in each model, providing information on the components and key interactions of each ecosystem, as well as the environmental drivers and human activities that affect them.

Each of the 13 ecosystems listed in Table 2 is described in Section 3 below, with separate illustrations for the components, key interactions, environmental drivers, and human activities (which contains climate change **stressors**). The icons displayed in the graphical illustrations for each ecosystem are underlined in the text at their first mention for easy reference. The environmental drivers, human activities (including climate change **stressors**) are described above in sections 2.3.2, 2.4.2, and 2.4.3.

Bolded terms in the body of the document are defined in a glossary in Appendix 1.

3 CONCEPTUAL MODELS

3.1 Rocky shore – high energy

3.1.1 General description

The rocky shore – high energy ecosystem consists of **intertidal** areas with rock substrate that is largely immobile (e.g., large boulders, bedrock), and high wave exposure. This ecosystem occurs along the outer coastal areas of BC (e.g., wave exposed bedrock shores on the west coast of Vancouver Island, Haida Gwaii, and on the central and northern coasts of BC).

The species assemblages in this ecosystem are structured across a vertical gradient from the low **intertidal** zone to high **intertidal** zone. In high energy ecosystems, there is also a spray zone above the high **intertidal** zone that is supported by wave spray. Species' locations along this gradient are determined by their ability to tolerate exposure to waves and air throughout the tidal cycle, as well as **predation**, and **competition** for space (Connell 1972). The high **intertidal** zone, which is exposed to the air for the longest period in the tidal cycle, is dominated by barnacles (e.g., acorn barnacle), which can withstand desiccation and high air temperatures. The mid **intertidal** zone is dominated by mussels (e.g., California mussel) and **macroalgae**, which are less tolerant to desiccation and high temperatures than barnacles but are better competitors for space. How low some of these mid **intertidal** zone invertebrate species occur is determined by seastar **predation** (e.g., ochre star; Connell 1972). The low **intertidal** zone is dominated by kelp and surfgrass (Stephenson and Stephenson 1949). Tidepools, isolated pockets of seawater trapped in depressions and crevices after the tide recedes, provide refuge from desiccation, temperature and salinity extremes, supporting species that would otherwise not survive **intertidal** conditions. Additional protection from desiccation and heat stress for species in this ecosystem is provided by algae species that lie flat at low tide when not supported by water. These algae form canopies that maintain moist and shaded microenvironments. In high energy environments, algae also provide refuge by dampening wave energy, allowing mobile species to persist despite not being strongly attached to the rocks.

Wave action is a key driver determining the species composition in the rocky shore – high energy ecosystem. The high levels of water movement create an environment rich in oxygen and nutrients that is beneficial for species, but these species must also withstand the physical stresses created by waves that increase risk of dislodgement and damage. Species in this ecosystem have adaptations to withstand wave forces and maintain their position on the rocks. For instance, California mussels attach to rocks with byssal threads that are highly elastic and extremely strong, with special proteins that allow them to adhere to rocks with twice the strength of mussel species found in low wave energy environments (Lee et al. 2011). Bull kelp fronds are streamlined to allow them to spread out laterally and minimize drag forces in high energy environments (Koehl 1984).

There are many biological, environmental, and anthropogenic features that influence conditions within this ecosystem, including species composition and distribution. Here, we describe the main ecological components and interactions (Figure 3 and Figure 4**Error! Reference source not found.**), environmental drivers (Figure 5), and human activities (Figure 6), as depicted in the rocky shore – high energy conceptual model illustrations.

3.1.2 Key ecological components and interactions

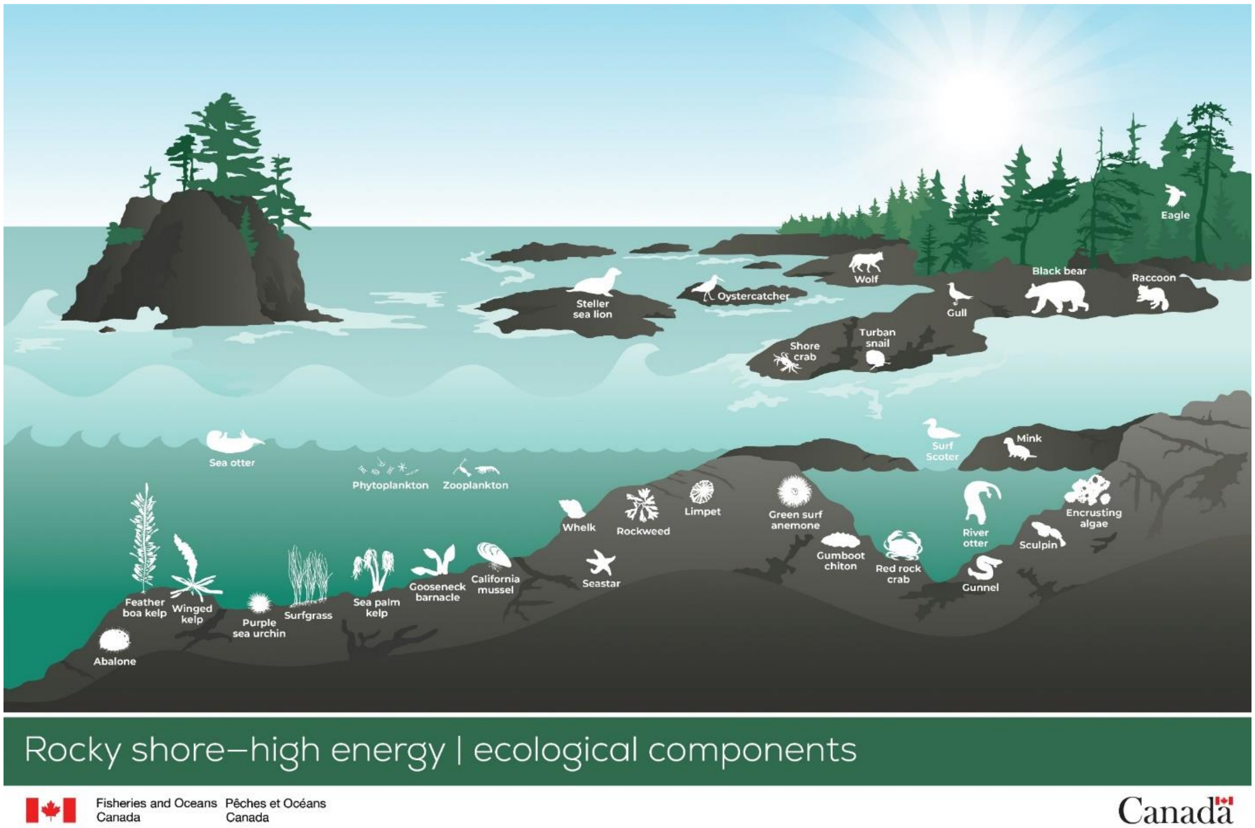

Figure 3. Key ecological components of the rocky shore, high energy ecosystem.

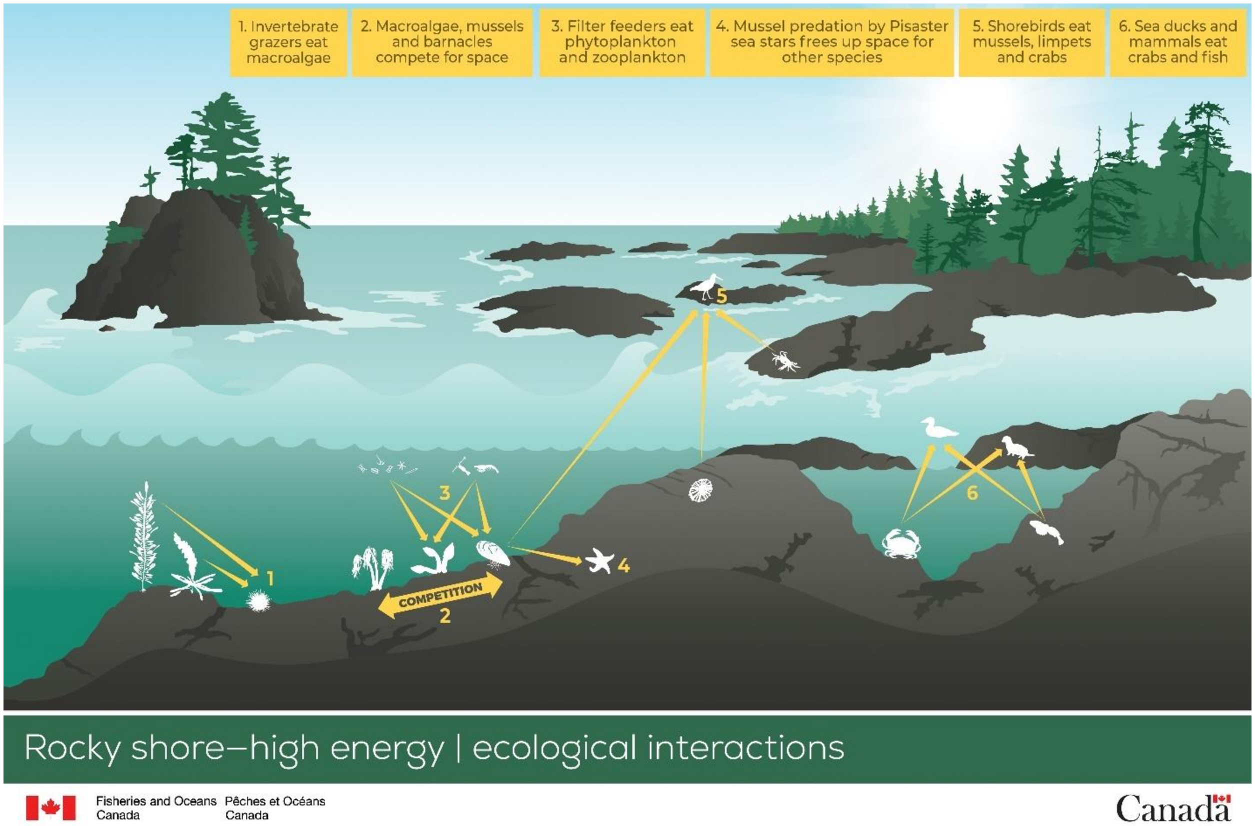

Figure 4. Key interactions among the ecological components of the rocky shore, high energy ecosystem.

Phytoplankton are microscopic marine algae that live in the water column and serve as an important food source for zooplankton and larger **filter feeding** invertebrates such as gooseneck barnacles and California mussels.

Zooplankton are small **filter feeding** invertebrates that live in the water column and serve as an important food source for **filter feeding** invertebrates such as gooseneck barnacles and California mussels. Common types of zooplankton are euphausiids (i.e., krill), copepods, as well as larval stages of crustaceans, molluscs, and fish.

Macroalgae anchor themselves strongly to the rocky substrate using holdfasts, which allow them to withstand disturbance from waves. **Macroalgae**, such as rockweed, winged kelp, feather boa kelp, and sea palm kelp, along with encrusting algae and surfgrasses grow attached to the rocky substrate and serve as key primary producers in this ecosystem. The **macroalgae** and surfgrasses provide complex three-dimensional habitat for invertebrates and fishes. In doing so, they also provide important shelter and refuge against physical stresses associated with exposure at low tides, such as temperature and desiccation (Bellgrove et al. 2017). In addition, **macroalgae** serve as a key food source for invertebrate grazers such as purple urchins, turban snails, and gumboot chitons (Ricketts et al. 1985).

Filter feeding invertebrates such as gooseneck barnacles and California mussels obtain energy and nutrients by filtering phytoplankton and zooplankton from the water column. These sedentary **filter feeding** organisms compete for space between themselves and other organisms, including **macroalgae**. Invertebrates and **macroalgae** found in this ecosystem form characteristic bands at various heights in the **intertidal** zone (Stephenson and Stephenson 1949).

Grazing invertebrates such as limpets, turban snails, purple urchins, Northern abalone, and gumboot chitons consume encrusting algae and attached **macroalgae**, thereby creating space for other organisms. **Grazing** and **filter feeding** invertebrates are in turn an important food source for **predatory** invertebrates, marine birds (e.g., gulls, oystercatchers), and terrestrial mammals such as racoons, mink, and black bears.

Predatory invertebrates in this ecosystem include seastars, whelks, shore crabs, and red rock crab that prey on barnacles, periwinkles, and mussels. The ochre seastar, *Pisaster ochraceus,* acts as a keystone species in this ecosystem. It maintains **biodiversity** by preying on bivalves, mussels in particular, creating space for barnacles, **macroalgae**, and other invertebrates that would otherwise be excluded through **competition** (Paine 1966; Menge et al. 1994). Other **predatory** invertebrates in this ecosystem include anemones like green surf anemones, which adhere to the rocky substrate and consume urchins, small fish, crabs, and detached mussels (Dayton 1975).

Benthic fishes such as sculpins and gunnels prey on small invertebrates including molluscs, polychaete worms, and crustaceans. These fish can tolerate extreme temperature and salinity changes that are common in this ecosystem.

Mammals in this ecosystem include both marine mammals such as Steller sea lions and sea otters that spend part of their time in the **intertidal** zone, and terrestrial mammals. Terrestrial mammals such as racoons, mink, wolves, river otters, black bears, and grizzly bears forage on invertebrates and fish in this ecosystem when the tide is low. This ecosystem is particularly important to Steller sea lions, which preferentially choose exposed rocky shorelines for their rookeries and haul-outs (Ban and Trites 2007).

The bird community includes marine birds such as gulls, shorebirds such as black oystercatchers, sea ducks such as surf scoters, and raptors such as bald eagles. These birds forage for invertebrates such as mussels, limpets, crabs, and fish in this ecosystem.

3.1.3 Environmental drivers

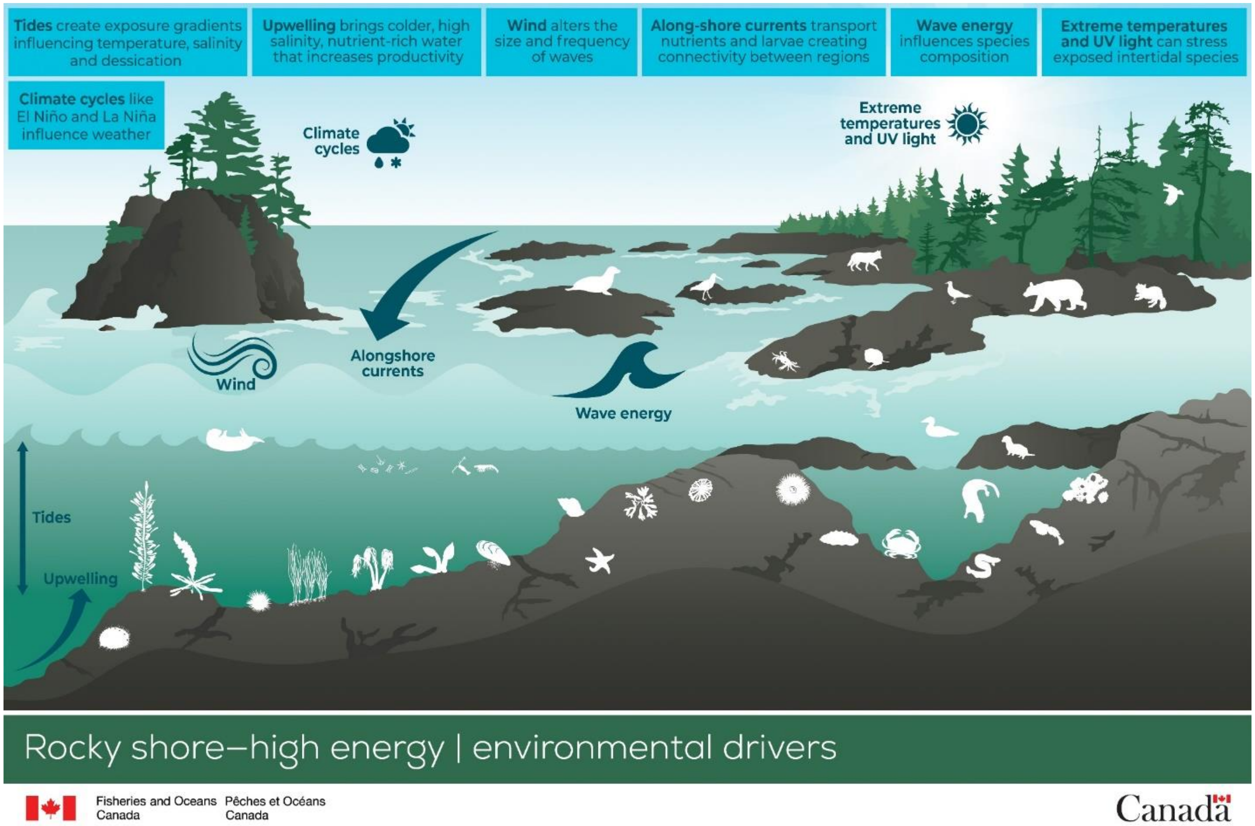

Figure 5. Main environmental drivers within the rocky shore, high energy ecosystem.

Many environmental drivers in the rocky shore – high energy ecosystem influence physical conditions within the ecosystem, as well as species composition and distribution. Here, we describe the main environmental drivers and their effects.

On high energy, rocky shores **intertidal zonation** created by exposure gradients from rising and falling tides are extended to higher elevations due to the spray effect from crashing waves that reduce desiccation risk for exposed organisms and allow them to live at higher elevations. Falling tides also expose organisms on rocky shores to terrestrial predators such as wolves and raccoons, while releasing them from marine predators.

Intertidal species exposed by low tides may experience extreme temperatures and UV light. To deal with these extreme conditions, **intertidal** species have special adaptations and behaviours and can withstand reasonable daily fluctuations in temperature, salinity, and exposure to air caused by tidal cycles. For instance, California mussels close their shells, holding in water to keep them from drying out (Foster 1971). Other species such as crabs, anemones, and sculpins seek shelter in tide pools, or under **macroalgae**. On high energy rocky shores, the spray effect from crashing waves helps to keep organisms cooler during these exposure events, compared to low energy ecosystems. However, when extreme temperatures coincide with low tides, the combination of temperature, UV, and salinity-related stresses can lead to significant physiological consequences for **intertidal** organisms, especially as the frequency, duration, and intensity of these extreme weather events increase with climate change.

In this ecosystem, wind is a strong driver impacting the frequency, size, and energy of waves. Wave energy caused by high winds, large swell, and storm surge can detach **macroalgae** holdfasts, and dislodge **benthic** invertebrates. Organisms living in this ecosystem have many adaptations that allow them to withstand the strong wave energy. However, waves can cause floating logs to be thrown against the shore, which can dislodge organisms that could otherwise withstand wave disturbance. Wind and waves are also important for transporting, dispersing, and supplying nutrients and larvae, which can lead to higher productivity in this ecosystem, compared to rocky shore - low energy ecosystems (Morgan et al. 2018). Waves can also dislodge or disrupt feeding by seastars and urchins, minimizing their consumption, and allowing for higher productivity of their invertebrate and **macroalgae** prey (Leigh et al. 1987).

Upwelling of colder, higher salinity and nutrient water to this ecosystem increases phytoplankton productivity and the **recruitment** of **sessile** invertebrates (e.g., barnacles and mussels; Menge and Menge 2013).

Along-shore currents transport nutrients and larvae, and strongly influence patterns of **recruitment**, as well as levels of connectivity between beaches (Kelly and Palumbi 2010; Meerhoff et al. 2020). They are more prevalent in wave-exposed ecosystems (NOAA n.d.) where they create greater ecological and genetic connectivity between regions compared to less wave-exposed ecosystems.

Climate cycles like El Niño and La Niña influence weather, leading to variation in other environmental drivers such as wind events, temperature, precipitation, currents, and the strength of **upwelling** events in rocky shore – high energy ecosystems. Climate cycles, and the associated changes in other drivers such as **upwelling**, leads to variability in levels of **recruitment** for some organisms in rocky shore ecosystems with higher rates experienced during La Niña when **upwelling** is strongest (Menge et al. 2011).

3.1.4 Human activities

Four main human activities are common in rocky shore – high energy ecosystems: recreational and commercial fishing, shipping, and coastal communities. Recreational and commercial fishers remove fish and may injure species caught as bycatch. Fishers who fish from shore may also trample organisms living on the rocky substrate. Shipping taking place near these ecosystems is a source of pollution, serves as a vector of invasive species spread, and introduces underwater noise and wakes that cause physical disturbance when they meet the shoreline. Coastal communities can be sources of pollution and marine debris, as well as human traffic that can trample **intertidal** organisms.

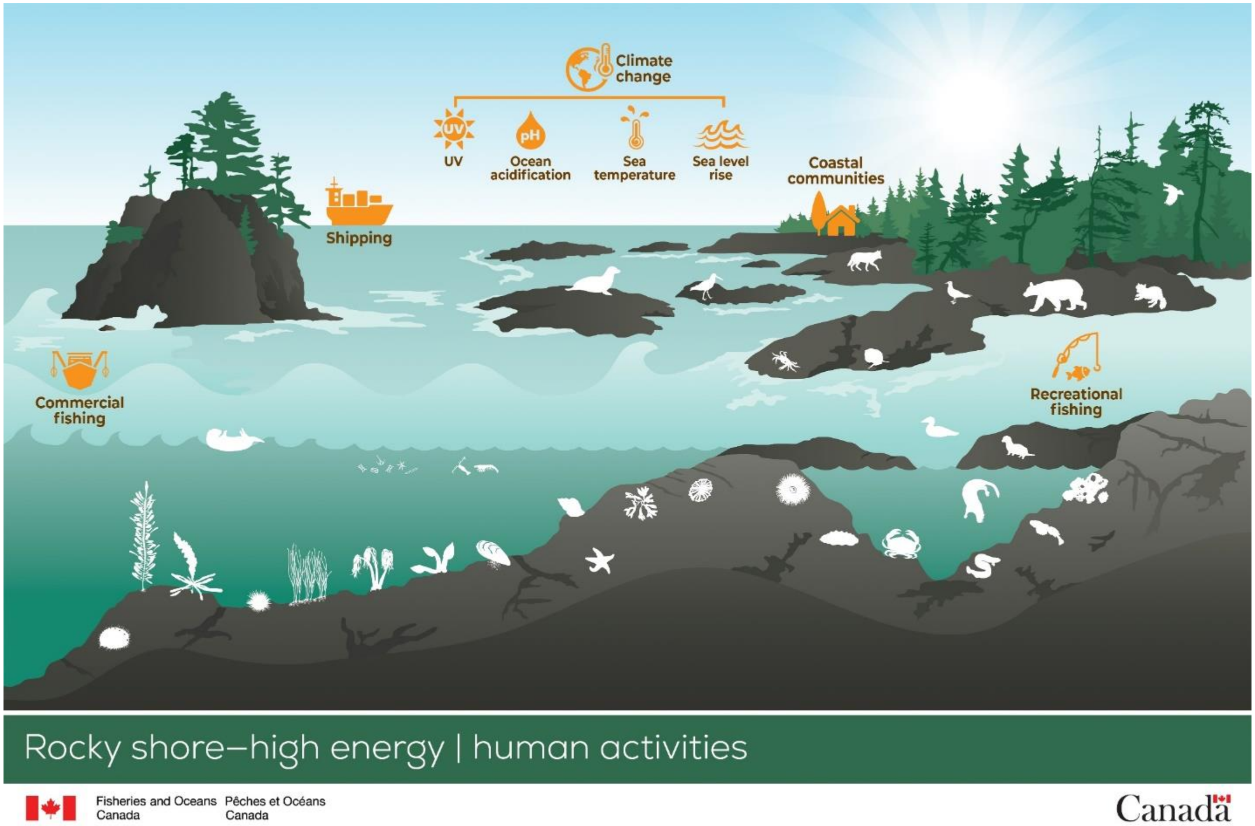

Figure 6. Relevant human activities within the rocky shore, high energy ecosystem.

3.1.4.1 Climate Change

The rocky shore – high energy ecosystem is impacted by many aspects of climate change, most notably, ocean acidification, increased sea temperature, increased UV radiation, and sea level rise. These effects, and other climate contributors (e.g., increased wave action, higher air temperatures, and increased freshwater input), can work synergistically affecting local communities, and may vary greatly depending on location.

This ecosystem is dominated by many calcifying organisms including barnacles, mussels, and **plankton**, which are vulnerable to the effects of ocean acidification. As this environment becomes more acidic, it will become increasingly difficult for these organisms to extract calcite and aragonite from the water to form body structures such as shells. Ocean acidification in rocky shore habitats will likely result in a decrease in **biodiversity** as calcifying invertebrates and algae are increasingly unable to form skeletons (Asnaghi et al. 2013), though additional modeling in nearshore environments would improve our understanding (Friesen et al. 2021).

Increased sea temperature will not affect all species equally. Some organisms in this ecosystem are tolerant of high temperatures, but many already live close to their thermal limits (Tomanek and Somero 1999). These species may be more negatively impacted by increased seawater temperatures in the short term. However, **macroalgae** in wave exposed ecosystems compared to sheltered ones have been shown to be more resilient to climate change **stressors** such as increased radiation and temperature, potentially due to splashing effects from waves, or the mixing from water motion that prevents warm water pockets from forming (Starko et al. 2019).

Species living in this ecosystem are also impacted by increased UV radiation, which can affect them physically, as well as indirectly through biochemical pathways. For instance, increased UV radiation inhibits photosynthesis, causes physical damage to **macroalgae**, and increases mortality for early life stages (Henelt et al. 2007). It also limits the uptake of nutrients by phytoplankton (Hessen et al. 1997), with cascading impacts for food chains in the ecosystem. Species or communities already stressed by more acidic and wamer waters may not withstand further impacts from increased UV radiation.

Sea level rise also has the potential to impact **intertidal** species, which will have varying abilities to adapt *in situ,* or through range expansion, to the rise. For example, where sea level rise floods new shoreline, **intertidal** organisms may respond by expanding into such areas if the conditions are suitable. These organisms may also shift northward or persist in sub-optimal or stressful conditions.

3.2 Rocky shore – low energy

3.2.1 General description

The rocky shore – low energy ecosystem is comprised of rocky substrates such as bedrock, boulder, and cobble in **intertidal** areas that do not experience frequent, large waves and high wind energy. It is a widespread ecosystem that is found in inlets and inshore coastal areas such as the gulf islands. Most species in this ecosystem live on the surface of the rocky substrates that dominate this ecosystem and **infaunal** organisms are rare.

The species assemblages in this ecosystem are structured across a vertical gradient from the low **intertidal** zone to high **intertidal** zone. Species' locations along this gradient are determined by their ability to tolerate exposure to waves and air throughout the tidal cycle, as well as **predation**, and **competition** for space (Connell 1972). The dynamic nature of the rocky **intertidal** zone gives rise to a range of environmental **stressors** for plants and animals that occupy these areas. The high **intertidal** zone remains exposed to air for prolonged periods of time between high tides, and species that occupy these areas (e.g., acorn barnacles, limpets, marine snails) can tolerate long periods of exposure to air, considerable fluctuations in temperature, and the ability to avoid **predation**. The mid-**intertidal** zone is regularly exposed to air for shorter periods of time and is occupied by a wide variety of species (e.g., seastars, blue mussels, rockweed). Species' ranges are limited in the upper middle **intertidal** by environmental conditions (e.g., temperature, exposure to air) and by **predation** in the low region of the middle **intertidal** zone. The low **intertidal** zone is typically only exposed to air at the lowest tides. Tidepools, isolated pockets of seawater trapped in depressions and crevices after the tide recedes, provide refuge from desiccation, temperature and salinity extremes, supporting species that would otherwise not survive **intertidal** conditions. Additional protection from desiccation and heat stress for species in this ecosystem is provided by algae species that lie flat at low tide when not supported by water. These algae form canopies that maintain moist and shaded microenvironments.

Species in the rocky shore – low energy ecosystem do not contend with the extreme wave forces that are found in the rocky shore – high energy ecosystem. This allows invertebrate species to be more mobile and algae species less streamlined. However, less wave action results in less replenishment of oxygen, nutrients, and food for filter feeders compared to higher energy ecosystems. Likely for these reasons, lower algal and invertebrate diversity, as well as reduced abundance of filter feeders, has been associated with lower levels of wave action when compared to high wave exposure sites (Arribas et al. 2014).

There are many biological, environmental, and anthropogenic features that influence conditions within this ecosystem, including species composition and distribution. Here, we describe the main ecological components and interactions (Figure 7 and Figure 8), environmental drivers (Figure 9), and human activities (Figure 10), as depicted in the rocky shore - low energy conceptual model illustrations.

3.2.2 Key ecological components and interactions

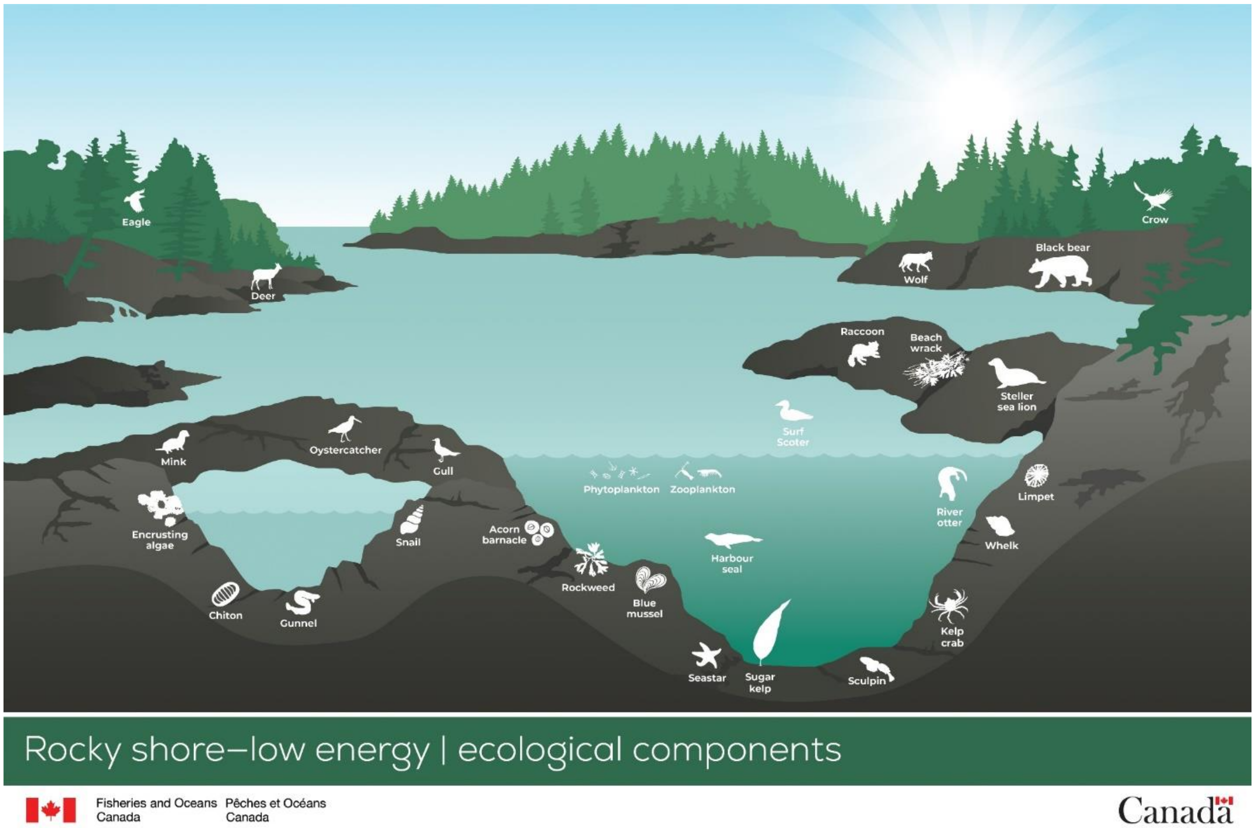

Figure 7. Key ecological components of the rocky shore – low energy ecosystem.

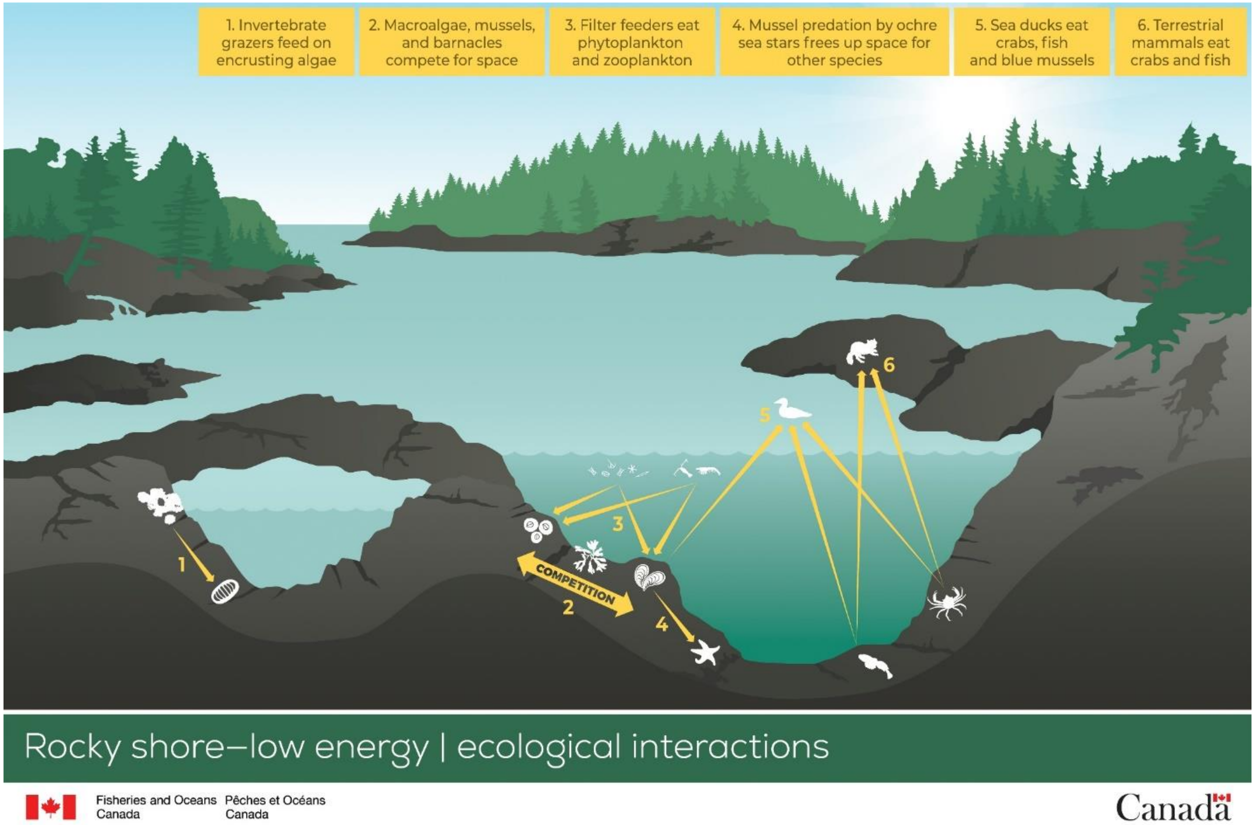

Figure 8. Key interactions among the ecological components of the rocky shore, low energy ecosystem.

Phytoplankton are microscopic marine algae that form the base of the food web in rocky shore low energy habitats. Phytoplankton are a food source for a wide variety of organisms, including zooplankton and **filter feeding** invertebrates such as acorn barnacles and blue mussels.

Zooplankton are small **filter feeding** invertebrates that live in the water column and serve as an important food source for **filter feeding** invertebrates such as acorn barnacles and blue mussels. Common species in the zooplankton community are euphausiids (i.e, krill) and copepods, as well as larval stages of crustaceans, molluscs, and fishes.

Beach wrack, which includes drift **macroalgae**, **seagrasses**, and carrion that have washed onto the rocky beach, provides a food source for microbes, invertebrate grazers, and scavengers that are subsequently ingested by higher trophic level terrestrial organisms (e.g., wolves) (Ince et al. 2007; Cardona and Garcia 2008; Schlacher et al. 2017). The amount of wrack accumulation depends on a variety of factors, including the amount and proximity of donor habitats (e.g., kelp forests, eelgrass beds), time of year (e.g., wrack biomass is higher in winter months), slope, and substrate type (Wickham et al. 2020). Beach wrack retention in this ecosystem is dependent on substrate type; bedrock substrate does not retain beach wrack to the same extent as boulders and cobble (Ince et al. 2007; Wickham et al. 2020).

Macroalgae such as rockweed and sugar kelp provide food and complex three-dimensional habitat for fishes, **grazing** invertebrates like snails and limpets, and herbivorous invertebrates including kelp crabs.

Filter feeding invertebrates in this habitat include several species (e.g., acorn barnacles, blue mussels) that obtain energy and nutrients by filtering phytoplankton and zooplankton from the water column.

These sedentary **filter feeding** organisms compete for space at suitable tidal elevations with conspecifics and other organisms, including **macroalgae**.

Grazing invertebrates such as snails (e.g., dogwinkles), limpets (e.g., mask limpet; plate limpet) and chitons (e.g., mossy chiton) consume encrusting algae and **macroalgae** that grow on rocks, creating space for other organisms. **Grazing** and **filter feeding** invertebrates are important food sources for **predatory** invertebrates (e.g., crabs and seastars), marine birds (e.g., gulls, black oystercatchers), and terrestrial mammals such as racoons, mink and black bears.

Predatory invertebrates in this habitat include whelks and seastars (e.g., ochre seastars) that prey on bivalves (e.g., blue mussels), and other invertebrates such as periwinkles, limpets, and chitons. Members of this group, particularly the ochre seastar, which is a keystone species, play an important role in maintaining **biodiversity** in rocky **intertidal** ecosystems (Paine 1966; Menge et al. 1994). By reducing the abundance of mussels through **predation**, space is created, which enables the growth and maintenance of a diverse assemblage of **macroalgae** and invertebrates.

Benthic fishes such as gunnels and sculpins inhabit tide pools and prey on small invertebrates including molluscs, polychaete worms, and crustaceans. In turn, they are an important food source for marine birds (e.g., gulls, surf scoters), migratory and non-migratory shorebirds (e.g., black oystercatchers), generalist birds (e.g., crows and bald eagles), and terrestrial mammals. Many fish species that occupy rocky shore – low energy ecosystems (e.g., crescent gunnels, tidepool sculpins) can tolerate extreme temperature and salinity changes that are common in these environments throughout the tidal cycle.

Marine mammals such as harbour seal and Steller sea lion use the rocky shore – low energy ecosystem as winter haul-out sites (DFO 2020b; Olesiuk, 2009; Olesiuk 2018). Terrestrial mammals such as deer, wolves and river otters forage in this rocky ecosystem.

Marine birds in this ecosystem include birds such as gulls (e.g., glaucous-winged gulls), shorebirds (e.g., black oystercatchers), sea ducks (e.g., surf scoters), raptors (e.g., bald eagles), and generalists (e.g., crows). Many of these bird taxa forage for invertebrates such as mussels, limpets, crabs, and fishes in the **intertidal** environment.

3.2.3 Environmental drivers

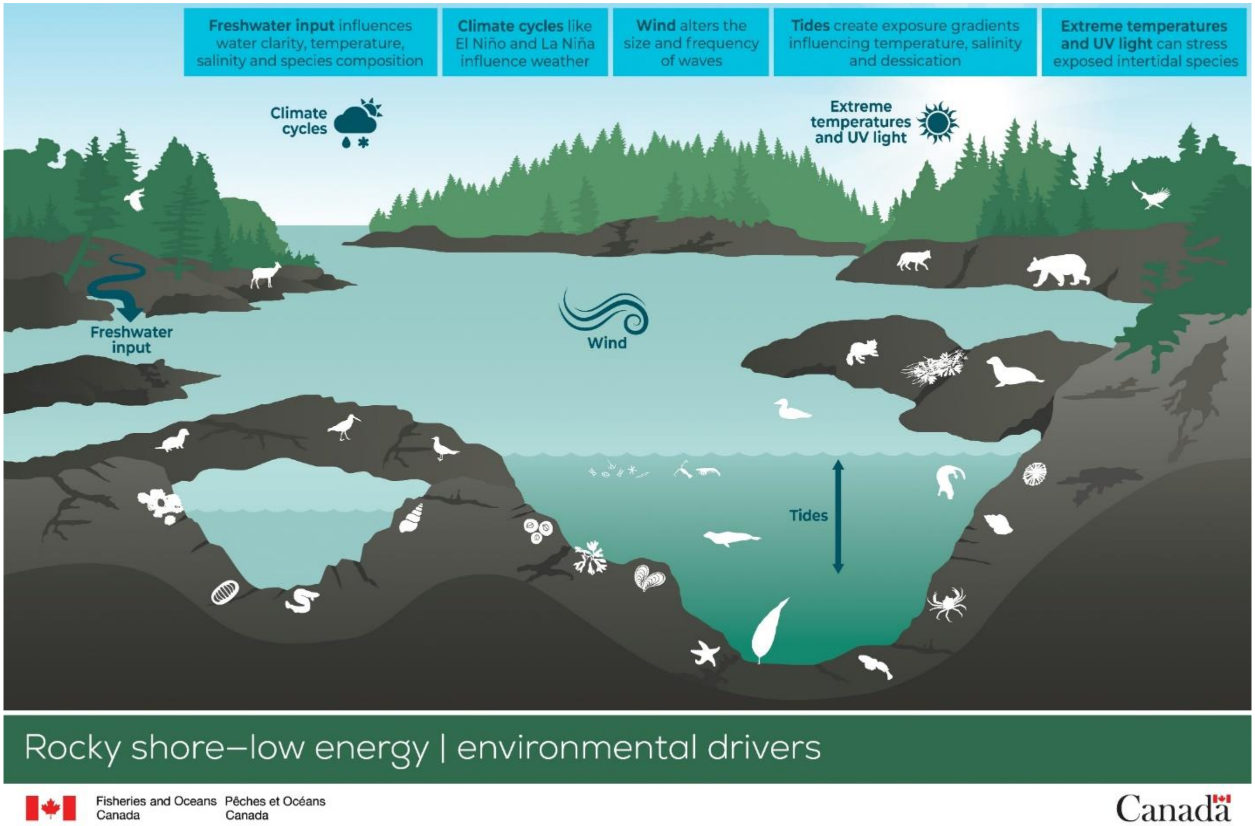

Figure 9. Main environmental drivers within the rocky shore, low energy ecosystem.

Many environmental drivers in the rocky shore – low energy ecosystem influence physical conditions within the ecosystem, as well as species composition and distribution. Here we describe the main environmental drivers and their effects.

Freshwater input from rivers, streams and terrestrial run-off more commonly affects low energy ecosystems due to the lower amounts of mixing compared to high energy **intertidal** ecosystems. Lower salinity due to freshwater input reduces species diversity and abundance in this ecosystem (Smyth and Elliot 2016), and may cause silting of the seafloor that also contributes to lower diversity in impacted areas.

On low energy rocky shores **intertidal zonation** created by exposure gradients from rising and falling tides are well defined. However, in this ecosystem there is no spray effect from crashing waves to allow organisms to extend their distribution to higher elevations as in high energy ecosystems. Tidal movement also exposes the rocky shores, providing feeding opportunities for terrestrial mammals such as wolves and raccoons.

Intertidal species exposed by low tides may experience extreme temperatures and UV light. To deal with these extreme conditions, **intertidal** species have special adaptations and behaviours and can withstand reasonable daily fluctuations in temperature, salinity, and exposure to air caused by tidal cycles. For instance, acorn barnacles and blue mussels close their shells, holding in water to keep them from drying out (Foster 1971). Other species such as kelp crabs, seastars, and sculpins seek shelter in tide pools, or under **macroalgae**. However, when extreme temperatures coincide with low tides, the combination of temperature, UV, and salinity-related stress can lead to high species mortality (Hesketh and Harley 2023), especially as the frequency, duration, and intensity of these extreme weather events increase with climate change.

Wind can cause desiccation to exposed organisms, and impacts the frequency, size, and energy of waves. Wind speeds in this ecosystem are generally lower than those experienced in rocky shore – high energy ecosystems. This results in smaller waves that are less effective for transporting, dispersing, and supplying nutrients and larvae, and less along-shore currents for creating connectivity between ecosystems (Morgan et al. 2018).

Climate cycles like El Niño and La Niña influence weather, leading to variation in other environmental drivers such as wind events, temperature, precipitation, and currents in rocky shore – low energy ecosystems. Climate cycles, and the associated changes in other drivers such as **upwelling**, leads to variability in levels of **recruitment** for some organisms in rocky shore ecosystems with higher rates experienced during La Niña when **upwelling** is strongest (Menge et al. 2011).

3.2.4 Human activities

In rocky shore – low energy ecosystems, shipping and land-based activities such as coastal communities, ports, and pulp and paper mills are the main human activities affecting the ecosystem. Shipping is a source of pollution, serves as a vector of invasive species, introduces underwater noise, and wakes that cause physical disturbance when they meet the shoreline. Coastal infrastructure, including ports, mills, and community infrastructure, can modify the shoreline, and may be a source of pollution and marine debris. Pulp and paper mills may also discharge wastewater into the environment, contributing to pollution.

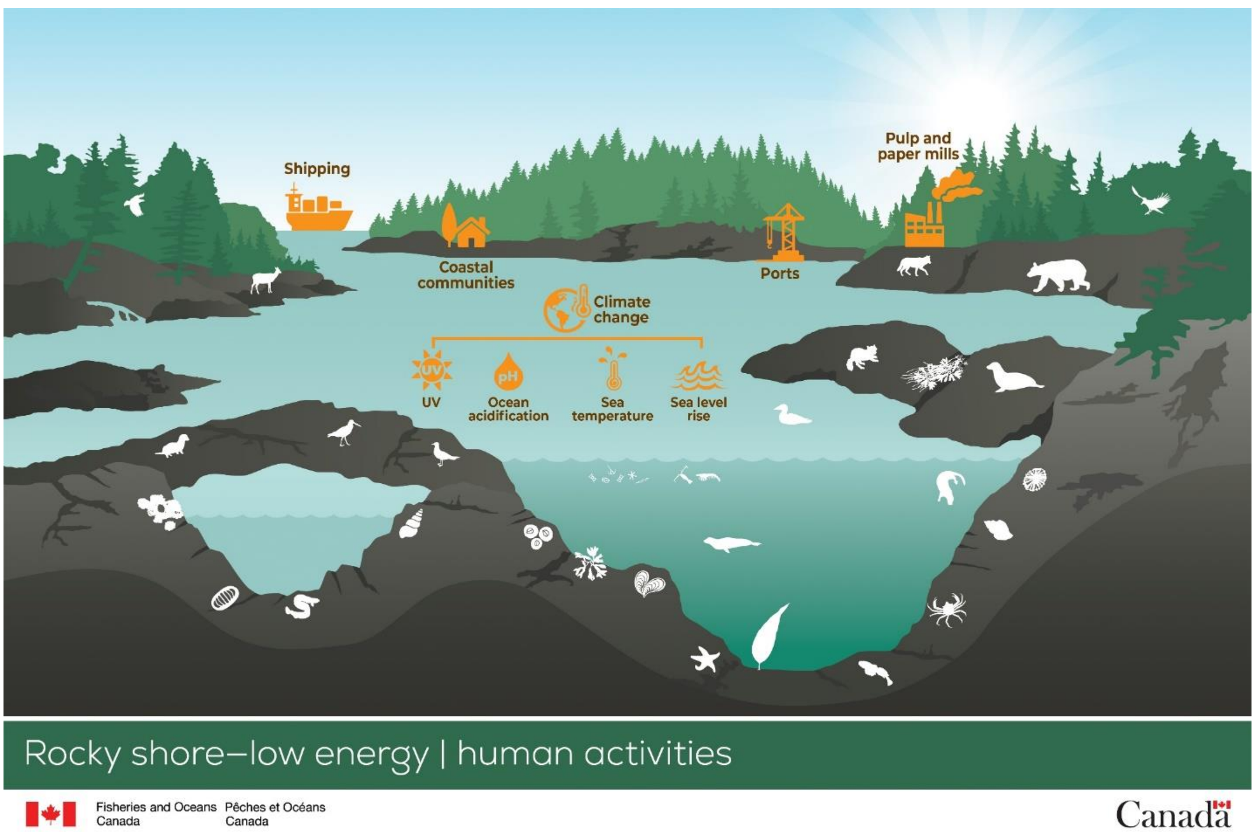

Figure 10. Relevant human activities within the rocky shore, low energy ecosystem.

3.2.4.1 Climate Change

Rocky shore-low energy ecosystems are influenced by many effects of climate change, most notably, ocean acidification, increased sea temperature, increased UV radiation, and sea level rise.

Ocean acidification is important for calcifying organisms including barnacles, mussels, and some **plankton** species, as well as calcifying algae (Hofmann et al. 2011). As in the rocky shore – high energy ecosystem, as seawater becomes more acidic it will become increasingly difficult for these organisms to extract calcite and aragonite from the water to form body structures such as shells.

Increases in seawater temperature will negatively impact species in this ecosystem that already live near their thermal limits. These species may not be able to tolerate the higher temperatures and may not survive, although others will be more tolerant (Tomanek and Somero 1999). Wave sheltered beaches in BC have experienced larger population declines in **macroalgae** during warm water periods, such as that experienced on the BC coast from 2013 to 2016, compared to wave exposed beaches (Starko et al. 2019), and thus may be impacted to a greater degree by sea temperature rise.

Increased UV radiation can add further stress to **intertidal** species; it is deleterious to many photosynthetic species (e.g., **macroalgae**, seagrasses). The harmful effects of increased UV radiation include decreased growth, biomass, productivity, and photosynthesis (Pessoa 2012). Increased UV radiation may also limit the uptake of nutrients by phytoplankton (Hessen et al. 1997), with cascading impacts for food chains in the ecosystem.

Sea level rise may shift **intertidal** communities to higher levels on the shore, depending on the specific location and availability of suitable habitat (Okey et al. 2012). If this happens, community structures will change due to shifts in **predation** and levels of **competition**

With climate change, some rocky **intertidal** species have been shown to shift their distribution northward (Węsławski et al. 2011). Not all species can do so though, which can result in organisms living in sub-optimal or stressful conditions, localized extinctions (Horn and Martin 2006), and changes to community structure.

3.3 Soft shore – high energy

3.3.1 General description

The soft shore – high energy ecosystem consists of sandy beaches that experience high wave action. Examples of this ecosystem in BC are Long Beach on the west coast of Vancouver Island and North Beach at the north end of Haida Gwaii.

The substrate in this ecosystem is comprised of sand from very fine to coarse grain size (smaller particles such as silt are washed away due to the high wave energy). The particle size of the substrate depends on the beach type. There are three main beach types (i.e., reflective, intermediate, or dissipative) that take into account waves, tides, currents, surf zone width and shape, and the dry portion of the beach. Reflective beaches have smaller waves (0.5 m) and longer wave periods, resulting in coarser sediment and steeper slopes. Waves hitting a reflective beach break at the base of the beach, run along the beach face, and are reflected directly back into the sea. Intermediate beaches are common on open coasts and have moderate waves (0.5–2.5 m) and fine to medium sand particles. They are characterized by a surf zone with one or two bars (i.e., submerged or partly exposed ridge of sand that is built by waves) up to 100 m wide. Dissipative beaches are characterized by large waves (>2.5 m) and fine sand. They have a low slope and a 300–500 m wide surf zone that contains at least two bars. On dissipative beaches, waves break on the outer and then inner bars, dissipating their energy as they move across the surf zone. The type of beach illustrated in the soft shore – high energy diagrams, and described in this section, is that of an intermediate or dissipative beach.

The frequency and size of waves in the soft shore – high energy ecosystem is dependent on local and offshore storm events; wave conditions in this ecosystem vary from very calm conditions (usually during summer months), to large and crashing swells (predominantly in winter months). The high wave action that can be experienced on these beaches creates harsh and highly variable hydrodynamic conditions. Despite this, exposed, dissipative sandy beaches can have relatively high biomass and species richness (Marin Jarrin 2007; Lercani 2010; McLachlan et al. 1993). However, the species that inhabit wave exposed sandy beaches are limited to those that can tolerate a lack of stable attachment points and are specialized for the harsh environment (Charbonnier et al. 2016). For instance, unlike rocky shores where attached plants and animals are prevalent, on wave exposed sandy shores **macroalgae** is limited to unattached individuals that drift in from other ecosystems, and **sessile benthic** invertebrates are largely absent. The drift **macroalgae** is a source of shelter and food for many fishes and invertebrates (Marin Jarrin & Shanks 2011). Marine fauna in this ecosystem consists largely of **pelagic** species, **benthic** fishes and crustaceans, and **infaunal** invertebrates (Marin Jarrin & Miller 2016; McLachlan 1990).

There are many biological, environmental, and anthropogenic features that influence conditions within this ecosystem, including species composition and distribution. Here, we describe the main ecological components and interactions (Figure 11 and Figure 12), environmental drivers (Figure 13), and human activities (Figure 14), as depicted in the soft shore – high energy conceptual model illustrations.

3.3.2 Key ecological components and key interactions

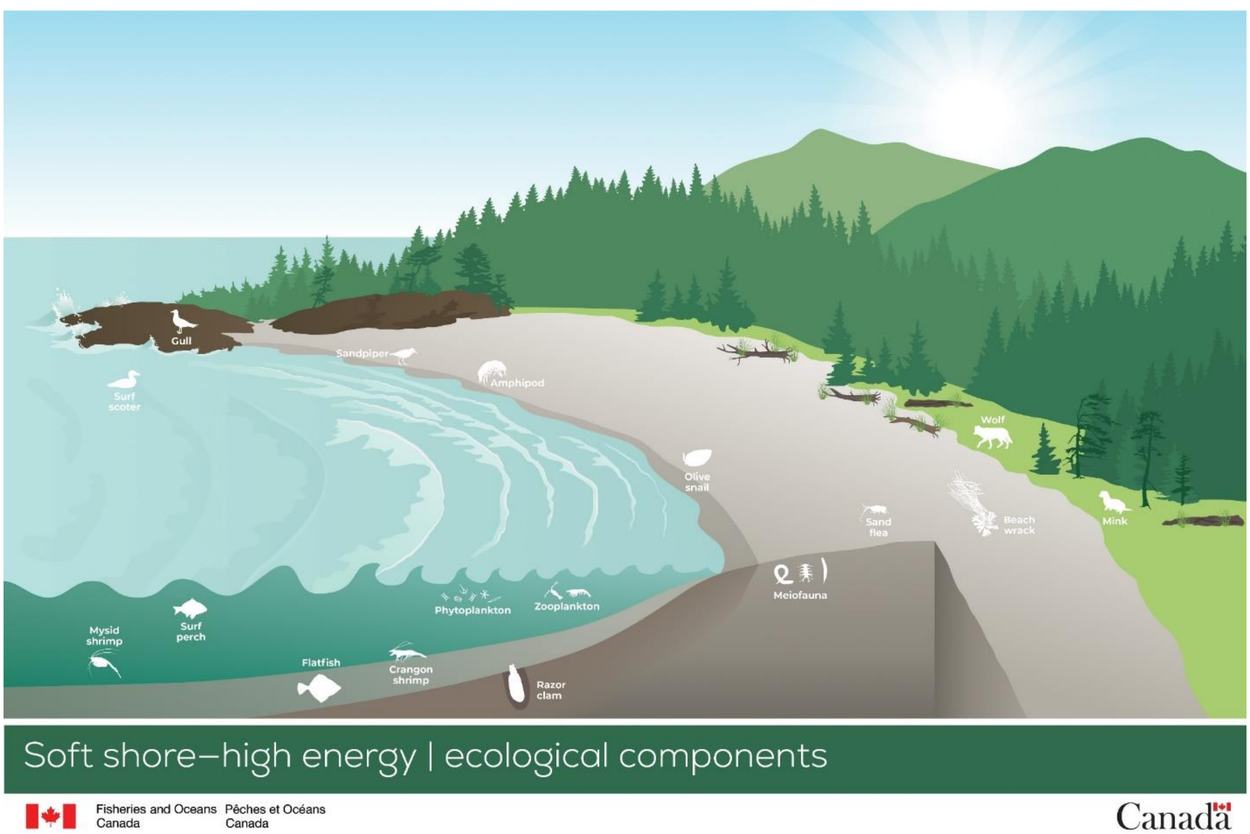

Figure 11. Key ecological components of the soft shore, high energy ecosystem.

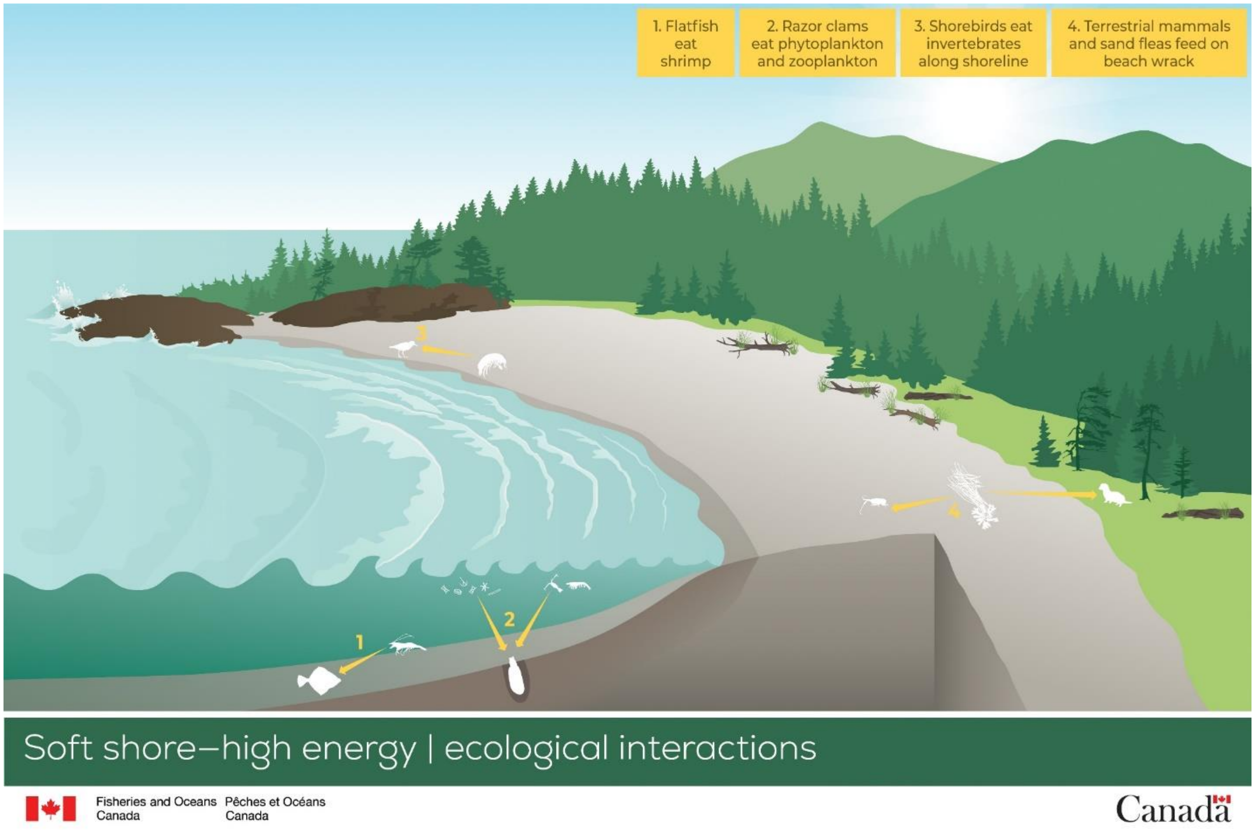

Figure 12. Key interactions among the ecological components of the soft shore, high energy ecosystem.

Phytoplankton are microscopic marine algae that form the base of food webs in soft shore – high energy ecosystems. Phytoplankton are the main source of **primary production** on sandy exposed beaches, including within the surf zone, and are largely dominated by blooms of surf diatoms (McLachlan 1990). Phytoplankton are a food source for zooplankton and a wide variety of **filter feeding** organisms, including razor clams.

Zooplankton are an important food source in soft shore – high energy ecosystems. They are consumed by **filter feeding** organisms such as mysid shrimp, crangon shrimp, and razor clams. Common zooplankton species in this habitat include adult, juvenile, and larval life stages of crustacean species, larval molluscs, and jellyfish (Marin Jarrin & Shanks 2011).

Meiofauna consist of species that are smaller than 1 mm and live between grains of sand. They include species from most phyla, including nematodes, flatworms, and rotifers. Meiofauna play a role in bioturbating the upper layer of the beach and provide food for **infaunal** predators such as worms.

Beach wrack consists of drift **macroalgae**, **seagrass**, and carrion. It is largely derived from the rocky shore – high energy, rocky **subtidal**, and soft shore ecosystems, and is widely considered a major energy subsidy in soft shore environments that do not support **macroalgae** growth of their own (Dugan et al. 2011). Beach wrack provides food and shelter for a variety of organisms (Marin Jarrin & Shanks 2011); beach wrack itself is consumed by amphipods (e.g., Sand Fleas) (Dugan et al 2011; Mews et al. 2006) and provides food for terrestrial mammals such as mink and wolves that are attracted to lower trophic level species that use the beach wrack as food or shelter (Wickham et al. 2020). Decomposing wrack on a beach is also an important source of nutrients that are absorbed by meiofauna in the sand (McGwynne et al. 1988).

Filter feeding invertebrates (e.g., razor clams and mysid shrimp) feed on phytoplankton and zooplankton respectively. Razor clams are particularly adapted to wave swept beaches, and are found exclusively in this ecosystem. Many **benthic** invertebrates, particularly clams, rely on wave swashes to provide transportation and to deliver food (McLachlan 1990).

Scavenging invertebrates (e.g., olive snails) feed opportunistically on small food items within the **intertidal** area (Kelly et al. 2021). Crangon shrimp are **predatory** invertebrates that feed on crustaceans (e.g., amphipods, mysid shrimp) and small clams (Jensen 1995; Marin Jarrin & Shanks 2008). Deposit feeding invertebrates are scarce on exposed sandy beaches, likely because the dynamic conditions on the beaches are not conducive to accumulating detritus (Defeo & McLachlan 2011).

Common members of the **pelagic** fish community in soft shore high energy ecosystems are silver and redtail surfperches (Lamb & Edgell 2010). These fish have a diverse diet consisting of crustaceans, small fishes, molluscs, and polychaetes (Bennet & Wydoski 1977).

Flatfishes are common **benthic** fishes in the soft shore – high energy ecosystem (Marin Jarrin & Shanks 2011).

Shorebirds such as sandpipers are found in high numbers in this ecosystem, particularly during their migration periods, where they feed on invertebrates (e.g., amphipods) in **intertidal** areas. Gulls and sea ducks such as surf scoters also use this habitat for foraging, loafing, and roosting.

3.3.3 Environmental drivers

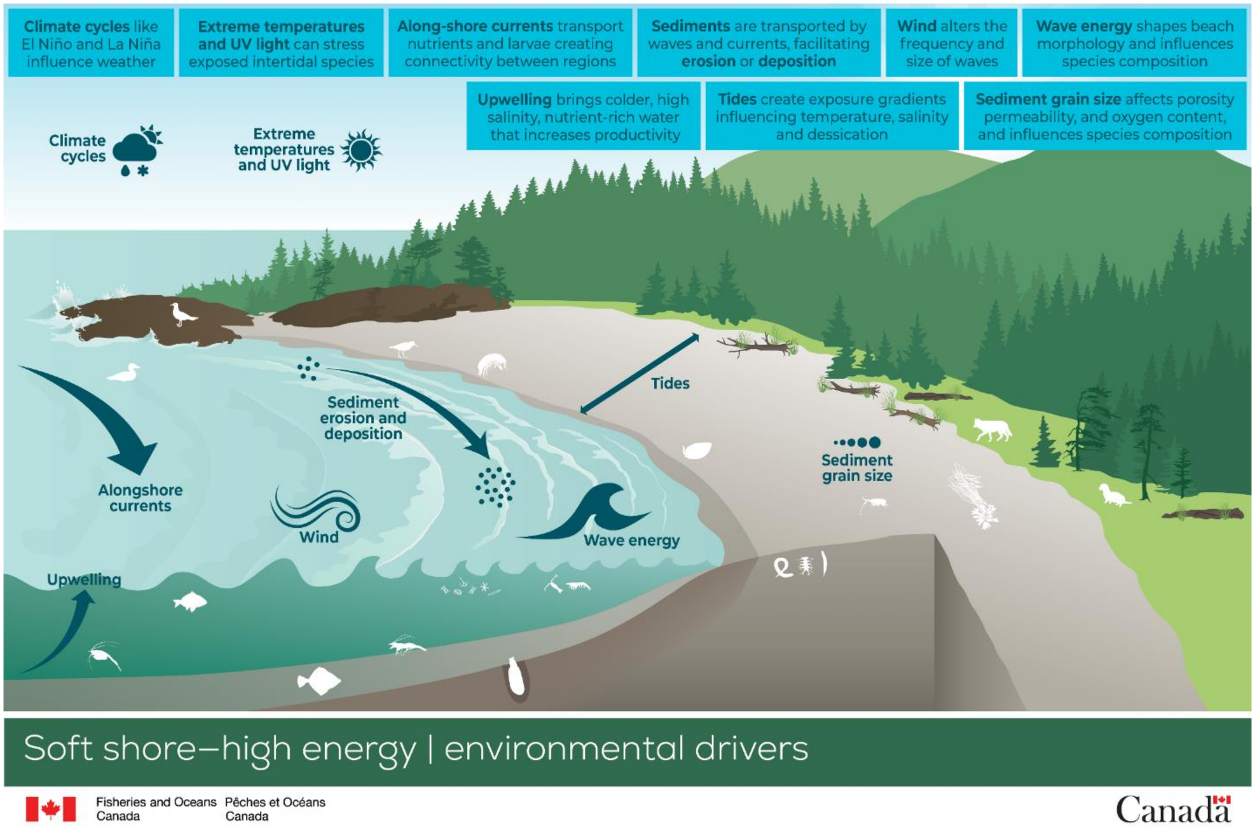

Figure 13. Main environmental drivers within the soft shore, high energy ecosystem.

Many environmental drivers in the soft shore – high energy ecosystem influence physical conditions, as well as species composition and distribution. Here, we describe the main environmental drivers and their effects.

Wave energy in this ecosystem drives surf zone productivity and is a major factor in determining the productivity of a beach (McLachlan 1990). Wave energy also determines species distribution and is associated with higher diversity (McLachlan 1990). Many **benthic** invertebrates rely on wave swashes to provide transportation and deliver food (McLachlan 1990). Wave energy also shapes beach morphology by creating currents that shift sediments either horizontally or vertically along a beach. The direction of sediment transport depends on several factors including the angle of the beach relative to the waves, and the strength and frequency of the waves (Amoudry & Souza 2011). Sediment transportation caused by waves and currents also creates peaks and valleys that provide habitat heterogeneity along the beach (Marin Jarrin & Miller 2016). On a larger scale, sediment transportation facilitated by waves creates areas of erosion where sediment is lost, and areas of deposition where the sediment is accreted (Amoudry & Souza 2011).

Wind alters the frequency and size of waves, thereby influencing levels of erosion, and deposition, as well as beach morphology. Longshore wind can also affect currents and influence sediment transport processes, leading to changes in sediment grain size distribution, and patterns of erosion and deposition. Storm surge and large waves caused by increased wind can lead to erosion and species strandings.

Sediment grain size in the soft shore – high energy ecosystem is influenced by the beach slope and amount of wave energy that it receives (McLachlan 1990). In turn, the size of particles on a beach influences species distribution and abundance (McLachlan 1990); within the range of grain sizes found on wave exposed beaches, finer sands retain more moisture and are positively correlated with higher species diversity and abundance than coarser sands that drain more quickly (McLachlan 1990). Sand particle sizes on wave exposed beaches tend to be larger than those with lower wave exposure, which allows better water penetration and leads to higher oxygen content in the water between sand particles (Rodriguez et al. 2003).

Zonation caused by tides on soft shores is not as visible as that on a rocky shore given that many of the species live within the sand, and the boundaries between zones are not as sharp (McLachlan 1990). However, zones dominated by different species do exist in soft shore – high energy ecosystems and are similarly driven by varying desiccation tolerances among species (McLachlan 1990). Many species in this ecosystem are able to bury in the soft sediment and avoid exposure, allowing them to have a larger vertical distribution than they would otherwise, especially with the presence of surf swashes that allow an even wider distribution. Tidal movement also exposes these shores, providing feeding opportunities for terrestrial mammals and birds such as wolves and sandpipers.

Intertidal species exposed by low tides may experience extreme temperatures and UV light. To deal with these extreme conditions, **intertidal** species have special adaptations and behaviours and can withstand reasonable daily fluctuations in temperature, salinity, and exposure to air caused by tidal cycles. In soft shore ecosystems, many species bury deeper to minimize temperature fluctuations and desiccation risk. However, when extreme temperatures coincide with low tides, the combination of temperature, UV, and salinity-related stress can lead to significant physiological consequences for **intertidal** organisms, especially as the frequency, duration, and intensity of these extreme weather events increase with climate change.

Along-shore currents transport nutrients and larvae, and strongly influence patterns of **recruitment**, as well as levels of connectivity between beaches (Kelly and Palumbi 2010; Meerhoff et al. 2020). They are more prevalent in wave-exposed ecosystems (NOAA n.d.) where they create greater ecological and genetic connectivity between regions compared to less wave-exposed ecosystems.

Upwelling of colder, higher salinity and nutrient water to this ecosystem increases phytoplankton productivity providing food for **infaunal** filter feeders (e.g., razor clams).

Climate cycles like El Niño and La Niña influence weather, leading to variation in other environmental drivers such as wind events, temperature, precipitation, currents, sediment transport, and the strength of **upwelling** events in soft shore – high energy ecosystems. These changes have ecological consequences: higher rates of erosion are experienced during El Niño and La Niña events, compared to neutral periods (Barnard et al. 2015); impacts of increased erosion on a wave exposed beach following an El Niño event included reduced biomass of invertebrates, reduced levels of beach wrack subsidies, and shorebird abundance (Revell et al. 2011).

3.3.4 Human activities

Three activities were identified as the main human activities affecting soft shore – high energy ecosystems. Recreational and commercial fishing remove fish and may injure species caught as bycatch. Coastal communities contribute to pollution and marine debris, and often modify shorelines, which alters sediment transport patterns.

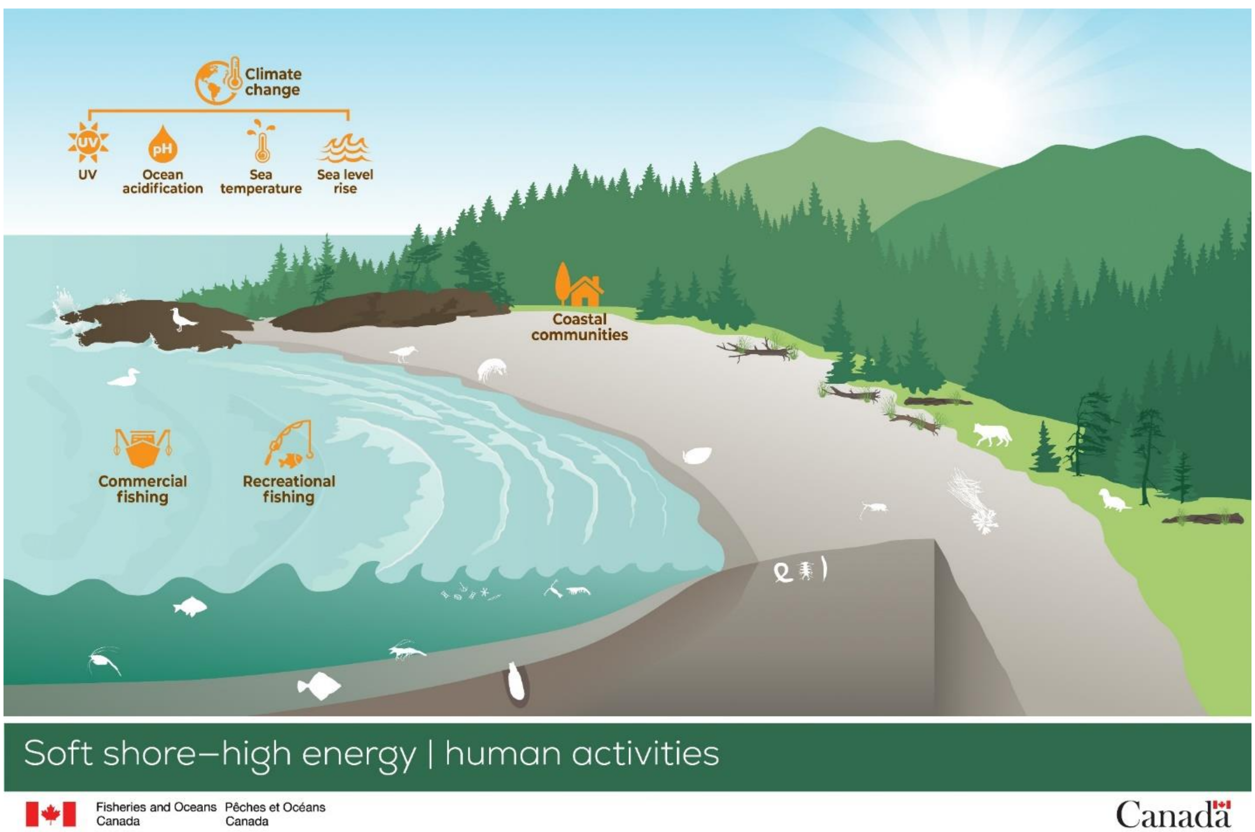

Figure 14. Relevant human activities within the soft shore, high energy ecosystem.

3.3.4.1 Climate Change

The soft shore –high energy ecosystem is influenced by many aspects of climate change; most notably ocean acidification, increased sea temperature, increased UV radiation, and sea level rise. However, little is known about climate **stressors** on **infaunal** organisms that are common in this ecosystem.

The species that inhabit this ecosystem are adapted to an environment that is constantly changing due to shifting sands and tides. Many mobile species, such as crustaceans and flatfishes, can move to other more suitable habitats if conditions become unsuitable. Since the species in this ecosystem can respond to changing conditions, it is possible they may be more resilient to some aspects of climate change, such as sea level rise and increased sea temperatures, than species in other ecosystems.

However, this ecosystem is rich in zooplankton and crustaceans, which require calcium to produce skeletons, and are therefore vulnerable to negative impacts from ocean acidification (Asnaghi et al. 2013; Portner et al. 2011). As the water becomes more acidic, it may become increasingly difficult for these organisms to extract calcite and aragonite from the water to form their exoskeletons, which could lead to decreased productivity in this ecosystem.

Depending on their thermal tolerances, **intertidal** species may be affected by increased seawater and air temperatures, especially if they already live near their thermal limits (Tomanek and Somero 1999). Even tolerant species may be unable to tolerate extreme heat events associated with climate change, which may lead to mortalities (Hesketh and Harley 2023). Again, there will be differences in species' abilities to survive extreme weather events such as heat waves, depending on factors such as their physiology and specific habitat.

In soft shore – high energy ecosystems, increased UV radiation can add further stress to **intertidal** organisms by causing physical damage and decreasing the productivity of phytoplankton due to the inhibition of nutrient uptake (Hessen et al. 1997). However, the impacts of increased UV radiation in this ecosystem may be lower that those on rocky shores, or low energy sandy shores, because many species that remain in **intertidal** areas at low tide in this ecosystem live within the sand and are thus protected from sun exposure (Brown and McLachlan 2002).

Depending on the specific location and the availability of suitable habitat, sea level rise may shift communities to higher levels in the **intertidal** (Okey et al. 2012). This may lead to changes in community structures due to shifts in **predation** and levels of **competition**, or a reduction in species diversity and abundance if suitable habitat is not available. Higher sea levels will also expose new shoreline areas to wave forces during storms, causing increased rates of erosion and deposition, with consequences for sand dune communities and the persistence of beaches (Walker and Barrie 2006).

3.4 Soft shore – low energy

3.4.1 General description

The soft shore – low energy ecosystem consists of beaches comprised mainly of mud or sand with low wave exposure (e.g., Spanish Banks, Baynes Sound, Qualicum Beach).

Substrates in this ecosystem range from relatively homogenous sand or mud, to heterogeneous and complex mixtures of silt and sand, with gravel and shell fragments. Sediment grain size and composition in the soft shore – low energy ecosystem is more variable than on wave exposed ones as reduced wave exposure allows for fine particles, such as silt, to persist on the least exposed beaches. The substrate composition in this ecosystem also varies with time; winter storm activity often washes sand high into the **intertidal** zone and the calm summer tidal action removes the sand, exposing underlying gravel or cobble.

The low wave energy environment in this ecosystem provides more stable conditions than the soft shore – high energy ecosystem, which allows for greater diversity of **infaunal** and **epifaunal** invertebrates, as well as **macroalgae** and vascular plants like eelgrass.

There are many biological, environmental, and anthropogenic features that influence conditions within this ecosystem, including species composition and distribution. Here, we describe the main ecological components and interactions (Figure 15 and Figure 16), environmental drivers (Figure 17), and human activities (Figure 18), as depicted in the soft shore – low energy conceptual model illustrations.

3.4.2 Key ecological components and key interactions

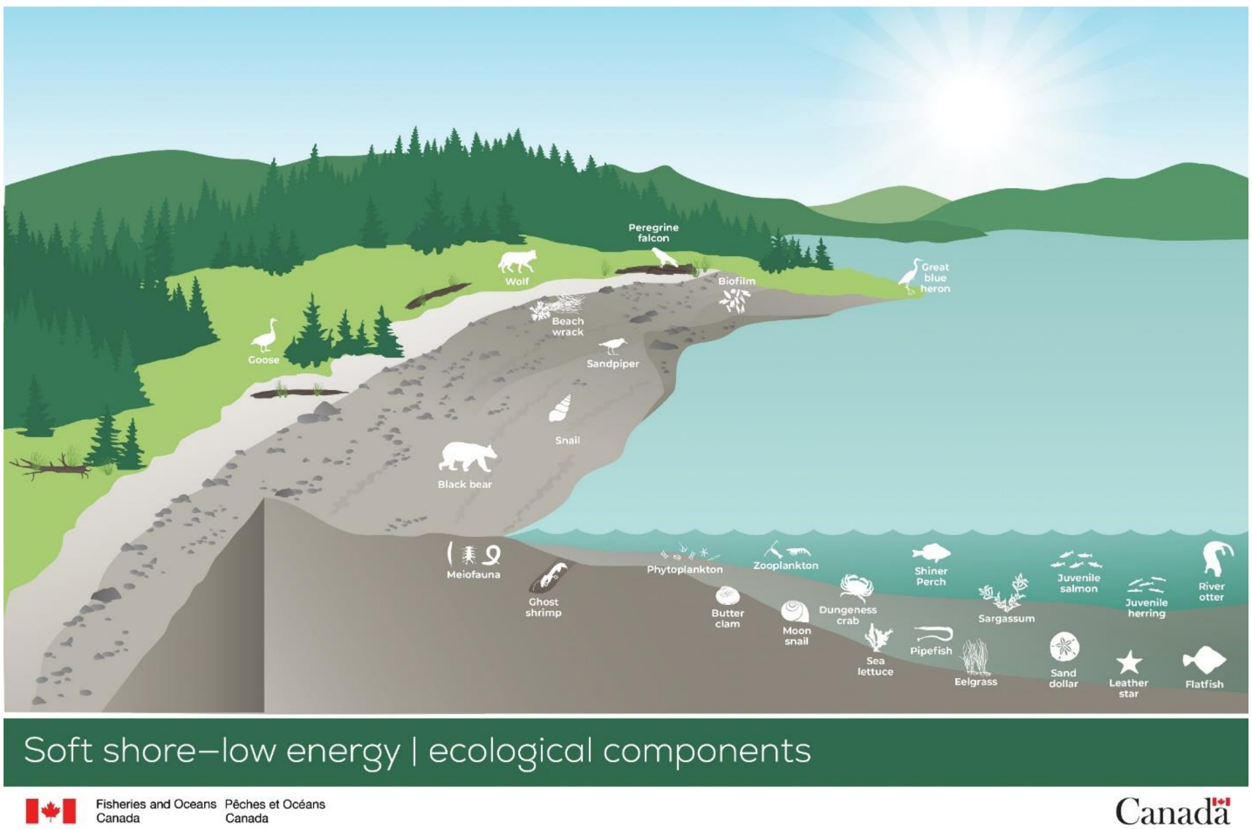

Figure 15. Key ecological components of the soft shore – low energy ecosystem.

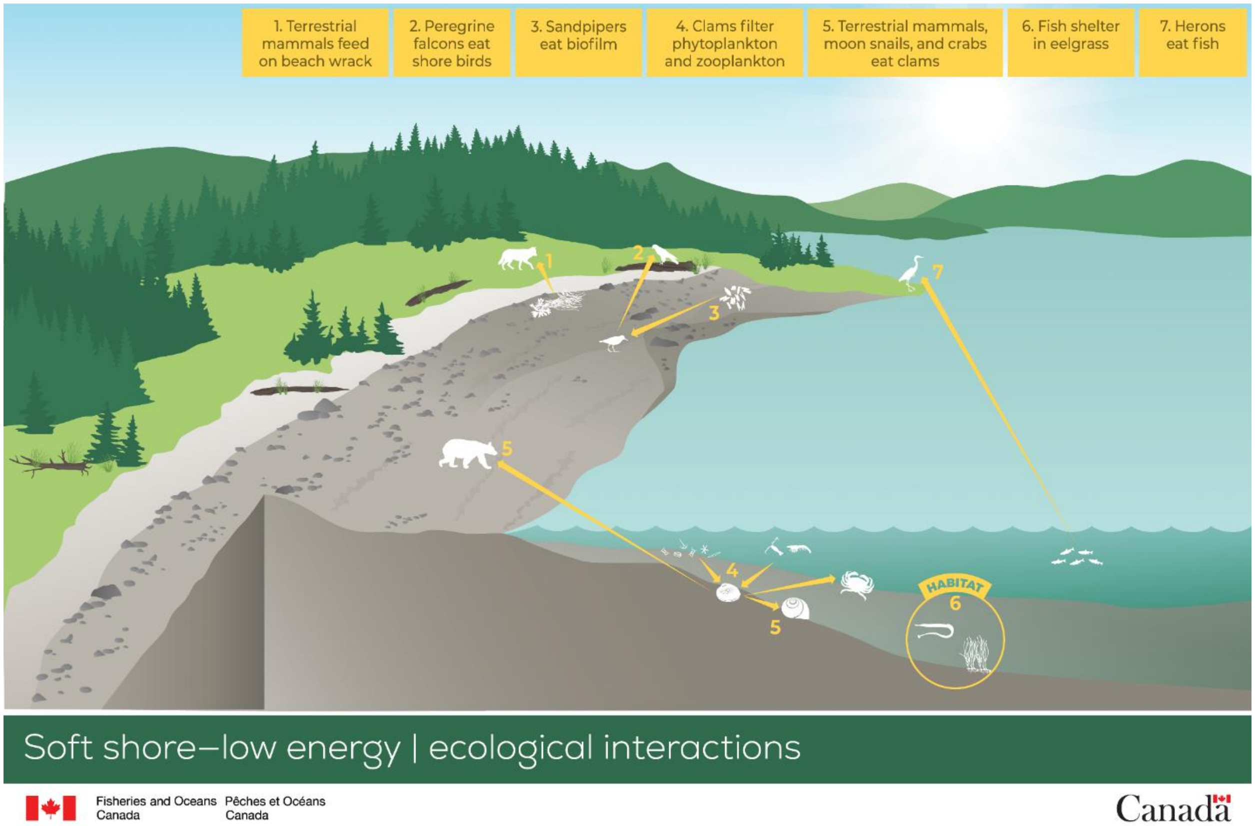

Figure 16. Key interactions among the ecological components of the soft shore, low energy ecosystem.

Phytoplankton are microscopic marine algae that form the base of the food web in soft shore – low energy ecosystems. Phytoplankton are a food source for a wide variety of **filter feeding** invertebrates in this ecosystem, including zooplankton, ghost shrimp and butter clams.

Zooplankton are an important food source in marine systems, providing nutrients for a variety of predators, from small **filter feeding** organisms to higher trophic level species such as baleen whales (e.g., humpback and grey whales). Common species in the zooplankton community are euphausiids (i.e., krill), copepods, cnidarians (e.g., jellyfish), as well as larval stages of crustaceans, molluscs, and fish. Zooplankton migrate vertically from the seafloor to surface waters to graze on phytoplankton, thereby coupling **benthic** and **pelagic** habitats.

Biofilm, a thin layer of adhering microorganisms, is an important food source for sandpipers and other shorebirds (Jiménez et al. 2015). The spatial and temporal accumulation of **biofilm** is determined by tidal cycles, sediment grain sizes characteristics (Decho 2000), as well as by light, temperature, and nutrient availability (Ubertini et al. 2015).

Beach wrack consists of drift **macroalgae**, **seagrass**, and carrion that is deposited on shore. As it decomposes, it enriches the sand and provides nutrients for terrestrial vegetation. Beach wrack is also an important food source for microbes, invertebrate grazers, and decomposers that are subsequently ingested by higher trophic level terrestrial organisms (Ince et al. 2007; Cardona and Garcia 2008; Schlacher et al. 2017). The presence of wrack on the beach shades **infaunal** organisms below, including eggs of forage fishes such as surf smelt and Pacific sand lance (Dethier et al. 2016). Another important marine nutrient source that enhances the productivity of terrestrial ecosystems is nutrients derived from **predation** on shellfish. This includes nitrogen, phosphorus, and calcium, which are transported to terrestrial ecosystems by clam predators such as coastal birds, mammals (e.g., black bears, river otters), and people (Cox et al. 2020). Shellfish-derived nutrients have a substantial influence on soil chemistry, forest productivity, and the diversity of primary producers at both regional and landscape levels (Cox et al. 2020).

Eelgrass, **macroalgae** including sea lettuce, and introduced *Sargassum* provide habitat structure, and a source of food for herbivorous grazers (e.g., leather stars and geese). Eelgrass grows in this ecosystem by anchoring into the soft substrate with its rhizomes. This anchoring stabilizes substrates and prevents erosion. Eelgrass supports diverse and productive invertebrate and fish assemblages (Stark et al. 2020) that are an important food source for geese, fishes, and shorebirds such as Great Blue Heron. Eelgrass also provides important nursery, foraging, and refuge habitat for a wide range of fish species including juvenile salmonids, juvenile herring, shiner perch and bay pipefish.

Many organisms in the soft shore – low energy ecosystem such as Dungeness crabs, sand dollars, snails, (e.g., moon snails), ghost shrimp, worms, and meiofauna contribute to **bioturbation**. **Bioturbation** enhances and replenishes oxygen and nutrient levels in the sediment, creates habitat structure, and contributes to the breakdown of organic matter by mixing, and altering the physical and chemical properties of the substrate.

Filter feeding clams (e.g., butter clams, cockles, horse clams, Pacific littleneck, and manila clams) obtain energy and nutrients by filtering phytoplankton and zooplankton from the water column, improving water quality and clarity. Indigestible material and waste components are discharged into the substrates. These species are also an important food source for many organisms, including Dungeness crabs, moon snails, flatfish, and terrestrial mammals (e.g., black bears, river otters). When clams die, their shells break down, which contributes shell fragments and shell hash as structure to the substrate and changes the chemistry of the sediment (Green et al. 2013; Ruesink et al. 2014; Greiner et al. 2018).

Terrestrial mammals, such as black bears, river otters, and grey wolves forage in soft shore – low energy ecosystems.

Marine birds in this habitat include shorebirds such as sandpipers that feed on **biofilm** and invertebrates. Great Blue Herons feed on **pelagic** fishes such as juvenile salmonids in nearshore habitats. Sandpipers are preyed upon by Peregrine Falcon.

3.4.3 Environmental drivers

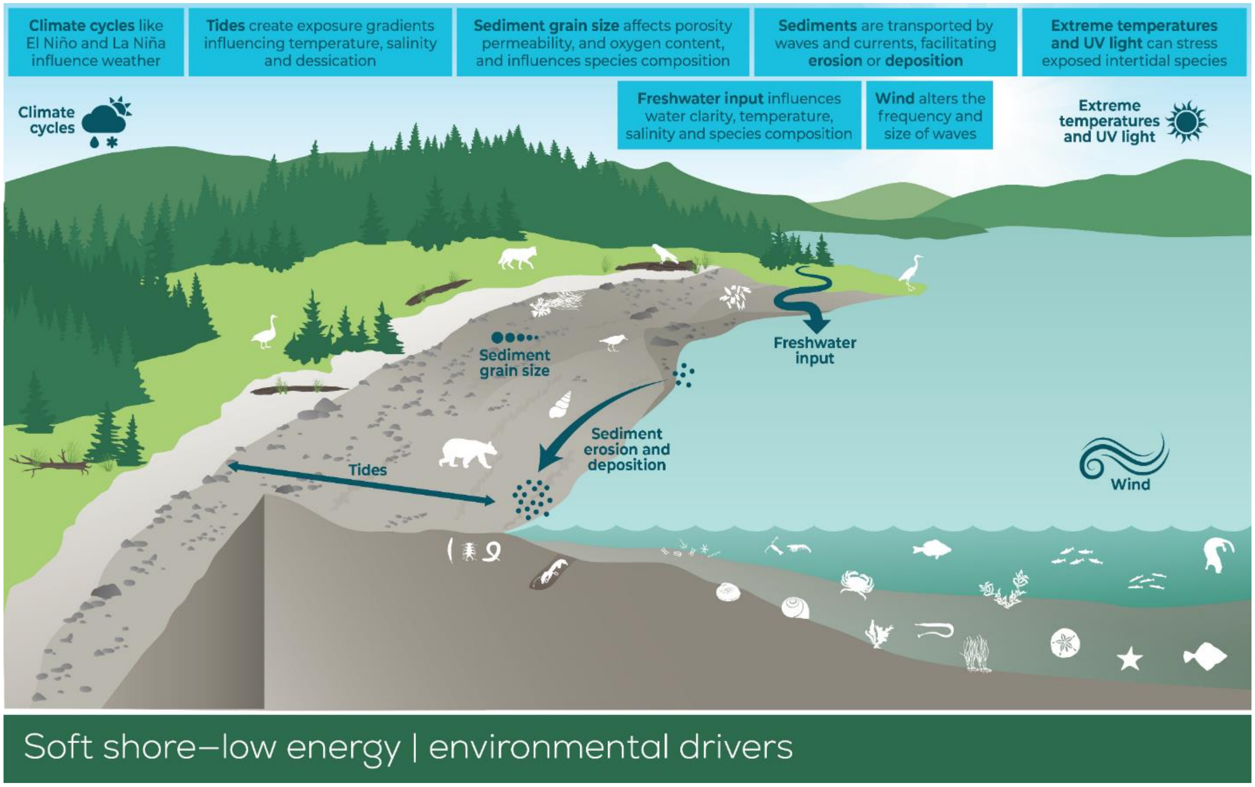

Figure 17. Main environmental drivers within the soft shore, low energy ecosystem.

Many environmental drivers in the soft shore – low energy ecosystem influence physical conditions, as well as species composition and distribution. Below, we describe the main environmental drivers and their effects.

Porosity, permeability, and the amount of available oxygen within sediment on a beach varies with sediment grain size, which in turn influences habitat suitability and species composition. For example, mudflats, sandflats, and clam gardens (**intertidal** features constructed by coastal First Nations of British Columbia, Washington State, and Alaska that accumulate shell hash and coarse material) have increasingly coarse grain sizes, and were found to support distinct **infaunal** communities (Cox et al. 2019). Grain size is particularly important for Pacific sand lance that spawn in **intertidal** and shallow **subtidal** substrates with very specific grain sizes (coarse sand and shell hash substrates with low silt content) (Winslade 1974; Pearson 1984; Tomlin et al. 2021).

Sediment erosion and deposition influences beach morphology and sediment grain size in soft shore – low energy ecosystems with consequential effects on habitat suitability and species composition.

Freshwater input from rivers, streams and terrestrial run-off more commonly affects low energy ecosystems due to the lower amounts of mixing compared to high energy **intertidal** ecosystems. Lower salinity due to freshwater input reduces species diversity and abundance in this ecosystem (Smyth and Elliot 2016).

Zonation caused by tides on soft shores is not as visible as that on a rocky shore given that many of the species live within the sand, and the boundaries between zones are not as sharp (McLachlan 1990). However, zones dominated by different species do exist in soft shore – low energy ecosystems and are similarly driven by varying desiccation tolerances among species (McLachlan 1990). Many species in this ecosystem are able to bury in the soft sediment and avoid exposure, allowing them to have a larger vertical distribution than they would otherwise. Tidal movement also exposes prey items buried in the beach, providing feeding opportunities for terrestrial mammals such as black bears to dig for clams and other buried invertebrates.

Intertidal species exposed by low tides may experience extreme temperatures and UV light. To deal with these extreme conditions, **intertidal** species have special adaptations and behaviours and can withstand reasonable daily fluctuations in temperature, salinity, and exposure to air caused by tidal cycles. In soft shore ecosystems, many species bury deeper to minimize temperature fluctuations and desiccation risk. However, when extreme temperatures coincide with low tides, the combination of temperature, UV, and salinity-related stresses can lead to significant physiological consequences for **intertidal** organisms, especially as the frequency, duration, and intensity of these extreme weather events increase with climate change.

Wind alters the frequency and size of waves, which can uproot eelgrass rhizomes and detach **macroalgae** holdfasts. Longshore wind can also affect currents and influence sediment transport processes, leading to changes in sediment grain size distribution and patterns of erosion and deposition. Storm surges, and large waves caused by increased wind, can lead to erosion and species strandings.

Climate cycles like El Niño and La Niña influence weather, leading to variation in other environmental drivers such as wind events, temperature, precipitation, currents, and the strength of **upwelling** events in soft shore – low energy ecosystems.

3.4.4 Human activities

A number of human activities can affect the soft shore – low energy ecosystem. Near the coast or upstream, human activities on land affecting soft shore ecosystems include extraction activities, such as forestry roads and cutblocks; mining; coastal communities; industrial facilities; and paved road networks. These activities are a source of shoreline modification, pollution, and sedimentation. On the water, the activities affecting this ecosystem include commercial and recreational fishing and aquaculture. Recreational and commercial fishers remove fish and can injure species caught as bycatch. Aquaculture alters the habitat, and can be a source of introduced species, disease, chemicals, nutrients, noise, and shading.

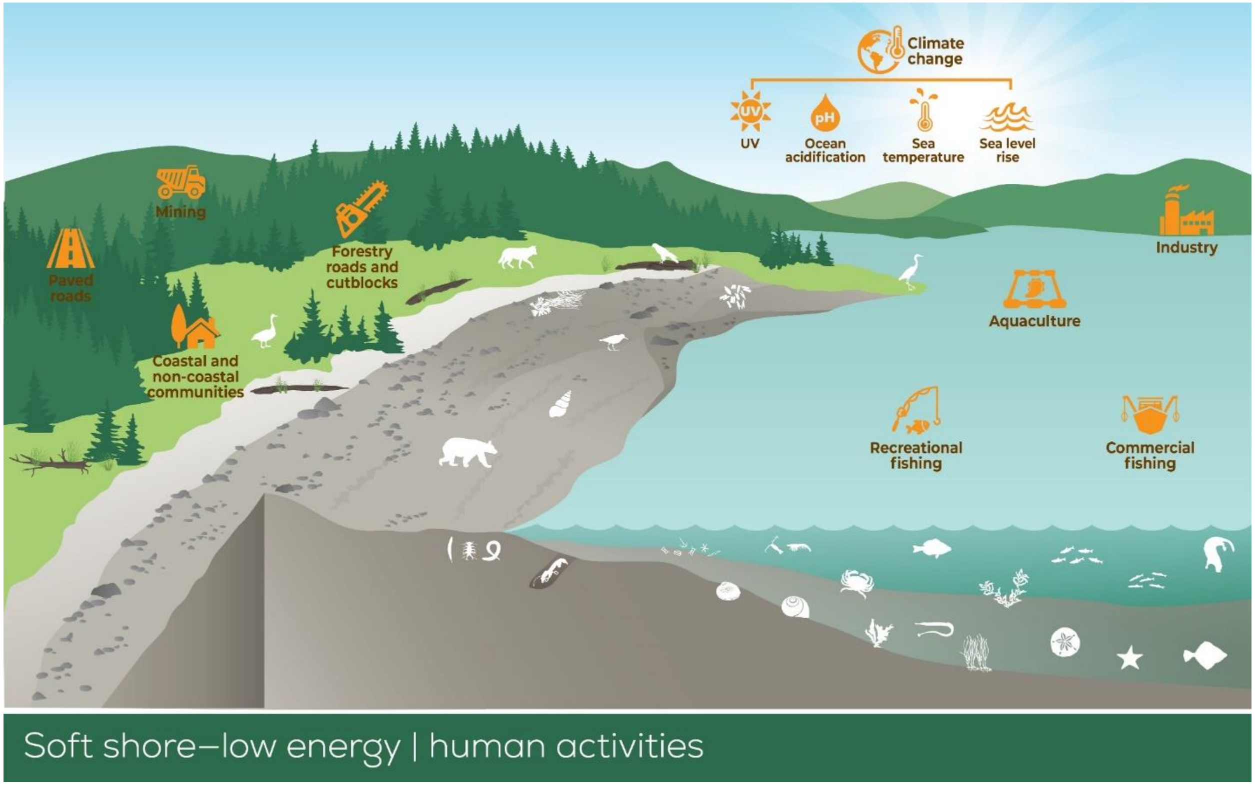

Figure 18. Relevant human activities within the soft shore – low energy ecosystem.

3.4.4.1 Climate Change

Soft shore – low energy ecosystems are influenced by many effects of climate change; most notably, ocean acidification, increased sea temperature, increased UV radiation, and sea level rise.

Eelgrass beds are common in the soft shore – low energy ecosystem. Increased carbon from climate change may benefit carbon-limited **seagrasses** by allowing increased photosynthesis; it has been suggested that **seagrasses** may replace **macroalgae** under changing climate conditions (Harley et al. 2006; Okey et al. 2012). However, the benefits from increased availability of carbon may be outweighed by the possibility of higher incidences of diseases, such as eelgrass wasting disease, that are more prevalent with increased sea temperatures, which is also associated with climate change (Groner et al. 2021).

Soft shore –low energy ecosystems support many calcifying organisms, including clams, snails, shrimp, crabs, and **plankton**, and impacts from ocean acidification can be expected for these organisms. That is, as the water becomes more acidic, it will become increasingly difficult for these organisms to extract calcite and aragonite from the water to form body structures such as shells.

The compounded effects of increased seawater temperature and increased UV radiation may make this **intertidal** ecosystem unsuitable for many species. Some species in this ecosystem may already be living near their thermal limits (Tomanek and Somero 1999), and may not be able to tolerate increased temperatures. Even tolerant species may be unable to tolerate extreme heat events associated with climate change, leading to mortalities (Hesketh and Harley 2023). Again, there will be differences in species abilities to survive extreme weather events, as noticed during the 2021 heat wave where deeper dwelling butter clams fared better than cockles, who live near the sediment surface and would experience higher temperatures (Raymond et al. 2022).

Species living in this ecosystem are also impacted by increased UV radiation, which can affect them physically, as well as indirectly through biochemical pathways. For instance, increased UV radiation inhibits photosynthesis, causes physical damage to **macroalgae**, and increases mortality for early life stages (Henelt et al. 2007).

Sea level rise may also significantly affect this ecosystem, depending on the location. Rising sea levels may shift species shoreward, if suitable habitat exists, but modified hardened shorelines and other anthropogenic impediments may pose barriers to movement, which would result in reduced habitat availability for displaced species.

3.5 Rocky subtidal

3.5.1 General description

The rocky **subtidal** ecosystem extends from the low **intertidal** to the edge of the continental shelf break at about 180 m depth. The shelf typically extends less than 45 km from shore, but in some parts of Queen Charlotte Sound it extends as far as 95 km (Thomson 1981). Substrates in this ecosystem are comprised of cobble, boulder, and bedrock. In general, rock substrate is more common in nearshore areas, with mud or sand being more prevalent as depth and distance from shore increases (Gregr et al. 2021). Approximately 45% of Canada's Pacific shelf is estimated to consist of rocky substrate (Gregr et al. 2021). Given that rocky substrates are more prevalent in nearshore on-shelf areas, the focus for the illustration of the rocky **subtidal** ecosystem was on shallower regions. Rocky **subtidal** areas occurring in deeper water would contain similar species, interactions, and human activities as those depicted in the seamount conceptual model, although environmental drivers for both shallow and deep on-shelf rocky **subtidal** areas would be similar.

Shallow regions of this ecosystem (< 20 m) generally have sufficient light penetration to support **macroalgae** growth and are often home to many species of kelp; the most conspicuous of these being canopy-forming bull kelp and giant kelp. These large kelp species form extensive forests and provide food and shelter for many fishes and invertebrates that live amongst the canopy and understory algae (Steneck et al. 2002). At deeper depths in this ecosystem, algae are noticeably absent due to insufficient light levels. Fish and invertebrate communities at these depths differ from shallow regions. Here species rely more upon the structural complexity of the seafloor (Tupper & Boutilier 1997), or other habitat forming species such as corals and sponges, for shelter. Similar to kelp forests that are found in shallow regions of this ecosystem, aggregations of corals and sponges provide three dimensional structure that are used as habitat and sources of prey items by many species, including rockfishes (Rooper et al. 2019). For the rocky **subtidal** ecosystem conceptual model, we considered species to be a part of this ecosystem if they associate with the seafloor or with habitat forming species growing from the seafloor (i.e., **benthic** fishes, as well as **pelagic** fishes associated with canopy kelp, such as schooling rockfishes and forage fishes).

There are many biological, environmental, and anthropogenic features that influence conditions within this ecosystem, including species composition and distribution. Here, we describe only the main ecological components and interactions (Figure 19 and Figure 20), environmental drivers (Figure 21), and human activities (Figure 22), as depicted in the rocky **subtidal** conceptual model illustrations.

3.5.2 Key ecological components and key interactions

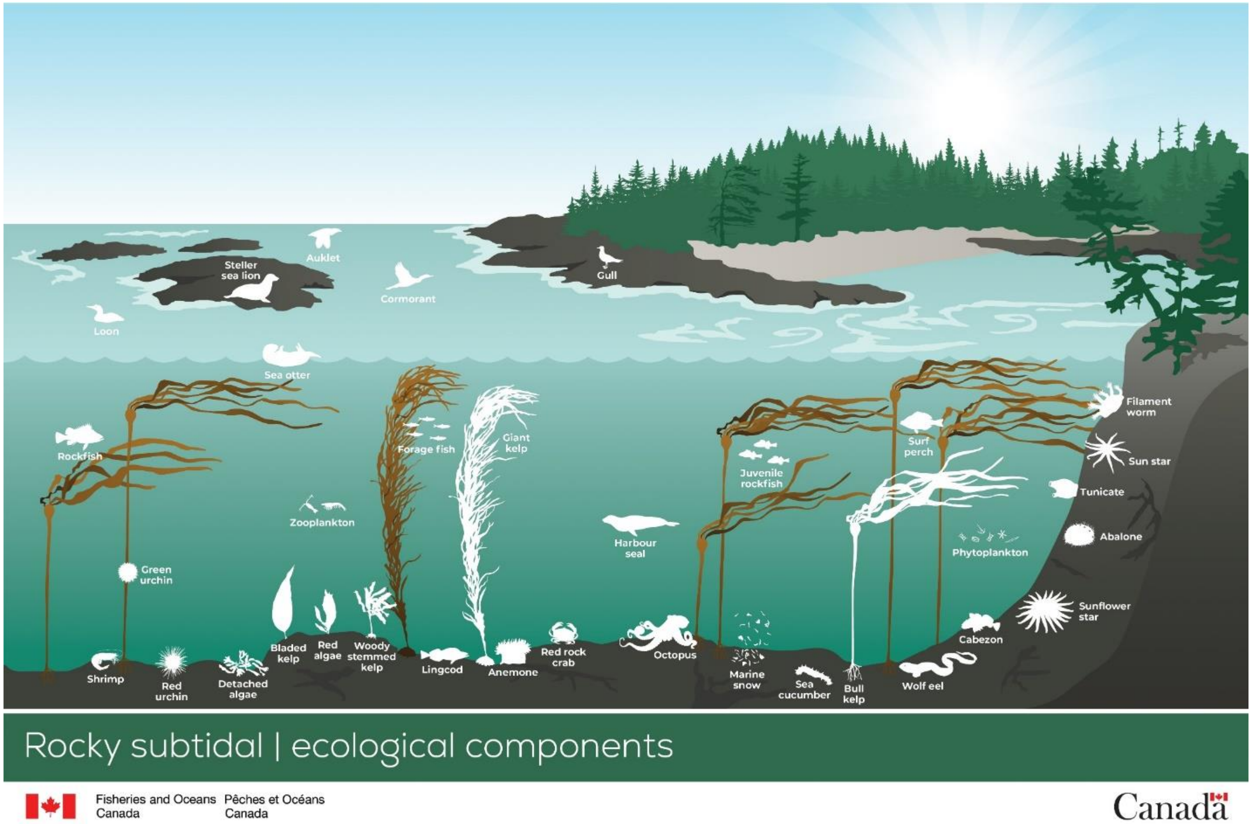

Figure 19. Key ecological components of the rocky subtidal ecosystem.

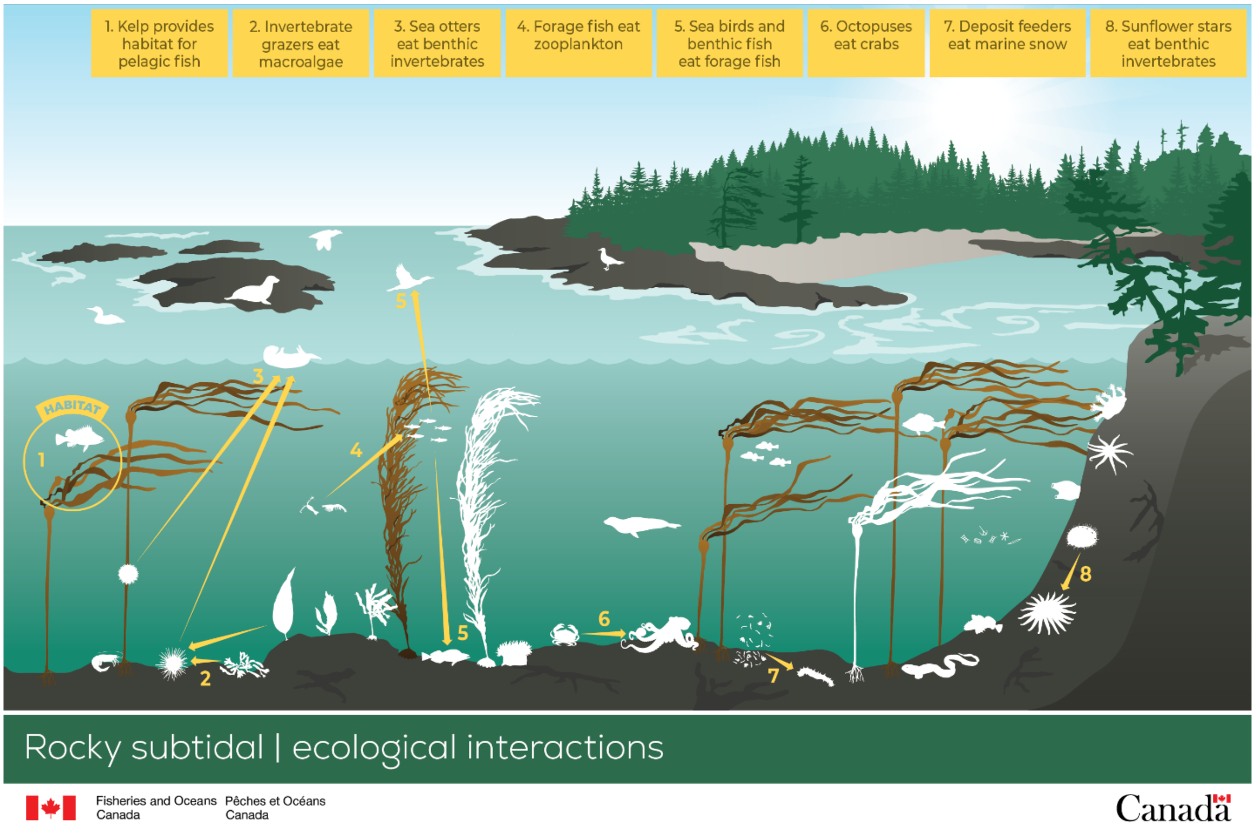

Figure 20. Key interactions among the ecological components of the rocky subtidal ecosystem.

Marine snow consists of detritus that falls from shallower waters and accumulates on the ocean floor. It includes dead phytoplankton, dead organisms, and fecal matter, as well as microbes and inorganic matter. Marine snow provides an important source of nutrients and is consumed by deposit feeders such as sea cucumbers.

Phytoplankton are microscopic marine algae that form the base of many food webs in rocky **subtidal** ecosystems. Phytoplankton **primary production** occurs at depths where light is sufficient for photosynthesis (i.e., the **photic zone**). Phytoplankton are a food source for **filter feeding** organisms in this ecosystem, including zooplankton and tunicates.

Zooplankton are an important food source in this ecosystem and provide nutrients for many organisms. Common species in the zooplankton community include euphausiids (i.e., krill), copepods, cnidarians (e.g., jellyfish), as well as larval stages of crustaceans, molluscs, and fishes. In rocky **subtidal** ecosystems, zooplankton are consumed by forage fishes, juvenile rockfishes, and filter feeders (e.g., filament worms).

A diverse array of **macroalgae** can be found in the shallow regions of this ecosystem, where light intensity is high enough to support plant growth. These **macroalgae** include canopy kelp such as bull kelp and giant kelp, as well as understory bladed kelp, woody-stemmed kelps (e.g., sugar kelp and walking kelp), and red algae. At deeper depths of this ecosystem, light intensity is too low to support plant life and these waters lack attached **macroalgae**. However, detached algae is regularly transported to deeper habitats where it is consumed by grazers and broken down into detritus (Krumhansl & Scheibling 2012; Steneck et al. 2002) that is consumed by deposit feeders such as sea cucumbers and shrimp. Suspended algal detritus is also fed upon by filter feeders (Krumhansl & Scheibling 2012).

Attached and detached algae are also an important food source for grazers such as red and green urchins and abalone within shallower depths (Krumhansl & Scheibling 2012).

Macroalgae, in particular canopy-forming kelps (bull kelp and giant kelp), provide habitat for many **pelagic** fishes including juvenile and adult rockfishes, forage fishes, and surf perches. The three-dimensional structure created by algae provides shelter, protection from **predation**, as well as feeding opportunities for these fishes (Trebilco et al. 2015; Steneck et al. 2002). Canopy-forming kelp distribution is strongly influenced by the presence of sea otters (Estes and Palmisano 1974; Watson and Estes 2011). Widely considered a keystone species, Sea otters are voracious predators that feed on many **benthic** invertebrate species, particularly grazers such as urchins and abalone (Lee et al. 2016). Where sea otters are present, **grazing** invertebrate densities are low, and kelp is abundant (Lee et al. 2016). In the absence of sea otters, urchins are abundant, and **grazing** by sea urchins limits the distribution of kelps to areas that urchins cannot inhabit: higher energy and shallow water refugia (Rinde et al. 2014).

Filter feeding invertebrates consume phytoplankton, zooplankton, microbes, marine snow, and suspended detritus. Many species of filter feeders inhabit rocky **subtidal** ecosystems, including tunicates and filament worms, whose colonies can cover large patches of the seafloor.

Predatory invertebrates such as octopuses, sunflower seastars, and sun stars consume **benthic** invertebrates in this ecosystem; for example, giant Pacific octopus prey on red rock crab and molluscs such as abalone (Chancellor et al. 2020), while **predatory** sunflower seastars feed on abalone, other seastars, and urchins (Duggins 1983). Octopuses inhabit dens in rocky areas and forage in the vicinity of their home base (Chancellor et al. 2020). Anemones, although not very mobile, are **predatory** and consume a variety of organisms that happen into their reach (Houtman et al. 1997).

Fish species that inhabit rocky **subtidal** ecosystems often seek shelter within kelp and other algae, or within cracks and crevices of the rocky seafloor. Many **benthic** fishes use rocky crevices for spawning purposes (e.g., wolf-eel, lingcod) (S. Jeffery personal observation; Withler et al. 2004). Rockfish species also inhabit rocky **subtidal** areas; some species live in close association with the seafloor (e.g., tiger, yelloweye, and china rockfishes), while others are primarily **pelagic** and school in groups (e.g., black, yellowtail, and deacon rockfishes). Other **pelagic** fishes that shelter within canopy kelp include forage fishes, juvenile rockfishes, and surf perches. Cabezon are also a conspicuous part of the **benthic** rocky **subtidal** fish community. Many of these rocky reef fish species feed on forage fishes.

Marine mammals such as harbour seals, sea otters, and Steller sea lions forage within rocky **subtidal** ecosystems. Harbour seals commonly haul out on land, both on rocky and sandy shores, and forage within 30 km of their haul-out locations, to depths up to 50 m (Tollit et al. 1998). They forage near the seafloor, and their diets reflect the species composition of the habitats near their haul-out sites (Tollit et al. 1998); seals hauling out on rocky shorelines would therefore tend to forage within the nearby rocky **subtidal** ecosystem. Steller sea lions also haul out on land, preferring more wave exposed rocky shores as haul-out areas (Ban & Trites 2007). They travel farther from land and dive deeper than harbour seals, and feed on forage fishes (e.g., capelin, Pacific herring, Pacific hake) (Merrick & Loughlin 1997). Sea otters inhabit wave exposed rocky **subtidal** habitat in the vicinity of kelp forests. They raft in large aggregations within kelp forests and forage on rocky seafloors where they consume a wide variety of **benthic** invertebrates including crabs, sea urchins, abalone, clams, and mussels (Riedman & Estes 1990). Sea otters typically dive to depths of 30 m or less and are generally found within 1-2 km of shore (Nichol et al. 2009). Although sea otters spend most of their time in rocky **subtidal** ecosystems, they also forage for clams in soft bottom **subtidal** ecosystems (Riedman & Estes 1990).

Marine birds in this habitat include species of cormorants, loons, auklets, and gulls that feed on a variety of forage fish species (including Pacific herring and Pacific sand lance).

3.5.3 Environmental drivers

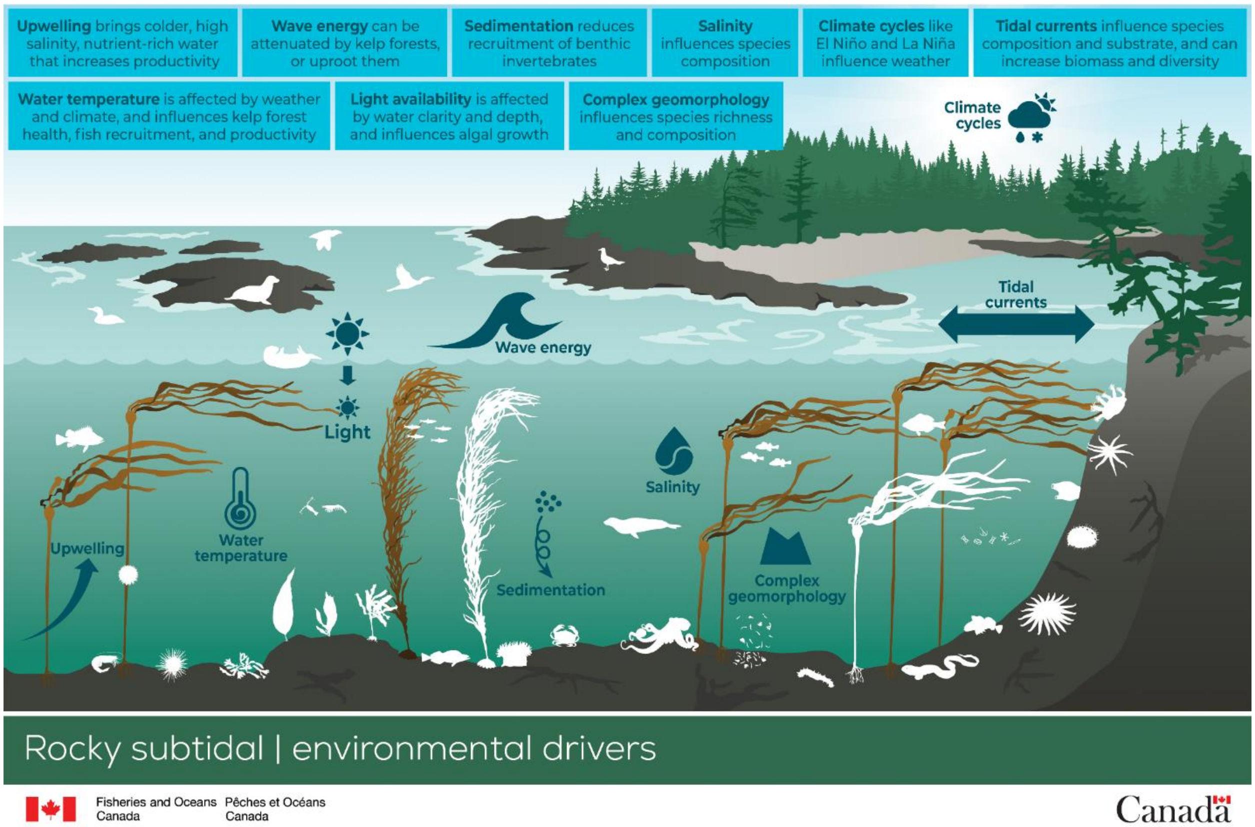

Figure 21. Main environmental drivers within the rocky subtidal ecosystem.

Many environmental drivers in the rocky **subtidal** ecosystem influence physical conditions, as well as species composition and distribution. Below, we describe the main environmental drivers and their effects.

Nutrients supplied by ocean **upwelling** play a large role in enhancing productivity in rocky **subtidal** ecosystems. Periods of weaker **upwelling** have been associated with nutrient limitation and reduced growth in the giant kelp (*Macrocystis pyrifera*)(Zimmerman & Robertson 1985).

The temperature of water in rocky **subtidal** ecosystems impacts the health of kelp forests, fish and invertebrate **recruitment**, and overall productivity (Dexter et al. 2014; Mueter et al. 2002; Talloni-Alvarez et al. 2019). Salinity levels influence species composition and distribution. For example, Gregr et al. (2018) found salinity to be an important predictor of kelp distribution in areas with significant freshwater input (few kelp species can tolerate low salinity), and there is also evidence of a positive correlation between salinity and giant kelp spore production (Buschmann et al. 2004).

Light is also an important driver of productivity in this ecosystem as it influences phytoplankton and macroalgal growth and distribution; **benthic macroalgae** is not mobile and can only occur where light levels are high enough to support its growth.

Wave energy influences species composition and distribution; in more wave exposed areas the depth distribution of shallow water species is shifted to deeper water where they can find respite from the crashing waves. Wave energy also impacts the distribution of kelp because of its ability to dislodge kelp from its substrate (Springer et al. 2007); however, kelp forests have the ability to attenuate wave energy, changing conditions on the leeward side of the bed. Losses of kelp biomass through dislodgement and erosion are greatest during storms that generate large amounts of wave energy (Krumhansl & Scheibling 2012). Water motion created by waves leads to areas of high mixing and increased oxygen levels that support higher species diversity and biomass (Starko et al. 2019).

Tidal currents are another source of water motion in rocky **subtidal** ecosystems that influence species composition and distribution (Nephin et al. 2020). The biomass and diversity of **benthic** invertebrates can be greater in areas of high tidal flow (Elahi et al. 2014). Both wave and tidal energy can cause algae loss and breakage, leading to greater detritus production that also contributes to productivity within this ecosystem.

Sedimentation can cover rocky substrates with a fine silt layer and reduce **recruitment** of **benthic** invertebrates leading to lower diversity and biomass (Fabricius 2005; Hanlon et al. 2018).

Complex geomorphology of the seafloor in rocky **subtidal** ecosystems is associated with higher species biomass and diversity (Parsons et al. 2016), in part due to a greater diversity of habitat types (Jalali et al. 2018). For example, studies have shown that the most topographical complex seafloors are home to the highest density of rockfish species (Frid et al. 2018).

Climate cycles like El Niño and La Niña influence weather, leading to variation in other environmental drivers such as wind events, temperature, precipitation, currents, and the strength of **upwelling** events in rocky **subtidal** ecosystems. Increased storm severity associated with El Niño events have caused increased dislodgement of **macroalgae** in rocky **subtidal** kelp forests, as well as reduced growth due to decreased nutrient availability (Zimmerman & Robertson 1985).

3.5.4 Human activities

Rocky **subtidal** ecosystems provide recreational boating and fishing opportunities, particularly near coastal communities with infrastructure to support these activities, such as marinas and small harbours. Anchoring by recreational vessels may damage kelp and seafloor communities in this ecosystem and can disturb wildlife such as marine birds and marine mammals. Commercial fishing using traps and hook and line fishing gear occur within rocky **subtidal** ecosystems. Fishing activities remove target fish and can injure other species caught as bycatch. Fishing vessels can also be a source of pollution, including contaminants, noise, and marine debris. Coastal communities at the edge of rocky shores can affect this ecosystem through by contributing pollution, marine debris, and modifying the shoreline.

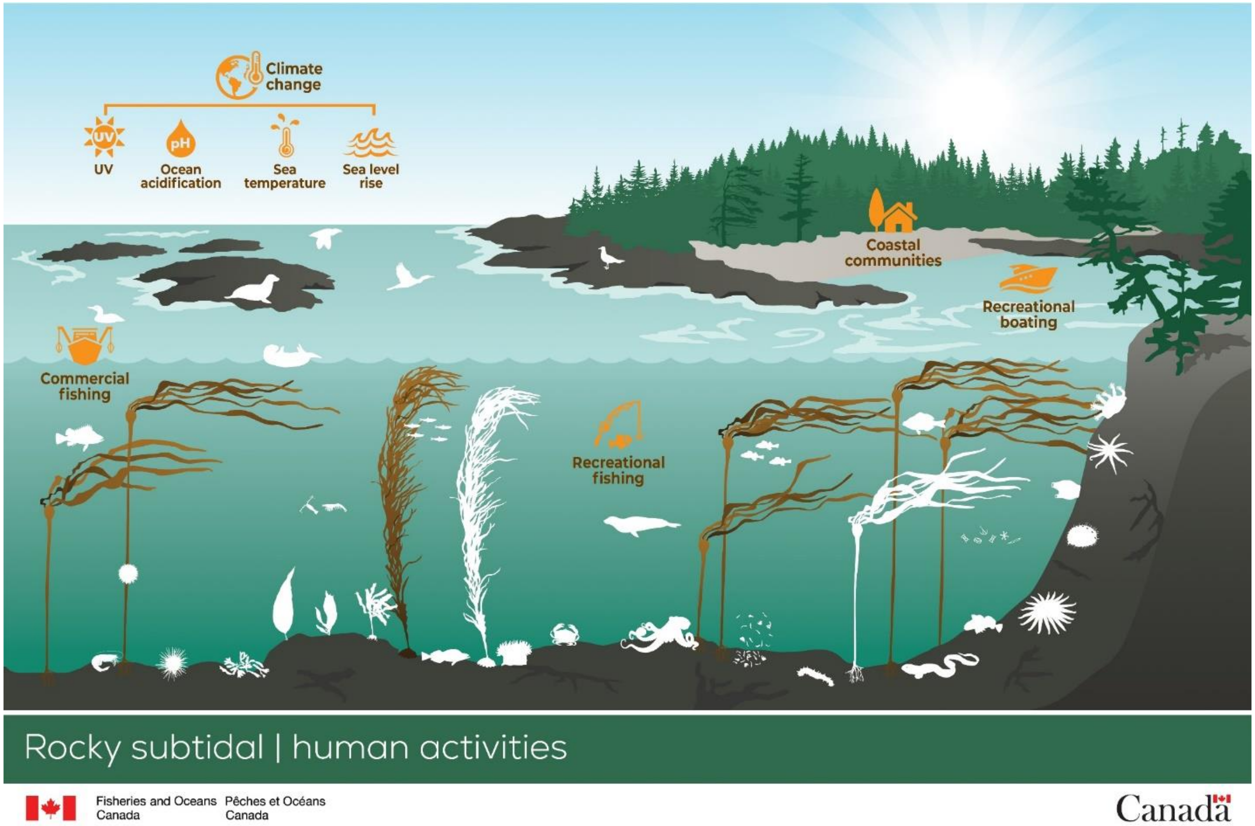

Figure 22. Relevant human activities within the rocky subtidal ecosystem.

3.5.4.1 Climate Change

Rocky **subtidal** ecosystems are influenced by many effects of climate change, including ocean acidification, increased sea temperature, increased UV radiation, and sea level rise.

Kelp forests are part of rocky **subtidal** ecosystems. They are composed of many macroalgal species, some which will fare better than others with sea level rise, ocean acidification, and increased sea temperatures. Because of this, the health and species composition of kelp forest communities may be impacted by climate change over time (Haigh et al., 2015).

Similar to other ecosystems, ocean acidification is important for calcifying organisms. As the water becomes more acidic, it will become increasingly difficult for calcifying organisms to extract calcite and aragonite from the water to form body structures such as shells. In rocky **subtidal** ecosystems, these calcifying organisms include **grazing** molluscs such as abalone, urchins, and chitons, as well as coralline algae. Calcifying invertebrates may grow thinner shells under acidified conditions, leaving them increasing vulnerable to **predation** (Haigh et al. 2015). Additionally, the presence of encrusting coralline algae is important for creating habitat and settlement cues for **benthic** species such as abalone (Roberts 2001), therefore, the loss of coralline algae habitat could have cascading effects for other species. Many red algae species may experience enhanced photosynthesis and growth with ocean acidification compared with kelp species such as Giant Kelp (Haigh et al. 2015) and coralline algae species.

Increased sea temperature will not affect all species equally. Some organisms in this ecosystem are tolerant of high temperatures, but many already live close to their thermal limits (Tomanek and Somero 1999). These species may be more negatively impacted by increased seawater temperatures in the short term. The impacts of higher temperatures will also vary spatially. For example, in some areas, bull kelp in rocky **subtidal** ecosystems has shown considerable decline in recent decades, following patterns of **macroalgae** decline associated with higher ocean temperatures in other ecosystems (Berry et al. 2021). However, several studies have shown that these decreases can be mitigated by water motion, such that kelp forests in wave exposed areas have exhibited less sensitivity to environmental **stressors** such as rising ocean temperature, while those in wave sheltered areas have declined in abundance (Berry et al. 2021; Starko et al. 2019).

For canopy kelp growing near the surface of the water, increased UV radiation may impair photosynthesis (Clendennen et al. 1996), or even cause tissue damage (Poulson et al. 2011). However, at depth **macroalgae** is often light limited, so the effect of increased radiation may serve to increase growth (Swanson and Fox 2007), providing sufficient nutrient availability, and a lack of impairment due to other climate change **stressors** such as increased temperature and ocean acidification.

3.6 Soft bottom subtidal

3.6.1 General description

Soft bottom **subtidal** ecosystems are comprised of sand and/or mud substrate, and extend from the low **intertidal** zone to where the continental shelf drops off at about 180 m depth. These soft substrates are sometimes interspersed with rocky outcroppings. Approximately 45% of Canada's Pacific shelf is estimated to consist of soft bottom substrate (Gregr et al. 2021). The shelf typically extends less than 45 km from shore, but in some parts of Queen Charlotte Sound it extends as far as 95 km (Thomson 1981). This ecosystem is characterized by a relatively flat topography, except for three large trenches in Queen Charlotte Sound that drop as deep as 450 m. Two important habitats are present in soft bottom **subtidal** ecosystems: eelgrass beds in shallow regions, and sponge reefs in deeper areas.

Phytoplankton and marine snow from **pelagic** waters form the base of soft bottom **subtidal** food webs, except in areas shallow enough for light to support the growth of **macroalgae** and plants. This ecosystem supports an array of deposit and **filter feeding** organisms, as well as a diverse assemblage of groundfish. The composition of the groundfish assemblage varies by depth, with the greatest number of species and biomass occurring at mid-depths (Perry et al. 1994, Thompson et al. 2022).

There are many biological, environmental, and anthropogenic features that influence conditions within this ecosystem, including species composition and distribution. Here, we describe the main ecological components and interactions (Figure 23 and Figure 24), environmental drivers (Figure 25), and human activities (Figure 26), as depicted in the soft bottom **subtidal** conceptual model illustrations.

3.6.2 Key ecological components and interactions

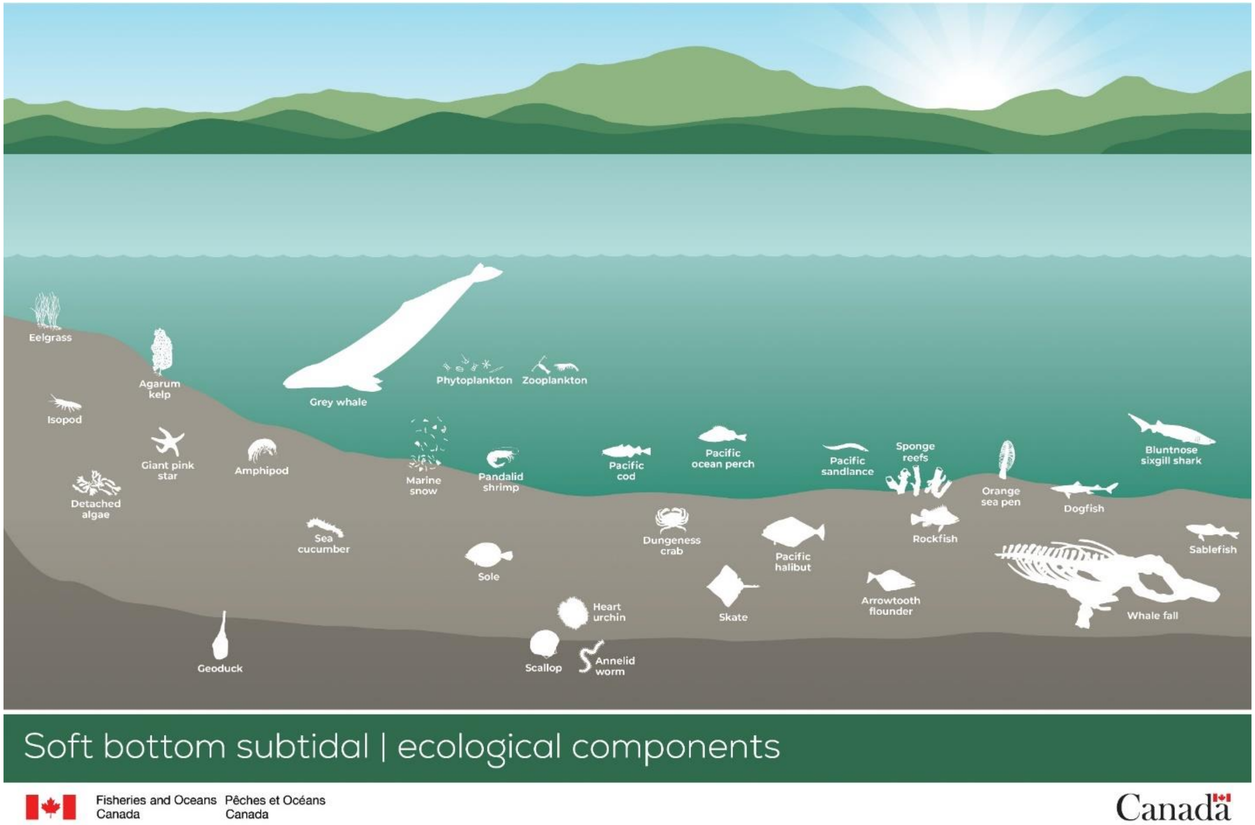

Figure 23. Key ecological components of the soft bottom subtidal ecosystem.

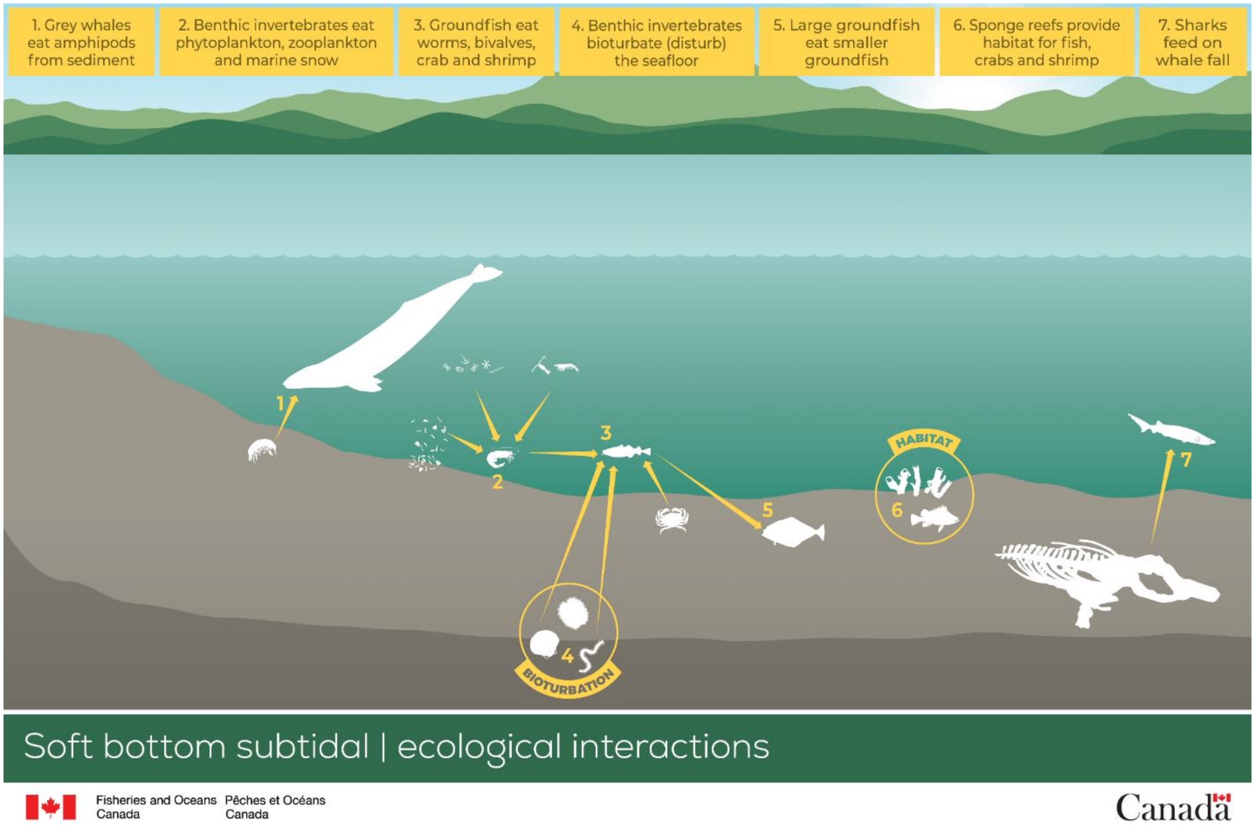

Figure 24. Key interactions among the ecological components of the soft bottom subtidal ecosystem.

Marine snow consists of detritus that falls from shallower waters and accumulates on the ocean floor. It includes phytoplankton, dead organisms, and fecal matter, as well as microbes and inorganic matter. Marine snow provides an important source of nutrients to areas where light is insufficient to sustain primary productivity (Turner 2015).

Phytoplankton form the base of food webs in the soft bottom **subtidal** ecosystem. **Primary production** occurs in surface waters (0 - 200 m) where light is sufficient to support photosynthesis (Herring et al. 2009), and reaches the seafloor when it falls through the water column as marine snow, or when it is consumed by zooplankton.

Zooplankton are an important food source for **filter feeding** invertebrates in the soft bottom **subtidal** ecosystem, including sea pens, sponges, and scallops. Most zooplankton migrate vertically from the seafloor to surface waters to graze on phytoplankton. The zooplankton assemblage is composed of diverse taxonomic groups, but euphausiids (i.e., krill) are a key member in this ecosystem (Evans et al. 2021).

Agarum kelp are found in shallow waters of this ecosystem where there is sufficient light for plant growth. Kelp requires hard substrate for attachment, however, it is found in soft bottom areas where sunken rocks or debris provide attachment locations. Kelp provides three-dimensional habitat for invertebrates such as shrimp and fishes in an otherwise flat seafloor.

Eelgrass grows in shallow areas in silt and sand substrates where it provides habitat for shallow fish communities, often acting as a nursery habitat (Philips 1984). Eelgrass plants contribute large amounts of plant material to detrital food chains and provide a subsidy to deeper regions of this ecosystem.

A diverse group of deposit feeding invertebrates live on the seafloor and feed upon detritus, much of which arrives as marine snow, and microbes (Lopez and Levinton 1987). Some organisms in this group live on the surface of the seafloor (e.g., amphipods, isopods, California sea cucumbers, and pandalid shrimps like the sidestripe shrimp, pink shrimp, and spot prawns), while others burrow into the soft sediment (e.g., heart urchins, annelid worms). Burrowing deposit feeding invertebrates are important to the ecosystem as they **bioturbate** the seafloor and recycle nutrients and energy back into the food web (Hollertz and Duchene 2001).

Filter feeding invertebrates in this ecosystem include several bivalve species (e.g., scallops, geoducks), and orange sea pens. These invertebrates obtain their energy and nutrients from phytoplankton, zooplankton, microbes, and marine snow that they filter from the water column. Like some deposit feeders, many bivalves burrow into the soft sediment and contribute to **bioturbation**.

The distribution of glass sponges is dependent on seabed substrate; glass sponges are predominantly found on rocky substrates (Dunham et al. 2018). However, some glass sponges form large (up to 19 m high and as large as 10 km^2) and complex sponge reefs in soft bottom **subtidal** ecosystems, in areas with exposed glacial till (Conway 1999). These sponge reefs were widespread around 174 million years ago, but are now found only on the Pacific Coast of BC and the USA (Leys et al. 2004, Dunham et al. 2018). Glass sponge reefs play important roles in carbon and nitrogen processing, act as silica sinks, and support diverse communities of invertebrates and fish (Chu et al. 2011; Dunham et al. 2018; Kahn et al. 2018).

Predatory invertebrates such as seastars (e.g., giant pink stars) feed primarily on bivalves, but also consume other invertebrates and will scavenge dead fish (Cowles 2002). Dungeness crabs are found to depths of 250 m but are most abundant at depths shallower than 50 m, and are both scavengers and predators, feeding on small fish, crustaceans, clams, and worms (Jamieson and Phillips 1988).

The groundfish community in the soft bottom **subtidal** ecosystem includes over 100 species of bony fishes, skates, and sharks that live on or near the seafloor (Anderson et al. 2019). The composition of this community varies with substrate type (e.g., mud vs. sand), and species tend to be strongly associated with given depth ranges (Perry et al. 1994, Thompson et al. 2022). This groundfish assemblage includes flatfishes (e.g., Pacific halibut, arrowtooth flounder, and several species of sole), sablefish, Pacific cod, spiny dogfish, as well as a diversity of rockfishes (including Pacific ocean perch). Many of these groundfish are opportunistic predators that feed on invertebrates such as worms, bivalves, crabs, shrimp, and smaller fishes (Buckley et al. 1999). These smaller fishes include forage fish species such as Pacific sandlance.

Marine mammal diversity is relatively low within soft bottom **subtidal** ecosystems. Grey whales feed by straining seafloor sediment containing invertebrate prey (e.g., amphipods and ghost shrimp) through their baleen plates (Dunham et al. 2002). Deceased whales that fall to the seafloor (whale falls) result in organic and sulfide-rich habitats that support a diverse sequence of microbial and metazoic fauna that follow overlapping successional stages as the whale carcass is decomposes (Smith et al. 2015). Six-gill sharks are particularly voracious scavengers of whale falls (Silva et al. 2021).

3.6.3 Environmental drivers

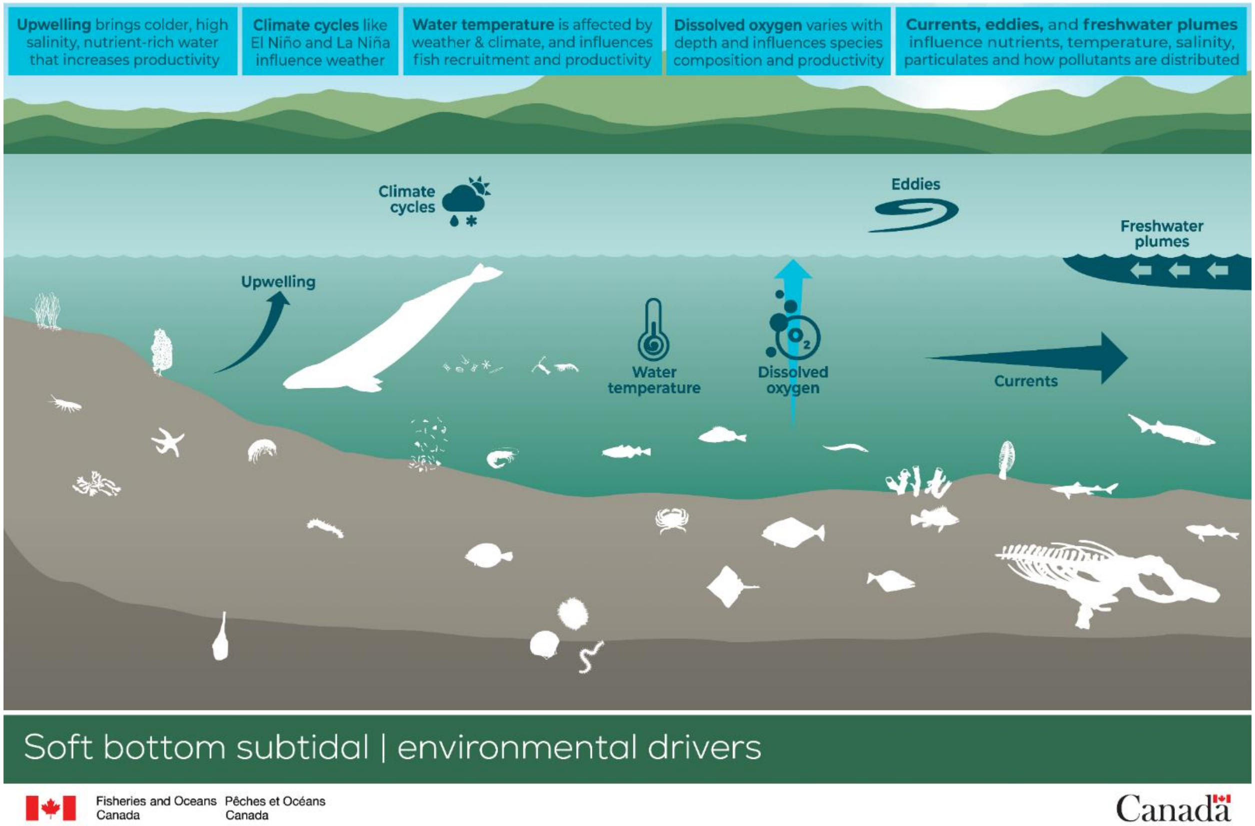

Figure 25. Main environmental drivers within the soft bottom subtidal ecosystem.

Many environmental drivers within soft bottom **subtidal** ecosystems influence physical conditions, as well as species composition and distribution. Here, we describe the main environmental drivers and their effects.

Upwelling of colder, higher salinity and nutrient water to this ecosystem increases phytoplankton productivity with cascading effects for higher trophic levels.

Currents, eddies, and freshwater plumes on the shelf influence nutrient levels, salinity, and temperature on the seafloor, and the flow of organic and inorganic particulates between ecosystems and habitats. This can influence dispersal patterns of organisms and structure population connectivity, especially for organisms with a **planktonic** larval stage, such as sea cucumbers, heart urchins and orange sea pens.

Temperature is closely linked to depth and affects many aspects of the soft bottom **subtidal** ecosystem, including fish and invertebrate **recruitment**, distribution, and overall productivity. Higher temperatures lead to greater metabolic demand in fishes and may also impact prey availability. The effect of warmer or cooler water temperatures varies by species, however. Warmer temperatures have been associated with declines in Pacific cod biomass (Barbeaux et al. 2020), but can also have positive effects on species occurring at the Northern extent of their range that are well adapted to warmer temperatures. Temperature also affects the distribution of groundfish species. For instance, many groundfish species shift their distribution to remain within their thermal tolerances during warming events (English et al. 2022).

Dissolved oxygen concentration in this ecosystem has a strong effect on species distributions. Lower dissolved oxygen concentrations are associated with decreases in density, diversity and biomass for groundfish species (e.g., rockfishes, sole)(Thompson et al. 2023). Changes in dissolved oxygen concentration have also led to shifts in groundfish species distributions (English et al. 2022).

Climate cycles like El Niño and La Niña influence weather, leading to variation in other environmental drivers such as wind events, temperature, precipitation, currents, and the strength of **upwelling** events in soft bottom **subtidal** ecosystems.

3.6.4 Human activities

Marine human activities occurring in soft bottom **subtidal** ecosystems are plentiful and include commercial and recreational fishing, shipping, disposal at sea, aquaculture, and recreational boating. These activities can damage or disturb **benthic** organisms through direct contact (e.g., bottom trawl and trap fishing and vessel anchoring), pollution (e.g., noise and chemicals), and invasive species introduction (e.g., ballast water or hull fouling from vessels).

Waves from shipping activities can also cause physical disturbance. Disposal at sea takes place in this ecosystem where non-hazardous substances from dredging operations are moved to designated marine areas. Aquaculture in this ecosystem can damage **benthic** organisms through nutrient and chemical pollution, disease, and smothering as infrastructure fouling falls to the bottom (e.g., discharging excess detritus), as well as shading **macroalgae** preventing photosynthesis.

Coastal human activities affecting the soft bottom **subtidal** ecosystem include ports or activities and infrastructure linked to coastal communities. These can be a source of pollution and marine debris. Finally, forestry practices such as deforestation of large cutblocks and the construction and use of forestry roads can increase sedimentation in river systems and ultimately affect ecosystems downstream.

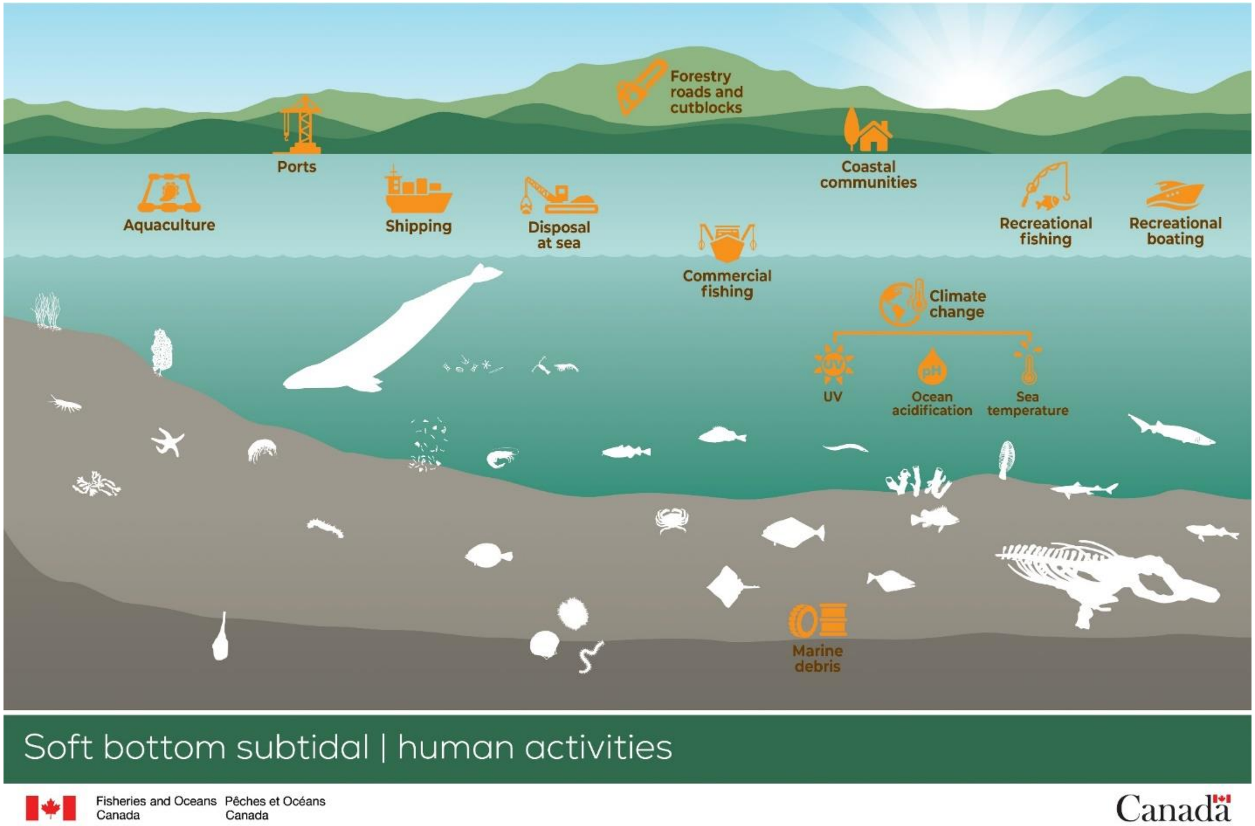

Figure 26. Relevant human activities within the soft bottom subtidal ecosystem.

3.6.4.1 Climate Change

Soft bottom **subtidal** ecosystems are impacted by many effects of the changing climate; most notably ocean acidification, increased sea temperature, and increased UV radiation.

There are many calcifying organisms that will be affected by ocean acidification in this ecosystem, particularly bivalves, shrimp, and crab. Shell production in molluscs such as clams is expected to be negatively affected by ocean acidification, particularly for larvae (Haigh et al. 2015). The formation of exoskeletons in adult crabs and shrimp is generally considered to be unaffected by ocean acidification. In fact, some are even able to fortify their skeletons under these conditions (Haigh et al. 2015). However, early life stages of crabs and shrimp are still expected to be sensitive to ocean acidification with cascading effects for development, and the overall impact for these species is expected to be negative.

Ocean acidification will also impact phytoplankton community structure as it is expected to cause a shift in the species composition from diatoms towards species that are currently carbon limited. This shift will have a negative impact on the ecosystem, as the species expected to increase are those with a lower nutritional value, and those associated with toxic algal blooms (e.g., *Heterosigma akashiwo*)(Haigh et al. 2015).

Over the next 20 to 40 years, increasing sea temperatures and associated dissolved oxygen loss are projected to result in a reorganization of the groundfish assemblage (Thompson et al. 2023). Warming waters are also projected to reduce groundfish diversity in shallow waters (<100 m) where warming is projected to be greatest. However, groundfish diversity is projected to increase in deeper regions of this ecosystem (>100 m), as species shift deeper to deal with warming conditions (Thompson et al. 2023).

Algae species found in this ecosystem are understory species, which are often light limited at depth. For these species, the effect of increased radiation may serve to increase growth (Swanson and Fox 2007), providing sufficient nutrient availability, and a lack of impairment due to other climate change **stressors** such as increased temperature and ocean acidification.

The soft bottom **subtidal** ecosystem is the only ecosystem suitable for the formation of glass sponge reefs. Both an increase in seawater temperature and ocean acidification threaten these reefs. These **stressors** affect pumping capacity, contributing to tissue withdrawal, and weaken the skeletal strength of the glass sponge *Aphrocallistes vastus* (Stevenson et al. 2020). Irreversible damage may be caused at sea temperatures 0.5°C above current conditions (Stevenson et al. 2020). This degree of change in sea temperature is within the range of projected warming expected by 2050 for BC areas with protected glass sponge reefs (Friesen et al. 2021).

3.7 Pelagic

3.7.1 General description

The **pelagic** ecosystem consists of the water column in the ocean that is not close to the shore or the seafloor. The depth of the **pelagic** ecosystem is determined by seafloor bathymetry, with areas over the continental shelf typically extending to less than 180 m, and areas in the deep ocean beyond the continental shelf extending to depths of 2,500 m or more (Thomson 1981).

The **pelagic** ecosystem is highly depth structured and can be delineated by vertical zones characterized by the amount of available sunlight. Vertical zones include the epipelagic (0-200 m), where light is sufficient to support photosynthesis; the mesopelagic (200-1,000 m), where less than 1% of light penetrates (del Giorgio and Duarte 2002); and the bathypelagic zone (1,000-4,000 m) where no light penetrates and life is supported by marine snow that falls from the zones above (Turner 2015). Phytoplankton form the base of the food web at all depths in this ecosystem and support a diversity of zooplankton; **pelagic** fishes including species of salmonids, tunas, and sharks; marine mammals including whales; as well as marine birds. For the purpose of this conceptual model, we have considered only the portion of the **pelagic** ecosystem that falls within epipelagic zone.

There are many biological, environmental, and anthropogenic features that influence conditions within this ecosystem, including species composition and distribution. Here, we describe the main ecological components and interactions (Figure 27 and Figure 28), environmental drivers (Figure 29), and human activities (Figure 30), as depicted in the **pelagic** conceptual model illustrations.

3.7.2 Key ecological components and interactions

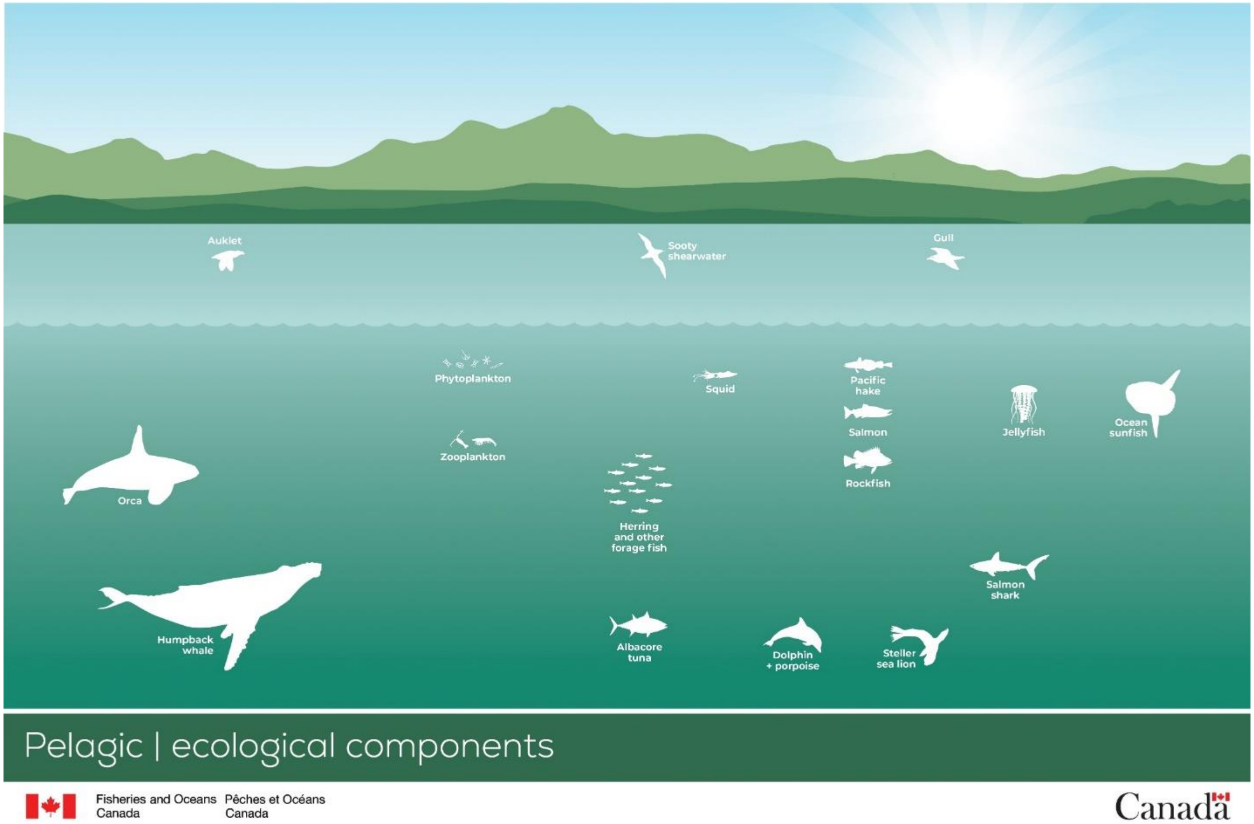

Figure 27. Key ecological components of the pelagic ecosystem.

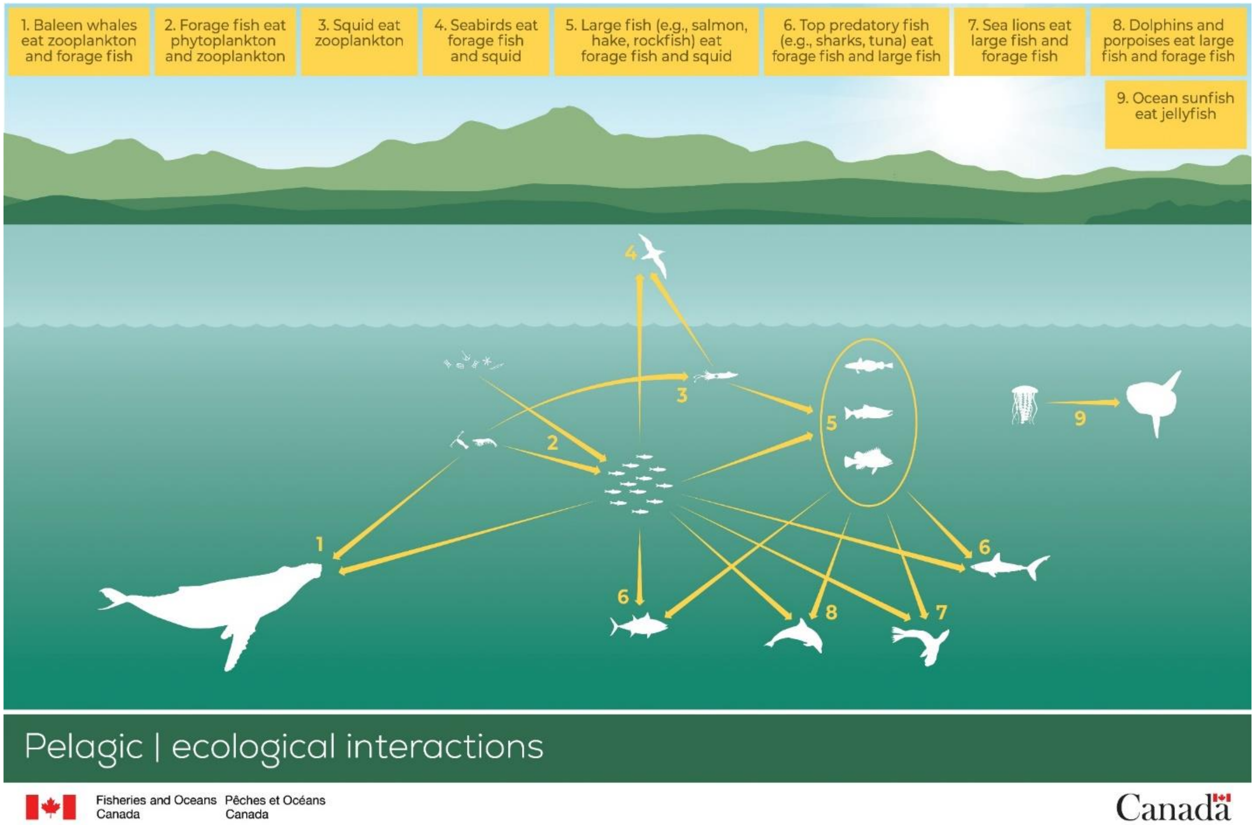

Figure 28. Key interactions among the ecological components of the pelagic ecosystem.

Phytoplankton are microscopic marine algae that live in the water column and form the base of food webs in the **pelagic** ecosystem. **Primary production** occurs in the epipelagic zone where light is sufficient to support photosynthesis (Herring 2009). Phytoplankton are consumed by zooplankton and forage fishes or fall to deeper waters as marine snow. Phytoplankton production in BC is estimated to be highest in the waters off the west coast of Vancouver Island (Peña et al. 2019).

Zooplankton are **planktonic** animals that serve as a food source for larger **pelagic** organisms such as forage fish, jellyfish, and baleen whales. The zooplankton assemblage is composed of diverse taxonomic groups, but euphausiids (i.e., krill) (Evans et al. 2021), as well as crustacean, fish, and invertebrate larvae, are key members in this ecosystem.

Invertebrates in the **pelagic** ecosystem include opal squid and jellyfish. Opal squid are highly mobile carnivores. Their diet consists mostly of euphausiids, but they also feed on other crustaceans, forage fishes, and other cephalopods (Walthers and Gillespie 2002). Opal squid are an important food source for many species of salmon, flatfishes, sharks, marine mammals, and marine birds (Walthers and Gillespie 2002). Jellyfish are gelatinous free-swimming invertebrates. Common species in BC include moon, by-the-wind sailor, lion's mane, and fried egg jellyfish (Baker 2015). All jellyfish are carnivorous, eating zooplankton, small fish, and other jellyfish. Jellyfish are often consumed by marine predators including fish (e.g., ocean sunfish), sea turtles, octopuses, marine birds, and other invertebrates (Hays et al. 2018).

Fishes in the **pelagic** ecosystem include forage fish species (e.g., Pacific herring, Northern anchovy, Pacific sand lance, Pacific sardine, and whitebait smelt) that feed on zooplankton (Pikitch et al. 2012); larger fish (e.g., salmon, Pacific hake, **pelagic** rockfish species) that feed on forage fishes and squids

(Brodeur et al. 2014); and top **predatory** fishes (e.g., albacore tuna, blue sharks, salmon sharks) that feed on forage fish, squid, and large fish (Camhi et al. 2008). Most fishes in the **pelagic** ecosystem are migratory, with species such as salmon and sharks migrating between inshore and offshore waters, and other species such as Pacific hake and Pacific sardine migrating north-south along the Pacific coast of North America (McFarlane et al. 2000).

The marine mammal assemblage in the **pelagic** ecosystem includes baleen whales (e.g., minke, humpback, grey) that feed on zooplankton such as krill; toothed whales (e.g., orcas, Pacific white-sided dolphin, harbour porpoise, Dall's porpoise), and Steller sea lions that feed on a wide range of fish, squid, and other invertebrates (Sinclair and Zeppelin 2002). In BC waters, there are three types of orcas (i.e., killer whales), termed residents, transients, and offshore (Baird 2001). The types differ in their diet, with resident Orcas feeding almost entirely on fish, particularly salmon; and transient Orcas feeding almost entirely on marine mammals, principally harbour seals (Baird 2001). Less is known about the diet of offshore orcas, but there is evidence that Pacific sleeper sharks form a component of their diet (Ford et al. 2011).

Marine birds in this ecosystem include Sooty Shearwaters, auklets (e.g., Cassin's Auklets, Rhinoceros Auklets), and gulls (e.g., Glaucous-winged and Herring Gulls, and Black-legged Kittiwakes). Some of the marine birds (e.g., shearwaters and auklets) dive and pursue their prey (forage fishes, squids, jellyfish, and crustaceans) by swimming underwater (Chu 1984).

3.7.3 Environmental drivers

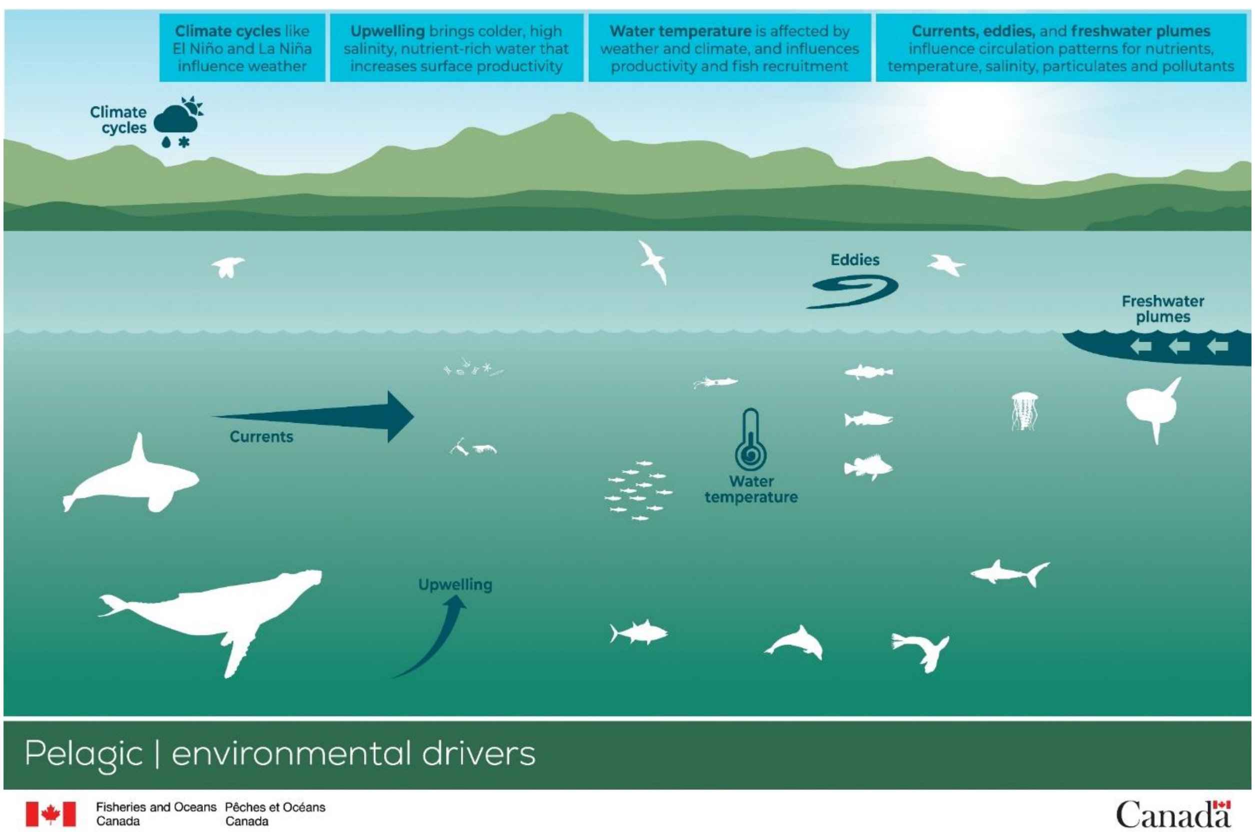

Figure 29. Main environmental drivers within the pelagic ecosystem.

Many environmental drivers influence physical conditions within the **pelagic** ecosystem, as well as species composition and distribution. Here, we describe the main environmental drivers and their effects.

Upwelling drives productivity in this ecosystem and influences the abundance, diversity and species composition of the **pelagic** fish community (Santora et al. 2017).

Currents, eddies, and freshwater plumes in **pelagic** ecosystems influence nutrient levels, salinity, and temperature, and the flow of organic and inorganic particulates between ecosystems and habitats. For instance, the supply of nutrients from the Fraser River plume contributes to high phytoplankton productivity in southern BC waters, with cascading effects on **pelagic** food webs (Ware and Thompson 2005). Similarly, nutrients trapped by the Juan de Fuca eddy enhance **primary production** along southern Vancouver Island (Marchetti et al. 2004).

Water temperature is closely linked to depth and affects many aspects of the **pelagic** ecosystem, including fish and invertebrate **recruitment**, distribution, and overall productivity. For instance, warmer temperatures have impacted the distribution of Pacific hake, which have shifted northward during past warming events (McFarlane & Beamish 1999).

Dissolved oxygen concentration in this ecosystem also has an effect on the vertical distribution of **pelagic** fishes, with many species shifting to shallower water during periods of low dissolved oxygen (Meyer-Gutbrod et al. 2021). Some species, such as jellyfish, are highly tolerant of lower dissolved oxygen concentrations and may outcompete **pelagic** fishes under low oxygen conditions (Brodeur et al. 2008).

Climate cycles like El Niño and La Niña influence weather, leading to variation in other environmental drivers such as wind events, temperature, precipitation, currents, and the strength of **upwelling** events in **pelagic** ecosystems.

3.7.4 Human activities

Commercial fishing is an important activity in **pelagic** ecosystems of the Canadian Pacific EEZ, targeting rockfish, tuna, herring, and salmon. Commercial fisheries deploy seine nets, gillnets, or hook and line fishing gear, each with varying amounts of bycatch. Additionally, lost and abandoned fishing gear can directly impact on whales and other marine organisms via entanglement.

In the **pelagic** ecosystem, there are important shipping corridors, transporting goods up and down the coast and across the Pacific Ocean. Shipping and recreational boating can be a source of invasive species, contaminants, and noise. Recreational boating more commonly affects coastal areas, particularly around the south coast of British Columbia, due to the concentration of coastal communities.

Pelagic ecosystems can also be affected by land-based agriculture activities and coastal communities. Tides and currents can transport contaminants, sediments, organic matter, and nutrients from coastal areas to **pelagic** ecosystems.

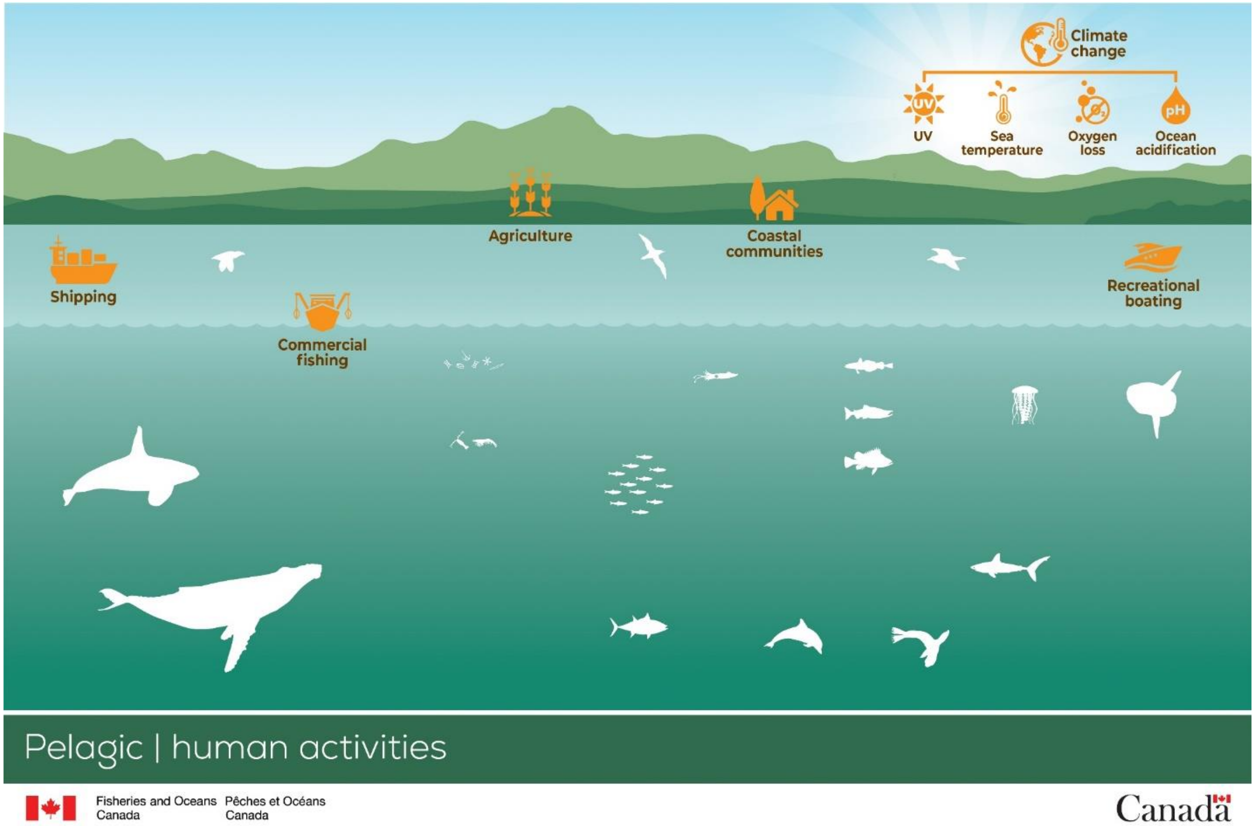

Figure 30. Relevant human activities within the pelagic ecosystem.

3.7.4.1 Climate Change

The **pelagic** ecosystem is influenced by many effects of climate change, including ocean acidification, dissolved oxygen loss, increased sea temperature, and increased UV radiation. Climate change impacts are resulting in warmer more acidic surface waters, with lower dissolved oxygen and nutrients (Okey et al. 2014).

Ocean acidification will impact the phytoplankton community structure as it is expected to cause a shift in the species composition from diatoms to species that are currently carbon limited and do not form calcium skeletons. This shift is expected to have a negative impact on the ecosystem, as the species expected to increase are those with a lower nutritional value and associated with toxic algal blooms (e.g., *Heterosigma akashiwo*)(Haigh et al. 2015). The effects of ocean acidification on **pelagic** fishes are expected to be indirect, largely caused by a reduction in prey availability (e.g., pteropods for juvenile pink salmon), and an increase in harmful algal blooms (Haigh et al. 2015).

Throughout coastal BC, declines in dissolved oxygen have been seen at all depths below the mixed surface layer, with the greatest decline just below the **photic zone** at 200-300 m depth (Cummins and Haigh 2010). Species shifts from deeper water may result as oxygen concentrations at these depths become too low and push species into shallower water where concentrations are relatively higher (Meyer Gutbrod et al 2021). These shifts could have cascading effects for food chains in **pelagic** ecosystems.

Changes to sea surface temperatures are expected to change the structure and functioning of **pelagic** communities (Edwards and Richardson 2004). For instance, increased sea surface temperature negatively affects the growth and survival of Pacific herring by decreasing food availability and increasing **predation** and **competition** (Hunter & Wade 2015 and references within). Increased water temperature may also cause less tolerant species to inhabit deeper waters; however, suitable conditions may not always exist at deeper depths (e.g., oxygen or aragonite concentrations may not be ideal at deeper depths) (Friesen et al. 2021), leading to negative impacts for these species. Warmer waters are associated with a shift from crustaceans to gelatinous zooplankton taxa (Brodeur et al. 2019), which may have cascading trophic effects within the food web. Increased sea surface temperature will also increase stratification of the water column and reduce mixing of water layers, which will serve to further reduce productivity (Hunter & Wade 2015).

The main effects of increased UV radiation in this ecosystem will also be experienced by the phytoplankton community. Increased UV can limit the uptake of nutrients by phytoplankton (Hessen et al. 1997), thereby reducing **productivity**, with cascading impacts for food chains in the ecosystem and others. Increased UV exposure may also cause physical harm to phytoplankton cells (Gao et al. 2017). The effects of UV exposure can be exacerbated by the increased stratification of the water column that may accompany climate change, as it can trap phytoplankton near the surface, keeping them exposed to the higher levels of radiation (Gao et al. 2017). Phytoplankton communities already stressed by more acidic and warmer waters may not withstand further impacts from increased UV radiation.

3.8 Estuary

3.8.1 General description

Estuaries exist where terrestrial, freshwater, and marine environments meet (i.e., the mouths of rivers and streams), and are characterized by highly variable oceanographic characteristics such as temperature and salinity (Pritchard 1967). Shoreline substrates are variable within estuaries; however, silty substrates prevail below the low tide mark due to the high input of fine sediment from rivers.

Estuaries are highly productive ecosystems. The delivery of nutrients from rivers and marine sources, as well as internally derived nutrients from detrital decomposition (Naiman and Sibert 1979), fuel high levels of **benthic** and **pelagic primary production** (Moore et al. 2015), which supports high densities of fishes and invertebrates. Given their high productivity, estuary ecosystems are important feeding grounds for waterbirds, and staging areas for migrating marine birds (Butler and Vermeer 1989).

Estuaries contain a diverse array of **intertidal** habitats, including salt marshes, eelgrass beds, wetlands, tidal marshes, and mud flats. These habitats provide many ecosystems services including water filtration, nutrient enrichment and recycling, detritus processing, and energy provisioning to support nearshore food webs (Ryder et al. 2007). Estuaries also serve an important role as nursery areas for juvenile invertebrates and fishes. High turbidity in estuaries, and the abundance of vegetation (i.e., salt marsh plants, eelgrass, **macroalgae**), protect juveniles, such as Pacific salmonids, from predators (Macdonald et al. 1988; Semmens 2008).

Estuaries are also a key transition area between freshwater and marine environments (Levings 2016) for anadromous species such as salmon, providing an area with intermediary conditions that allows them to acclimatize from salt to fresh water, and vice versa.

There are many biological, environmental, and anthropogenic features that influence conditions within this ecosystem, including species composition and distribution. Here, we describe the main ecological components and interactions (Figure 31 and Figure 32), environmental drivers (Figure 33), and human activities (Figure 34), as depicted in the estuary conceptual model illustrations.

3.8.2 Key ecological components and key interactions

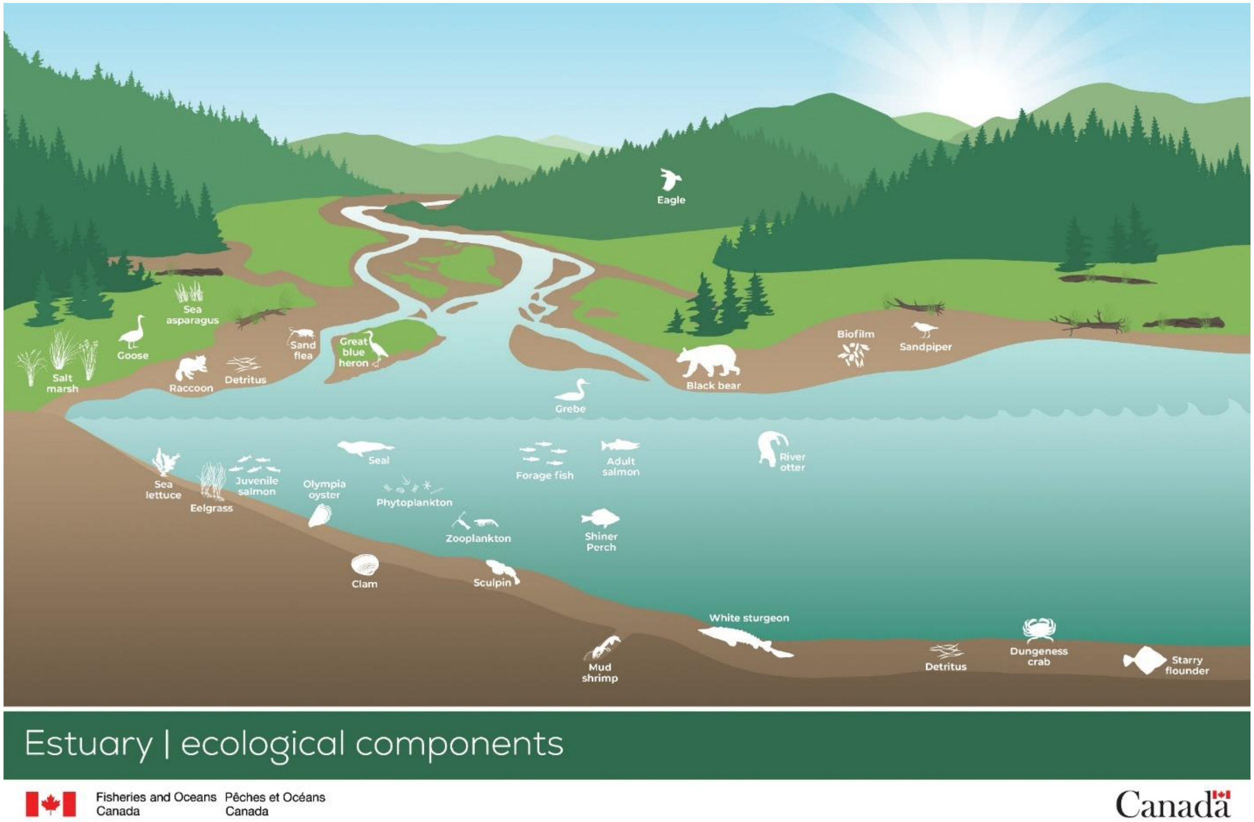

Figure 31. Key ecological components of the estuary ecosystem.

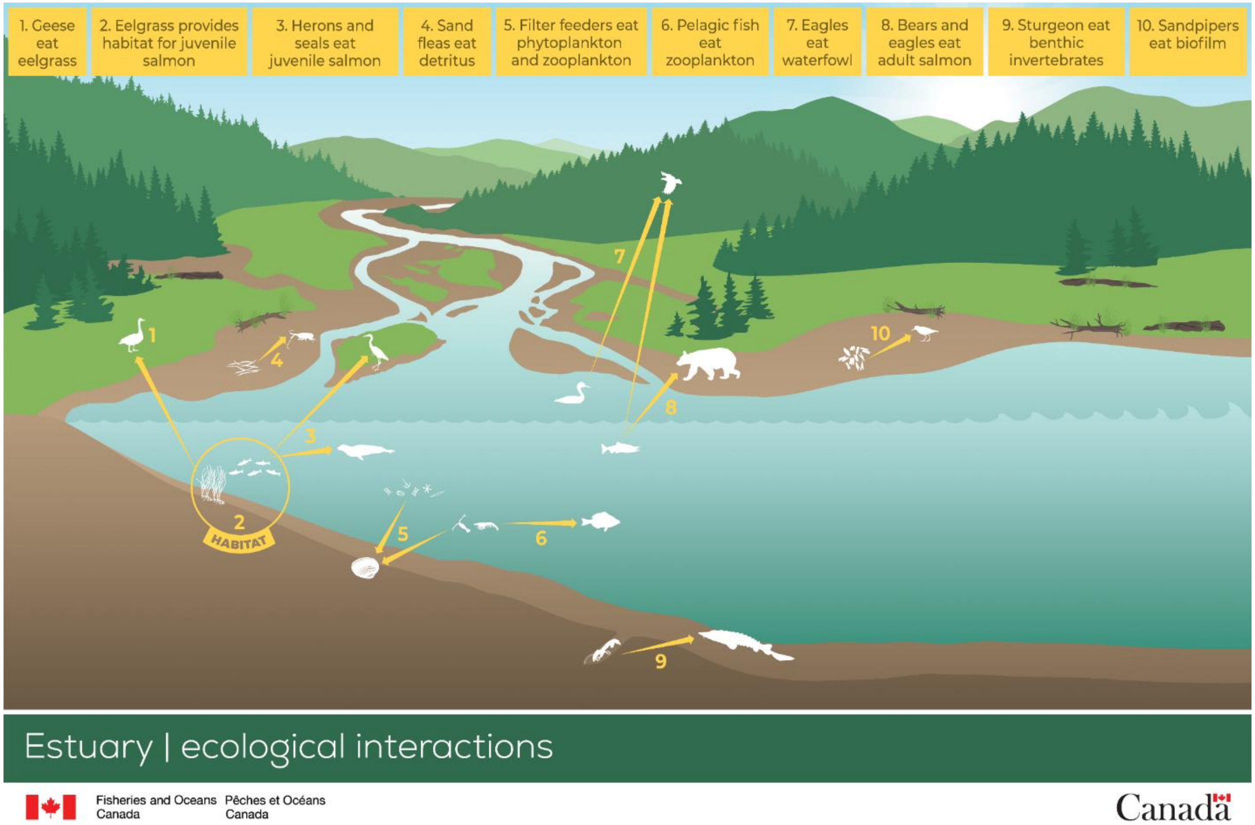

Figure 32. Key interactions among the ecological components of the estuary ecosystem.

Detritus is derived from dead phytoplankton, vascular plant, and animal material (Wilson & Wolkovich 2011). Detritus is plentiful in estuaries due to the abundance of source plant material and is an important part of estuarine food webs (Harfmann et al. 2019). Bacteria and zooplankton in estuaries derive much of their nutrition from plant-based detritus (Harfmann et al. 2019; Zagursky et al. 1985), as do a variety of invertebrates, including **intertidal** sand fleas (Mews et al. 2006).

Biofilm, composed of a thin layer of adhering microorganisms, is an important food source for sandpipers and other shorebirds (Jiménez et al. 2015). The spatial and temporal accumulation of **biofilm** is determined by tidal cycles, sediment grain size characteristics (Decho 2000), as well as by light, temperature, and nutrient availability. **Biofilm** areal coverage can be extensive because of the availability of suitable habitat in estuaries (Nocker et al. 2007), and its contribution to the functioning of the ecosystem is great (Rouke et al. 2016).

Phytoplankton are microscopic marine algae that form the base of many food webs in nearshore ecosystems. Phytoplankton are a food source for many organisms, including zooplankton and **filter feeding** invertebrates such as clams, olympia oyster, and mud shrimp. **Primary production** from phytoplankton can be very high in estuaries due to nutrient and organic matter input from rivers (Cloern et al. 2014).

Zooplankton are an important food source in marine systems, providing nutrients for many predators. Common species in the zooplankton community are Euphausiids (i.e, krill), copepods, cnidarians (e.g., jellyfish), as well as larval stages of crustaceans, molluscs, and fishes. Zooplankton communities in estuaries are highly variable in space and time owing to the dynamic nature of environmental conditions within the estuary (Winder & Jassby 2011). The composition and abundance of zooplankton in estuaries has been linked to the abundance of many **pelagic** fish species that rely on them for food, including forage fishes (e.g., herring and sand lance) and juvenile salmon (Winder & Jassby 2011; Boldt et al. 2019).

Many plants and **macroalgae** inhabit estuaries, including **seagrasses (**e.g., eelgrass) and sea lettuce, as well as salt marsh plants (e.g., sea asparagus). These species provide food for herbivorous grazers such as geese and contribute large amounts of plant material to detrital food chains. Salt marsh plants and **seagrass** can cover extensive areas within estuaries and prevent shoreline erosion, provide nutrient and oxygen inputs, and baffle shoreline wave energy (Vandermeulen 2009). Habitat formed by eelgrass and salt marsh plants provides important nursery, foraging, and refuge habitat for juvenile salmonids, forage fishes, and shiner perch (Phillips 1984).

Filter feeding invertebrates like clams, olympia oyster, and burrowing shrimp such as mud shrimp, feed on suspended detritus, phytoplankton, and zooplankton from the water column. **Filter feeding** invertebrates are also food for many other estuary species; for instance, mud shrimp are a major food source for white sturgeon (Dumbauld et al. 2008).

Dungeness crab are abundant in estuaries, where juveniles benefit from higher growth compared to non-estuary habitats due to higher temperatures and greater food supplies (Gunderson et al. 1990).

Estuaries are an important ecosystem for many fishes, some of the more common being juvenile and adult salmon, forage fishes, shiner perch, starry flounder, sculpins (e.g., staghorn sculpin), and white sturgeon. Forage fishes such as Pacific herring and surf smelt can constitute more than half the **pelagic** fish biomass in an estuary, providing an important link between zooplankton and higher trophic levels of the ecosystem (Reum et al. 2011).

Juvenile and adult salmonids transit through estuaries during their migrations to and from freshwater ecosystems. Estuaries are especially important to the fitness of juvenile salmonids, as they provide optimal prey resources, protection from **predation**, and suitable environmental conditions for the physiological transition to a marine environment (Levings 2016). Much of juvenile salmonid feeding within estuaries is reliant upon detritus-based food webs (Maier & Simenstad 2009). Estuaries are also an acclimatization area for spawning adults on route to freshwater spawning grounds.

Many marine and terrestrial mammals also inhabit estuaries. River otters and harbour seals forage extensively in productive estuarine waters, while black bears and raccoons forage in **intertidal** areas, particularly when migrating adult salmon are present.

Estuaries are also highly important to many resident and migratory bird species. Estuarine habitats such as mud and sand flats are critical stopover sites for shorebirds (e.g., sandpipers). As well, estuaries provide an abundance of food (vegetation and invertebrates) for many waterfowl (e.g., Canada Goose) (Butler et al. 2001; Canham et al. 2021). Non-migratory, resident birds, such as Red-necked Grebe, Bald Eagle, and Great Blue Heron commonly occur in estuaries (Badzinski et al. 2008), some of which feed extensively on migrating salmonids (Sherker et al. 2021; Walters et al. 2021). Raptors such as Bald Eagles also benefit from the abundant waterfowl in estuaries, feeding on birds such as grebes.

3.8.3 Environmental drivers

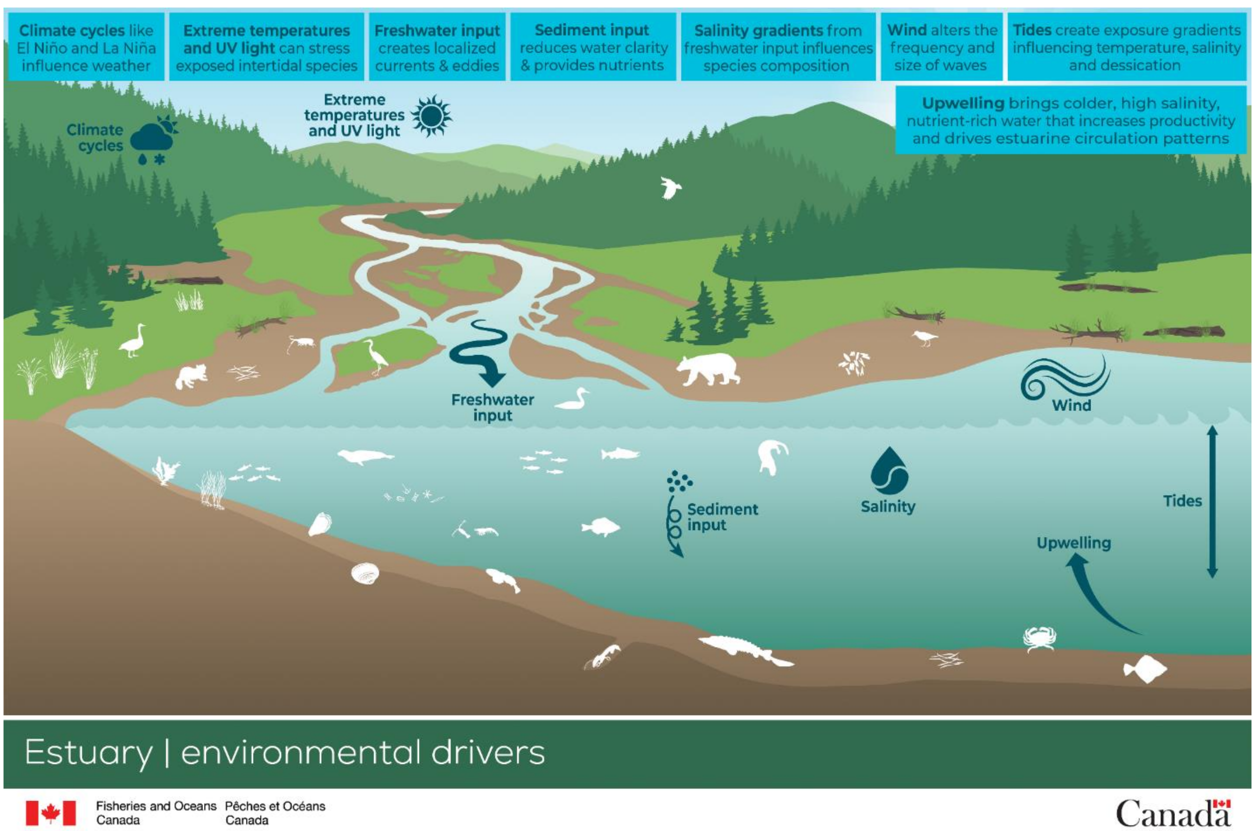

Figure 33. Main environmental drivers within the estuary ecosystem.

Many environmental drivers influence physical conditions within the estuary ecosystem, as well as species composition and distribution. Here, we describe the main environmental drivers and their effects.

Estuaries are dynamic ecosystems characterized by fluctuations in salinity from freshwater and marine inputs that vary over daily, yearly, and multi-year cycles (Reum et al. 2011). Salinity levels in an estuary vary in space and time due to location within the estuary, tides, river flow rates, depth, and circulation patterns. Salinity levels influence species composition within an estuary; for instance, the diversity and density of **infaunal** invertebrates decreases with decreasing salinity (Dashtgard et al. 2012).

Freshwater input from rivers, and **upwelling** from deep offshore waters, work together in estuaries to drive estuarine circulation patterns and productivity. Freshwater input flows seaward near the surface, while nutrient-rich water from ocean **upwelling** is drawn in along the seafloor toward the mouth of the estuary, creating a circular flow pattern and high nutrient levels (Davis et al. 2014). These nutrients drive high levels of productivity within estuarine ecosystems.

High turbidity resulting from riverine sediment input reduces light penetration and slows plant growth during these times. However, it also reduces underwater visibility for predators, providing refuge for young fish and enhancing the role of estuaries as a nursery habitat. Sediment delivery from rivers influences estuary morphology (Dashtgard et al. 2012) as it is deposited in low flow areas to create mudflats (Uncles & Stephens 2000).

Estuarine circulation levels fluctuate seasonally. When freshwater flow is high, and **upwelling** is reduced, estuarine circulation is low, and stratification of the water column increases. These conditions cause low salinity water to get trapped in surface layers, with high salinity and nutrient rich water from ocean **upwelling** beneath it (Pena et al. 2016). Wind events mix the water layers, reducing stratification and allowing nutrient rich waters from depth to reach the surface (Pena et al. 2016; Reum et al. 2011). Wind on a larger scale also drives **upwelling**, and in turn estuarine circulation patterns (Davis et al. 2014).

On smaller temporal and spatial scales, tides also impact circulation within an estuary creating turbulence, currents, and vertical mixing, which impacts the concentration and location of high salinity water (Geyer & Farmer 1989; Griffin & Leblond 1990). Tidal movement also exposes **intertidal** mud flats and salt marshes, providing feeding opportunities for terrestrial mammals and birds such as black bears that dig for clams and geese that graze on exposed eelgrass plants.

Climate cycles like El Niño and La Niña influence weather, which in turn leads to variation in wind events, temperature, precipitation, currents, and the strength of **upwelling** events. A major consideration of climate cycles for estuaries is altered river flow rates that in turn impact estuarine circulation and levels of sediment and nutrient input (Kiffney et al. 2002).

When extreme temperatures co-occur with low tides, the combination of temperature, UV and salinity-related stress can lead to high species mortality for organisms exposed by the low tide (Hesketh and Harley 2023), especially as the frequency, duration, and intensity of these extreme weather events increase with climate change. To deal with these changing environments, **intertidal** species have special adaptations and behaviours. In estuary ecosystems, many species bury deeper to minimize temperature fluctuations and desiccation risk, or retreat with the falling tide. However, extreme low temperatures during a low tide can freeze **intertidal** organisms and cause mass mortalities. Similarly, extreme high temperatures have caused large die offs of **intertidal** organisms exposed during low tide events (Hesketh and Harley 2023).

3.8.4 Human activities

Many human activities occur in estuaries. **Stressors** from forestry roads and cutblocks, pulp and paper mills, agriculture, mining, and other industries include increased sedimentation into waterways and pollutants, which reach estuaries as runoff and through river networks. Paved roads and coastal/non-coastal communities are also a source of contaminated runoff.

Ports are often located in estuaries. The largest shipping terminals in BC are found in the Fraser River and Skeena estuaries. Ports can be a source of contaminants, noise, and invasive species. They also often modify the shoreline and alter the functioning of estuary ecosystems.

Activities such as recreational boating are a source of pollution, noise, and introduced invasive species. Recreational fishing and commercial fishing activities in estuaries remove fish, may cause injury to non-target bycatch species, and depending on the gear, can alter bottom substrates and communities.

Additionally, aquaculture can disturb **benthic** organisms (e.g., by discharging excess detritus), be a pollution source (e.g., nutrients and chemicals), shade aquatic plants, and introduce disease.

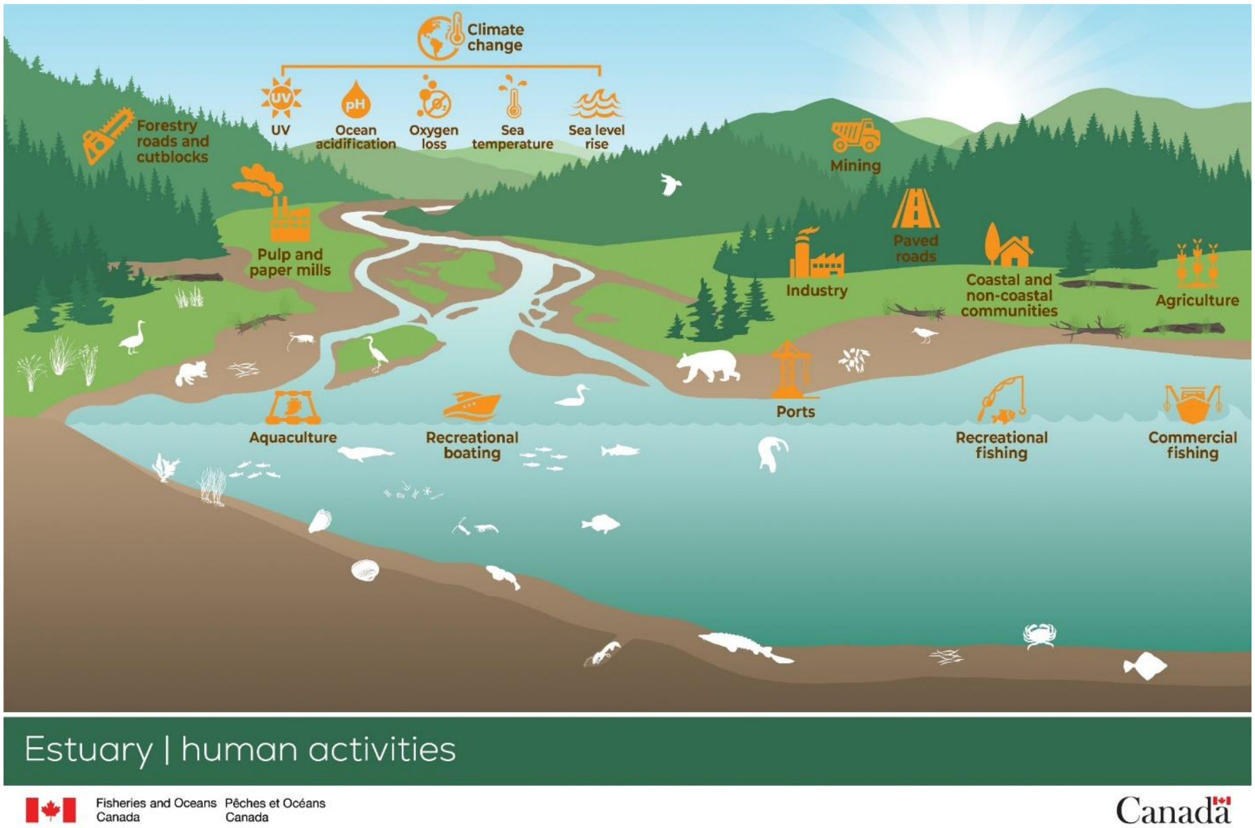

Figure 34. Relevant human activities within the estuary ecosystem.

3.8.4.1 Climate Change

Estuary ecosystems are influenced by many effects of climate change, including ocean acidification, dissolved oxygen loss, increased sea temperature, increased UV radiation, and sea level rise**.**

Dramatically changing conditions are common in estuaries due to seasonal changes in freshwater input that impact temperature, salinity, and water circulation patterns. However, these changes are expected to be more severe with a changing climate. As environmental conditions vary spatially within and estuary, so too will the impacts of climate change.

As in other ecosystems, ocean acidification will impact the ability of calcifying organisms to extract calcite and aragonite from the water to form shells. Thinner shells resulting from this impact may increase the vulnerability of shelled molluscs common in estuaries (such as clams and oysters) to **predation** (Haigh et al. 2015). It is also anticipated that larval survival of these molluscs will be reduced with ocean acidification (Haigh et al. 2015). Due to terrestrial and riverine influences experienced by estuaries, they are anticipated to experience more acidic and variable conditions compared to open ocean environments; therefore, the effects of ocean acidification will be greater in these ecosystems (Hofmann et al. 2011).

Dissolved oxygen in the Fraser River estuary, a major estuary in the region, has been declining in recent years, leading to the possibility that there will not be enough oxygen in future years to support important species such as Pacific salmon (Chambers 2022). Estuaries often have high nutrient levels from river sources and high rates of detrital decomposition. With changing climate conditions, these high nutrient levels, in combination with increased water temperatures, water column stratification, and lower oxygen, are anticipated to lead to more and larger hypoxic (no oxygen) zones (Altieri & Gedan 2015). Hypoxic zones are linked to fish kills and negatively impact the **biodiversity** and functioning of ecosystems in which they occur.

Species use estuaries for a variety of reasons, some are resident species, some use estuaries as spawning or rearing habitats, while others use them as a migration corridor between rivers and oceans. This variety of uses for estuaries leads to variable responses between organisms when conditions change. Many key species, however, are associated with cool waters in estuaries, and may respond negatively to increased temperatures (e.g., Pacific herring, English sole) (Feyrer et al. 2015).

Increased UV radiation will impact the phytoplankton communities in estuaries in much the same way as other ecosystems; namely by limiting the uptake of nutrients by phytoplankton (Hessen et al. 1997), thereby reducing productivity, with cascading impacts for food chains in the ecosystem. Increased UV radiation has also been shown to decrease growth of some salt marsh plants (Costa et al. 2016; Zhang et al. 2013), and negatively impact meiofauna communities in estuarine mudflats (Nozais et al. 1999).

Sea level rise will have consequences for many habitats within estuary ecosystems. For example, models predict that salt marsh vegetation will need to migrate landward in order to persist with rising ocean levels (Kirwan and Murray 2008). This is predicted to result in a loss of biomass, especially if landward migration is blocked by coastal modifications like dykes. The replacement of highly productive vegetation with less productive vegetation is also predicted, further reducing productivity.

3.9 Fjords

3.9.1 *General description*

Fjords ecosystems are characterized by steep, rocky walls, and silty seafloors (Gasborro 2017), and often have one or more **sills** created by receding glaciers (Farmer & Freeland 1983). Fjords have deep basins (up to 700 m) that are relatively close to land, given the steep sides of the fjord walls (Tunnicliffe & Syvitski 1983). This unique feature brings deeper habitats near land, and the impacts from coastal and land-based human activities. Fjords also typically contains an estuary, given that most have river inputs at the head; thus, many of the environmental drivers described for estuaries also apply to this ecosystem.

Fjords function as corridors leading from more open ocean waters, inland to river systems. Because of this, fjords have strong ocean-estuarine gradients along their lengths, ranging from the oceanic influence at the mouth of the fjord to the riverine and terrestrial influences at the head of the fjord. These differences in environment from one end of the fjord to the other lead to gradients in environmental conditions, and subsequently gradients in species composition (Gasborro 2017).

There are many biological, environmental, and anthropogenic features that influence conditions within this ecosystem, including species composition and distribution. Here, we describe the main ecological components and interactions (Figure 35 and Figure 36), environmental drivers (Figure 37), and human activities (Figure 38), as depicted in the fjords ecosystem conceptual model illustrations. For the purpose of this ecosystem model, only the **subtidal** portion of the ecosystem is considered. **Intertidal** areas in fjords are covered by other ecosystem models (i.e., soft shore – low energy and rocky shore – low energy), and the head of the fjord, wherever river inputs exist, is covered by the estuary ecosystem.

3.9.2 Key ecological components and key interactions

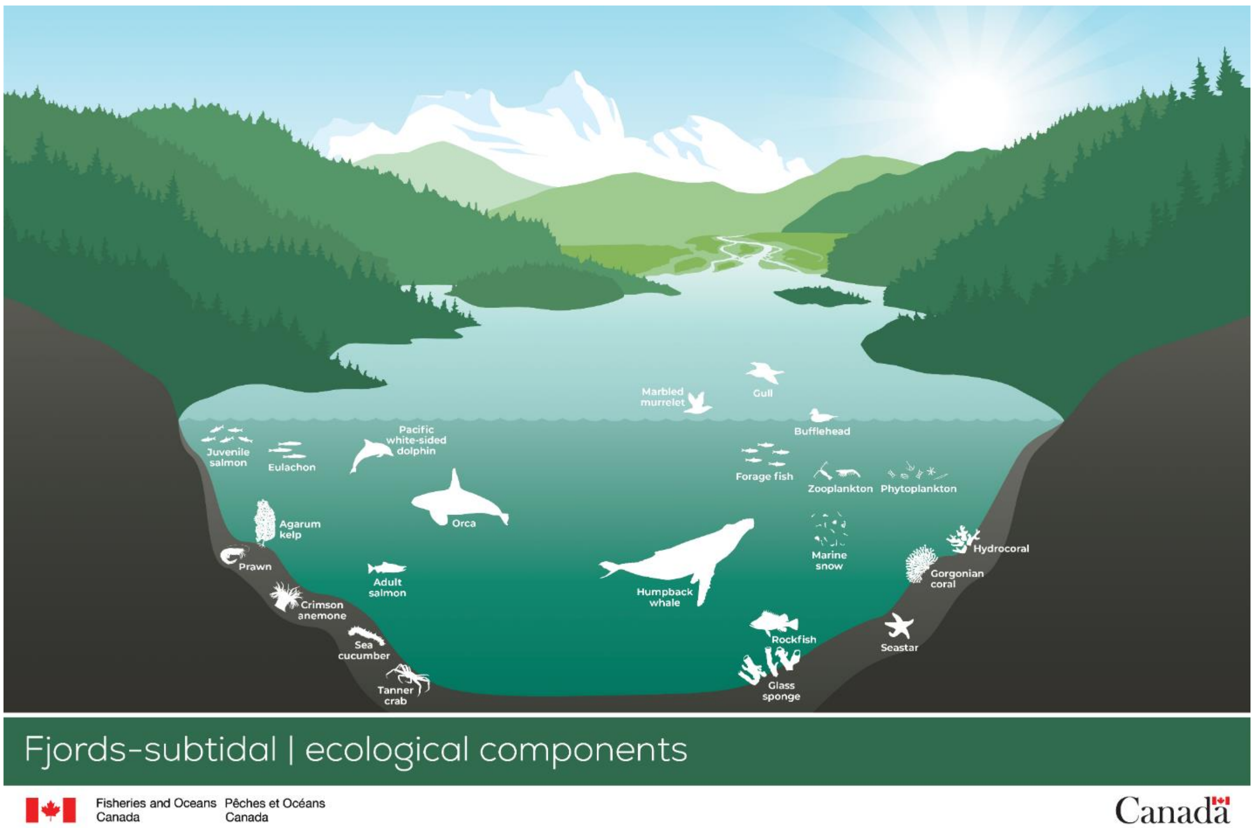

Figure 35. Key ecological components of the fjord ecosystem.

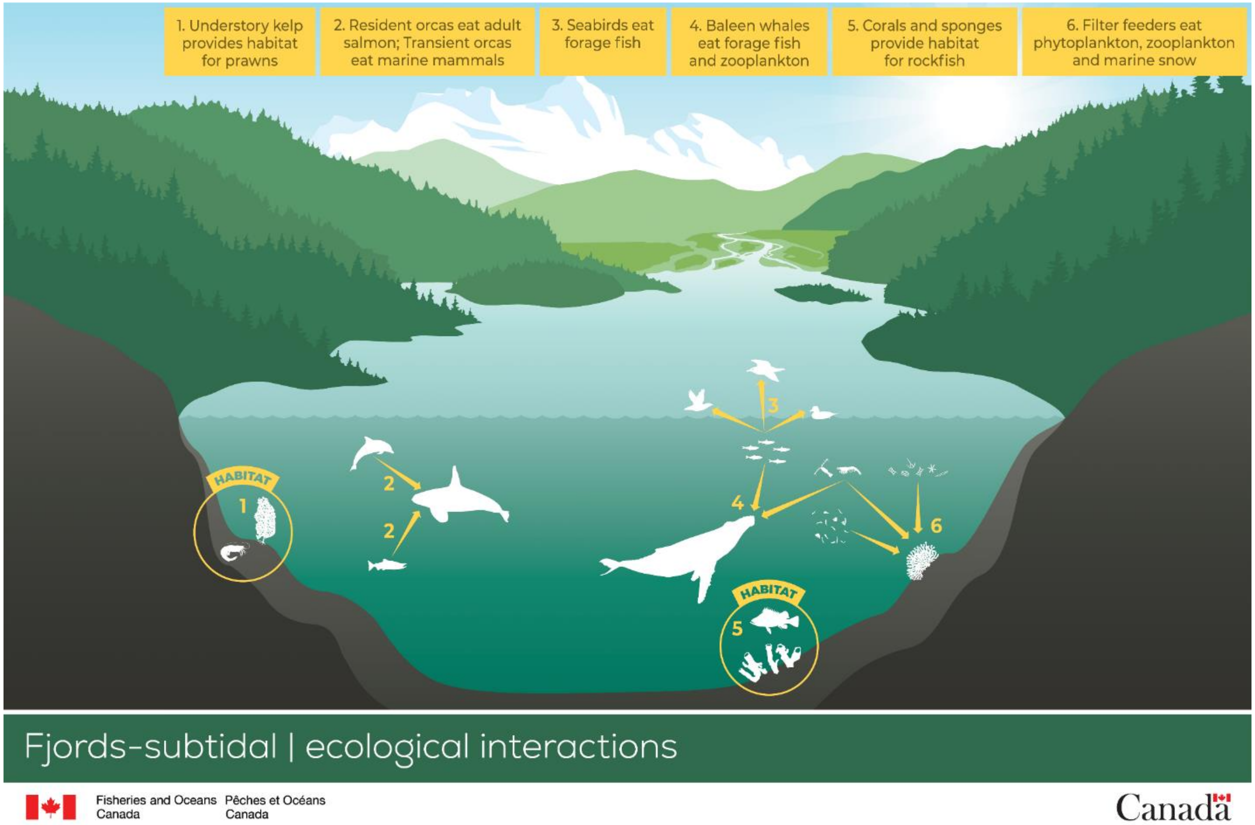

Figure 36. Key interactions among the ecological components of the fjord ecosystem.

Phytoplankton are microscopic marine algae that form the base of most food webs in fjord ecosystems. Phytoplankton **primary production** occurs in surface waters at depths where light is sufficient for photosynthesis (i.e., the **photic zone**). Phytoplankton are consumed by zooplankton and forage fishes, or fall to deeper waters as marine snow as they die.

Zooplankton are **planktonic** animals that live in the water column and serve as an important food source for other **filter feeding** invertebrates, fishes and humpback whales in fjord ecosystems. Most zooplankton species migrate vertically from the seafloor to surface waters to graze on phytoplankton. The zooplankton community is composed of diverse taxonomic groups, including euphausiids (i.e., krill), copepods, cnidarians (e.g., jellyfish), as well as larval stages of crustaceans, molluscs, and fishes.

Understory kelps such as *Agarum* provide three-dimensional habitat in shallower depths of the fjords ecosystem where there is sufficient light to support plant growth. Many species, including prawns, make use of kelp for shelter, particularly as juveniles (Marliave & Roth 1995). Understory kelps also contribute to primary productivity within this ecosystem.

Deposit feeders, such as sea cucumbers, can be prevalent on rocky substrates within fjords (Duprey 2012; Zhou & Shirley 1996), where they largely feed on detritus such as marine snow (Da Silva et al. 1986). A variety of seastars, such as cookie, sunflower, and velcro seastars also inhabit rocky habitats in the fjords ecosystem.

The steep rocky walls of the fjords ecosystem are home to many **benthic** invertebrates (Gasborro et al. 2018). These vertical walls prevent the settlement of high loads of silt present in this ecosystem, meaning **sessile benthic** invertebrates are less likely to be smothered on these steep walls compared to more horizontal surfaces (Gasborro et al. 2018). The steep walls also enhance currents, improving feeding opportunities for **filter feeding** invertebrates and **sessile predatory** invertebrates such as crimson anemone. **Filter feeding** invertebrates such as hydrocorals, gorgonian corals, and glass sponges can be abundant on the steep rocky walls within this ecosystem because of the low silt settlement and enhanced feeding opportunities (Gasborro et al. 2018). The filter feeders eat bacteria, zooplankton, phytoplankton, and marine snow and provide three-dimensional structure as habitat for other species, including rockfishes, squat lobster, and crinoids (feather stars) (Gasborro et al. 2018; Rooper et al. 2019).

The fjord basin generally consists of soft-bottom substrates from the deposition of marine snow and sediments from terrestrial run off. Mobile scavengers such as tanner crabs can be common in fjord basins (Zhou & Shirley 1997). Glass sponge reefs have been found in the Howe Sound fjord basin near Vancouver, BC (Leys et al. 2004). Many fjord basins on the BC coast remain unexplored, so these glass sponge reefs may be more common than we currently know.

Because the fjords ecosystem extends to such great depths, many species that are generally found in deep offshore areas can also be found within fjords, including Pompom Anemones and the stony coral, *Lophelia pertusa*.

Many migratory fishes, including eulachon and juvenile and adult Pacific salmon, transit through fjords, from rivers to the open ocean as juveniles, and back to rivers as adults. The narrow geography of fjords creates bottlenecks where migratory species are aggregated during migration. These migratory fishes in fjords fall prey to marine mammal predators during their time in fjords; resident orcas feed on adult salmon, and humpback whales and Pacific white-sided dolphins feed on eulachon and other forage fishes within fjords (Keen et al. 2017).

Transient orcas feed on marine mammals like Pacific white-sided dolphins, porpoises, and sea lions (Heise et al. 2003).

A variety of seabirds feed on forage fishes, including Buffleheads, Marbled Murrelets and gulls.

3.9.3 Environmental drivers

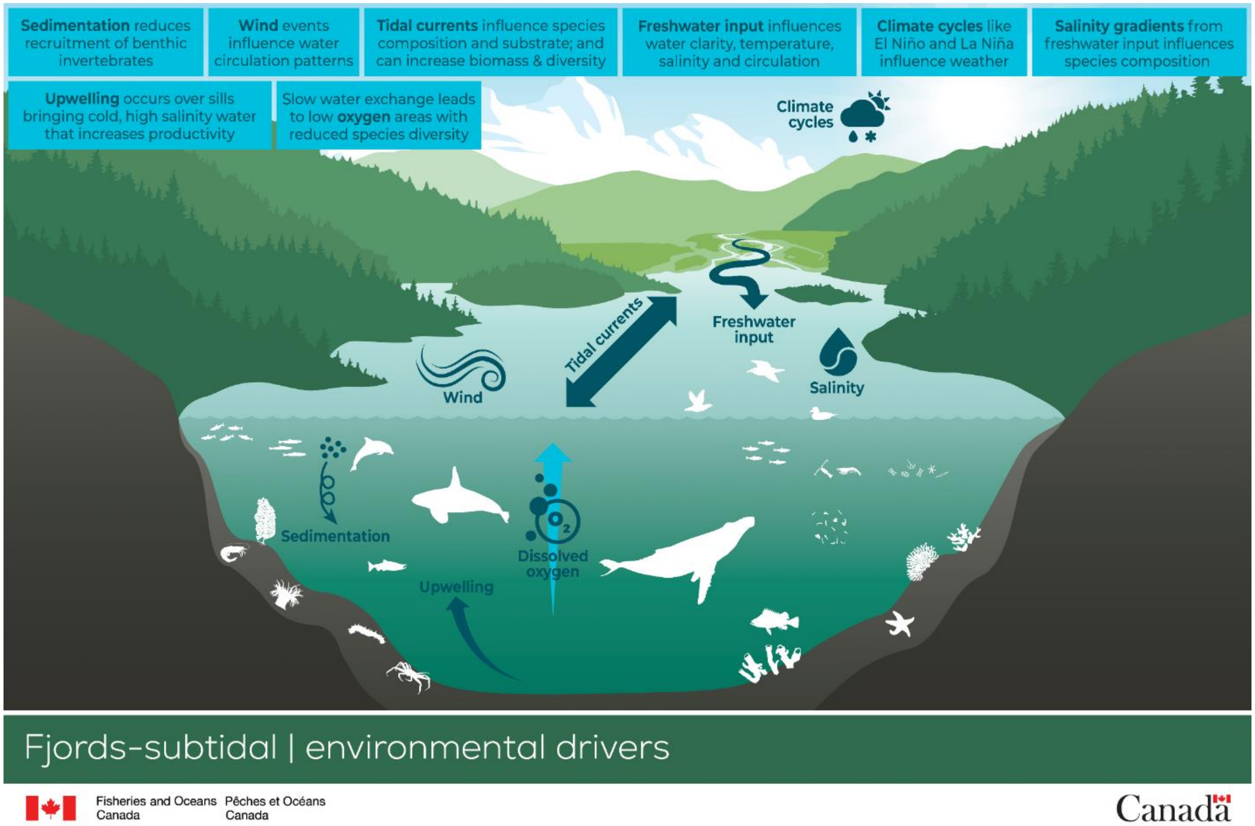

Figure 37. Main environmental drivers within the fjord ecosystem.

Many environmental drivers influence physical conditions within the fjord ecosystem, as well as species composition and distribution. Here, we describe the main environmental drivers and their effects.

Fjord ecosystems have strong horizontal and vertical environmental gradients. Horizontal along-fjord gradients are created by the presence of different influencing environments at either end of the fjord; the inland end of a fjord is influenced by rivers, and the seaward end is influenced by ocean conditions. Environmental conditions within fjords also differ vertically by depth, especially in the presence of **sills**, which restrict water flow. Circulation within upper water layers is similar to estuaries with freshwater input from rivers at the surface, and **upwelling** water from offshore beneath (Gilmartin et al. 1964; Wan et al. 2017). Below **sill** height, there is little movement in the deep basin water, but it does undergo renewal during periods of **upwelling** along the coast that drive cold, higher salinity water from offshore into basin areas (Wan et al. 2017).

Wind also influences water circulation patterns in fjords. In the summer, the predominant winds travel in an up-fjord direction, slowing down the surface outflow currents and thickening the low salinity surface layer, which causes strong stratification (Wan et al. 2017). In contrast, the predominant wind direction in the winter is down the fjord, which speeds up surface outflows and enhances estuarine circulation (Wan et al. 2017). Wind and associated waves can also cause mixing of surface water, disrupting the layering. This is most prevalent in the winter when storms are more frequent, and the water layers are less strongly stratified (Keen et al. 2017).

Upwelling occurs within fjords as tidal currents move deep water up and over the glacial **sills** (Ebbesmeyer & Barnes 1980). The top of a **sill** can be very productive due to the upwelled water and tidal currents, and often supports high biomass and diversity of **benthic** invertebrates such as corals

(Tunnicliffe & Syvitski 1983). These tidal currents may also generate internal waves as they pass over the **sills**. As these waves break over the top of the **sill**, they can push high salinity, nutrient rich water from the deep into surface layers, causing mixing and reducing stratification (Shen et al. 2020).

Freshwater inputs to fjords bring heavy sediment loads that remain suspended in the water column. As the freshwater plume moves from its source at the head of a fjord along its length, sedimentation occurs (Farrow et al. 1983). Sedimentation is most concentrated near the source of the particles, and less concentrated at the open end of the fjord (Farrow et al. 1983). Sedimentation can negatively affect the abundance and diversity of species within the fjord, especially for **benthic** invertebrates (Farrow et al. 1983) as their **recruitment** can be reduced by a heavy silt layer.

Salinity within fjords is often reduced in surface waters and near the head of the fjord due to freshwater input from rivers (Gilmartin 1964). River outflows are influenced by glacial melting during the spring and summer, and by rains in the fall and winter (Wan et al. 2017). Salinity influences species composition, with lower salinity being associated with lower species diversity (Zacharias & Roff 2001).

Dissolved oxygen in fjords is generally high near the surface and low in deep basin areas where oxygen is depleted by respiration, and is slow to be replenished due to restricted water flow over the **sills** (Gilmartin 1964). Low dissolved oxygen concentration leads to reduced species diversity because few species can tolerate exceptionally low oxygen levels (Gooday et al. 2010).

Climate cycles like El Niño and La Niña influence weather, leading to variation in other environmental drivers such as wind events, temperature, precipitation, currents, and the strength of **upwelling** events in fjord ecosystems.

3.9.4 Human activities

Like other coastal ecosystems, fjord ecosystems are affected by human activities taking place on the water, coast, and inland areas. Commercial fishing occurs in this ecosystem, removing fish with varying levels of bycatch. Mining and forestry roads and cutblocks can increase erosion and sedimentation, which can move downstream into fjords. Coastal communities and industries (e.g., pulp and paper mills) in fjords are also a source of contaminants and debris.

The fjords in the Central and North coast of BC are important navigation corridors providing goods and services to communities up and down the coast, and tourism opportunities during the summer months. However, shipping is a source of pollution, noise, and invasive species, and vessels can disturb **benthic** habitats during anchoring. Noise pollution from shipping can be significantly amplified within narrow fjord corridors (Barclay & Lin 2019).

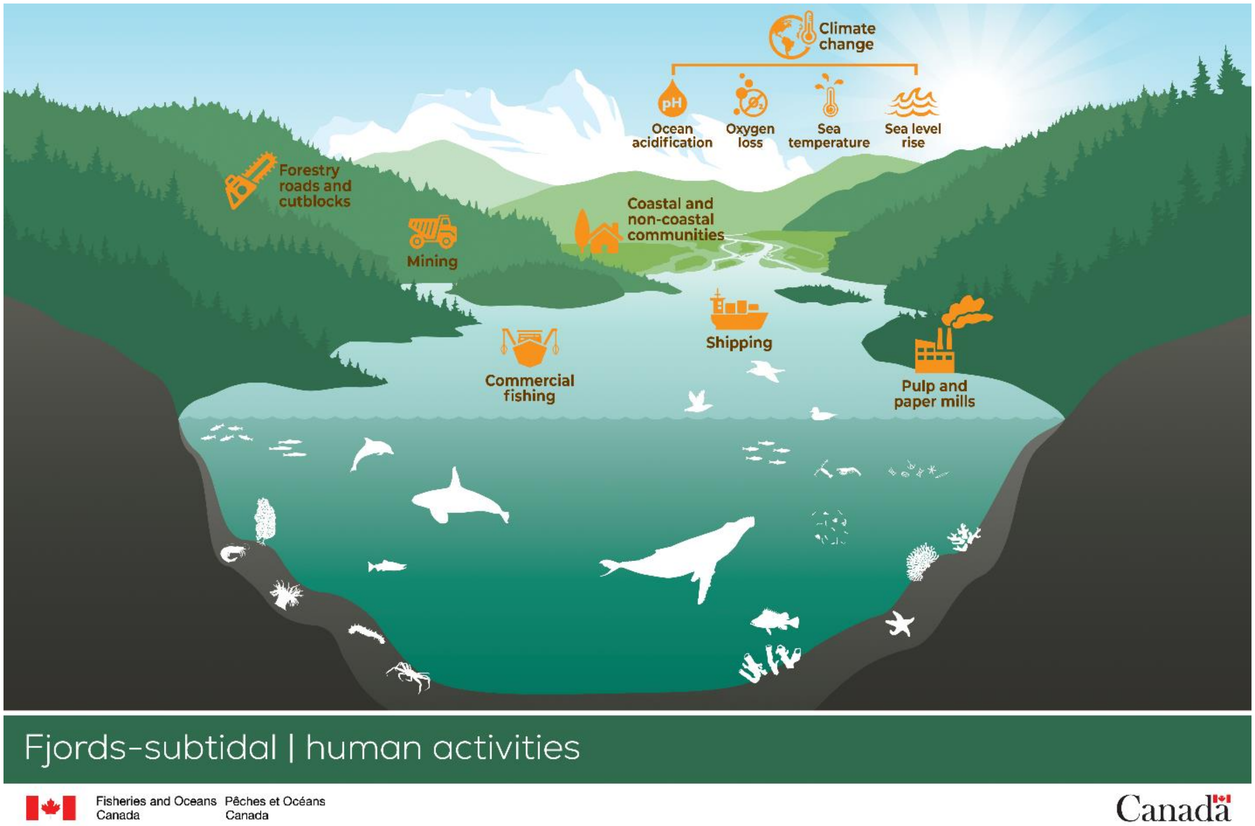

Figure 38. Relevant human activities within the fjord ecosystem.

3.9.4.1 Climate Change

Fjord ecosystems are influenced by many effects of climate change, including ocean acidification, dissolved oxygen loss, increased sea temperature, and sea level rise. Additionally, climate change will impact the amount of freshwater entering this ecosystem from rainfall and river discharge. Reductions in annual rainfall will change the thickness and extent of the low-salinity layer, slow the rate of deep-water renewal, and decrease bottom water oxygen concentrations (Bianchi et al. 2020).

Plankton and cold-water corals are calcifying species common in fjords ecosystems that may be impacted by ocean acidification. As this ecosystem becomes more acidic, it will become increasingly difficult for these organisms to extract calcite and aragonite from the water to form body structures.

Stony corals (e.g., *Lophelia pertusa*) use the aragonite form of calcium carbonate to form skeletons. Many of these corals are found near the aragonite saturation depth limit (Guinotte et al. 2006), which is shallowing with climate change. Further decreases in this saturation depth will place many corals in marginal conditions, causing weakened stony coral skeletons and decreased growth rates (Guinotte et al. 2006). Future acidic conditions, and reduced **plankton** from warming waters, will likely negatively impact the fitness of cold-water corals (Buscher et al. 2017; Guinotte et al. 2006; Haigh et al. 2015).

The geology of fjord ecosystems makes them naturally predisposed to poor water mixing and low dissolved oxygen conditions, which may be exacerbated by climate change. In this ecosystem, dissolved oxygen may be naturally very low due to shallow **sills** often located at the mouth of fjords that prevents or hinders mixing of fjord water with oxygenated offshore waters (Dallimore et al. 2005; Dallimore and Jmieff 2010). Research in Rivers Inlet, a fjord on the Central Coast of BC, shows a trend of decreasing oxygen concentration from 1951–2020 in deep waters (Jackson 2021), as well as the identification of a persistent, and often hypoxic, subsurface oxygen minimum layer that could reach as shallow as 60 m if this trend continues (Jackson et al. 2021). Decreasing oxygen concentrations from the bottom to 60 m is anticipated to have impacts on biological systems in this ecosystem

Rising sea temperatures will impact fjord ecosystems in a variety of ways. Changes to species distribution is anticipated, both vertically and poleward (Weslawski et al. 2011). The timing and abundance of phytoplankton and zooplankton production is expected to be negatively impacted by warming surface waters, with cascading effects for higher trophic levels (Quigg et al. 2013).

Sea level rise may impact **subtidal** habitats through changes to environmental conditions, such as light and nutrient availability, sediment load, and turbidity, and the resulting impacts to biotic communities will depend on their ability to adapt (Rullens et al 2022).

3.10 Hydrothermal vents

3.10.1 General description

Hydrothermal vents are deep **benthic** marine ecosystems where **reduced chemicals** emanate from the seafloor. They are found at depths ranging from approximately 600 m to over 3,000 m (DFO 2019). These highly productive ecosystems are fueled by **chemosynthetic** microbes that supply energy to support a diverse array of unique organisms, and also supply energy to the surrounding **pelagic** and **bathyal plains** ecosystems (Levin et al. 2016). In the Canadian Pacific Ocean, hydrothermal vents are located on, or near, the Northeast Pacific spreading ridge system, which ranges from 185-280 km off the west coast of Vancouver Island and from 41-52°N latitude.

Globally, hydrothermal vents are relatively rare and unique geological features associated with tectonic activity. Hydrothermal fluids, which vent from cracks in the oceanic crust, are typically rich in hydrogen sulphide and a variety of metal oxides, allowing for multiple different pathways for **primary production** by **chemosynthetic** microbes. Sulphides and metals precipitating from the hydrothermal fluid accrete to create elaborate sulphide structures capable of supporting high biomass. The organisms living in this ecosystem are highly specialized to cope with physical, chemical, and thermal extremes. As a result, most species living within hydrothermal vents communities have been estimated to be very limited in distribution (McArthur and Tunicliffe 1998). The hydrothermal vents of the Northeast Pacific Ocean are grouped as a distinct biogeographical province by several species distribution modelling studies (Tunnicliffe 1997; Mironov et al. 1998; Tunnicliffe et al. 1998; Tyler and Young 2003; Desbruyeres et al. 2006; and Bachraty et al. 2009), indicating that this area is unique among the hydrothermal vents of the world.

There are many biological, environmental, and anthropogenic features that influence conditions within this ecosystem, including species composition and distribution. Here, we describe only the main ecological components and interactions (Figure 39 andFigure 40), environmental drivers (Figure 41), and human activities (Figure 42), as depicted in the hydrothermal vents conceptual model illustrations.

3.10.2 Key ecological components and interactions

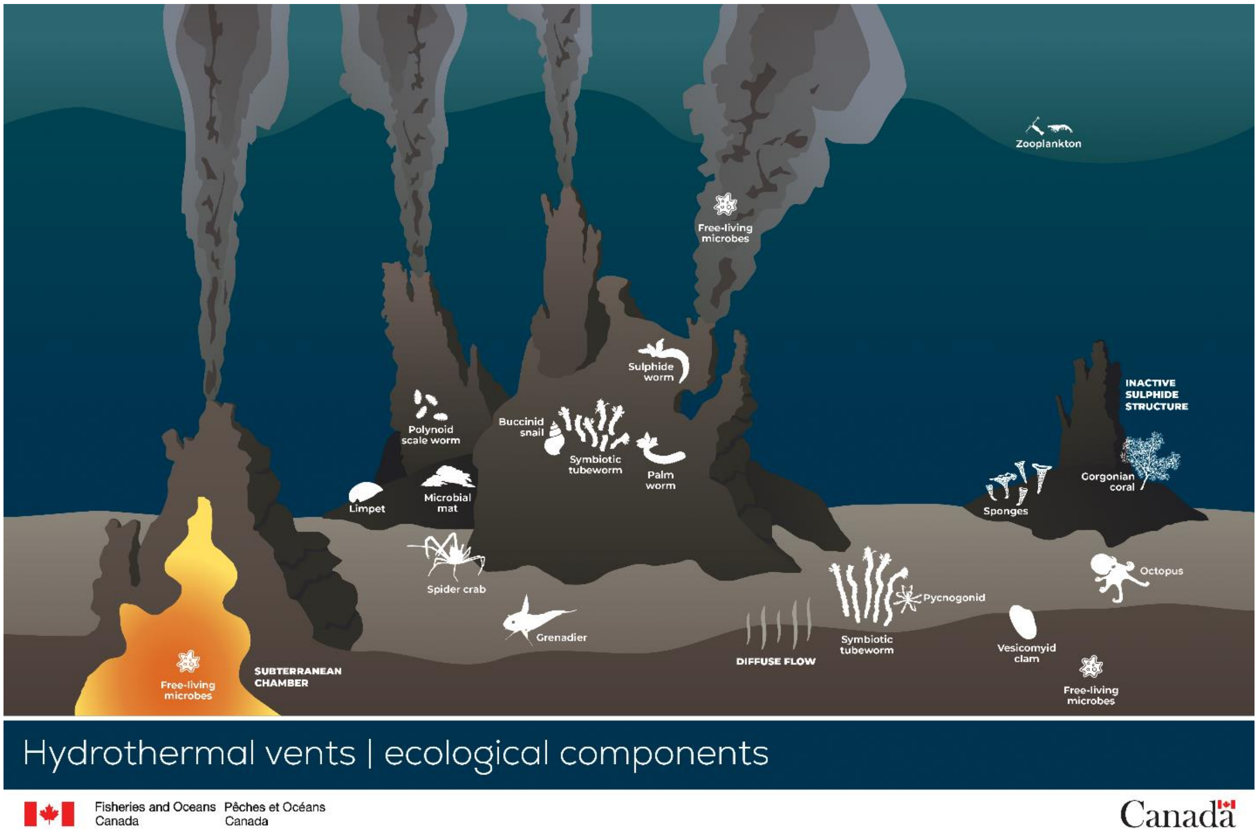

Figure 39. Key ecological components of the hydrothermal vent ecosystem.

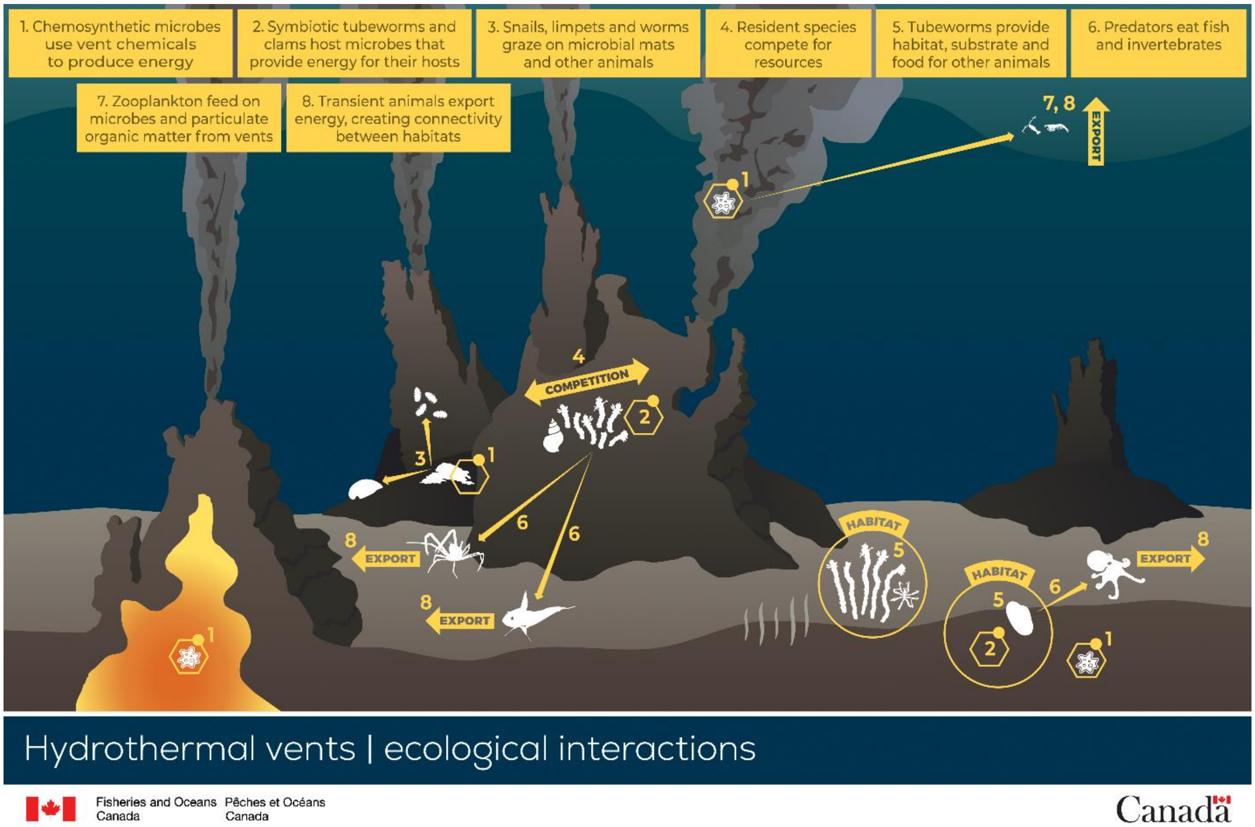

Figure 40. Key interactions among the ecological components of the hydrothermal vent ecosystem.

Chemosynthetic free-living microbes use vent chemicals to produce energy, playing the ecologically significant role of primary producers (Wang et al. 2009). They are ubiquitous in vent ecosystems, and are found in subterranean chambers that feed the vents, in **diffuse flow** areas, in sediments, in hydrothermal fluids, in mats covering vent substrates, on the tubes and bodies of vent organisms, and in elaborate symbioses with hydrothermal vent invertebrates. Microbes can be so dense that they form visible, thick microbial mats that are grazed upon by vent fauna. The extreme temperatures and reduced metal compounds found in hydrothermal vent fluids and substrates support a variety of microbial metabolic pathways, most importantly that of sulphid oxidation.

Zooplankton feed on microbes and particulate organic matter originating from vents. Vertically migrating zooplankton feeding at vents transfer hydrothermal energy to **pelagic** food webs (Burd and Thomson 1994; Cowen et al. 2001; Bennett et al. 2011). Zooplankton are a food source for several invertebrate and fish species in this ecosystem.

Symbiotic invertebrates, such as tubeworms and vesicomyid clams, host **chemosynthetic** microbes that provide energy for their hosts. The polychaete tubeworm, *Ridgeia piscesae*, and vesicomyid clams, *Calyptogena* sp., participate in **primary production** through symbioses with sulphide oxidizing bacteria. The invertebrate hosts provide sulphide, oxygen, and carbon dioxide for the microbial symbionts and receive fixed carbon in return (Southward et al. 1995; Juniper et al. 1992).

In addition to assisting with **primary production**, the tubeworm, *R. piscesae* acts as an **ecosystem engineer**, providing settlement substrate, habitat, and a food source for other vent and non-vent organisms. *R. piscesae* colonizes a range of hard substrates creating dense ‘forests’ that greatly increase the surface area available for colonization, and host diverse communities of vent organisms (Tsurumi and Tunnicliffe 2003).

Grazing invertebrates such as limpets, buccinid snails, and polynoid scale worms feed on microbial mats and other animals such as tubeworms.

Resident species, such as sulphide worms and palm worms, compete for resources, which can be highly localized and ephemeral (e.g., point-sources of vent fluid flow that become cut-off after tectonic events). This **competition** creates a patchy distribution of species, centered on areas of high resource availability, and also creates source-sink dynamics for many species (Tunnicliffe et al. 2014).

Predatory invertebrates and fishes, such as pycnogonid sea spiders, spider crabs, graneledone octopus, and grenadiers eat invertebrates, such as tubeworms and clams.

Transient animals feeding at vents export energy, creating connectivity between habitats. Hydrothermal vents ecosystems support a diverse array of organisms that are not obligate vent species, and are ecologically important in transferring chemoautotrophic production from hydrothermal vents to the surrounding deep sea. For example, mobile **benthic** scavengers and predators, such as crabs, fishes, and octopus, feed on vent-obligate organisms and export hydrothermal vent production to surrounding **bathyal plain** ecosystems (Tunnicliffe and Jensen 1987; Marques and Porteiro 2000; Voight 2000; MacAvoy et al. 2002, 2003, 2008). Transient animals also use vents for other important life functions; some skates and sharks use vents as nursery grounds (Treude et al. 2011).

Inactive sulphide structures host novel species assemblages and geomorphic features even though venting has ceased. Assemblages tend to resemble those of seamount communities, with organisms typically being **sessile**, **filter feeding**, long-lived, and slow-growing (Boschen et al. 2013). These communities include fewer vent obligates, a more even representation of species, and the presence of typical deep-sea taxa such as gorgonian corals and sponges (Tsurumi and Tunicliffe 2003).

3.10.3 Environmental drivers

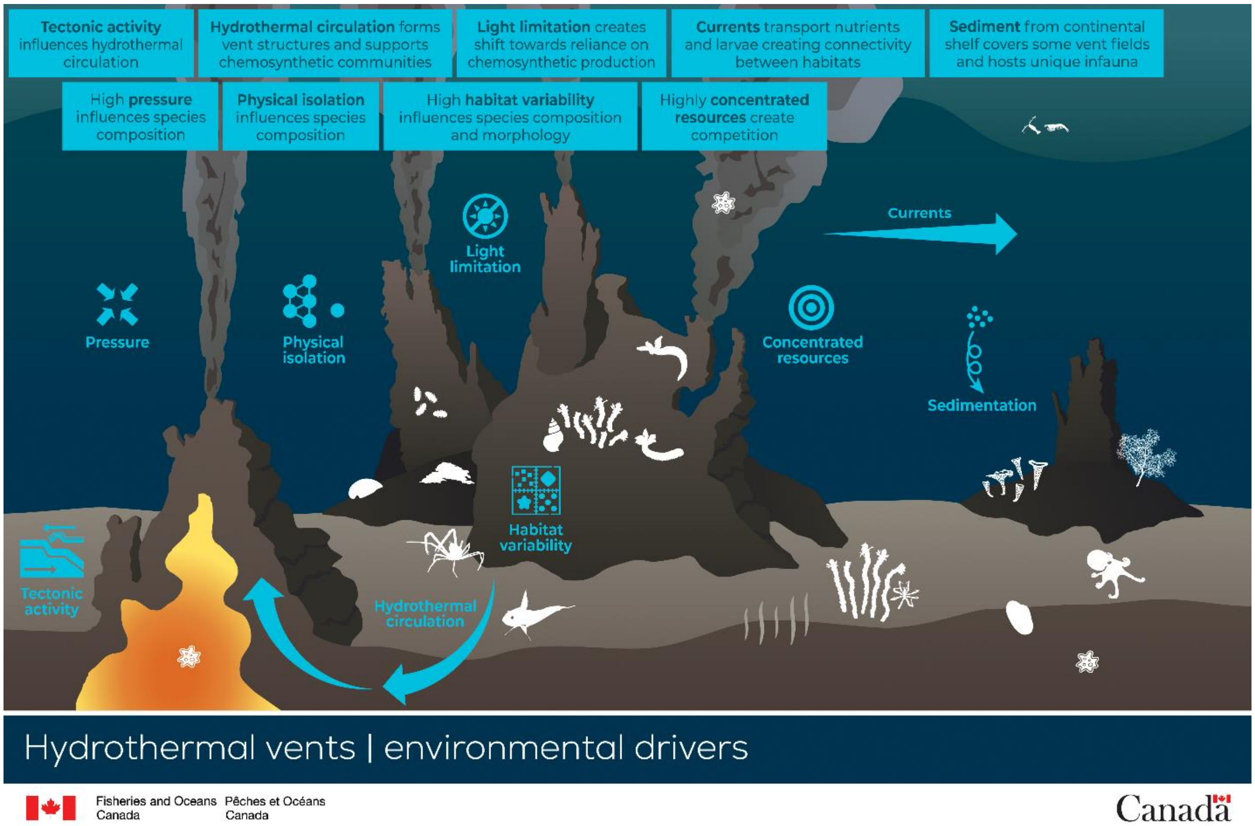

Figure 41. Main environmental drivers within the hydrothermal vent ecosystem.

Many environmental drivers influence physical conditions within the hydrothermal vents ecosystem, as well as species composition and distribution. Below, we describe the main environmental drivers and their effects.

<u>Tectonic activity</u> at spreading ridges influences hydrothermal circulation. It can both increase or strangle hydrothermal fluid flow, causing the formation and growth of new sulphide structures, or the senescence and/or collapse of existing ones (Tunnicliffe and Juniper 1990).

<u>Hydrothermal circulation</u> forms vent structures and supports **chemosynthetic** communities on the vents and in the hydrothermal plume, a neutrally buoyant layer of hydrothermal fluid 150-300 m above the vent field. This plume of water is a nutrient rich layer that supports unique bacterial and viral communities (Juniper et al. 1998), zooplankton communities (Burd et al. 1992; Burd and Thomson 1994), and hydrothermal vent larvae (Mullineaux et al. 1995).

Light does not penetrate to the depths of hydrothermal vents ecosystems. <u>Light limitation</u> in this ecosystem creates a reliance on **chemosynthetic** production, rather than **primary production** from phytoplankton that is the basis of most food webs in the **photic zone**.

<u>Currents</u> transport nutrients and larvae. Currents can influence dispersal patterns of organisms and structure population connectivity, especially for organisms with a **planktonic** larval stage such as corals and sponges. There is some evidence that ocean currents limit gamete dispersal to within hydrothermal vent field valleys (Thomson et al. 2003, 2005, 2009), increasing the likelihood that larvae will settle in suitable habitat.

Sedimentation derived from the continental shelf occurs in this ecosystem, covering some vent fields and creating soft substrates that host unique **infauna**. Some hydrothermal vent fields in the Canadian Pacific Region are heavily sedimented, covered in 200 to over 1,000 m of sediment from the continental shelf (Hannington et al. 2005). This sediment cover retains heat and precipitated metals, and protects sulphide deposits from seafloor weathering and oxidation, promoting the formation of some of the world's largest polymetallic sulphide deposits (Hannington et al. 2005). Hydrothermal venting at sedimented sites occurs both from active sulphide structures projecting up through the sediment, and from focused areas where hydrothermal fluid upwells through the sediment. The hydrothermal sediment habitat in this region hosts a unique **infaunal** assemblage that is not present on bare basalts and sulphide structures, and with different species than at other sedimented hydrothermal sites in the world (Juniper et al. 1992).

High pressure influences species composition. Extreme pressure in these deep ecosystems creates a shift towards species with cartilaginous or fluid-filled body structures without compressible air spaces (Robison 2004).

Physical isolation influences species composition. Hydrothermal vents on the Juan de Fuca Ridge in the Northeast Pacific Ocean are located 185-280 km off the west coast of North America and are physically isolated from the coast, as well as other hydrothermal vent sites in the Pacific Ocean. Tunnicliffe (1988) estimates that 50% of the macrofaunal species observed at sampling sites on the Juan de Fuca Ridge are endemic to hydrothermal vents of the Northeast Pacific Ocean. Additionally, the Northeast Pacific is recognized as its own separate biogeographic province when considering species distribution at hydrothermal vents worldwide (Tunnicliffe 1997; Mironov et al. 1998; Tunnicliffe et al. 1998; Tyler and Young 2003; Desbruyeres et al. 2006; and Bachraty et al. 2009). Globally rare or unique species at the Northeast Pacific hydrothermal vents include the tubeworm, *R. piscesae;* the vesicomyid clam, *Calyptogena sp*.; Sulfide Worm; Palm Worm; Juan de Fuca Limpet; and the snail, *Depressigyra globulus*.

High habitat variability influences species composition and morphology. Venting temperatures can range from near ambient to over 400°C, with associated differences in chemical concentrations. This high variability leads to a mosaic of habitat types on each structure, which influences the faunal composition. Sarrazin et al. (1997) describes six recurring faunal assemblages on hydrothermal structures in the Pacific Region, and these form a mosaic of decimeter to meter scale patches covering over 90% of the sulphide structure studied.

Highly concentrated resources create **competition**. The resources necessary for **chemosynthesis**, such as the chemicals in vent fluid, are concentrated at point sources of fluid flow, such as on sulfide structures and cracks in the basalt. This creates **competition** which, in turn, creates a patchy distribution of species centered on areas of high resource availability, and also creates source-sink dynamics for many species (Tunnicliffe et al. 2014).

3.10.4 Human activities

Relatively few human activities take place near hydrothermal vents due to their remoteness and depth. Scientific activities have taken place in hydrothermal vents ecosystems off the coast of BC since they were first discovered in the early 1980s. Although scientific surveys are often low impact, submersibles and other tools can disturb sea bottoms and leave small amounts of debris, such as ballast weights and markers. Marine debris originating from both land and sea-based activities has been found within this ecosystem.

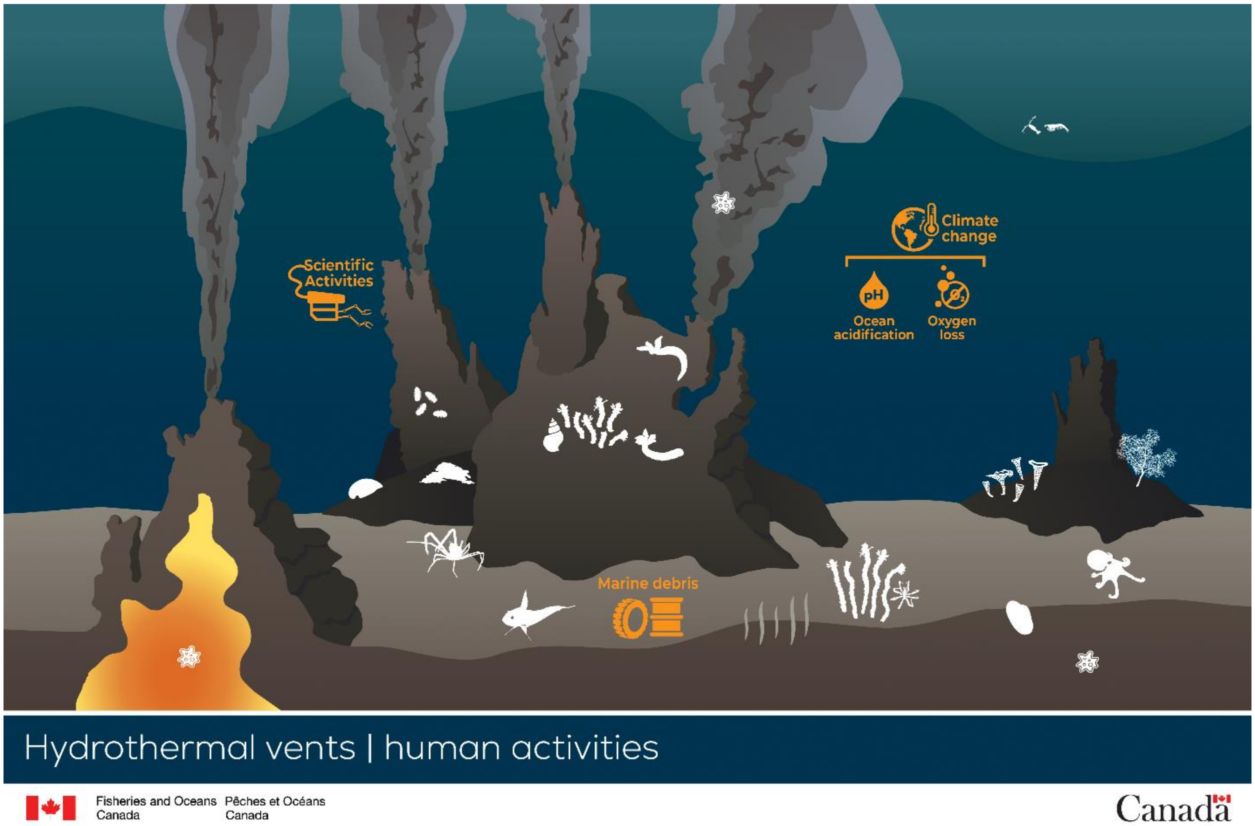

Figure 42. Relevant human activities within the hydrothermal vent ecosystem.

3.10.4.1 Climate Change

Hydrothermal vent ecosystems are primarily influenced by two effects of climate change, ocean acidification, and dissolved oxygen loss.

With increasing ocean acidification, offshore regions of BC are projected to reach aragonite saturation levels low enough to dissolve aragonite shells (such as those built by vesicomyid clams (Lutz et al. 1988)). Because hydrothermal vent ecosystems are already undersaturated, or limited in available calcite and aragonite, ocean acidification will make it even more difficult for species such as **plankton**, crabs, corals, tubeworms, and limpets, to access calcite and aragonite as the saturation state continues to decrease. These calcifying organisms are important to ecosystem functioning in hydrothermal vents, as many of them are involved in habitat formation and **primary production**.

Under changing climate conditions dissolved oxygen concentrations are projected to decrease overall in offshore **benthic** areas that may include hydrothermal vent ecosystems (Friesen et al. 2021). However, dissolved oxygen levels in these ecosystems are already extremely low (Friesen et al. 2021), and so how and if this change will impact this ecosystem is largely uncertain (Van Dover 2014).

3.11 Seamounts

3.11.1 General description

Seamounts are defined as submarine mountains with summit elevations exceeding 1,000 m above the surrounding seafloor. They are roughly circular or elliptical in shape, and are usually volcanic in origin

(United States Board of Geographic Names 1981). Seamounts ecosystems are found throughout the offshore Canadian Pacific EEZ, west of the continental shelf and slope, with the largest concentration in the southern half of this area. Within Canada's Pacific Ocean, there are 19 named, and at least 43 unnamed (predicted or confirmed) seamounts, with summit depths ranging from 28 to 2,600 m below the surface (DFO 2021b). Features less than 1,000 m in elevation are considered hills and knolls and are discussed in the **Bathyal Plains** ecosystem section of this report.

The summit depth of one seamount, SGaan Kinghlas-Bowie (24 m) is within photic depths (0-200 m), which allows **benthic** photosynthetic production. However, most seamounts occur in deeper water where photosynthesis is not possible and are instead supported to varying degrees by marine snow (i.e., detritus) that falls from above (DFO 2019). Common species groups inhabiting these seamounts include crustaceans, anthozoans, gastropods, bivalves, echinoids, ophiuroids, asteroids, polychaetes, hexactinellids, bony fishes, and elasmobranchs (Birkeland 1971; Morato and Pauly 2004; Du Preez et al. 2015; DFO 2021b). Distinct bands of species assemblages form along vertical gradients on the steep walls of the seamounts, driven by gradients in environmental conditions (Wishner et al. 1990) and biological factors (e.g., **competition**; Victorero et al. 2018). Change in species composition with depth is summarized in DFO (2019).

Given their volcanic and tectonic origins, seamounts also have the potential for hydrothermal venting activity, as evidenced by hydrothermal deposits on Dellwood Seamount, which is now considered an inactive vent (Piper et al. 1975).

There are many biological, environmental, and anthropogenic features that influence conditions within this ecosystem, including species composition and distribution. Here, we describe the main ecological components and interactions (Figure 43 andFigure 44), environmental drivers (Figure 45), and human activities (Figure 46), as depicted in the seamount conceptual model illustrations.

3.11.2 Key ecological components and interactions

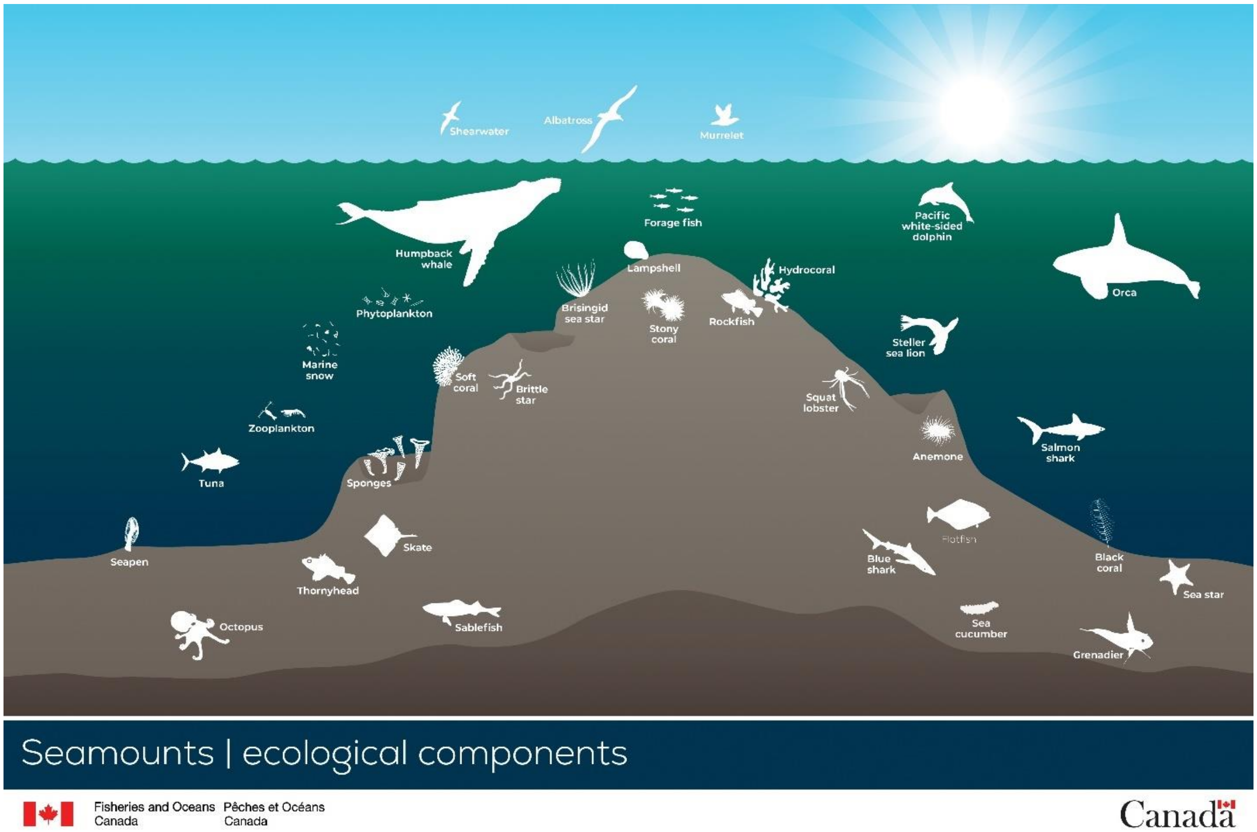

Figure 43. Key ecological components of the seamount ecosystem.

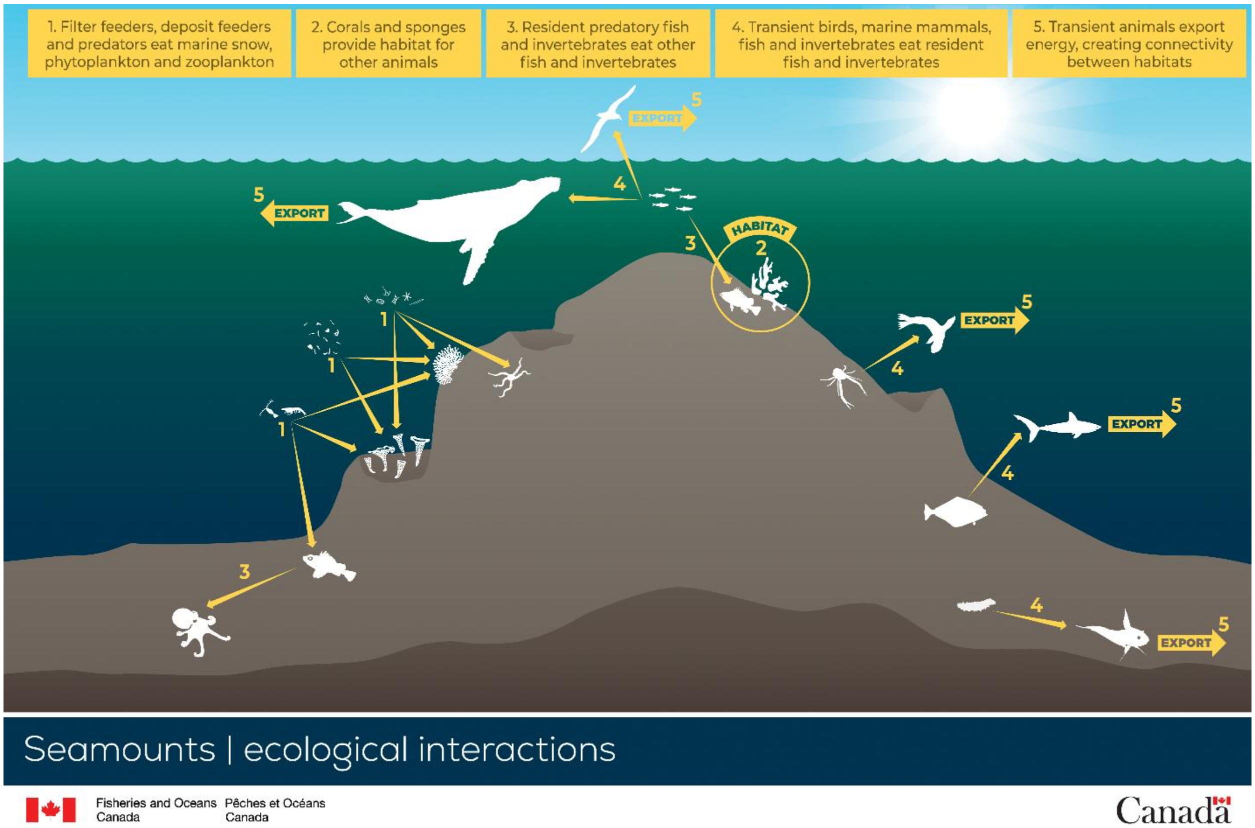

Figure 44. Key interactions among the ecological components of the seamount ecosystem.

Marine snow consists of detritus that falls from shallower waters and accumulates on the ocean floor. It includes phytoplankton, dead organisms, and fecal matter, as well as microbes and inorganic matter. Marine snow provides an important source of nutrients to areas where light is insufficient to sustain primary productivity (Turner 2015).

Zooplankton are small **filter feeding** organisms that live in the water column and serve as an important food source for other **filter feeding** invertebrates. Marine snow, and zooplankton migrating from the **photic zone**, bring energy from the **photic zone** to deeper waters creating connections between ecosystems (Genin and Dower 2007). Filter feeders, such as sponges, corals (soft coral, hydrocoral, stony coral and black coral), sea pens, lampshells, and brisingid seastars eat marine snow, phytoplankton, and zooplankton.

Deposit feeders, such as sea cucumbers, seastars, and brittle stars eat marine snow. Predators such as anemones, squat lobsters, forage fishes, rockfishes, and thornyheads eat zooplankton and other small prey.

Corals and sponges provide habitat for other animals such as rockfishes and thornyheads. Coldwater corals and sponges provide a broad range of ecosystem functions including substrate for attachment, shelter, and feeding, thereby supporting higher levels of **biodiversity** and productivity than surrounding habitats (Buhl-Mortensen et al. 2010). These habitat-forming species occur on all seamounts surveyed to date within Canadian waters (DFO 2021b; Canessa et al. 2003; Stone and Shotwell 2007; Lundsten et al. 2009; Du Preez et al. 2015).

Resident **predatory** fishes and invertebrates, such as rockfishes, thornyheads, flatfishes, skates, and octopuses, eat other fishes and invertebrates. For example, SGaan Kinghlas-Bowie Seamount likely supports a self-sustaining population of widow rockfish that may be prey for Pacific halibut, sablefish, and other rockfishes (Beamish and Neville 2003; Yamanaka 2005). Also, evidence suggests that rougheye rockfish may be a keystone species at SGaan Kinghlas-Bowie Seamount; the loss of which may lead to a decline or disappearance of sablefish and Pacific halibut (Beamish and Neville 2003).

Seamounts are used as feeding grounds by transient birds, marine mammals, fishes, and invertebrates (Kaschner 2008; Santos et al. 2008; Thompson 2008), such as Sooty Shearwaters, Black-footed Albatrosses, Murrelets, humpback whales, Pacific white-sided dolphins, orcas, Steller sea lions, salmon sharks, blue sharks, tunas, grenadiers, and sablefish. These animals exploit the higher productivity associated with seamounts by feeding on resident fishes and invertebrates. This exploitation creates habitat connectivity with other offshore and inshore ecosystems when the transient animals feeding at seamounts move on and export energy elsewhere. For example, sablefish move continuously back and forth between the coast and SGaan Kinghlas-Bowie Seamount (Kabata et al. 1988; Whitaker and McFarlane 1997; Kimura et al. 1998; Beamish and Neville 2003).

Seamount ecosystems were once thought to support highly endemic fauna that comprised unique communities, distinct from other comparable ecosystems (Rowden et al. 2010). However, in recent years, this paradigm in seamount ecology has been shown to be unsubstantiated (Rowden et al. 2010). Instead, seamounts appear to offer suitable, alternative habitat for a subset of continental and deep-sea species, especially near-slope seamounts (Howell et al. 2010).

3.11.3 Environmental drivers

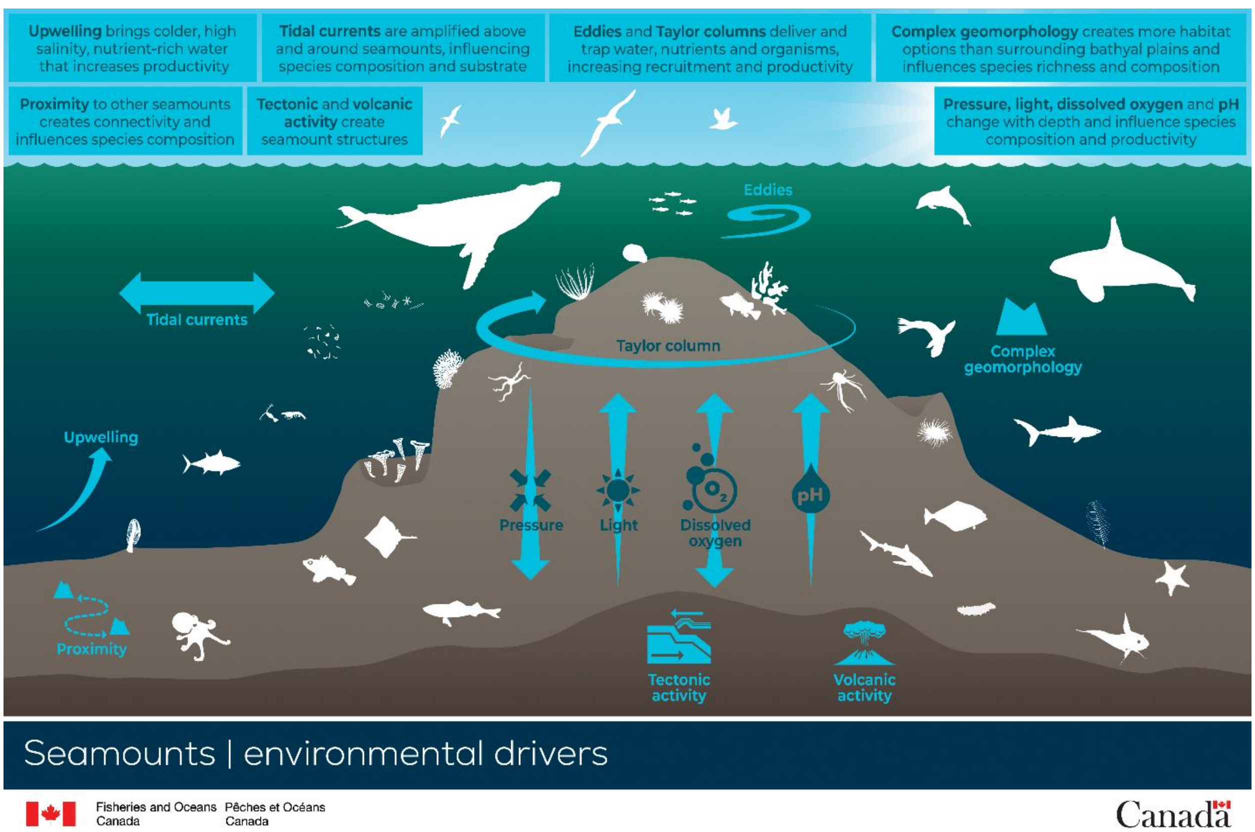

Figure 45. Main environmental drivers within the seamount ecosystem.

Many environmental drivers within the seamount ecosystem influence physical conditions within the ecosystem, as well as species composition and distribution. Below, we describe the main environmental drivers and their effects.

Seamounts have varying effects on local water circulation patterns, depending on their height, shape, and orientation (Ban et al. 2016), and in turn, these effects drive ecosystem dynamics at seamounts. **Upwelling** is enhanced along the slopes of seamounts, and brings cold, high salinity, nutrient-rich water that increases productivity (Mashayek et al. 2021). Eddies and Taylor columns that form around seamount peaks can deliver and trap water, nutrients, and organisms (Eriksen 1991), increasing **recruitment** and productivity. Tidal currents are also amplified above and around seamounts (Noble and Mullineaux 1989), which influences species composition and substrate. Depending on the summit depth, the oceanographic influence of seamount summits can trap prey near the surface, providing a source of food over the seamount.

Canadian seamounts formed as a result of tectonic and volcanic activity along the Cascadia subduction zone (Desonie and Duncan 1990). The tectonic or volcanic settings of seamounts may also support hydrothermal vent activity, and the presence of hydrothermal vents is considered to be an important distinguishing feature among seamounts (Clark et al. 2010, 2011). Within the Canadian Pacific EEZ, Dellwood Seamount is unique for its associated hydrothermal vents, but these are presently considered inactive (Piper et al. 1975). See the hydrothermal vents section (3.10) of this report for more information.

Seamounts are biologically diverse, in part owing to high habitat heterogeneity (Rowden et al. 2010; Du Preez et al. 2016). The complex geomorphology within seamount ecosystems creates more habitat diversity than surrounding **bathyal plains**, which influences species richness and composition. Seamounts generally have a varied and complex topography of pinnacles, plateaus, terraced flanks, cones, and craters that create numerous habitat types (e.g., descriptions in Chaytor et al. 2007). Given the volcanic origins of the Canadian seamounts, they contain unique hard substrata for settlement and growth (Watling and Auster 2017) in the otherwise mud-dominated surrounding **bathyal plains** (Ban et al. 2016) and continental slope (Pearcy et al. 1982; Bornhold and Yorath 1984). The potential habitats for **filter feeders** such as corals and sponges on seamounts is enhanced by the rugose topography of the seamounts, and the increased water flow around them (Genin et al. 1986). On Cobb Seamount, rugosity was the second strongest environmental proxy of community-structuring processes after depth (Du Preez et al. 2016).

Proximity to other seamounts and the continental slope creates connectivity and influences species composition. Seamount assemblages are generally a subset of fauna found in other comparable habitats (e.g., continental slope, deep sea); however, it is likely that each location supports distinct and discrete biological communities, unique assemblages, and unusual patterns of distribution and abundance (Boehlert and Genin 1987; Tunnicliffe et al. 1998; McClain et al. 2009; Curtis et al. 2015).

Seamounts span a wide range of depths in the Canadian Pacific EEZ, with the summit of SG̲aan K̲inghlas-Bowie reaching to 24 m depth, and the bases of deeper seamounts predicted to be at depths greater than 3,800 m (Kitchingman and Lai 2004, Manson 2009, Kim and Wessel 2011, Yesson et al. 2011). Several environmental drivers vary across this broad depth range, including pressure, light, dissolved oxygen, and pH, which influences species composition and productivity. **Benthic** fauna on seamounts is primarily distributed within depth-stratified bands that encircle the seamount (Clark et al. 2010; as documented on Cobb Seamount by Du Preez et al. 2016). Although depth-distributed assemblages are not uncommon in other **benthic** ecosystems, bands may be more predominant on seamounts because of their steep flanks (Du Preez et al. 2016).

Pressure increases with depth and drives a shift towards species with cartilaginous or fluid-filled body structures without compressible air spaces (Robison 2004).

Light decreases with depth and influences productivity and species composition. The summit of SGaan Kinghlas-Bowie is within photic depths and this seamount benefits from increased production provided by encrusting and **macroalgae** that occurs there. However, the other Canadian Pacific seamounts are below photic depths (200 m). Deeper seamounts likely rely on nutrient input from the **photic zone** or nutrient trapping by the various oceanographic processes previously mentioned. Light limitation also creates a shift in deeper seamount organisms towards less pigmentation, smaller eyes, and the use of bioluminescence (Robinson 2004).

Dissolved oxygen varies with depth and influences productivity and species composition. Portions of all Canadian Pacific seamounts intersect the **OMZ** (DFO 2019, 2021). Low oxygen can be physiologically stressful, and many species are unable to survive and/or thrive in the **OMZ** (Ross et al. 2020). However, low-oxygen specialist species, like glass sponges, can thrive (Ross et al. 2020). In fact, the **OMZ** is home to the highest diversity of coral and sponge species in seamount ecosystems (Chu et al. 2019). The dissolved oxygen concentrations on seamount summits are considered to be an important distinguishing feature among seamounts (Clark et al. 2011).

pH decreases with depth and influences the availability of calcite and aragonite. These mineral components of hard shells are fully saturated in surface waters where pH is relatively high, making it easier for organisms to form shells. As pH decreases with depth, calcite and aragonite concentrations also decrease, making it harder for organisms to build shells and skeletal structures in deeper areas on seamounts. At depths where these minerals are severely undersaturated, calcified organisms such as corals are absent (Auscavitch et al. 2020).

3.11.4 Human activities

Relatively few human activities take place near seamounts due to their remoteness. Commercial fishing using traps is one of the few human activities occurring in these unique ecosystems. Scientific activities studying these fragile ecosystems are low impact but can have a detrimental effect if they are not conducted with care. Marine debris from anthropogenic sources, such as lost fishing gear, have been documented in these ecosystems.

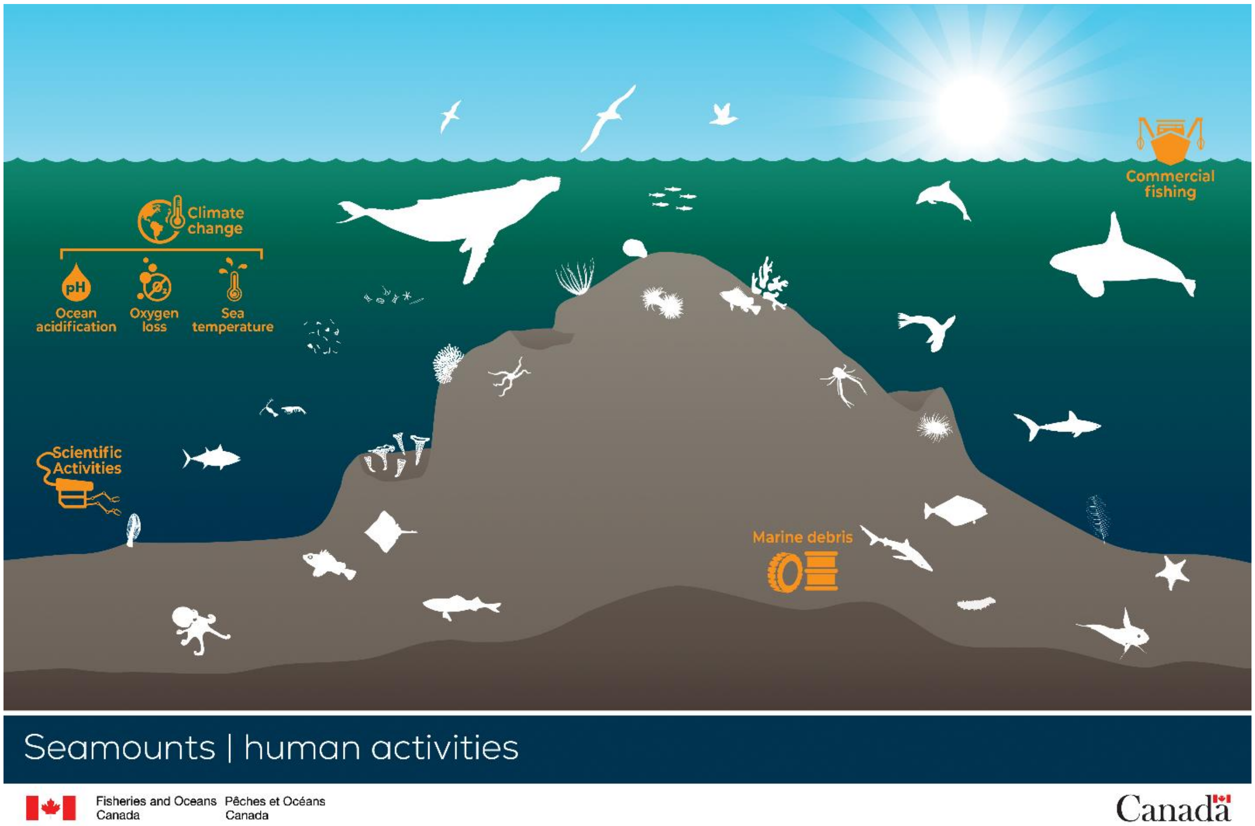

Figure 46. Relevant human activities within the seamount ecosystem.

3.11.4.1 Climate Change

Seamount ecosystems are most influenced by three main climate change stressors: ocean acidification, dissolved oxygen loss, increased sea temperature. Seamounts in the Pacific Ocean are areas of high productivity and diversity due to ongoing **upwelling** of nutrient rich waters from the deep. The high diversity associated with seamounts exists both on the seafloor of the seamount (Du Preez et al. 2016), and in the **pelagic** zone surrounding them (Morato et al. 2010), and it is expected that adverse effects of climate change will impact the structure and functioning of communities throughout this ecosystem (Clark et al. 2012).

Cold water corals are **bioengineers**, providing structural habitat for a diversity of species on seamounts (Buscher et al. 2017). Corals are particularly sensitive to ocean acidification as they build skeletons from carbonate ions (calcite and aragonite) whose concentration is reduced in more acidic conditions, leading to increased energetic costs to form calcified body parts (Spalding et al. 2017). Surface waters are saturated in carbonate ions, but the depth to which they are saturated is becoming shallower (particularly for aragonite), leaving more and more habitat in under saturated conditions (Ross et al. 2020). Aragonite is required for skeleton formation in stony corals (Guinotte et al. 2006), and many will be impacted as aragonite concentrations decrease in more areas. As a result, stony corals are likely to build weaker skeletons and experience slower growth (Guinotte et al. 2003).

Oxygen levels in the upper 3,000 m of the water column (a zone intersected by many seamounts) in the Northeast Pacific Ocean have declined by 15%, and the **OMZ**, where oxygen levels create unsuitable habitat for many fishes and crustaceans (Chu & Gale 2017), has expanded by extending into deeper waters (Ross et al. 2020). The reduction in dissolved oxygen and the expansion of the **OMZ** is expected to impact seamount communities. Species may respond to reduced oxygen levels by relocating if they are mobile, but for **sessile** species the changes may be lethal. Cold water corals and sponges on seamounts in the region inhabit areas considered oxygen deficient (Chu et al. 2019), but oxygen concentration in these areas is declining such that they may become fatal to even these highly tolerant species (Ross et al. 2020).

Water temperature generally decreases with depth and so is varied on seamounts due to the wide range of depths they occupy. Regional ocean models show that near bottom temperatures off the continental shelf are not projected to increase in the next 20-40 years (Friesen et al. 2021). However, large temperature increases are projected for surface waters, which shallower seamounts (e.g., SGaan Kinghlas-Bowie) intersect (Friesen et al. 2021). Therefore, the direct effect of increased temperatures on organisms inhabiting seamounts will vary by depth. Indirect effects of rising sea temperatures on seamounts will be similar to those predicted for other ecosystems, including a decrease in surface productivity (Hunter & Wade 2015) on which many seamount species rely.

3.12 Bathyal plains

3.12.1 General overview

Most of the ocean floor beyond the continental slope falls within the bathyal zone (between 1,000 and 4,000 m depth), with approximately 36% defined exclusively as **bathyal plains** (i.e., not hydrothermal vent or seamounts). **Bathyal plains** ecosystems occur across a tectonically complex area, with the Juan de Fuca and Explorer oceanic plates moving under the North American continental plate at the Cascadia subduction zone, which runs parallel to North America. Although the bathyal and abyssal (> 4,000 m depth) plains are generally considered to be relatively flat, these tectonic processes have created several topographical features (<1,000 m in elevation), such as hills, knolls, channels, and trenches. This heterogeneous bathymetry creates structural complexity within the **bathyal plains** ecosystem that supports distinct species assemblages compared with the flatter plains areas.

The **bathyal plains** ecosystem has no local **primary production**; therefore, it is energy or food limited. The ecosystem depends on nutrient import from adjacent ecosystems, such as hydrothermal vents and cold seep (Levin et al. 2016), and the **photic zone** (marine snow, whale and **wood falls**; Carey 1981; Smith et al. 2006, 2008). Interestingly, whale and **wood falls** have allowed for the evolution of a unique community dependent on organic remains or falls, primarily whale carcasses. Whales have lipid-rich bones that provide large amounts of nutrients when a carcass sinks into the abyss. These transient sites provide “habitat islands” containing diverse and unique species (Smith et al. 2015). Similar to hydrothermal vents or cold seeps ecosystems, the basis of these communities are microorganisms: bacteria that breakdown sulphur and methanogenic archaea that release chemicals into organic carbon (Smith et al. 2015).

There are many biological, environmental, and anthropogenic features that influence conditions within this ecosystem, including species composition and distribution. Here, we describe only the main ecological components and interactions (Figure 47 and Figure 48), environmental drivers (Figure 49), and human activities (Figure 50), as depicted in the **bathyal plains** conceptual model illustrations.

A feature that intersects bathyal depths is the continental slope, ranging from approximately 200-2,500 m depth. While the continental slope is not discussed as a separate ecosystem in this report, features (e.g., submarine ridges and canyons) and drivers (e.g., variable dissolved oxygen) discussed for the **bathyal plains** ecosystem are applicable to the lower portion of the continental slope as well.

3.12.2 Key ecological components and interactions

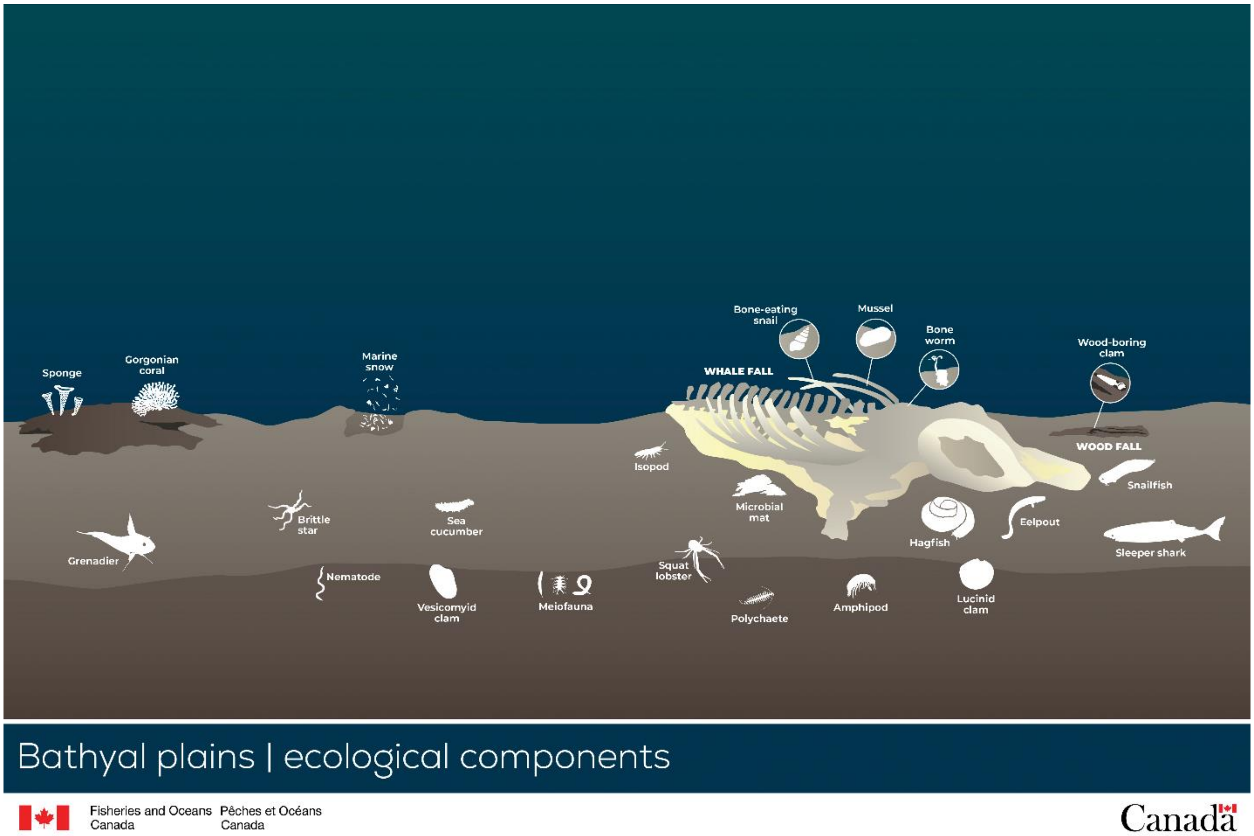

Figure 47. Key ecological components of the bathyal plains ecosystem.

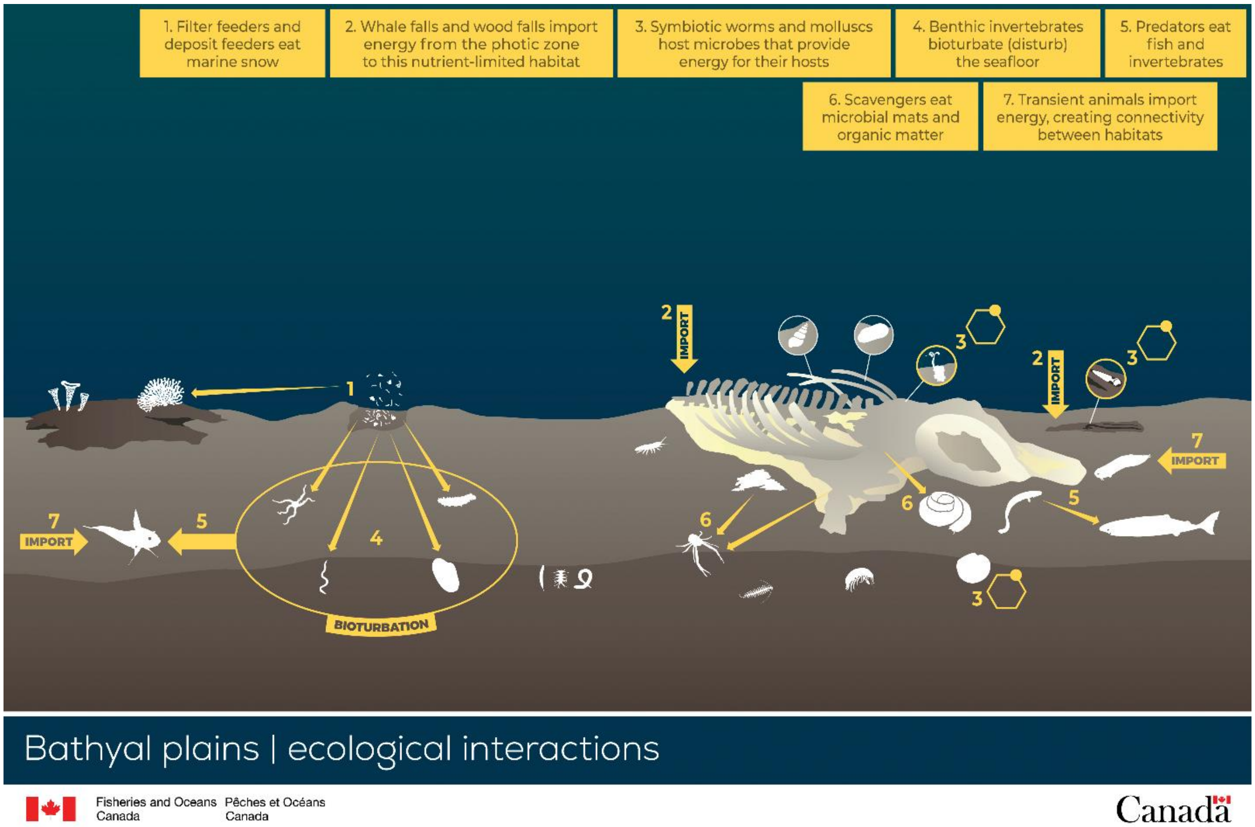

Figure 48. Key interactions among the ecological components of the bathyal plains ecosystem.

Microbes use **reduced chemicals** from the degradation of organic falls (e.g., **wood** and **whale falls**) to produce energy, playing the ecologically significant role of primary producers. They are found in sediments, in dense microbial mats covering the substrate, and in elaborate symbioses with invertebrates that live on or within organic falls. The microbial mats are grazed on by deep sea fauna.

Filter feeding and deposit feeding invertebrates, such as sponges, gorgonian corals, nematodes, sea cucumbers, and brittle stars, eat marine snow originating from photosynthesis in the **photic zone**, as well as zooplankton and microbes that inhabit the **bathyal plains**, or that migrate from adjacent ecosystems (e.g., cold seeps, hydrothermal vents, seamounts).

Grazing invertebrates, such as isopods, polychaetes, and amphipods, feed on microbial mats and other animals such as mussels.

Infaunal invertebrates, such as meiofauna, nematodes, and vesicomyid and lucinid clams **bioturbate** (i.e. disturb and mix) the seafloor by burrowing. Deposit feeding and **grazing** invertebrates can also cause **bioturbation** during feeding and digestion. This acts to recycle nutrients and energy from the seafloor into the food web.

Whale falls and **wood falls** supply energy from the **photic zone** to this nutrient-limited ecosystem. These organic falls support high biomass and diverse communities of organisms (Smith et al. 2015; Amon et al. 2017). They create localized community dynamics, such as **competition** and succession (Smith and Baco 2003; Lundsten et al. 2010a, 2010b; Smith et al. 2015). They also support unique invertebrates, such as wood-boring clams, bone worms and bone-eating snails, that are specialized for boring into and feeding on wood, bone, and bone lipids (Amon et al. 2017; Smith and Baco 2003; Smith et al. 1989, 2015).

Symbiotic worms and molluscs, such as bone worms, wood-boring clams, and vesicomyid and lucinid clams, host **chemosynthetic** microbes that provide energy for their hosts. For example, the vesicomyid clam, *Calyptogena* sp., participates in **primary production** through symbiosis with sulphide oxidizing bacteria. The invertebrate host provides sulphide, oxygen, and carbon dioxide for the microbial symbionts and receives fixed carbon in return (Juniper et al. 1992).

Predatory fishes, such as grenadier, and sleeper shark, eat other invertebrates and fishes, such as worms and eelpout.

Scavengers, such as squat lobsters and hagfish, eat microbial mats and dead organic matter.

Transient animals import energy from other, more productive ecosystems, creating connectivity between ecosystems. For example, mobile **benthic** scavengers and predators, such as snailfish and grenadiers, feed on vent and seep obligate organisms and import this production to the surrounding **bathyal plain** ecosystem (Levin et al. 2016; Tunnicliffe and Jensen 1987; Marques and Porteiro 2000; Voight 2000; MacAvoy et al. 2002, 2003, 2008).

3.12.3 Environmental drivers

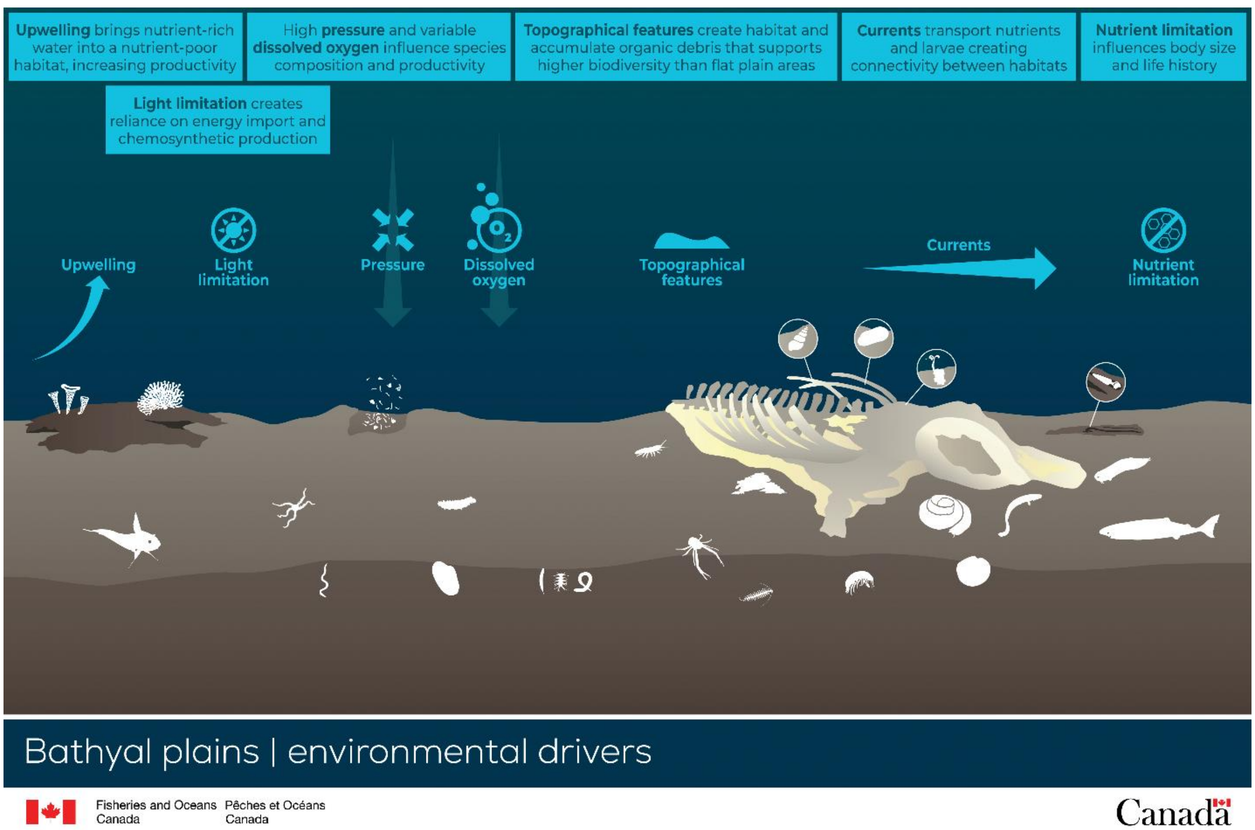

Figure 49. Main environmental drivers within the bathyal plains ecosystem.

Many environmental drivers within the ecosystem influence physical conditions within **bathyal plains** ecosystems, as well as species composition and distribution. Below, we describe the main environmental drivers and their effects.

Upwelling brings nutrient-rich water into this generally nutrient-poor ecosystem, increasing productivity. **Upwelling** in this ecosystem happens when Atlantic Ocean bottom water, flowing northwards after passing through the southern Pacific Ocean (Thomson et al. 1995), moves northward in the North Pacific (Knauss 1962). This results in relatively high particulate organic carbon (POC) flux in areas, including the lower bathyal zone (Watling et al. 2013).

Currents transport nutrients and larvae within this ecosystem. This can influence dispersal patterns of organisms and structure population connectivity, especially for organisms with a **planktonic** larval stage such as corals and sponges.

Pressure influences species composition. Extreme pressure in this deep sea ecosystem creates a shift towards species with cartilaginous or gelatinous body plans without compressible air spaces (Robinson 2004).

Light does not penetrate to the depths of **bathyal plains** ecosystems. Light limitation makes this ecosystem reliant on nutrient import from the **photic zone** and adjacent, more productive ecosystems, such as hydrothermal vents and cold seeps (Levin et al. 2016). Light limitation also creates a shift in species toward less pigmentation, smaller eyes, and the use of bioluminescence (Robinson 2004)

Dissolved oxygen concentration influences species composition and productivity. **Bathyal plains** ecosystems are generally characterized by well-oxygenated waters (Smith et al. 2006, 2008). However, **bathyal plain** depths in the Pacific Region (1,000-4,000 m) include the bottom of the **oxygen minimum zone**. The **OMZ** contains some of the lowest oxygen levels in the ocean, worldwide (Paulmier & Ruiz-Pino 2009), making the upper bathyal depths oxygen-limited. Low oxygen can be physiologically stressful, and thus many species are unable to survive and/or thrive in **bathyal plains** regions that intersect the **OMZ**. At the depth range covered by **bathyal plains** ecosystems, there is a general trend of increasing oxygen with deeper depths.

Bathyal plains ecosystems contain seafloor heterogeneity, rather than a featureless expanse of silt, particularly in the southern portion of BC (Manson 2009). The topographical features (e.g., hills, knolls) contributing to this heterogeneity contain hard substrates that are home to distinct species compared with soft sediment habitats elsewhere in the **bathyal plains** ecosystem (Smith et al. 2006). These features create habitat and accumulate organic debris that supports higher **biodiversity** than flat plain areas (e.g., Stefanoudis et al. 2016; Carey 1981).

Nutrient limitation influences body size and life history. Organisms inhabiting the **bathyal plains** generally have a smaller body size (Rex et al. 2006), and slower metabolic rate (Smith et al. 2006) than those in other, more productive, ecosystems. Meiofauna (41-500 µm benthic animals) and bacteria dominate this habitat (Smith et al. 2015), and their diversity can be high (Snelgrove and Smith 2002).

3.12.4 Human activities

Very few human activities occur in remote and deep ecosystems, such as the **bathyal plains**. Commercial fishing and scientific activities, which are sources of marine debris, were identified as having a potential impact on these ecosystems. Submarine cables criss-crossing these ecosystems can disturb **benthic** organisms during deployment or maintenance (i.e., crushing species or substrata) and by generating electromagnetic fields.

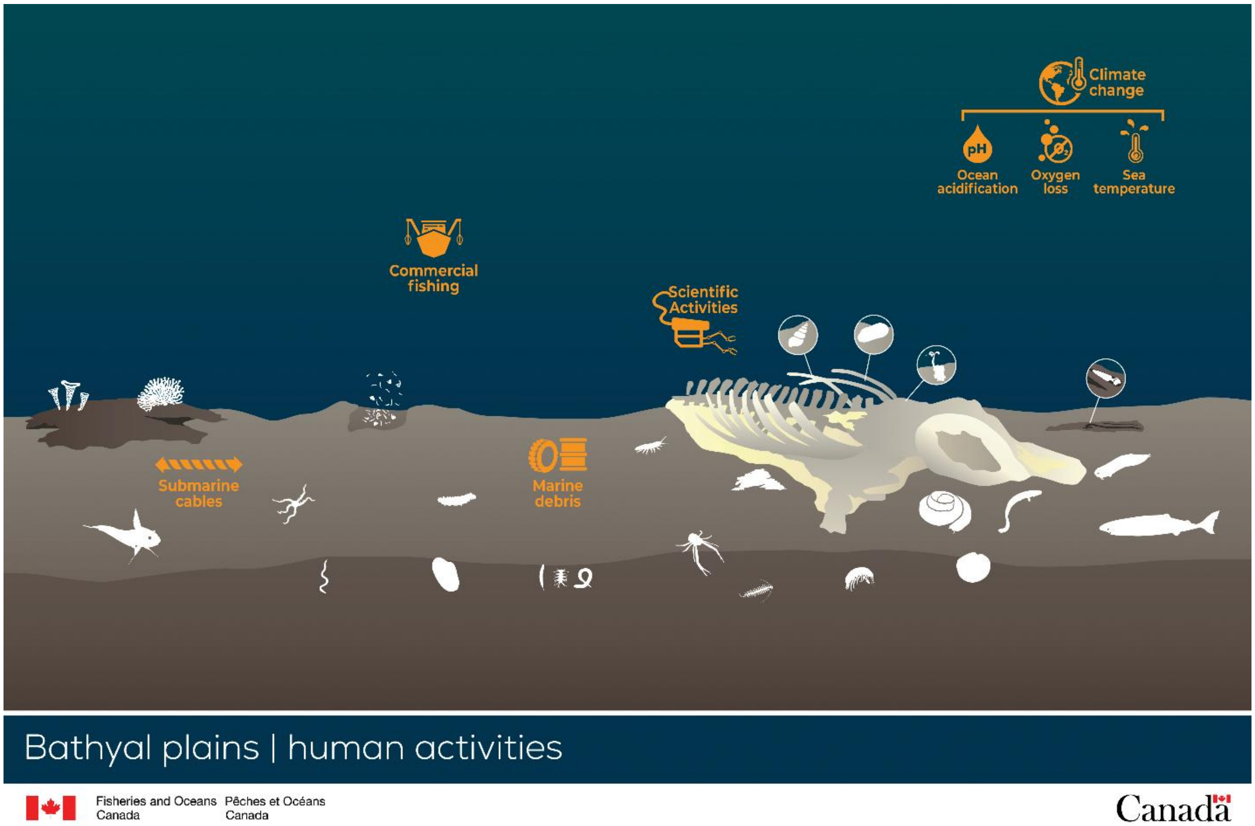

Figure 50. Relevant human activities within the bathyal plains ecosystem.

3.12.4.1 Climate Change

Bathyal plain ecosystems are influenced mainly by three climate change stressors, ocean acidification, dissolved oxygen loss, increased sea temperature. The deep ocean is already a repository of heat and CO_2 (Levin 2019), and with climate change it is becoming warmer, more acidic, and undersaturated in carbonate.

Deep waters are becoming acidified by the subduction of high CO_2 waters through thermohaline circulation (Levin and Lebris 2015). This ecosystem is home to many calcifying species, including molluscs and corals. These species are reliant on carbonate and with decreasing carbonate concentrations it will be increasingly difficult for them to create shells.

Most deep-sea species live in stable thermal regimes and may be intolerant to warming (Levin and LeBris 2015). Warming may result in stress, shifts in depth preference, or altered species interactions (Levin and LeBris 2015). Increases in sea temperature may also open the ecosystem up to invading predators (Levin and Lebris 2015). Indirect effects of increased sea temperature on this ecosystem may include a reduction of energy imports due to reduced productivity in surface waters (Hunter & Wade 2015) to an already energy poor ecosystem.

Projections suggest that abyssal (3,000–6,000 m) ocean temperatures could increase by 1°C over the next 84 years, while abyssal seafloor habitats under areas of deep-water formation may experience reductions in water column oxygen concentrations by as much as 0.03 mL L–1 by 2100. Bathyal depths (200–3,000 m) worldwide will undergo the most significant reductions in pH in all oceans by the year

2100 (0.29 to 0.37 pH units). Dissolved oxygen concentrations will also decline in the bathyal Northeast Pacific and Southern Oceans, with losses up to 3.7% or more, especially at intermediate depths.

3.13 Cold seeps

3.13.1 General description

Cold seeps, also referred to as methane seeps or hydrocarbon seeps, are **benthic** marine ecosystems where **reduced chemicals** emanate from the seafloor. These highly productive ecosystems are fueled by **chemosynthetic** microbes that supply energy to the surrounding **pelagic** and **bathyal plain** ecosystems (Levin et al. 2016). Cold seep fluids are typically enriched with hydrocarbons (namely methane) and hydrogen sulphide (Le Bris *et al.* 2016; Suess 2014).

In the Canadian Pacific, cold seeps have been observed between ~130 and 2300 m depth. Plumes, which indicate the possible presence of seeps, are observed most frequently at 500 m along the Cascadia margin (Johnson et al. 2015). Cold seep ecosystems have been observed in three of the four Pacific bioregions (Northern Shelf, Southern Shelf, and Offshore Pacific Bioregions; Figure 2), and in a variety of settings, including on the continental shelf (in Hecate Strait), the continental slope, and in several submarine canyons (DFO 2018). In addition, many gas plumes have been detected using single- and multi-beam echo-sounders, suggesting the existence of thousands to even tens of thousands of cold seeps that have not yet been explored (DFO 2018).

There are many biological, environmental, and anthropogenic features that influence conditions within this ecosystem, including species composition and distribution. Here, we describe only the main ecological components and interactions (Figure 51 and Figure 52), environmental drivers (Figure 53), and human activities (Figure 54), as depicted in the cold seep conceptual model illustrations.

3.13.2 Key ecological components and interactions

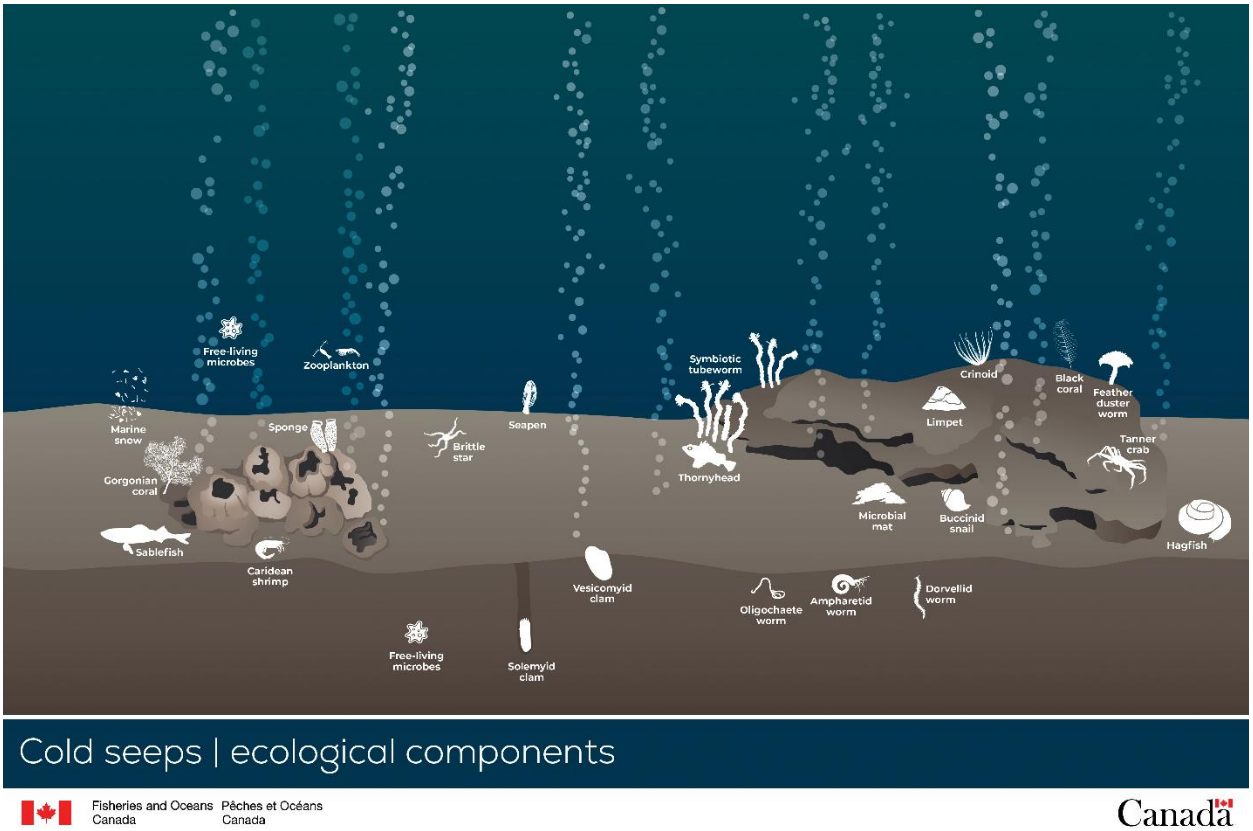

Figure 51. Key ecological components of the cold seep ecosystem.

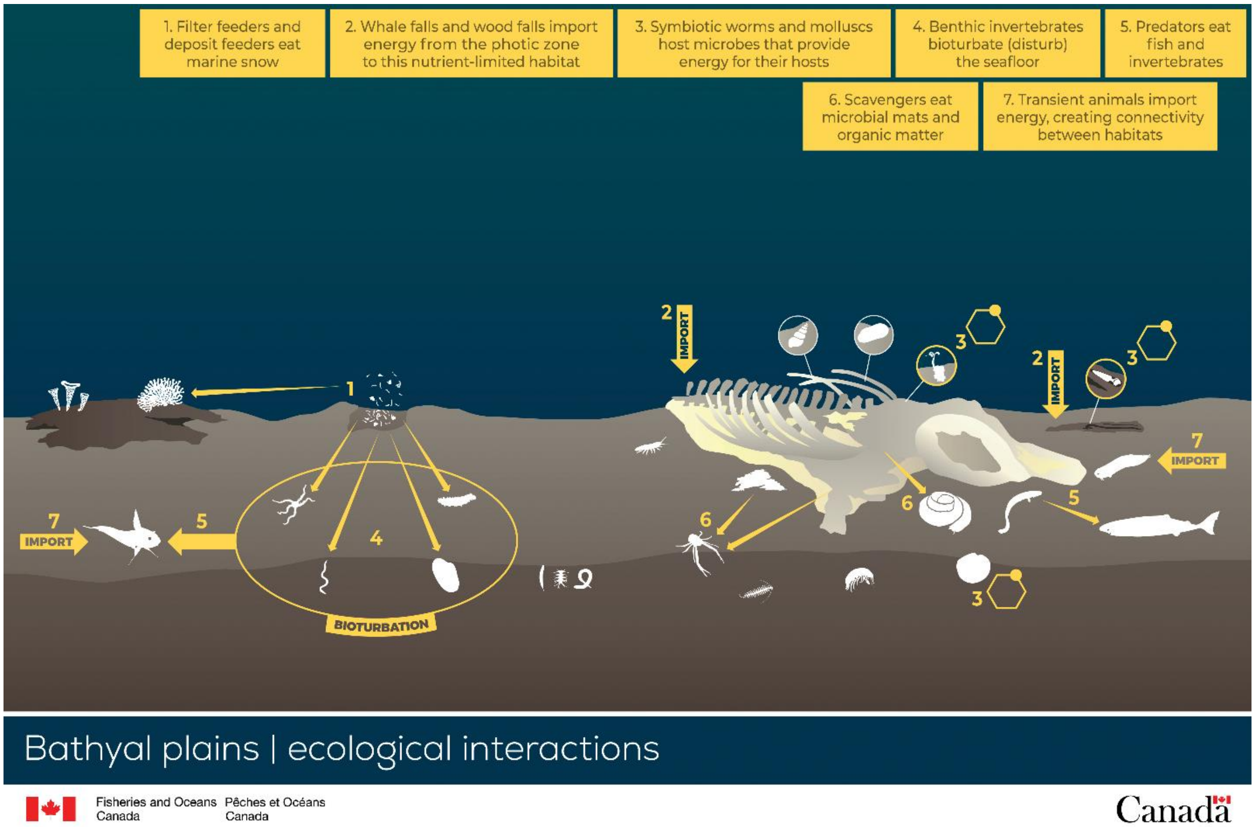

Figure 52. Key interactions among the ecological components of the cold seep ecosystem.

Chemosynthetic free-living microbes use seep chemicals to produce energy, playing the ecologically significant role of primary producers. They are found in sediments, in seep fluids, in mats covering seep substrates, on the tubes and bodies of seep organisms, and in elaborate symbioses with cold seep invertebrates. Microbes can be so dense that they form visible, thick microbial mats that are grazed on by seep fauna. The variety of reduced compounds in cold seep fluids (namely methane, but also ethane, propane, butane, pentane, hydrogen sulfide, and potentially more complex hydrocarbons; Le Bris *et al.* 2016; Suess 2014) supports several metabolic pathways.

Zooplankton feed on microbes and particulate organic matter originating from both **chemosynthesis** at the cold seeps, and photosynthesis from the **photic zone** (in the form of marine snow). Common species in the zooplankton community are Euphausiids (i.e, krill), copepods, cnidarians (e.g., jellyfish), as well as larval stages of crustaceans, molluscs, and fish. Vertically migrating zooplankton feeding at seeps transfer cold seep production to **pelagic** food webs (Levin et al. 2016). Zooplankton are a food source for several invertebrate and fish species in this ecosystem.

Filter feeding and **deposit feeding** invertebrates, such as sponges, black corals, gorgonian corals, sea pens, crinoids, solemyid clams, and feather duster, oligochaete, ampharetid, and dorvellid worms, eat zooplankton, marine snow (originating from photosynthesis from the **photic zone**), and microbes (originating from **chemosynthesis** at the cold seep ecosystem).

Symbiotic invertebrates, such as tubeworms and clams, host **chemosynthetic** microbes that provide energy for their hosts. The symbiotic tubeworm, *Lamellibrachia barhami*, and vesicomyid clams, *Calyptogena* sp., participate in **primary production** through symbioses with microbes. The invertebrate hosts provide reduced compounds (often hydrogen sulfide, but can also include methane, hydrocarbons, and hydrogen) for the symbionts, and receive fixed carbon in return (e.g., Juniper et al. 1992).

In addition to assisting with **primary production**, the tubeworm, *L. barhami*, acts as an **ecosystem engineer**, providing settlement substrate, habitat, and a food source for other vent and non-vent organisms. *L. barhami* colonizes a range of hard substrates creating dense "forests" that greatly increase the surface area available for colonization, and host diverse communities of organisms (Tunnicliffe 1988).

Grazing invertebrates and predators, such as limpets, snails (e.g., buccinid snails), caridean shrimp, and brittle stars), feed on microbial mats and other animals such as tubeworms.

Cold seep ecosystems support a diverse array of transient animals that are ecologically important in transferring chemoautotrophic production from cold seeps to the surrounding deep sea, creating connectivity between ecosystems. For example, mobile **benthic** scavengers and predators, such as tanner crabs, sablefish, hagfish, rockfishes, and thornyheads, feed on seep-obligate organisms and export cold seep production to surrounding **bathyal plain** ecosystems (Levin 2016). Transient animals also use seeps for other important life functions. For example, some skates and sharks use seeps as nursery grounds (Astrom et al. 2020).

Inactive carbonate deposits host novel species assemblages and geomorphic features even though seeping has ceased. Assemblages tend to resemble those of seamount communities, with organisms typically being **sessile**, **filter feeding**, long-lived, and slow-growing (summarized in Boschen et al. 2013). These communities include fewer seep obligates, a more even representation of species, and the presence of typical deep-sea taxa such as corals and sponges (Tsurumi and Tunicliffe 2003).

3.13.3 Environmental drivers

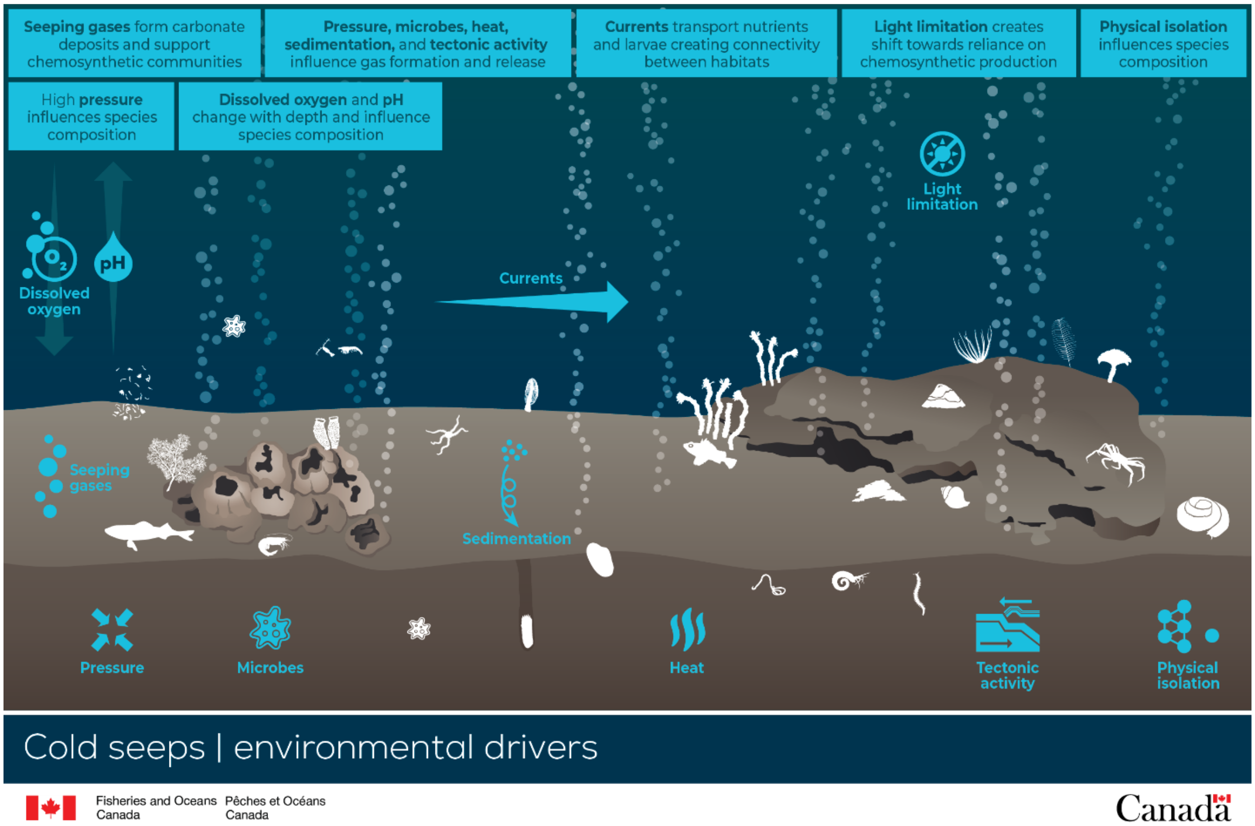

Figure 53. Main environmental drivers within the cold seep ecosystem.

Many environmental drivers influence physical conditions within cold seep ecosystems, as well as species composition and distribution. Below, we describe the main environmental drivers and their effects.

Seeping gasses, and associated carbonate deposits, are rich in reduced compounds that support a variety of **chemosynthetic** organisms. Carbonate deposits serve as attachment sites for a diverse **suspension feeding** community including sponges, corals, and crinoids, as well as mobile fish and invertebrates in cold seep ecosystems (Levin et al. 2016).

Pressure, microbes, heat, sedimentation, and tectonic activity influence gas formation and release. The vertical pressure of sediment accumulation on tectonic plates, and the horizontal pressure on sediments when these plates are subducted under continental margins through tectonic activity, can lead to dewatering of sediments, along with increased temperature, which can further dehydrate sediments. The resulting fluids move upwards through faults and fractures (Suess 2014), and these fluids are frozen into methane hydrate under particular temperature-pressure conditions. Areas where sediments accumulate quickly (e.g., deltas, productive continental shelves, canyons, depressions, and pockmarks), are frequently rich in organic material and favor sulfate reduction and methanogenesis by microbes in the absence of oxygen (Suess 2014). Methane hydrate is stable if temperature and pressure remain constant, but increases in temperature, or decreases in pressure, can cause hydrates to melt, releasing methane into sediments and leading to its eventual migration into the water column as seeping gas and fluid (Johnson et al. 2015).

Currents transport nutrients and larvae within this ecosystem. This can influence dispersal patterns of organisms and structure population connectivity, especially for organisms with a **planktonic** larval stage such as corals and sponges.

Light limitation creates a shift toward reliance on **chemosynthetic** production. Light does not penetrate to these depths and there is limited nutrient input from the **photic zone**. The availability of reduced compounds in this habitat supports a variety of **chemosynthetic** pathways for **primary production**.

Physical isolation influences species composition. Most cold seeps are located far from the coast and from other cold seep organisms, creating a high rate of endemism (Le Bris et al. 2016).

Pressure influences species composition. Extreme pressure in this ecosystem creates a shift towards species with cartilaginous or fluid-filled body structures without compressible air spaces (Robison 2004).

Dissolved oxygen varies with depth and influences productivity and species composition. Several Canadian Pacific cold seeps intersect the **OMZ** (DFO 2018). Low oxygen can be physiologically stressful, and thus many species are unable to survive and/or thrive in the **OMZ**, resulting in different species assemblages in areas within and outside the **OMZ**. At the depths where cold seeps are found, there is a general trend of increasing oxygen with deeper depths.

pH decreases with depth and influences the availability of calcite and aragonite. These mineral components of hard shells are fully saturated in surface waters where pH is relatively high, making it easier for organisms to form shell material. As pH decreases with depth, calcite and aragonite saturation also decrease, making it harder for organisms to build shells and skeletal structures. This causes a shift toward organisms that are not reliant on shells or bony structures. At depths where these minerals are severely undersaturated, calcified organisms such as corals are absent (Auscavitch et al. 2020).

3.13.4 Human activities

Very few human activities occur in remote and deep ecosystems, such as **cold seeps**. Human activities identified as having a potential impact on cold seeps ecosystems include commercial fishing, shipping, and scientific activities. Marine debris has been found within these ecosystems; the sources can be from lost fishing gear, shipping containers, and cargo and land-based activities.

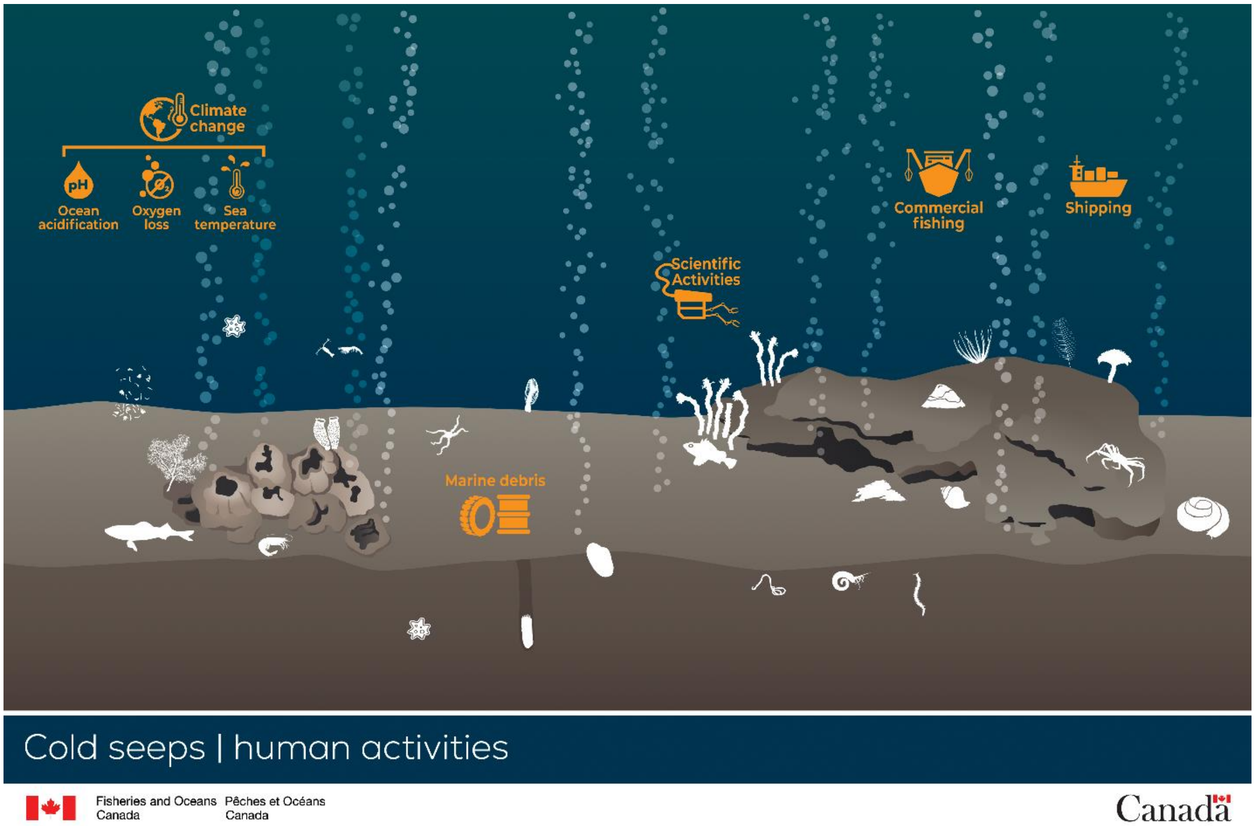

Figure 54. Relevant human activities within the cold seep ecosystem.

3.13.4.1 Climate Change

Cold seep ecosystems are influenced primarily by increased ocean acidification, dissolved oxygen loss, and sea temperature. Species that live in this ecosystem are adapted to conditions of low oxygen, low pH, and cold temperatures (Astrom et al. 2020).

While **benthic** temperatures are predicted to be relatively stable in deep continental shelf and offshore areas (Friesen et al. 2021), increasing seawater temperature is changing oceanic circulation patterns and mixing, as well as reducing oxygen levels and exacerbating ocean acidification (IPCC 2018; Mora et al. 2018; Levin and Bris 2015; Astrom et al. 2020), which will impact cold seep ecosystems. Cold seep ecosystems rely on nutrients derived from **chemosynthetic** microbes, as well as input from the **photic zone**. Changes in circulation patterns will alter delivery of these nutrients, which will have negative effects on deep, isolated ecosystems like this one.

Dissolved oxygen concentrations are projected to decrease overall in offshore **benthic** areas under changing climate conditions (Friesen et al. 2021). Additionally, with increasing ocean acidification, offshore regions of BC are projected to reach aragonite concentration levels low enough to dissolve aragonite shells (such as those built by limpets in cold seep ecosystems (Sato et al. 2020)). Because cold seep ecosystems are already low in dissolved oxygen and are undersaturated or limited in available calcite and aragonite, ocean acidification will make it even more difficult for species such as **plankton**, crabs, corals, tubeworms, and limpets, to access calcite and aragonite as the saturation state continues to decrease. These calcifying organisms are important to ecosystem functioning in cold seeps, as many of them are involved in important processes such as habitat formation and **primary production**.

4 DISCUSSION

4.1 Application of conceptual models

The conceptual models developed for Canada's Pacific coast provide a general overview of the **biodiversity** found within the described ecosystems, as well as the ecological, physical, and human influences that shape them. These models were created at a broad scale to foster an understanding of marine ecosystems within the Pacific Region. As such, they are relevant to many planning initiatives.

Most directly, the key ecological components and interactions identified within each ecosystem can inform MSP processes in the Southern BC planning area, which encompasses the Strait of Georgia and Southern Shelf bioregions, where early planning is underway with partners and stakeholders (DFO 2023a). In the short-term, the conceptual models also support the creation of an atlas of spatial datasets relevant to MSP in the Pacific region (DFO 2023b), by highlighting key ecosystems, species, and habitats that will be important to consider in the development of future marine spatial plans. The models can also aid the identification of ecological and human pressure indicators to support the monitoring of **MPAs** and **MPA networks** (see Section 4.1.1). Further, the conceptual models are relevant to ongoing work in the Canadian Pacific to develop cumulative impact maps (Murray et al 2015; see Section 4.1.2) and provide insight into the larger ecological context in which species vulnerable to oil are found (see Section 4.1.3). Here we describe how these models can be used to inform **MPA** monitoring and indicator selection, cumulative impact mapping, and oil vulnerability frameworks.

4.1.1 Indicator selection and MPA monitoring

Indicators are defined as a measurable characteristic of the structure (e.g., habitat, such as macrophyte abundance), composition (e.g., species), or function (e.g., process, such as nutrient input) of ecosystems that respond to changing pressures in human activities over time (US EPA 2002). Defining and monitoring indicators can help scientists identify and evaluate changes in ecosystem status and trends, and help managers assess the impacts of MSP and policy decisions.

Conceptual models can inform indicator selection for monitoring ecosystems by helping to identify representative species that provide information on the health of the broader ecosystem, and key species, interactions, environmental drivers, and human activities that influence it. This information can build hypotheses of expected and often cascading changes if human activities were to change within the ecosystem. Indicators are directly linked to management goals and **conservation** objectives for species, habitats, or spatial zones.

Conceptual models can improve understanding of the linkages between the species and ecosystems (the condition of which may be identified as **conservation** objectives), and their responses to human activities. A recent example is the use of conceptual models to develop candidate indicators within the Gwaii Haanas National Marine **Conservation** Area Reserve (NMCAR), and hopefully inform the development of a monitoring plan (Martone et al. 2016). Martone and co-authors developed indicators to help evaluate how the status of the ecosystems meet the objectives laid out in the management plan for the NMCAR. The selection of ecosystems and their components was guided by a literature review and expert knowledge and selected indicators were mapped to the objectives in the NMCAR management plan based on a hierarchical framework that incorporated information on their sensitivity and specificity (Martone et al. 2016).

The conceptual models in this report can be used to identify indicators for monitoring marine **conservation** areas in other parts of the BC coast. This is a first step in developing monitoring plans for a

conservation area such as a **MPA** or other spatial management zone, as has been done in other jurisdictions (e.g., Andrews et al. 2013; Martone et al. 2016). For example, we can use the conceptual models to identify the ecosystems present within a newly proposed Caamaño Sound / Douglas Fjord System area of interest (AOI) for an **MPA** under Canada's *Oceans Act*. In this case nine of the ecosystems we have described are present in the AOI:: 1) Rocky shore – high energy, 2) Rocky Shore – low energy, 3) Soft shore – high energy, 4) Soft shore low energy, 5) Rocky Subtidal, 6) Soft bottom subtidal, 7) Pelagic, 8) Estuary, and 9) Fjords. Then, using environmental information for important physical characteristics of these ecosystems (e.g., exposure, substrate, and depth), we could map where these ecosystems occur within the AOI. The final step in this process would be to cross-reference the conceptual models with the **conservation** priorities (i.e., species and habitats) identified for the proposed **MPA** to focus monitoring on those ecosystems that most support the **conservation** objectives.

In this way, the conceptual models presented here lay a foundation for indicator selection, and are used to stratify survey effort to ensure that key ecosystems within a marine **conservation** area are monitored from the beginning, perhaps even during the process of formally establishing the **MPA** and developing management and monitoring plans. This work can be further enhanced if linked with ongoing efforts to develop a representative suite of metrics that can be measured for each identified indicator within a given ecosystem.

4.1.2 Cumulative impact mapping

Cumulative impact mapping was used to define and identify components of the conceptual models, in the ecosystem classification and the human activities that affect them. Following a method described originally by Halpern and colleagues (Halpern et al. 2008), and since applied in multiple jurisdictions including Pacific Canada (Agbayani et al. 2015; Ban et al. 2010; Clarke Murray et al. 2015a; Clarke Murray et al. 2015b; Perry 2019; Singh et al. 2020), cumulative impact mapping uses high quality spatial data to look at the extents and overlaps of ecosystems and anthropogenic activities to assess ecosystem impacts.

The conceptual model ecosystem selection was, in part, based on the habitat classifications developed to support cumulative impact mapping in the Canadian Pacific. The habitat classification was first produced by Ban et al. (2010), subsequently updated in 2013 (Agbayani et al. 2015; Murray et al. 2015), and again in 2021 to support the MSP initiative (Agbayani and Murray (*in press*)). This classification is a generalized data-driven characterization of offshore and inshore marine environments. The classification uses existing spatial data to define 37 habitat classes, resulting in polygon spatial data with habitat class information as attributes (comparison in

Table 7). The habitat classification focuses on a finer level than the classes developed for many of the conceptual models, which were developed at the ecosystem level. The spatial datasets incorporated into the habitat classification work also provide an important basis for the development of spatial datasets that depict the ecosystems represented in the cumulative models.

In turn, the linkages and components of the conceptual models can be used to refine the habitats and human activities used in future iterations of cumulative impact mapping. This will ensure that additional information on the vulnerabilities of individual habitats to human activities can be included in the cumulative impact mapping. The depictions of the ecosystems, components, drivers, and activities included within the conceptual models are an important tool to give managers a more fulsome picture of ecosystem complexity during the development of future marine spatial plans.

Table 7. Comparison of ecosystem/habitat classifications used for conceptual models and cumulative impact mapping (Murray et al. 2015).

Comparison Feature	Conceptual Model Ecosystems	Cumulative Impacts Classes
Number of classes	13	37
Depth stratification	General definitions: Shore, On-shelf Subtidal (0 m – 180 m), Off shelf	Intertidal (~0 m), Shallow (<30 m), On-shelf (30-200 m), Slope (200-2000 m), Deep (>2000 m)
Substrate classes	Rocky, Soft	Soft, Rocky, Hard, Undefined, Mixed
Biogenic habitat as unique classes	Not separate ecosystems, but highlighted in the descriptions and illustrations	Yes – eelgrass and kelp are unique classes
Exposure level	High and low energy	Not included
Habitat classes based on discrete features	Seamounts, estuaries, hydrothermal vents, cold seeps, fjords	Rocky reefs, seamounts
Spatial data used to derive classification	No	Yes

4.1.3 Oil vulnerability framework

The conceptual models in this paper provide insight into the larger ecological context in which species vulnerable to oil are found. In 2017, a national framework was developed to determine the vulnerability of marine biological organisms to a ship-source oil spill (Thornborough et al. 2017), and applied to the Pacific region (Hannah et al. 2017). It has been updated in subsequent years to incorporate new information on species vulnerability and specific oil types (DFO 2023c, DFO in press). The vulnerability framework is the best tool available for the Department of Fisheries and Oceans' (DFO's) Environmental Incident Coordinators (EICs) to identify which species or species groups are most vulnerable to oil. EICs use the framework application outputs to prioritize 'Resources at Risk' during spill response, and to inform spill response planning processes.

The ecosystem conceptual models in this report can act as a starting place to develop similar products for the oil vulnerability framework targeted to EICs, oil spill responders, and local communities. These models can include visual tools and documents to help EICs, responders, and communities understand the potential impacts of different oil types on various ecosystems. These modified conceptual models would provide information on potential impacts to ecosystems and species, as well as possible strategies for protecting, sampling, and monitoring areas where a spill has occurred.

5 LIMITATIONS

The conceptual models presented in this report are generalized depictions of the marine and coastal ecosystems within the Canadian Pacific EEZ. These models do not include the full suite of species, interactions, environmental drivers, or human activities that can be found in each ecosystem, nor is every possible ecosystem included. Rather, our focus was on major ecosystems in the Canadian Pacific EEZ, and to include components considered representative or iconic within each ecosystem at a coastwide scale. The species, interactions, environmental drivers, and human activities depicted in the illustrations, and described in this report, provide a summary of the key components in each ecosystem, their interactions, and a basic understanding of the processes shaping each one.

Further, the elements described for each ecosystem exist on a continuum, and do not always fit neatly into the strict definitions we made for each ecosystem. For example, **subtidal** areas are not strictly divided into soft and rocky bottoms; many areas are comprised of a mix of both soft and rocky substrates, and the ecological components and other aspects of these areas will include aspects of both ecosystems. As such, the models provide an important, but generalized, overview of the ecosystems to make them understandable to a broad audience, and ensure that information on the major ecosystems in the Canadian Pacific EEZ is available for MSP initiatives currently underway.

6 NEXT STEPS

For MSP, the conceptual models will be used to guide the collection and development of spatial data products. Design guidance for **MPA network** planning in the Northern Shelf Bioregion, a component of MSP in the Pacific North Coast, recommended the inclusion of broad-scale ecosystem information that is representative of the study area to ensure that data-poor species, habitats, and ecological processes classifications are captured in analyses and planning work (Lieberknecht et al. 2016). The conceptual models can therefore help to spatially delineate ecosystems and ensure those data can be related to the finer-scale species and habitats they contain, but for which data may not be available in all areas of the coast.

The models can also highlight species and habitats that are representative or iconic within an ecosystem, and for which detailed spatial information will be key when developing marine spatial plans. As areas are identified for **conservation**, the conceptual models can be a starting point for the development of more detailed food webs and indicators that can assess the status and trends being observed within the ecosystems to support monitoring (Section 4.1.1) within individual **MPAs** or for broader regions. In coastal ecosystems, quantitative modelling based on survey data is being used to characterize **benthic** invertebrate and algal community assemblages. These quantitative outputs will be classified according to the ecosystem types presented here, which will allow the nearshore ecosystem types to be mapped across the region. A similar approach could be taken using existing models of groundfish assemblages (Thompson et al. 2023; CJFAS) to map the rocky **subtidal** and soft bottom **subtidal** ecosystems.

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APPENDIX 1: GLOSSARY

Bathyal plains: Ocean floor between 1000 and 4000 m depth that is neither seamount nor hydrothermal vent (DFO 2019).

Benthic: Relating to the bottom of a body of water, such as the seafloor.

Biodiversity: The full range of variety and variability within and among living organisms and the ecological complexes of which they are a part (Canada-BC MPA Network Strategy 2014).

Bioengineer: a species that creates biogenic structure in an ecosystem.

Biofilm: a thin layer of adhering microorganisms, is an important food source for sandpipers and other shorebirds. Biofilm is composed of single-celled benthic microalgae (e.g., diatoms), bacteria, and detritus that are bound together and adhere to the sediment in a matrix of extracellular polymeric substances.

Biogenic structure/habitat: Habitat or structure created by a living organism (e.g., eelgrass beds, sponge reefs, etc.).

Bioturbation / Bioturbate: The reworking of sediments as organisms feed, burrow, or construct habitations (Denny & Gaines 2007).

Chemosynthetic: Organisms that synthesize organic compounds using energy from inorganic chemical reactions.

Chemosynthesis: The process of producing organic compounds using energy from inorganic chemical reactions.

Conservation: The in-situ maintenance of ecosystems and natural and semi-natural habitats and of viable populations of species in their natural surroundings (International Union for Conservation of Nature).

Conservation concern: Applies to species which have been assessed/designated as "at risk" or of conservation concern through global, national, and regional lists of conservation status (COSEWIC, SARA, IUCN Red List, the General Status of Species in Canada, NatureServe, BCList and CITES), supplemented by expert advice for species such as invertebrates and fishes that are under-represented on formal lists. This work was initiated to inform **MPA** network planning in the Northern Shelf Bioregion (Gale et al. 2019) and expanded to the South Coast of BC using the same criteria.

Competition: An interaction between organisms that are trying to utilize the same limited resource (Denny & Gaines 2007).

Diffuse flow: a term used to describe fluids that slowly discharge through structures on hydrothermal vents and cold seeps.

Ecosystem engineer: a species that modifies its environment in a significant manner by either creating new habitat, or modifying existing habitat.

Epifauna / Epifaunal: Organisms that live on the substrate or on another organism (Mirriam-Webster.com).

Filter feeding: a form of suspension feeding where water is actively pumped through a biological filter to capture suspended organic material and other small particles or organisms.

Grazing: Feeding on organisms that are primary producers (Denny & Gaines 2007).

Infauna / Infaunal: Organisms that live in the soft sediments of a body of water (Denny & Gaines 2007).

Intertidal: The area of coastal land that is underwater at high tide and exposed to air at low tide (Denny & Gaines 2007).

Macroalgae: Algae that is large enough to see without magnification (Denny & Gaines 2007).

Marine protected area (MPA): A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (International Union for Conservation of Nature).

MPA network: A collection of individual MPAs that operates cooperatively and synergistically, at various spatial scales, and with a range of protection levels, in order to fulfill ecological aims more effectively and comprehensively than individual sites could alone (International Union for the Conservation of Nature).

Marine spatial planning: "Public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process" (Ehler and Douvere 2009).

Oxygen Minimum Zone (OMZ): The **oxygen minimum zone** (**OMZ**) is an area of the ocean where the lowest dissolved oxygen concentrations occur. In the Northeast Pacific this zone occurs at approximately ~480 – 1,700 m (Ross et al. 2020). Oxygen concentrations are high in surface waters due to production from photosynthesis and being dissolved from the atmosphere. From the surface dissolved oxygen concentration declines with depth to the **OMZ** where it reaches a minimum. Below the **OMZ**, dissolved oxygen often increases due to its increased solubility under the low temperature and high pressure conditions.

Pelagic: Area of the ocean that is unbounded by land, i.e., the mid- and upper layers of the open ocean (Denny & Gaines 2007).

Photic zone: The uppermost area of water through which sunlight penetrates (Denny & Gaines 2007).

Plankton / Planktonic: Plants and animals in the water column that are unable to swim against currents (Denny & Gaines 2007).

Predation / Predatory: An interaction between organisms or species where one consumes another (Denny & Gaines 2007).

Primary production: The use of inorganic materials to create organic compounds through the use of solar energy (photosynthesis) or chemical energy (chemosynthesis) (Denny & Gaines 2007).

Recruitment: New individuals arriving into a population (Denny & Gaines 2007).

Reduced chemical: hydrocarbons such as methane and hydrogen sulphide that have been reduced (i.e. a hydrogen atom has been added).

Seagrass: Seagrasses are grass-like flowering plants that can form dense meadows in shallow marine areas (Smithsonian n.d.:b).

Sessile: An organism that is attached to a substrate and does not move from its attached location (Denny & Gaines 2007).

Sill: A submerged ridge between two water basins that is at a relatively shallow depth (Mirriam-Webster.com).

Stressor: “Any physical, chemical, or biological means that, at some given level of intensity, has the potential to change an ecosystem or one or more of its components” (O et al. 2015).

Subtidal: The area below the low intertidal zone that is over the continental shelf (Mirriam-Webster.com).

Suspension feeding: The process through which an organism collects suspended organic material from the water column for consumption (Denny & Gaines 2007).

Upwelling: Upwelling on the coast of BC brings cold, high salinity, nutrient-rich water from the deep onto the continental shelf, which increases the productivity of nearshore ecosystems (Peña et al. 2019). Upwelling is driven by along-shore winds, and primarily occurs in the summer when the predominant wind direction is from the north-east (Davis et al. 2014). Features of seafloor topography such as shelf-break canyons can also increase upwelling (Davis et al. 2014). Levels of upwelling are also influenced by El Niño and La Niña climate cycles (Jacox et al. 2015). Upwelling promotes primary production (Peña et al. 2019) and structures beach communities by influencing the availability of larvae and food supplies (Rodil et al. 2014). Upwelling is described in detail in Andrews et al. (2013).

Whale fall: The carcass of a whale that has sunk to the sea floor and become a food source to the organisms in the deep sea (NOAA 2023)

Wood fall: Wood that has sunk to the sea floor and become a food source to the organisms in the deep sea (McClain lab n.d).

Zonation: Intertidal zonation refers to the pattern formed by species distributions along a gradient from the low to high tide line whereby distinct zones of species are found along bands at different tidal heights (Helmuth 2015).

APPENDIX 2: SPECIES – ECOSYSTEM LITERATURE REVIEW

This Species-Ecosystem research table is a compilation of all Ecologically Significant Species (ESS) identified for the Northern Shelf Bioregion (NSB), and species of **Conservation Concern** (CC) identified across the Pacific Exclusive Economic Zone. The table was updated to include any species depicted in the conceptual model illustrations that were not on the ESS or CC lists. These additional species are representative of the ecosystems they are depicted in. Bird species were not assessed for status as ESSs but were assessed as potential **conservation** priority (CP) species in Gale et al. (2019). Bird species listed as **conservation** priorities in Table 23 of Gale et al. (2019) are identified as CP in Tables A.

Research was conducted to verify each species-ecosystem combination present in the illustrations, and a reference for each intersection is provided. References for other species-ecosystem intersections were included as they were found, but these combinations were not researched exhaustively. Not all of the ESS and CC species listed in the species-ecosystem table are depicted in the graphic illustrations; an attempt was made to include as many as possible, but some species were just not iconic for any of the ecosystems identified here, and so were not included in any illustration.

Table A2a: List of Ecologically Significant Species for the Northern Shelf Bioregion (NSB ESS), species of Conservation Concern (CC), and bird species listed as Conservation Priorities (CP), plus additional species that were depicted in the conceptual model illustrations that were not on the ESS or CC lists. The category for each species (NSB ESS, CC or Additional species) is indicated in the conservation category column. All species included in an ecosystem illustration are indicated by a green highlight for the corresponding cell and have a reference to justify the ecosystem was a principle one for the species. Rocky shore, soft shore, rocky subtidal and soft bottom subtidal ecosystems are included in this table, all other ecosystems are included in Table A2b.

Group	Common Name	Species	Conceptual model illustration label text	Conservati on category	Listed as model compone nt?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Plants	Bull kelp	*Nereocystis leutkeana*	Bull kelp	NSB ESS	Y	Lamb & Hanby 2005	Lamb & Hanby 2005	–	–	Druehl & Clarkson 2016	–
Plants	Eelgrass	*Zostera marina*	Eelgrass	NSB ESS	Y	–	–	–	Johnson et al. 2003	–	Johnson et al. 2003
Plants	Encrusting algae	e.g. *Corallina* spp.	Encrusting algae	Additional	Y	Druehl & Clarkson 2016	Lamb & Hanby 2005	–	–	Dethier 1990	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Plants	Feather boa kelp	*Egregia menziesii*	Feather boa kelp	Additional	Y	Druehl & Clarkson 2016	–	–	–	Druehl & Clarkson 2016	–
Plants	Giant kelp	*Macrocystis* sp.	Giant kelp	NSB ESS	Y	Druehl & Clarkson 2016	Druehl & Clarkson 2016	–	–	Druehl & Clarkson 2016	–
Plants	Japanese wireweed	*Sargassum muticum*	Sargassum	Additional	Y	–	Druehl & Clarkson 2016	–	Druehl & Clarkson 2016	Druehl & Clarkson 2016	–
Plants	Kelp understory species	e.g. *Laminaria bongardiana, Costaria costata, Saccharina latissima*	Bladed kelp / Sugar kelp	Additional	Y	Johnson et al. 2003	Druehl & Clarkson 2016	–	Druehl & Clarkson 2016	Johnson et al. 2003	–
Plants	Kelp woody stemmed	*Pterygophora californica, Laminaria setchelii, Eisenia arborea*	Woody stemmed kelp	Additional	Y	Lamb & Hanby 2005	–	–	–	Druehl & Clarkson 2016	–
Plants	Phytoplankton	e.g. diatoms, dinoflagellates	Phytoplankton	NSB ESS	Y	Kavanaugh et al. 2009	Mackas et al. 2007	Mackas et al. 2007	Mackas et al. 2007	Mackas et al. 2007	Mackas et al. 2007
Plants	Red algae	e.g. *Chondrocanthus* sp.	Red algae	Additional	Y	Druehl & Clarkson 2016	Druehl & Clarkson 2016	–	–	Druehl & Clarkson 2016	–
Plants	Rockweed	*Fucus* spp.	Rockweed	Additional	Y	Druehl & Clarkson 2016	Druehl & Clarkson 2016	–	–	–	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Plants	Salt marsh plants	e.g. *Glaux maritima, Carex lyngbyei*	Salt marsh	Additional	Y	–	Druehl & Clarkson 2016	–	Druehl & Clarkson 2016	–	–
Plants	Sea asparagus / Pickleweed	*Salcicornia sp.*	Sea asparagus	Additional	Y	–	–	–	Fretwell & Starzomski 2013	–	–
Plants	Sea lettuce	*Ulva* spp.	Sea lettuce	Additional	Y	–	Hillis & Horne 1984	–	Burd et al. 2008	0	0
Plants	Sea palm kelp	*Postelsia palmaeformis*	Sea palm kelp	Additional	Y	Druehl & Clarkson 2016	–	–	–	–	–
Plants	Seive kelp	*Agarum* sp.	Agarum kelp	Additional	Y	–	–	–	–	Lamb & Hanby 2005	Archipelago 2005
Plants	Surfgrass	*Phyllospadix* spp.	Surfgrass	NSB ESS	Y	Rubidge et al. 2020	–	Rubidge et al. 2020	–	Rubidge et al. 2020	–
Plants	Winged kelp	*Alaria marginata*	Winged kelp	Additional	Y	Johnson et al. 2003	–	–	–	Johnson et al. 2003	–
Invertebrates	Acorn barnacle	*Balanus glandula*	Acorn barnacle	Additional	Y	Cowles 2005d	Cowles 2005d	–	–	Lamb & Hanby 2005	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Invertebrates	Ampharetid worms	Ampharetidae (family)	Ampharetid worm	Additional	Y	–	–	–	–	–	Kathman et al. 1983
Invertebrates	Bay ghost shrimp	*Neotrypaea californiensis*	Ghost shrimp	NSB ESS	Y	–	–	–	Jensen 2014	–	Jensen 2014
Invertebrates	Black corals	Antipatharia e.g. Antipathes spp.	Black coral	NSB ESS	Y	–	–	–	–	–	–
Invertebrates	Blue mussel	*Mytilus trossulus*	Blue mussel	Additional	Y	Cowles 2005e	Cowles 2005e	–	–	Lamb & Hanby 2005	–
Invertebrates	Boneeating snail	*Rubyspira sp*	Boneeating snail	Additional	Y	–	–	–	–	–	–
Invertebrates	Boneeating worm / zombie worm	*Osedax* sp.	Bone worm	Additional	Y	–	–	–	–	–	–
Invertebrates	Brisingid sea stars	Brisingidae (Family)	Brisingid sea star	Additional	Y	–	–	–	–	–	–
Invertebrates	Buccinid snails (whelk)	e.g. *Buccinum thermophilum*	Buccinid snail	Additional	Y	–	–	–	Lamb & Hanby 2005	–	Lamb & Hanby 2005

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Invertebrates	Butter clam	*Saxidomus gigantea*	Clam / Butter clam	NSB ESS	Y	–	–	–	Lucas et al. 2007	–	Lucas et al. 2007
Invertebrates	California mussel	*Mytilus californianus*	California mussel	NSB ESS	Y	Pellegrin et al. 2007	–	–	–	Lamb & Hanby 2005	–
Invertebrates	Caridean shrimp	various species	Caridean shrimp	Additional	Y	Jensen 2014	Jensen 2014	Jensen 2014	Jensen 2014	Jensen 2014	Ban et al. 2016
Invertebrates	Cockles	*Clinocardium nuttalli*	Clam	NSB ESS	Y	–	–	–	Lucas et al. 2007	–	Jensen et al. 2018
Invertebrates	Coonstripe/dock Shrimp	*Pandalus danae*	Shrimp	NSB ESS	Y	–	Jensen 2014	–	Jensen 2014	Jensen 2014	Jensen 2014
Invertebrates	Crangon shrimp	*Crangon* spp.	Crangon shrimp	Additional	Y	–	–	Jensen 2014	Jensen 2014	–	Ban et al. 2016
Invertebrates	Crimson anemone	*Cribrinopsis fernadi*	Crimson anemone	Additional	Y	–	–	–	–	Gasbarro 2017	–
Invertebrates	Crustacean larvae	e.g. crab and shrimp larvae	Zooplankton	NSB ESS	Y	Gaines et al. 1985	Gaines et al. 1985	Dethier 1990	Shaffer et al. 2020	Shaffer et al. 2020	Shaffer et al. 2020

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Invertebrates	Deep sea Amphipods	Amphipoda	Amphipod	Additional	Y	–	–	–	–	–	–
Invertebrates	Deep sea brittle stars	Ophiuroidea	Brittle star	Additional	Y	–	–	–	–	–	–
Invertebrates	Deep sea crinoids	*e.g. Hyocrinus* sp., *Psathyrometra* sp.	Crinoid	Additional	Y	–	–	–	–	–	–
Invertebrates	Deep sea infaunal polychaete worms	Annelida	Polychaete	Additional	Y	–	–	–	–	–	–
Invertebrates	Deep sea isopods	Isopoda	Isopod	Additional	Y	–	–	–	–	–	–
Invertebrates	Deep sea limpets	e.g. *Lepetodrilus* sp., *Pyropelta* sp.	Limpet	Additional	Y	–	–	–	–	–	–
Invertebrates	Deep sea nematodes	Nematoda	Nematode	Additional	Y	–	–	–	–	–	–
Invertebrates	Deep sea sea cucumbers	e.g. *Pannychia* sp.	Sea cucumber	Additional	Y	Lucas et al. 2007	Lucas et al. 2007	–	Lucas et al. 2007	Pellegrin et al. 2007	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Invertebrates	Demosponges	Demospongiae	Sponge / Sponges	NSB ESS	Y	Lamb & Hanby 2005	Lamb & Hanby 2005	–	–	Rubidge et al. 2020	–
Invertebrates	Dorvellid (bristle) worms	Dorvelleidae (Family)	Dorvellid worm	Additional	Y	–	–	–	–	–	Kathman et al. 1983
Invertebrates	Dungeness crab	*Metacarcinus magister*	Dungeness crab	Additional	Y	–	–	Dethier 1990	Jensen 2014; Rubidge et al. 2020	–	Jensen 2014; Rubidge et al. 2020
Invertebrates	Euphausiids	Euphausiacea	Zooplankton	NSB ESS	Y	Keen 2012	Keen 2012	Keen 2012	Keen 2012	Shaffer et al. 2020	Ban et al. 2016
Invertebrates	Feather duster worms	Serpulidae	Feather duster worm	Additional	Y	Dethier 1990	Cowles 2005b	–	–	Dethier 1990	Kathman et al. 1983
Invertebrates	Filament worm	e.g. *Dodecaria* sp.	Filament worm	Additional	Y	–	Jensen et al. 2018	–	–	Jensen et al. 2018	–
Invertebrates	Gelatinous zooplankton (jellyfish)	e.g. *Aurelia aurita, Cyanea capillata, Phacellophora camtschatica*	Jellyfish	Additional	Y	–	–	–	–	Shaffer et al. 2020	–
Invertebrates	Giant Pacific octopus	*Enteroctopus dofleini*	Octopus	NSB ESS	Y	–	Cowles 2005i	–	Cowles 2005i	Rubidge et al. 2020	Lucas et al. 2007

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Invertebrates	Giant pink sea star	*Pisaster brevispinus*	Giant pink star	Additional	Y	–	Lambert 2000	Lambert 2000	Lambert 2000	Dethier 1990	Gasbarro 2017
Invertebrates	Glass sponges	*Hexactinellida (e.g. Heterochone, Aphrocallistes, Farrea)*	Glass sponge / Sponges / Sponge reef	NSB ESS	Y	–	–	–	–	Ban et al. 2016	Ban et al. 2016
Invertebrates	Gooseneck barnacle	*Pollicipes polymerus*	Gooseneck barnacle	NSB ESS	Y	Rubidge et al. 2020	–	–	–	Rubidge et al. 2020	–
Invertebrates	Gorgonian coral	e.g. *Paragorgia pacifica, Primnoa pacifica*	Gorgonian coral / Soft coral	NSB ESS	Y	–	–	–	–	Rubidge et al. 2020	–
Invertebrates	Green surf anemone	*Anthopleura xanthogrammica*	Green surf anemone	Additional	Y	Dethier 1990	–	–	–	Cowles 2012	–
Invertebrates	Green urchin	*Stronglyocentrotus droebachiensis*	Green urchin	Additional	Y	Cowles 2002	Cowles 2002	–	–	Rubidge et al. 2020	–
Invertebrates	Gumboot chiton	*Cryptochiton stelleri*	Gumboot chiton	Additional	Y	U. of Wash. 2008	Cowles 2005g	–	Jensen et al. 2018	Dethier 1990	–
Invertebrates	Hard / stony corals	e.g. *Balanophyllia elegans, Lophelia pertusa*	Stony coral	NSB ESS	Y	Cowles 2005c	Cowles 2005c	–	–	Ban et al. 2016	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Invertebrates	Heart urchin	*Brisaster latifrons*	Heart urchin	Additional	Y	–	–	–	0	–	Ban et al. 2016
Invertebrates	Horse clam/Fat Gaper	*Tresus capax* *Tresus nuttallii*		NSB ESS	N	–	–	Cowles 2005p	Lucas et al. 2007	–	Lucas et al. 2007
Invertebrates	Humpback shrimp	*Pandalus hypsinotus*	Shrimp	NSB ESS	Y	–	Jensen 2014	–	Jensen 2014	Jensen 2014	Jensen 2014
Invertebrates	Hydrocoral	e.g. *Stylaster* spp.	Hydrocoral	Additional	Y	Lamb & Hanby 2005	–	–	–	Dethier 1990	–
Invertebrates	Hydrothermal vent copepods		Zooplankton	Additional	Y	–	–	–	–	–	–
Invertebrates	Idasola mussel	*Idasola washingtonius*	Mussel	Additional	Y	–	–	–	–	–	–
Invertebrates	Infaunal cold seep oligochaete worms	Annelida: Oligochaeta	Oligochaete worm	Additional	Y	–	–	–	–	–	–
Invertebrates	Infaunal onshelf isopods	Isopoda	Isopod	Additional	Y	–	–	Dethier 1990	Dethier 1990	–	Dethier 1990

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Invertebrates	Intertidal chitons	e.g. Tonicella lineata, Leptochiton rugatus, Mopalia muscosa	Chiton	Additional	Y	Lamb & Hanby 2005	Cowles 2005f	–	–	Cowles 2005f	–
Invertebrates	Intertidal limpets	e.g. *Lottia* spp, *Diodora aspera*	Limpet	Additional	Y	Lamb & Hanby 2005	Lamb & Hanby 2005	–	–	Lamb & Hanby 2005	–
Invertebrates	Intertidal whelks	e.g. *Lirabuccinum dirum* (dire whelk)	Whelk	Additional	Y	Cowles 2005o	Cowles 2005o	–	Lamb & Hanby 2005	Cowles 2005o	Lamb & Hanby 2005
Invertebrates	Kelp crab	*Pugettia* spp.	Kelp crab	Additional	Y	Jensen 2014	Jensen 2014	–	Cowles 2005h	Lucas et al. 2007	–
Invertebrates	Lampshells	Brachiopoda (e.g *Laqueus californianus*)	Lampshell	Additional	Y	–	–	–	–	–	–
Invertebrates	Leather star	*Dermasterias imbricata*	Sea star / Leather star	Additional	Y	–	Lambert 2000	–	Lambert 2000	Lambert 2000	Lambert 2000
Invertebrates	Littleneck clam	*Leukoma staminea*	Clam	NSB ESS	Y	–	–	Lucas et al. 2007	Lucas et al. 2007	–	Lucas et al. 2007
Invertebrates	Littorina snail	*Littorina* sp.	Snail	NSB ESS	Y	Dethier 1990	Cowles 2004	–	–	0	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Invertebrates	Lucinid clam	*Lucinoma annulata*	Lucinid clam	Additional	Y	–	–	–	–	–	–
Invertebrates	Moon snail	*Euspira lewisii*	Moon snail	Additional	Y	–	–	–	Dethier 1990	–	Dethier 1990
Invertebrates	Mud shrimp	*Upogebia pugettensis*	Mud shrimp	Additional	Y	–	–	–	Jensen 2014	–	–
Invertebrates	Mysid shrimp	Mysidae	Mysid shrimp	Additional	Y	–	–	Dethier 1990	Dethier 1990	Shaffer et al. 2020	Kathman et al. 1983
Invertebrates	Neocalanus copepods	*Neocalanus* sp.	Zooplankton	NSB ESS	Y	–	–	–	–	Costalago et al. 2020	Costalago et al. 2020
Invertebrates	NonCrustacean zooplankton	Non-crustacean Zooplankton	Zooplankton	NSB ESS	Y	Lucas et al. 2007	Lucas et al. 2007	Lucas et al. 2007	Lucas et al. 2007	Lucas et al. 2007	Ban et al. 2016
Invertebrates	Northern abalone	*Haliotis kamtschatkana*	Abalone	CC	Y	Lucas et al. 2007	Lucas et al. 2007	–	–	Rubidge et al. 2020	–
Invertebrates	Ochre star	*Pisaster ochraceus*	Sea star	NSB ESS	Y	Gale et al. 2019	Jensen et al. 2018	–	–	Jensen et al. 2018	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Invertebrates	Octopus	e.g. *Graneledone boreopacifica*	Octopus	Additional	Y	–	–	–	–	–	–
Invertebrates	Olive snail	*Olivella* spp.	Olive snail	Additional	Y	–	–	Dethier 1990	Cowles 2005j	–	Cowles 2005j
Invertebrates	Olympia oyster	*Ostrea lurida*	Olympia oyster	CC	Y	–	Cowles 2017	–	Cowles 2017	Cowles 2017	Cowles 2017
Invertebrates	On shelf infaunal amphipods	Amphipoda	Amphipod	Additional	Y	–	–	Dethier 1990	Dethier 1990	–	Burd et al. 2008
Invertebrates	On shelf infaunal annelids	Annelida	Annelid worm	Additional	Y	–	–	Pellegrin et al. 2007	Pellegrin et al. 2007	–	Pellegrin et al. 2007
Invertebrates	Opal squid	*Doryteuthis opalescens*	Squid	NSB ESS	Y	–	Lucas et al. 2007	–	Lucas et al. 2007	Lucas et al. 2007	Lucas et al. 2007
Invertebrates	Pacific geoduck	*Panopea generosa*	Geoduck	Additional	Y	–	–	–	Lucas et al. 2007	–	Lucas et al. 2007
Invertebrates	Palm worms	*Paralvinella palmiformis*	Palm worm	Additional	Y	–	–	–	–	–	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Invertebrates	Polynoid scaleworms	Polynoidae	Polynoid worm	Additional	Y	Lamb & Hanby 2005	Cowles 2009	–	–	Cowles 2009	Ban et al. 2016
Invertebrates	Purple sea urchin	*Strongylocentrotus purpuratus*	Purple sea urchin	CC	Y	Dethier 1990	–	–	–	Rubidge et al. 2020	–
Invertebrates	Razor clam	*Siliqua patula*	Razor clam	NSB ESS	Y	–	–	Lucas et al. 2007	–	–	Lucas et al. 2007
Invertebrates	Red rock crab	*Cancer productus*	Red rock crab	Additional	Y	Dethier 1990	Dethier 1990	Dethier 1990	Dethier 1990	Dethier 1990	Dethier 1990
Invertebrates	Red urchin	*Mesocentrotus franciscanus*	Red urchin	Additional	Y	Cowles 2005l	Jensen et al. 2018	–	–	Rubidge et al. 2020	–
Invertebrates	Sand dollar	*Dendraster excentricus*	Sand dollar	Additional	Y	–	–	Cowles 2006	Dethier 1990	–	Dethier 1990
Invertebrates	Sand fleas (amphipods)	e.g. *Traskorchestia* sp., *Erichthonius rubricornis*	Sand flea	Additional	Y	–	Lamb & Hanby 2005	Lamb & Hanby 2005	Lamb & Hanby 2005	Lamb & Hanby 2005	–
Invertebrates	Scallop	e.g. Weathervane scallop - *Patinopecten caurinus*	Scallop	Additional	Y	–	–	Lamb & Hanby 2005	Lamb & Hanby 2005	–	Harbo 1997

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Invertebrates	Sea anemones	e.g. *Urticina* spp.	Anemone	Additional	Y	Lamb & Hanby 2005	Dethier 1990	Lamb & Hanby 2005	Lamb & Hanby 2005	Dethier 1990	Lamb & Hanby 2005
Invertebrates	Sea cucumbers	*e.g. Apostichopus californicus, Apostichopus leukothele, Psolus squamatus*	Sea cucumber	Additional	Y	–	Pellegrin et al. 2007	–	Pellegrin et al. 2007	Pellegrin et al. 2007	Pellegrin et al. 2007
Invertebrates	Sea pens	e.g. *Ptilosarcus gurneyi, Umbellula* sp.	Orange sea pen / Seapen	NSB ESS	Y	–	–	–	0	–	Ban et al. 2016
Invertebrates	Sea spider	Pycnogonids	Pycnogonid	Additional	Y	–	–	–	–	Jensen etel. 2018	Ban et al. 2016
Invertebrates	Sea star	*e.g. Patiria miniata, Dermasterias imbricata, Mediaster aequalis, Ceramaster spp.*	Sea star	Additional	Y	Cowles 2005m	Jensen et al. 2018	–	Jensen et al. 2018	Jensen et al. 2018	Jensen et al. 2018
Invertebrates	Shore crab	*Hemigrapsus* spp.	Shore crab	Additional	Y	Jensen 2014	1	–	1	–	–
Invertebrates	Sidestripe shrimp	*Pandalopsis dispar*	Pandalid shrimp	NSB ESS	Y	–	–	–	–	–	Ban et al. 2016

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Invertebrates	Smooth pink shrimp	*Pandalus jordani*	Pandalid shrimp	NSB ESS	Y	–	–	–	Jensen et al. 2018	–	Ban et al. 2016
Invertebrates	Solemyid clam	*Solemya reidi*	Solemyid clam	Additional	Y	–	–	–	–	–	Cowles 2007
Invertebrates	Spider crab	*Macroregonia macrochira*	Spider crab	Additional	Y	–	–	–	–	–	–
Invertebrates	Spiny or northern pink shrimp	*Pandalus borealis*	Pandalid shrimp	NSB ESS	Y	–	–	–	–	–	Ban et al. 2016
Invertebrates	Spot prawn	*Pandalus platyceros*	Pandalid shrimp / Prawn	NSB ESS	Y	–	–	–	–	Jensen 2014	Cowles 2005k
Invertebrates	Squat lobster	*Munida quadrispina*	Squat lobster	Additional	Y	–	–	–	–	Dethier 1990	Ban et al. 2016
Invertebrates	Sulphide worms	*e.g. Paralvinella sulfincola*	Sulphide worm	Additional	Y	–	–	–	–	–	–
Invertebrates	Sun star	*Solaster* spp.	Sun star	Additional	Y	Cowles 2005n	Jensen et al. 2018	–	Jensen et al. 2018	Jensen etel. 2018	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Invertebrates	Sunflower sea star	*Pycnopodia helianthoides*	Sunflower star	NSB ESS	Y	Cowles 2005a	Cowles 2005a	Cowles 2005a	Cowles 2005a	Rubidge et al. 2020	Dethier 1990
Invertebrates	Symbiotic tubeworms	*e.g. Ridgeia piscesae, Lamellibrachia sp.*	Symbiotic tubeworm	Additional	Y	–	–	–	–	–	–
Invertebrates	Tanner crab	*Chionoecetes bairdi*	Tanner crab	Additional	Y	–	–	–	–	–	Jensen 2014
Invertebrates	Tunicates	e.g. *Halocynthia* sp.	Tunicate	Additional	Y	–	0	–	0	Dethier 1990	–
Invertebrates	Turban snails	*e.g. Pomaulax gibberosus, Tegula spp.*	Turban snail	Additional	Y	Dethier 1990	–	–	–	Lamb & Hanby 2005	–
Invertebrates	Vesicomyid clams	Vesicomyidae (e.g. *Calyptogena* spp.)	Vesicomyid clam	Additional	Y	–	–	–	–	–	–
Invertebrates	Woodboring clam	*e.g. Xylophaga washingiona*	Woodboring clam	Additional	Y	–	–	–	–	–	–
Fishes	Albacore tuna	*Thunnus alalunga*	Albacore tuna / Tuna	NSB ESS, CC	Y	–	–	–	–	–	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Fishes	Arrowtooth flounder	*Atheresthes stomias*	Arrowtooth flounder	NSB ESS	Y	–	–	–	–	0	Lucas et al. 2007
Fishes	Basking shark	*Cetorhinus maximus*		CC	N	–	–	–	–	–	–
Fishes	Bay pipefish	*Syngnathus leptorhynchus*	Pipefish	Additional	Y	–	–	–	Johnson et al. 2003	Johnson et al. 2003	Johnson et al. 2003
Fishes	Big skate	*Beringraja binoculata*	Skate	NSB ESS	Y	–	–	–	King et al. 2015	0	Lamb & Edgell 2010
Fishes	Blue shark	*Prionace glauca*	Blue shark	NSB ESS, CC	Y	–	–	–	–	–	–
Fishes	Bluntnose sixgill shark	*Hexanchus griseus*	Bluntnose sixgill	NSB ESS, CC	Y	–	–	–	–	–	Gale et al. 2019
Fishes	Bocaccio	*Sebastes paucispinis*	Rockfish / Juvenile rockfish	NSB ESS, CC	Y	–	Love et al. 2002	–	Lamb & Edgell 2010; Rubidge et al. 2020	Lamb & Edgell 2010	Lamb & Edgell 2010; Hart 1973

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Fishes	Cabezon	*Scorpaenichthys marmoratus*	Cabezon	Additional	Y	–	Hart 1973; Lamb & Edgell 2010	–	–	Hart 1973; Lamb & Edgell 2010	Froese & Pauly 2020
Fishes	Canary rockfish	*Sebastes pinniger*	Rockfish / Juvenile rockfish	CC	Y	–	Lamb & Edgell 2010	–	–	Lamb & Edgell 2010	Lamb & Edgell 2010
Fishes	Capelin	*Mallotus villosus*	Forage fish	NSB ESS	Y	–	–	–	Schweigert et al.2007; Gale et al. 2019	Froese & Pauly 2020	Froese & Pauly 2020
Fishes	China rockfish	*Sebastes nebulosus*	Rockfish / Juvenile rockfish	CC	Y	Lamb & Edgell 2010	–	–	Gale et al. 2019; Johnson et al. 2003	Lamb & Edgell 2010	–
Fishes	Chinook salmon	*Oncorhynchus tshawytscha*	Adult salmon / Juvenile salmon / Salmon	NSB ESS, CC	Y	–	–	–	Hyatt et al. 2007	Shaffer et al. 2020	–
Fishes	Chum salmon	*Oncorhynchus keta*	Adult salmon / Juvenile salmon / Salmon	NSB ESS	Y	–	–	–	Hyatt et al. 2007	Johnson et al. 2003	–
Fishes	Coho salmon	*Oncorhynchus kisutch*	Adult salmon / Juvenile salmon / Salmon	NSB ESS, CC	Y	–	–	–	Johnson et al. 2003	Shaffer et al. 2020	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Fishes	Copper rockfish	*Sebastes caurinus*	Rockfish / Juvenile rockfish	CC	Y	–	0	–	Johnson et al. 2003	Johnson et al. 2003	Johnson et al. 2003
Fishes	Cutthroat trout	*Oncorhynchus clarkii*		NSB ESS	N	–	–	–	Shaffer et al. 2020	–	Gale et al. 2019
Fishes	Darkblotched rockfish	*Sebastes crameri*	Rockfish	CC	Y	–	–	–	–	Love et al. 2002	Love et al. 2002
Fishes	Deep sea snailfish	e.g. *Careproctus* sp.	Snailfish	Additional	Y	–	–	–	–	–	–
Fishes	Dolly varden	*Salvelinus malma lordi*		NSB ESS	N	–	–	–	Johnson et al. 2003	Johnson et al. 2003	Johnson et al. 2003
Fishes	Eelpouts	Zoarcidae	Eelpout	Additional	Y	–	–	–	–	0	Lamb & Edgell 2010
Fishes	Eulachon	*Thaleichthys pacificus*	Eulachon	NSB ESS, CC	Y	–	–	–	Dethier 1990	Froese & Pauly 2020	–
Fishes	Flatfish deep sea	e.g. *Embassichthys bathybius*	Flatfish	Additional	Y	–	–	–	–	–	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Fishes	Flatfish on shelf	*e.g. Citharichthys spp., Limanda aspera*	Flatfish / Sole	Additional	Y	–	–	Gale et al. 2019	Gale et al. 2019; Johnson et al. 2003	Lamb & Edgell 2010; Johnson et al. 2003	Gale et al. 2019; Johnson et al. 2003
Fishes	Green sturgeon	*Acipenser medirostris*		CC	N	–	–	–	–	Levesque & Jamieson 2015	Gale et al. 2019
Fishes	Grenadiers (rattails)	e.g. *Coryphaenoides* spp.	Grenadier	Additional	Y	–	–	–	–	–	–
Fishes	Gunnels	e.g. *Pholis* sp.	Gunnel	Additional	Y	Johnson et al. 2003	Lamb & Edgell 2010	Dethier 1990	Johnson et al. 2003	Johnson et al. 2003	Johnson et al. 2003
Fishes	Hagfish	*Eptatretus stoutii*	Hagfish	Additional	Y	–	–	–	–	–	Ban et al. 2016
Fishes	Lingcod	*Ophiodon elongatus*	Lingcod	NSB ESS	Y	–	Lucas et al. 2007	–	Hart 1973; Rubidge et al 2020	Gale et al. 2019	Johnson et al. 2003
Fishes	Longfin smelt	*Spirinchus thaleichthys*	Forage fish	CC	Y	–	–	–	Lamb & Edgell 2010	Froese & Pauly 2020	Froese & Pauly 2020

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Fishes	Longnose skate	*Beringraja rhina*	Skate	NSB ESS	Y	–	–	–	Froese & Pauly 2020	Kuhnz et al. 2019	Gale et al. 2019
Fishes	Longspine thornyhead	*Sebastolobus altivelis*	Thornyhead	CC	Y	–	–	–	–	–	Gale et al. 2019
Fishes	Northern anchovy	*Engraulis mordax*	Forage fish	Additional	Y	–	–	–	–	Froese & Pauly 2020	0
Fishes	Northern lampfish	*Stenobrachius leucopsarus*		NSB ESS	N	–	–	–	–	–	–
Fishes	Northern smoothtongue	*Leuroglossus schmidti*		NSB ESS	N	–	–	–	–	–	–
Fishes	Ocean sunfish	*Mola mola*	Ocean sunfish	CC	Y	–	–	–	–	–	–
Fishes	Pacific cod	*Gadus macrocephalus*	Pacific cod	NSB ESS	Y	–	–	–	Johnson et al. 2003	Johnson et al. 2003	Gale et al. 2019
Fishes	Pacific hake	*Merluccius productus*	Pacific hake	NSB ESS	Y	–	–	–	–	–	Lamb & Edgell 2010

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Fishes	Pacific halibut	*Hippoglossus stenolepis*	Halibut	NSB ESS	Y	–	–	–	–	Carlson et al. 2005	Lamb & Edgell 2010
Fishes	Pacific herring	*Clupea pallasii*	Forage fish / Juvenile herring / Herring	NSB ESS	Y	Rubidge et al. 2020	Thompson 2017	–	Schweigert et al.2007	Thompson 2017; Shaffer et al. 2020	Schweigert et al.2007
Fishes	Pacific ocean perch	*Sebastes alutus*	Rockfish / Pacific ocean perch	CC	Y	–	–	–	–	Du Preez et al. 2015	Gale et al. 2019
Fishes	Pacific sand lance	*Ammodytes hexapterus*	Forage fish / Pacific sandlance	NSB ESS	Y	–	–	Dethier 1990	Shaffer et al. 2020	Shaffer et al. 2020	Schweigert et al.2007; Gale et al. 2019
Fishes	Pacific sardine	*Sardinops sagax*		CC	N	–	–	–	–	Froese & Pauly 2020	–
Fishes	Pacific sleeper shark	*Somniosus pacificus*	Sleeper shark	NSB ESS	Y	–	–	–	–	–	Gale et al. 2019
Fishes	Pink salmon	*Oncorhynchus gorbuscha*	Adult salmon / Juvenile salmon / Salmon	NSB ESS	Y	–	–	–	Feist et al.1992	Johnson et al. 2003	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Fishes	Quillback rockfish	*Sebastes maliger*	Rockfish / Juvenile rockfish	CC	Y	–	–	–	Johnson et al. 2003	Gale et al. 2019	Johnson et al. 2003
Fishes	Redbanded rockfish	*Sebastes babcocki*	Rockfish	CC	Y	–	–	–	–	Love et al. 2002	Hart 1973
Fishes	RougheyeBlackspotted rockfish	*Sebastes aleutianus, Sebastes melanostictus*	Rockfish	NSB ESS, CC	Y	–	–	–	–	Lucas et al. 2007	Hart 1973
Fishes	Roughtail skate	*Bathyraja trachura*	Skate	NSB ESS	Y	–	–	–	–	Kuhnz et al. 2019	Kuhnz et al. 2019
Fishes	Sablefish / Black cod	*Anoplopoma fimbria*	Sablefish	NSB ESS	Y	–	–	0	0	Pirtle et al. 2019	Pirtle et al. 2019
Fishes	Salmon shark	*Lamna ditropis*	Salmon shark	NSB ESS	Y	–	–	–	–	–	–
Fishes	Sculpins	e.g. *Olligocottus* spp., *Leptocottus armatus*	Sculpin	Additional	y	Lamb & Edgell 2010	Lamb & Edgell 2010	Dethier 1990	Johnson et al. 2003	Dethier 1990	Johnson et al. 2003
Fishes	Shiner perch	*Cymatogaster aggregata*	Shiner perch	NSB ESS	Y	–	–	Dethier 1990	Schweigert et al.2007; Johnson	Schweigert et al.2007; Johnson	Schweigert et al.2007; Johnson

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
									et al. 2003	et al. 2003	et al. 2003
Fishes	Shortraker rockfish	*Sebastes borealis*	Rockfish	NSB ESS, CC	Y	–	–	–	–	Lucas et al. 2007	Lucas et al. 2007
Fishes	Shortspine thornyhead	*Sebastolobus alascanus*	Thornyhead	CC	Y	–	–	–	–	–	Gale et al. 2019
Fishes	Silvergray rockfish	*Sebastes brevispinis*	Rockfish / Juvenile rockfish	CC	Y	–	–	–	–	Love et al. 2002	0
Fishes	Sockeye salmon	*Oncorhynchus nerka*	Adult salmon / Juvenile salmon / Salmon	NSB ESS, CC	Y	–	–	–	Hyatt et al. 2007	Froese & Pauly 2020	–
Fishes	Sole	*e.g. Glyptocephalus zachirus, Parophrys vetulus, Lyopsetta exilis*	Flatfish / Sole	Additional	Y	–	–	Gale et al. 2019	Gale et al. 2019; Johnson et al. 2003	–	Gale et al. 2019
Fishes	Spiny dogfish	*Squalus suckleyi*	Dogfish	NSB ESS, CC	Y	–	–	–	–	Froese & Pauly 2020	Gale et al. 2019

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Fishes	Starry flounder	e.g. *Platichthys stellatus*	Flatfish / Starry flounder	Additional	Y	–	–	Gale et al. 2019	Gale et al. 2019; Johnson et al. 2003	Lamb & Edgell 2010; Johnson et al. 2003	–
Fishes	Steelhead	*Oncorhynchus mykiss*		NSB ESS, CC	N	–	–	–	Shaffer et al. 2020	Hyatt et al. 2007	Hyatt et al. 2007; Rubidge et al. 2020
Fishes	Surf smelt	*Hypomesus pretiosus*	Forage fish	NSB ESS	Y	–	–	Dethier 1990	Schweigert et al.2007	Shaffer et al. 2020	–
Fishes	Surfperch misc	*e.g. Embiotoca lateralis, Damalichthys vacca*	Surf perch	Additional	Y	–	Schweigert et al. 2007; Lamb & Edgell 2010	–	Schweigert et al. 2007; Lamb & Edgell 2010	Schweigert et al.2007; Johnson et al. 2003	–
Fishes	Surfperch silver	*Hyperprosopon ellipticum*	Surf perch	Additional	Y	–	–	Schweigert et al. 2007; Lamb & Edgell 2010	–	Froese & Pauly 2020	Froese & Pauly 2020
Fishes	Tiger rockfish	*Sebastes nigrocinctus*	Rockfish / Juvenile rockfish	CC	Y	–	–	–	–	Lamb & Edgell 2010	–
Fishes	Walleye pollock	Gadus chalcogrammus		NSB ESS	N	–	–	–	Johnson et al. 2003	Johnson et al. 2003	Washington 1977

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Fishes	White sturgeon	*Acipenser transmontanus*	White sturgeon	CC	Y	–	–	–	–	Levesque & Jamieson 2015	Froese & Pauly 2020
Fishes	Whitebait smelt	*Allosmerus elongatus*	Forage fish	Additional	Y	–	–	–	–	Froese & Pauly 2020	–
Fishes	Widow rockfish	*Sebastes entomelas*	Rockfish / Juvenile rockfish	CC	Y	–	–	–	–	Lamb & Edgell 2010	0
Fishes	Wolfeel	*Anarrhichthys ocellatus*	Wolf eel	Additional	Y	–	–	–	–	Lamb & Edgell 2010	–
Fishes	Yelloweye rockfish	*Sebastes ruberrimus*	Rockfish / Juvenile rockfish	NSB ESS, CC	Y	–	–	–	–	COSEWIC 2008	Love et al. 2002
Fishes	Yellowmouth rockfish	*Sebastes reedi*	Rockfish	CC	Y	–	–	–	–	COSEWIC 2010	–
Fishes	Yellowtail rockfish	*Sebastes flavidus*	Rockfish / Juvenile rockfish	CC	Y	–	–	–	Johnson et al. 2003	Lamb & Edgell 2010	Johnson et al. 2003; Lamb & Edgell 2010

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Reptiles	Leatherback	*Dermochelys coriacea*		CC	N	–	–	–	–	–	–
Birds	Albatross	e.g. *Phoebastria nigripes, P. immutabilis P. albatrus*	Albatross		Y	–	–	–	–	–	–
Birds	American crow	*Corvus brachyrhynchos*	Crow		Y	Dethier 1990	Butler 2015	Butler 2015	Butler 2015	–	–
Birds	Auklet	e.g. *Ptychoramphus aleuticus, Cerorhina monocerata, Fratercula cirrhata, & F. corniculata*	Auklet		Y	–	–	–	–	Cannings et al. 2016	Cannings et al. 2016
Birds	Bald eagle	*Haliaeetus leucocephalus*	Eagle		Y	Dethier 1990	Cannings et al. 2016	Cannings et al. 2016	Cannings et al. 2016	Barry 2015	–
Birds	Black oystercatcher	*Haematopus bachmani*	Oystercatcher		Y	Gale et al. 2019	Gale et al. 2019	–	Hipfner 2015	–	–
Birds	Bufflehead	*Bucephala albeola*	Bufflehead		Y	Dethier 1990	Cannings et al. 2016	–	Cannings et al. 2016	Dethier 1990	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Birds	Cormorant	*Phalacrocorax penicillatus, P. auritu, P. pelagicus*	Cormorant		Y	Dethier 1990	Cannings et al. 2016	–	Hipfner 2015	Dethier 1990	–
Birds	Goose	e.g. *Branta canadensis*	Goose		Y	–	–	–	Dethier 1990	–	–
Birds	Great blue heron	*Ardea herodias*	Great blue heron		Y	–	Butler & Vennesland 2015	Dethier 1990	Dethier 1990	Dethier 1990	–
Birds	Grebe	e.g. *Podiceps auritus, Aechmophorus occidentalis*	Grebe		Y	–	Cannings et al. 2016	Dethier 1990	Dethier 1990	Dethier 1990	–
Birds	Gull	e.g. *Larus glaucescens,L. argentatus smithsonianus, L. californicus*	Gull		Y	Dethier 1990	Barry 2015	Dethier 1990	Dethier 1990	Dethier 1990	–
Birds	Loon	*e.g. Gavia immer, G. pacifica, G. adamsi*	Loon		Y	–	Cannings et al. 2016	Dethier 1990	Cannings et al. 2016	Dethier 1990	Cannings et al. 2016
Birds	Murrelets	*e.g. Brachyramphus marmoratus*	Murrelet / Marbled murrelet		Y	–	–	–	–	Cannings et al. 2016	–
Birds	Peregrine falcon	*Falco peregrinus*	Peregrine falcon		Y	–	–	Cannings et al. 2016	Cannings et al. 2016	–	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Birds	Sooty shearwater	*Puffinus griseus*	Shearwater / Sooty shearwater		Y	–	–	–	–	–	–
Birds	Surf scoter	*Melanitta perspicillata*	Surf scoter		Y	Dethier 1990	Cannings et al. 2016	Dethier 1990	Cannings et al. 2016	Dethier 1990	Dethier 1990
Birds	Western sandpiper	*Calidris mauri*	Sandpiper		Y	–	–	Dethier 1990	Dethier 1990	–	–
Mammals	Black bear	*Ursus americanus*	Black bear		Y	Fox et al. 2010	Fox et al. 2015	–	Wickham and Proudfoot 2014	–	–
Mammals	Blue whale	*Balaenoptera musculus*		CC	N	–	–	–	–	–	–
Mammals	California sea lion	*Zalophus californianus*		NSB ESS	N	Ford 2014	Ford 2014	–	Ford 2014	Ford 2014	–
Mammals	Common minke whale	*Balaenoptera acutorostrata*		NSB ESS, CC	N	–	–	–	–	–	–
Mammals	Dall's porpoise	*Phocoenoides dalli*	Dolphin & Porpoise	NSB ESS	Y	–	–	–	–	–	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Mammals	Deer	*Odocoileus hemionus columbianus*	Deer		Y	Dethier 1990	Fox et al. 2015	–	–	–	–
Mammals	Fin whale	*Balaenoptera physalus*		CC	N	–	–	–	–	–	–
Mammals	Grey whale	*Eschrichtius robustus*	Grey whale	CC	Y	–	–	–	–	Scordino et al. 2017	Gale et al. 2019
Mammals	Harbour porpoise	*Phocoena phocoena*	Dolphin & Porpoise	NSB ESS, CC	Y	–	–	–	–	–	–
Mammals	Harbour seal	*Phoca vitulina*	Harbour seal / Seal	NSB ESS	Y	Ford 2014	Ford 2014	Ford 2014	Ford 2014	Ford 2014	Ford 2014
Mammals	Humpback whale	*Megaptera novaeangliae*	Humpback whale	CC	Y	–	–	–	–	–	–
Mammals	Mink	*Neogale vison*	Mink		Y	Dethier 1990	Hatler 1976	Hatler 1976	–	–	–
Mammals	North Pacific right whale	*Eubalaena japonica*		CC	N	–	–	–	–	–	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Mammals	Northeast Pacific northern resident orca	*Orcinus orca*	Orca	NSB ESS, CC	Y	–	–	–	Williams et al. 2009	Rubidge et al. 2020	–
Mammals	Northeast Pacific offshore orca	*Orcinus orca*	Orca	NSB ESS, CC	Y	–	–	–	–	–	–
Mammals	Northeast Pacific southern resident orca	*Orcinus orca*	Orca	NSB ESS, CC	Y	–	–	–	–	Rubidge et al. 2020	–
Mammals	Northern elephant seal	*Mirounga angustirostris*		NSB ESS, CC	N	Ford 2014	–	Ford 2014	Ford 2014	–	Ford 2014
Mammals	Northern fur seal	*Callorhinus ursinus*		NSB ESS, CC	N	Ford 2014	–	–	–	–	–
Mammals	Pacific whitesided dolphin	*Lagenorhynchus obliquidens*	Pacific whitesided dolphin	NSB ESS	Y	–	–	–	–	–	–
Mammals	Raccoon	*Procyon lotor*	Raccoon		Y	Dethier 1990	Simmons et al. 2014	–	–	–	–

Group	Common Name	Species	Conceptual model illustration label text	Conservation category	Listed as model component?	Rocky shore high energy	Rocky shore low energy	Soft shore high energy	Soft shore low energy	Rocky subtidal	Soft bottom subtidal
Mammals	River otter	*Lontra canadensis*	River otter		Y	Ben-David et al. 1995	Ben-David et al. 1995	–	Buzzell et al. 2014	–	–
Mammals	Sea otter	*Enhydra lutris*	Sea otter	NSB ESS, CC	Y	Ford 2014	Ford 2014	–	–	Ford 2014	Heise et al. 2006
Mammals	Sei whale	*Balaenoptera borealis*		CC	N	–	–	–	–	–	–
Mammals	Sperm whale	*Physeter macrocephalus*		NSB ESS, CC	N	–	–	–	–	–	–
Mammals	Steller sea lion	*Eumetopias jubatus*	Steller sea lion	NSB ESS, CC	Y	Ford 2014	Ford 2014	–	–	Heise et al. 2006	–
Mammals	West coast transient orca	*Orcinus orca*	Orca	NSB ESS, CC	Y	–	–	–	–	Rubidge et al. 2020	–
Mammals	Wolf	*Canis lupus*	Wolf		Y	Fox et al. 2015	Suraci et al. 2017	Darimont and Paquet 2000	Darimont and Paquet 2000	–	–

Table A2b: List of Ecologically Significant Species for the Northern Shelf Bioregion (NSB ESS), species of Conservation Concern (CC), and bird species listed as Conservation Priorities (CP), plus additional species that were depicted in the conceptual model illustrations that were not on the ESS or CC lists. The category for each species (ESS, CC or Additional species) is indicated in the conservation category column. All species included in an ecosystem illustration are indicated by a green highlight for the corresponding cell and have a reference to justify the ecosystem was a principle one for the species. Pelagic, estuary, fjord, hydrothermal vent, seamount, bathyal plain and cold seep ecosystems are included in this table, all other ecosystems are included in Table A2a.

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Plants	Bull kelp	*Nereocystis leutkeana*	Bull kelp	NSB ESS	Y	–	Dethier 1990	McDaniel 2018	–	–	–	–
Plants	Eelgrass	*Zostera marina*	Eelgrass	NSB ESS	Y	–	Rubidge et al. 2020	–	–	–	–	–
Plants	Encrusting algae	e.g. *Corallina* spp.	Encrusting algae	Additional	Y	–	–	McDaniel 2018	–	Du Preez et al. 2015	–	–
Plants	Feather boa kelp	*Egregia menziesii*	Feather boa kelp	Additional	Y	–	–	–	–	–	–	–
Plants	Giant kelp	*Macrocystis* sp.	Giant kelp	NSB ESS	Y	–	–	–	–	–	–	–
Plants	Japanese wireweed	*Sargassum muticum*	Sargassum	Additional	Y	–	Druehl & Clarkson 2016	–	–	–	–	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Plants	Kelp understory species	*e.g. Laminaria bongardiana, Costaria costata, Saccharina latissima*	Bladed kelp / Sugar kelp	Additional	Y	–	Dethier 1990	McDaniel 2018	–	Canessa et al. 2003	–	–
Plants	Kelp woody stemmed	*Pterygophora californica, Laminaria setchelii, Eisenia arborea*	Woody stemmed kelp	Additional	Y	–	Dethier 1990	–	–	–	–	–
Plants	Phytoplankton	e.g. diatoms, dinoflagellates	Phytoplankton	NSB ESS	Y	DFO 2019	Mackas et al. 2007	Mackas et al. 2007	–	DFO 2019	–	–
Plants	Red algae	e.g. *Chondrocanthus* sp.	Red algae	Additional	Y	–	Dethier 1990	McDaniel 2018	–	McDaniel et al. 2003	–	–
Plants	Rockweed	*Fucus* spp.	Rockweed	Additional	Y	–	Druehl & Clarkson 2016	–	–	–	–	–
Plants	Salt marsh plants	e.g. *Glaux maritima, Carex lyngbyei*	Salt marsh	Additional	Y	–	Druehl & Clarkson 2016	–	–	–	–	–
Plants	Sea asparagus / Pickleweed	*Salcicornia sp.*	Sea asparagus	Additional	Y	–	Dethier 1990	–	–	–	–	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Plants	Sea lettuce	*Ulva* spp.	Sea lettuce	Additional	Y	–	Druehl & Clarkson 2016	–	–	–	–	–
Plants	Sea palm kelp	*Postelsia palmaeformis*	Sea palm kelp	Additional	Y	–	–	–	–	–	–	–
Plants	Seive kelp	*Agarum* sp.	Agarum kelp	Additional	Y	–	Dethier 1990	Marliave & Challenger 2009	–	–	–	–
Plants	Surfgrass	*Phyllospadix* spp.	Surfgrass	NSB ESS	Y	–	–	–	–	–	–	–
Plants	Winged kelp	*Alaria marginata*	Winged kelp	Additional	Y	–	Dethier 1990	–	–	–	–	–
Invertebrates	Acorn barnacle	*Balanus glandula*	Acorn barnacle	Additional	Y	–	Cowles 2005d	McDaniel 2018	–	–	–	–
Invertebrates	Ampharetid worms	Ampharetidae (family)	Ampharetid worm	Additional	Y	–	–	Kathman et al. 1983	DFO 2019	–	Campany-Llovet & Snelgrove 2018	Campany-Llovet & Snelgrove 2018

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Invertebrates	Bay ghost shrimp	*Neotrypaea californiensis*	Ghost shrimp	NSB ESS	Y	–	Jensen 2014	–	–	–	–	–
Invertebrates	Black corals	Antipatharia e.g. Antipathes spp.	Black coral	NSB ESS	Y	–	–	Gasbarro 2017	–	Du Preez et al. 2015	–	Lundsten et al. 2010
Invertebrates	Blue mussel	*Mytilus trossulus*	Blue mussel	Additional	Y	–	Wheelock 2018	–	–	–	–	–
Invertebrates	Boneeating snail	*Rubyspira sp*	Boneeating snail	Additional	Y	–	–	–	–	–	DFO 2019	–
Invertebrates	Boneeating worm / zombie worm	*Osedax* sp.	Bone worm	Additional	Y	–	–	–	–	–	DFO 2019	Lundsten et al. 2010
Invertebrates	Brisingid sea stars	Brisingidae (Family)	Brisingid sea star	Additional	Y	–	–	–	–	Du Preez et al. 2015	–	Merle et al. 2016
Invertebrates	Buccinid snails (whelk)	e.g. *Buccinum thermophilum*	Buccinid snail	Additional	Y	–	–	Kathman et al. 1983	DFO 2019	–	–	Doya et al. 2017
Invertebrates	Butter clam	*Saxidomus gigantea*	Clam / Butter clam	NSB ESS	Y	–	Lucas et al. 2007	Pellegrin et al. 2007	–	–	–	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Invertebrates	California mussel	*Mytilus californianus*	California mussel	NSB ESS	Y	–	–	–	–	McDaniel et al. 2003	–	–
Invertebrates	Caridean shrimp	various species	Caridean shrimp	Additional	Y	–	Pellegrin et al. 2007	Marliave & Roth 1995	–	DFO 2019	Ban et al. 2016	Doya et al. 2017
Invertebrates	Cockles	*Clinocardium nuttalli*	Clam	NSB ESS	Y	–	Lucas et al. 2007	McDaniel 2018	–	–	–	–
Invertebrates	Coonstripe/dock Shrimp	*Pandalus danae*	Shrimp	NSB ESS	Y	–	Dethier 1990	DFO 2017	–	–	–	–
Invertebrates	Crangon shrimp	*Crangon* spp.	Crangon shrimp	Additional	Y	–	Jensen 2014	–	–	–	Ban et al. 2016	–
Invertebrates	Crimson anemone	*Cribrinopsis fernadi*	Crimson anemone	Additional	Y	–	–	Gasbarro 2017	–	Du Preez et al. 2015	–	–
Invertebrates	Crustacean larvae	e.g. crab and shrimp larvae	Zooplankton	NSB ESS	Y	DFO 2019	Shaffer et al. 2020	Mackas et al. 2007	DFO 2019	Canessa et al. 2003	DFO 2019	–
Invertebrates	Deep sea Amphipods	Amphipoda	Amphipod	Additional	Y	–	–	–	Skebo 2004	DFO 2019	DFO 2019	Campany-Llovet & Snelgrove 2018

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Invertebrates	Deep sea brittle stars	Ophiuroidea	Brittle star	Additional	Y	–	–	–	DFO 2019	Du Preez et al. 2015	DFO 2019	Doya et al. 2017
Invertebrates	Deep sea crinoids	*e.g. Hyocrinus sp., Psathyrometra* sp.	Crinoid	Additional	Y	–	–	–	–	Du Preez et al. 2015	Ban et al. 2016	DFO 2018
Invertebrates	Deep sea infaunal polychaete worms	Annelida	Polychaete	Additional	Y	–	–	–	–	–	DFO 2019	–
Invertebrates	Deep sea isopods	Isopoda	Isopod	Additional	Y	–	–	–	DFO 2019	McDaniel et al. 2003	DFO 2019	Lundsten et al. 2010
Invertebrates	Deep sea limpets	e.g. *Lepetodrilus* sp., *Pyropelta* sp.	Limpet	Additional	Y	–	–	–	DFO 2019	–	–	DFO 2018
Invertebrates	Deep sea nematodes	Nematoda	Nematode	Additional	Y	–	–	–	–	–	DFO 2019	–
Invertebrates	Deep sea sea cucumbers	e.g. *Pannychia* sp.	Sea cucumber	Additional	Y	–	–	–	–	Du Preez et al. 2015	DFO 2019	Doya et al. 2017
Invertebrates	Demosponges	Demospongiae	Sponge / Sponges	NSB ESS	Y	–	–	Rubidge et al. 2020	DFO 2019	Du Preez et al. 2015	Ban et al. 2016	DFO 2018

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Invertebrates	Dorvellid (bristle) worms	Dorvelleidae (Family)	Dorvellid worm	Additional	Y	–	Dethier 1990	Kathman et al. 1983	DFO 2019	–	DFO 2019	Campany-Llovet & Snelgrove 2018
Invertebrates	Dungeness crab	*Metacarcinus magister*	Dungeness crab	Additional	Y	–	Jensen 2014; Rubidge et al 2020	Lucas et al. 2007	–	–	–	–
Invertebrates	Euphausiids	Euphausiacea	Zooplankton	NSB ESS	Y	DFO 2019	Mackas et al. 2007	Mackas et al. 2007	Skebo 2004	Canessa et al. 2003	DFO 2019	–
Invertebrates	Feather duster worms	Serpulidae	Feather duster worm	Additional	Y	–	–	DFO 2017	–	–	–	DFO 2018
Invertebrates	Filament worm	e.g. *Dodecaria* sp.	Filament worm	Additional	Y	–	–	–	–	–	–	–
Invertebrates	Gelatinous zooplankton (jellyfish)	e.g. *Aurelia aurita, Cyanea capillata, Phacellophora camtschatica*	Jellyfish	Additional	Y	DFO 2019	Mackas et al. 2007	Mackas et al. 2007	Skebo 2004	Gauthier et al. (Cnidaria) 2018	Ban et al. 2016	Doya et al. 2017
Invertebrates	Giant Pacific octopus	*Enteroctopus dofleini*	Octopus	NSB ESS	Y	–	–	Rubidge et al. 2020	–	DFO 2019	–	–

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Invertebrates	Giant pink sea star	*Pisaster brevispinus*	Giant pink star	Additional	Y	–	Dethier 1990	Gasbarro 2017	–	–	–	–
Invertebrates	Glass sponges	*Hexactinellida (e.g. Heterochone, Aphrocallistes, Farrea)*	Glass sponge / Sponges / Sponge reef	NSB ESS	Y	–	–	Rubidge et al. 2020	DFO 2019	Gauthier et al. 2018; Du Preez et al. 2015	Ban et al. 2016	Merle & Embley 2016
Invertebrates	Gooseneck barnacle	*Pollicipes polymerus*	Gooseneck barnacle	NSB ESS	Y	–	–	Rubidge et al. 2020	–	–	–	–
Invertebrates	Gorgonian coral	e.g. *Paragorgia pacifica, Primnoa pacifica*	Gorgonian coral / Soft coral	NSB ESS	Y	–	–	Gasbarro 2017		Du Preez et al. 2015	Ban et al. 2016	Lundsten et al. 2010
Invertebrates	Green surf anemone	*Anthopleura xanthogrammica*	Green surf anemone	Additional	Y	–	–	–	–	–	–	–
Invertebrates	Green urchin	*Strongylocentrotus droebachiensis*	Green urchin	Additional	Y	–	–	McDaniel 2018	–	–	–	–
Invertebrates	Gumboot chiton	*Cryptochiton stelleri*	Gumboot chiton	Additional	Y	–	–	McDaniel 2018	–	Canessa et al. 2003	–	–

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Invertebrates	Hard / stony corals	e.g. *Balanophyllia elegans, Lophelia pertusa*	Stony coral	NSB ESS	Y	–	–	Gasbarro 2017	–	Du Preez et al. 2015	–	Lundsten et al. 2010
Invertebrates	Heart urchin	*Brisaster latifrons*	Heart urchin	Additional	Y	–	–	Burd et al. 2008	–	–	–	–
Invertebrates	Horse clam/Fat Gaper	*Tresus capax Tresus nuttallii*		NSB ESS	N	–	Pellegrin et al. 2007	Pellegrin et al. 2007	–	–	–	–
Invertebrates	Humpback shrimp	*Pandalus hypsinotus*	Shrimp	NSB ESS	Y	–	–	Gasbarro 2017	–	–	–	–
Invertebrates	Hydrocoral	e.g. *Stylaster* spp.	Hydrocoral	Additional	Y	–	Dethier 1990	McDaniel 2018	–	Du Preez et al. 2015	–	
Invertebrates	Hydrothermal vent copepods		Zooplankton	Additional	Y	–	–	–	DFO 2019	–	–	–
Invertebrates	Idasola mussel	*Idasola washingtonius*	Mussel	Additional	Y	–	–	–	DFO 2019	–	DFO 2019	–
Invertebrates	Infaunal cold seep oligochaete worms	Annelida: Oligochaeta	Oligochaete worm	Additional	Y	–	–	–	–	–	–	DFO 2018

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Invertebrates	Infaunal onshelf isopods	Isopoda	Isopod	Additional	Y	–	Dethier 1990	DFO 2017	–	–	–	–
Invertebrates	Intertidal chitons	e.g. Tonicella lineata, Leptochiton rugatus, Mopalia muscosa	Chiton	Additional	Y	–	Dethier 1990	McDaniel 2018	–	–	–	–
Invertebrates	Intertidal limpets	e.g. *Lottia* spp, *Diodora aspera*	Limpet	Additional	Y	–	Lamb & Hanby 2005	McDaniel 2018	–	–	–	–
Invertebrates	Intertidal whelks	e.g. *Lirabuccinum dirum* (dire whelk)	Whelk	Additional	Y	–	–	Kathman et al. 1983	–	–	–	–
Invertebrates	Kelp crab	*Pugettia* spp.	Kelp crab	Additional	Y	–	Dethier 1990	McDaniel 2018	–	Canessa et al. 2003	–	–
Invertebrates	Lampshells	Brachiopoda (e.g *Laqueus californianus*)	Lampshell	Additional	Y	–	Dethier 1990	McDaniel 2018	–	Gauthier et al. 2018	–	–
Invertebrates	Leather star	*Dermasterias imbricata*	Sea star / Leather star	Additional	Y	–	–	–	–	Gauthier et al. 2018	–	–

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Invertebrates	Littleneck clam	*Leukoma staminea*	Clam	NSB ESS	Y	–	Lucas et al. 2007	Pellegrin et al. 2007	–	–	–	–
Invertebrates	Littorina snail	*Littorina* sp.	Snail	NSB ESS	Y	–	Dethier 1990	–	–	–	–	–
Invertebrates	Lucinid clam	*Lucinoma annulata*	Lucinid clam	Additional	Y	–	–	–	–	–	DFO 2019	–
Invertebrates	Moon snail	*Euspira lewisii*	Moon snail	Additional	Y	–	Dethier 1990	–	–	–	–	–
Invertebrates	Mud shrimp	*Upogebia pugettensis*	Mud shrimp	Additional	Y	–	Dumbauld et al. 2011	–	–	–	–	–
Invertebrates	Mysid shrimp	Mysidae	Mysid shrimp	Additional	Y	Ban et al. 2016	Dethier 1990	Kathman et al. 1983	–	McDaniel et al. 2003	DFO 2019	Chauvet et al. 2018
Invertebrates	Neocalanus copepods	*Neocalanus* sp.	Zooplankton	NSB ESS	Y	DFO 2019	Mackas et al. 2007	Mackas et al. 2007	Skebo 2004	–	–	De Leo et al. 2018
Invertebrates	NonCrustacean zooplankton	Non-crustacean Zooplankton	Zooplankton	NSB ESS	Y	Ban et al. 2016	Mackas et al. 2007	Mackas et al. 2007	Skebo 2004	Canessa et al. 2003	DFO 2019	Doya et al. 2017

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Invertebrates	Northern abalone	*Haliotis kamtschatkana*	Abalone	CC	Y	–	–	–	–	–	–	–
Invertebrates	Ochre star	*Pisaster ochraceus*	Sea star	NSB ESS	Y	–	–	–	–	–	–	–
Invertebrates	Octopus	e.g. *Graneledone boreopacifica*	Octopus	Additional	Y	–	–	–	DFO 2019	Du Preez et al. 2015	Ban et al. 2016	Merle & Embley 2016
Invertebrates	Olive snail	*Olivella* spp.	Olive snail	Additional	Y	–	–	–	–	–	–	–
Invertebrates	Olympia oyster	*Ostrea lurida*	Olympia oyster	CC	Y	–	Gillespie 2009	Gillespie 2009	–	–	–	–
Invertebrates	On shelf infaunal amphipods	Amphipoda	Amphipod	Additional	Y	–	Burd et al. 2008	Kathman et al. 1983	–	–	–	–
Invertebrates	On shelf infaunal annelids	Annelida	Annelid worm	Additional	Y	–	Dethier 1990	Kathman et al. 1983	–	–	–	–
Invertebrates	Opal squid	*Doryteuthis opalescens*	Squid	NSB ESS	Y	Walthers & Gillespie 2002	–	–	–	–	–	–

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Invertebrates	Pacific geoduck	*Panopea generosa*	Geoduck	Additional	Y	–	Dethier 1990	Pellegrin et al. 2007	–	–	–	–
Invertebrates	Palm worms	*Paralvinella palmiformis*	Palm worm	Additional	Y	–	–	–	DFO 2019	–	–	–
Invertebrates	Polynoid scaleworms	Polynoidae	Polynoid worm	Additional	Y	–	Lamb & Hanby 2005	Lamb & Hanby 2005	DFO 2019	–	–	Lundsten et al. 2010
Invertebrates	Purple sea urchin	*Strongylocentrotus purpuratus*	Purple sea urchin	CC	Y	–	–	–	–	McDaniel et al. 2003	–	–
Invertebrates	Razor clam	*Siliqua patula*	Razor clam	NSB ESS	Y	–	–	–	–	–	–	–
Invertebrates	Red rock crab	*Cancer productus*	Red rock crab	Additional	Y	–	Dethier 1990	McDaniel 2018	–	–	–	–
Invertebrates	Red urchin	*Mesocentrotus franciscanus*	Red urchin	Additional	Y	–	–	Gasbarro 2017	–	Du Preez et al. 2015	–	–
Invertebrates	Sand dollar	*Dendraster excentricus*	Sand dollar	Additional	Y	–	Dethier 1990	–	–	–	–	–

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Invertebrates	Sand fleas (amphipods)	e.g. *Traskorchestia* sp., *Erichthonius rubricornis*	Sand flea	Additional	Y	–	Lamb & Hanby 2005	–	–	–	–	–
Invertebrates	Scallop	e.g. Weathervane scallop - *Patinopecten caurinus*	Scallop	Additional	Y	–	–	–	–	–	–	–
Invertebrates	Sea anemones	e.g. *Urticina* spp.	Anemone	Additional	Y	–	Dethier 1990	DFO 2017	–	Du Preez et al. 2015	–	–
Invertebrates	Sea cucumbers	*e.g. Apostichopus californicus, Apostichopus leukothele, Psolus squamatus*	Sea cucumber	Additional	Y	–	Dethier 1990	Zhou & Shirley 1996	–	Du Preez et al. 2015	–	–
Invertebrates	Sea pens	e.g. *Ptilosarcus gurneyi, Umbellula* sp.	Orange sea pen / Seapen	NSB ESS	Y	–	Dethier 1990	Gasbarro 2017	–	Gauthier et al. 2018; Du Preez et al. 2015	Dolan 2008	DFO 2018
Invertebrates	Sea spider	Pycnogonids	Pycnogonid	Additional	Y	–	–	–	DFO 2019	McDaniel et al. 2003	Ban et al. 2016	DFO 2018
Invertebrates	Sea star	*e.g. Patiria miniata, Dermasterias imbricata, Mediaster*	Sea star	Additional	Y	–	–	DFO 2017	–	DFO 2019	–	–

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		aequalis, Ceramaster spp.										
Invertebrates	Shore crab	*Hemigrapsus* spp.	Shore crab	Additional	Y	–	–	–	–	–	–	–
Invertebrates	Sidestripe shrimp	*Pandalopsis dispar*	Pandalid shrimp	NSB ESS	Y	Lucas et al. 2007	–	–	–	–	–	–
Invertebrates	Smooth pink shrimp	*Pandalus jordani*	Pandalid shrimp	NSB ESS	Y	–	–	Gasbarro 2017	–	–	–	–
Invertebrates	Solemyid clam	*Solemya reidi*	Solemyid clam	Additional	Y	–	–	–	–	–	–	DFO 2018
Invertebrates	Spider crab	*Macroregonia macrochira*	Spider crab	Additional	Y	–	–	–	DFO 2019	–	DFO 2019	–
Invertebrates	Spiny or northern pink shrimp	*Pandalus borealis*	Pandalid shrimp	NSB ESS	Y	–	–	DFO 2017	–	–	–	–
Invertebrates	Spot prawn	*Pandalus platyceros*	Pandalid shrimp / Prawn	NSB ESS	Y	–	–	Anderson & Bell 2014	–	–	–	–

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Invertebrates	Squat lobster	*Munida quadrispina*	Squat lobster	Additional	Y	–	–	Gasbarro 2017	DFO 2019	Gauthier et al. 2018	DFO 2019	Chauvet et al. 2018
Invertebrates	Sulphide worms	*e.g. Paralvinella sulfincola*	Sulphide worm	Additional	Y	–	–	–	DFO 2019	–	–	–
Invertebrates	Sun star	*Solaster* spp.	Sun star	Additional	Y	–	Dethier 1990	McDaniel 2018	–	Du Preez et al. 2015	–	0
Invertebrates	Sunflower sea star	*Pycnopodia helianthoides*	Sunflower star	NSB ESS	Y	–	Dethier 1990	McDaniel 2018	–	Du Preez et al. 2015	–	DFO 2018
Invertebrates	Symbiotic tubeworms	*e.g. Ridgeia piscesae, Lamellibrachia sp.*	Symbiotic tubeworm	Additional	Y	–	–	–	DFO 2019	–	–	DFO 2018
Invertebrates	Tanner crab	*Chionoecetes bairdi*	Tanner crab	Additional	Y	–	–	Fong & Dunham 2007	–	DFO 2019	–	Seabrook et al. 2019
Invertebrates	Tunicates	e.g. *Halocynthia* sp.	Tunicate	Additional	Y	–	–	DFO 2017	–	–	–	–
Invertebrates	Turban snails	*e.g. Pomaulax gibberosus, Tegula spp.*	Turban snail	Additional	Y	–	–	–	–	–	–	–

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Invertebrates	Vesicomyid clams	Vesicomyidae (e.g. *Calyptogena* spp.)	Vesicomyid clam	Additional	Y	–	–	–	DFO 2019	DFO 2018	DFO 2019	Campany-Llovet & Snelgrove 2018
Invertebrates	Woodboring clam	*e.g. Xylophaga washingiona*	Woodboring clam	Additional	Y	–	–	–	–	–		–
Fishes	Albacore tuna	*Thunnus alalunga*	Albacore tuna / Tuna	NSB ESS, CC	Y	Schweigert et al.2007	–	–	–	Newton & Devogelaere 2013	–	–
Fishes	Arrowtooth flounder	*Atheresthes stomias*	Arrowtooth flounder	NSB ESS	Y	–	–	Pirtle et al. 2019	–	Canessa et al. 2003	–	–
Fishes	Basking shark	*Cetorhinus maximus*		CC	N	DFO 2011	–	–	–	Canessa et al. 2003	–	–
Fishes	Bay pipefish	*Syngnathus leptorhynchus*	Pipefish	Additional	Y	–	Johnson et al. 2003	–	–	–	–	–
Fishes	Big skate	*Beringraja binoculata*	Skate	NSB ESS	Y	–	–	Gray et al. 2019	–	Gauthier et al. 2018	–	–

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Fishes	Blue shark	*Prionace glauca*	Blue shark	NSB ESS, CC	Y	Maxwell et al. 2019	–	–	–	Canessa et al. 2003	–	–
Fishes	Bluntnose sixgill shark	*Hexanchus griseus*	Bluntnose sixgill	NSB ESS, CC	Y	Ban et al. 2016	–	–	–	Du Preez et al. 2015	–	–
Fishes	Bocaccio	*Sebastes paucispinis*	Rockfish / Juvenile rockfish	NSB ESS, CC	Y	Lamb & Edgell 2010; Hart 1973	Rubidge et al. 2020	Frid & McGreer 2018	–	Gauthier et al. 2018	–	–
Fishes	Cabezon	*Scorpaenichthys marmoratus*	Cabezon	Additional	Y	Wilson et al. 2008	Schwartzkopf et al. 2020	–	–	–	–	–
Fishes	Canary rockfish	*Sebastes pinniger*	Rockfish / Juvenile rockfish	CC	Y	Lamb & Edgell 2010	–	Frid & McGreer 2018	–	Canessa et al. 2003	–	–
Fishes	Capelin	*Mallotus villosus*	Forage fish	NSB ESS	Y	Logerwell et al. 2010	Froese & Pauly 2020	Schweigert et al.2007	–	–	–	–
Fishes	China rockfish	*Sebastes nebulosus*	Rockfish / Juvenile rockfish	CC	Y	Lucas et al. 2007	–	–	–	Gauthier et al. 2018	–	–

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Fishes	Chinook salmon	*Oncorhynchus tshawytscha*	Adult salmon / Juvenile salmon / Salmon	NSB ESS, CC	Y	Hyatt et al. 2007	Hyatt et al. 2007	Hyatt et al. 2007	–	Ban et al. 2016	–	–
Fishes	Chum salmon	*Oncorhynchus keta*	Adult salmon / Juvenile salmon / Salmon	NSB ESS	Y	Hyatt et al. 2007	Feist et al.1992	Hyatt et al. 2007	–	–	–	–
Fishes	Coho salmon	*Oncorhynchus kisutch*	Adult salmon / Juvenile salmon / Salmon	NSB ESS, CC	Y	Hyatt et al. 2007	Hyatt et al. 2007	Hyatt et al. 2007	–	–	–	–
Fishes	Copper rockfish	*Sebastes caurinus*	Rockfish / Juvenile rockfish	CC	Y	Lucas et al. 2007	Dauble et al. 2012	McDaniel 2018	–	Ban et al. 2016	–	–
Fishes	Cutthroat trout	*Oncorhynchus clarkii*		NSB ESS	N	Gale et al. 2019	Gale et al. 2019	–	–	–	–	–
Fishes	Darkblotched rockfish	*Sebastes crameri*	Rockfish	CC	Y	Hart 1973; Gale et al. 2019	–	–	–	Gauthier et al. 2018	–	–
Fishes	Deep sea snailfish	e.g. *Careproctus* sp.	Snailfish	Additional	Y	–	–	–	–	Canessa et al. 2003	DFO 2019	DFO 2018

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Fishes	Dolly varden	*Salvelinus malma lordi*		NSB ESS	N	Hart 1973; Dunham et al. 2008	Johnson et al. 2003	–	–	–	–	–
Fishes	Eelpouts	Zoarcidae	Eelpout	Additional	Y	–	–	Gasbarro 2017	Skebo 2004	Gauthier et al. 2018	DFO 2019	Doya et al. 2017
Fishes	Eulachon	*Thaleichthys pacificus*	Eulachon	NSB ESS, CC	Y	Schweigert et al.2007	COSEWIC 2011	COSEWIC 2011	–	–	–	–
Fishes	Flatfish deep sea	e.g. *Embassichthys bathybius*	Flatfish	Additional	Y	–	–	–	–	Gauthier et al. 2018	–	–
Fishes	Flatfish on shelf	*e.g. Citharichthys spp., Limanda aspera*	Flatfish / Sole	Additional	Y	–	Hurst et al. 2007; Johnson et al. 2003	Gasbarro 2017	–	Gauthier et al. 2018	–	–
Fishes	Green sturgeon	*Acipenser medirostris*		CC	N	Gale et al. 2019	Gale et al. 2019	–	–	–	–	–
Fishes	Grenadiers (rattails)	e.g. *Coryphaenoides* spp.	Grenadier	Additional	Y	0	–	0	DFO 2019	Gauthier et al. 2018	DFO 2019	Doya et al. 2017

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Fishes	Gunnels	e.g. *Pholis* sp.	Gunnel	Additional	Y	–	Johnson et al. 2003	–	–	Gauthier et al. 2018	–	–
Fishes	Hagfish	*Eptatretus stoutii*	Hagfish	Additional	Y	–	–	Benson et al. 2001	–	–	DFO 2019	Chatzievangelou et al. 2016
Fishes	Lingcod	*Ophiodon elongatus*	Lingcod	NSB ESS	Y	–	Longo et Al. 2020	DFO 2017	–	Gauthier et al. 2018	–	–
Fishes	Longfin smelt	*Spirinchus thaleichthys*	Forage fish	CC	Y	Gale et al. 2019	Gale et al. 2019	–	–	–	–	–
Fishes	Longnose skate	*Beringraja rhina*	Skate	NSB ESS	Y	–	–	–	–	Gauthier et al. 2018	0	–
Fishes	Longspine thornyhead	*Sebastolobus altivelis*	Thornyhead	CC	Y	Love et al. 2002	–	–	–	Gauthier et al. 2018	Ban et al. 2016	Chauvet et al. 2018
Fishes	Northern anchovy	*Engraulis mordax*	Forage fish	Additional	Y	Schweigert et al.2007	Schweigert et al.2007	Schweigert et al.2007	–	–	–	–
Fishes	Northern lampfish	*Stenobrachius leucopsarus*		NSB ESS	N	Hart 1973; Beamis	–	–	–	–	Ban et al. 2016	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
						h et al. 1999						
Fishes	Northern smoothtongue	*Leuroglossus schmidti*		NSB ESS	N	Schweigert et al.2007	–	Schweigert et al.2007	–	–	–	–
Fishes	Ocean sunfish	*Mola mola*	Ocean sunfish	CC	Y	Williams et al. 2010	–	Sjeffery personal observation	–	DFO 2019	–	–
Fishes	Pacific cod	*Gadus macrocephalus*	Pacific cod	NSB ESS	Y	–	Johnson et al. 2003	Pirtle et al. 2019	–	Gauthier et al. 2018	–	–
Fishes	Pacific hake	*Merluccius productus*	Pacific hake	NSB ESS	Y	Gale et al. 2019	–	–	–	DFO 2019	–	–
Fishes	Pacific halibut	*Hippoglossus stenolepis*	Halibut	NSB ESS	Y	–	Batanov et al. 2017	Gasbarro 2017	–	Gauthier et al. 2018	–	Doya et al. 2017
Fishes	Pacific herring	*Clupea pallasii*	Forage fish / Juvenile herring / Herring	NSB ESS	Y	Schweigert et al.2007	Liu et al. 2011	Thompson 2017	–	Freon & Missund 1999	–	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Fishes	Pacific ocean perch	*Sebastes alutus*	Rockfish / Pacific ocean perch	CC	Y	Gale et al. 2019; Hart 1973	–	Carlson & Haight 1976	–	Du Preez et al. 2015	–	–
Fishes	Pacific sand lance	*Ammodytes hexapterus*	Forage fish / Pacific sandlance	NSB ESS	Y	Robinson et al. 2013	Johnson et al. 2003	–	–	–	–	–
Fishes	Pacific sardine	*Sardinops sagax*		CC	N	Schweigert et al.2007	Emmett et al. 2005	Schweigert et al.2007	–	–	–	–
Fishes	Pacific sleeper shark	*Somniosus pacificus*	Sleeper shark	NSB ESS	Y	Gale et al. 2019	–	–	–	Canessa et al. 2003	DFO 2019	–
Fishes	Pink salmon	*Oncorhynchus gorbuscha*	Adult salmon / Juvenile salmon / Salmon	NSB ESS	Y	Hyatt et al. 2007	Feist et al.1992	Hyatt et al. 2007	–	–	–	–
Fishes	Quillback rockfish	*Sebastes maliger*	Rockfish / Juvenile rockfish	CC	Y	Lucas et al. 2007	Swartzkopf 2020	DFO 2017	–	Canessa et al. 2003	–	–
Fishes	Redbanded rockfish	*Sebastes babcocki*	Rockfish	CC	Y	0	–	Gasbarro 2017	–	Gauthier et al. 2018	–	DFO 2018

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Fishes	RougheyeBlackspotted rockfish	*Sebastes aleutianus, Sebastes melanostictus*	Rockfish	NSB ESS, CC	Y	Hart 1973	–	DFO central coast survey ROV data	–	Gauthier et al. 2018	Ban et al. 2016	–
Fishes	Roughtail skate	*Bathyraja trachura*	Skate	NSB ESS	Y	Ban et al. 2016	–	–	Kuhnz et al. 2019	-	Kuhnz et al. 2019	–
Fishes	Sablefish / Black cod	*Anoplopoma fimbria*	Sablefish	NSB ESS	Y	–	–	–	–	Gauthier et al. 2018; Du Preez et al. 2015	Ban et al. 2016	Chatzievangelou et al. 2016
Fishes	Salmon shark	*Lamna ditropis*	Salmon shark	NSB ESS	Y	Williams et al. 2010	–	Williams et al. 2010	–	Du Preez et al. 2015	–	–
Fishes	Sculpins	e.g. *Olligocottus* spp., *Leptocottus armatus*	Sculpin	Additional	y	–	Dethier 1990	–	–	–	–	–
Fishes	Shiner perch	*Cymatogaster aggregata*	Shiner perch	NSB ESS	Y	Woods 2007	Schweigert et al.2007; Johnson et al. 2003	DFO 2017	–	–	–	–
Fishes	Shortraker rockfish	*Sebastes borealis*	Rockfish	NSB ESS, CC	Y	Lucas et al. 2007; Love et al. 2002	–	–	–	Gauthier et al. 2018	–	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Fishes	Shortspine thornyhead	*Sebastolobus alascanus*	Thornyhead	CC	Y	Hart 1973; Lucas et al. 2007	–	Bechtol 2000	–	Gauthier et al. 2018	–	Doya et al. 2017
Fishes	Silvergray rockfish	*Sebastes brevispinis*	Rockfish / Juvenile rockfish	CC	Y	0	–	DFO 2017	–	Gauthier et al. 2018	–	–
Fishes	Sockeye salmon	*Oncorhynchus nerka*	Adult salmon / Juvenile salmon / Salmon	NSB ESS, CC	Y	Hyatt et al. 2007	Hyatt et al. 2007	Hyatt et al. 2007	–	–	–	–
Fishes	Sole	*e.g. Glyptocephalus zachirus, Parophrys vetulus, Lyopsetta exilis*	Flatfish / Sole	Additional	Y	Froese & Pauly 2020	Hurst et al. 2007; Johnson et al. 2003	Reum & Essington 2011	–	DFO 2019	Ban et al. 2016	–
Fishes	Spiny dogfish	*Squalus suckleyi*	Dogfish	NSB ESS, CC	Y	Gale et al. 2019	Dethier 1990	–	–	Canessa et al. 2003	–	–
Fishes	Starry flounder	e.g. *Platichthys stellatus*	Flatfish / Starry flounder	Additional	Y	–	Hurst et al. 2007; Johnson et al. 2003	Gasbarro 2017	–	Gauthier et al. 2018	–	–
Fishes	Steelhead	*Oncorhynchus mykiss*		NSB ESS, CC	N	Hyatt et al. 2007	Ruggerstone et al. 1990	Ruggerstone et al. 1990	–	–	–	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Fishes	Surf smelt	*Hypomesus pretiosus*	Forage fish	NSB ESS	Y	Schweigert et al.2007	Schweigert et al.2007	Schweigert et al.2007	–	–	–	–
Fishes	Surfperch misc	*e.g. Embiotoca lateralis, Damalichthys vacca*	Surf perch	Additional	Y	–	Dethier 1990	–	–	–	–	–
Fishes	Surfperch silver	*Hyperprosopon ellipticum*	Surf perch	Additional	Y	Froese & Pauly 2020	–	–	–	–	–	–
Fishes	Tiger rockfish	*Sebastes nigrocinctus*	Rockfish / Juvenile rockfish	CC	Y	0	–	Marliave & Challenger 2009	–	Gauthier et al. 2018	–	–
Fishes	Walleye pollock	Gadus chalcogrammus		NSB ESS	N	Gale et al. 2019	Johnson et al. 2003	DFO 2017	–	Gauthier et al. 2018	–	–
Fishes	White sturgeon	*Acipenser transmontanus*	White sturgeon	CC	Y	Challenger et al. 2017	Nelson et al. 2004	–	–	–	–	–
Fishes	Whitebait smelt	*Allosmerus elongatus*	Forage fish	Additional	Y	Kaltenberg et al. 2010	–	–	–	–	–	–
Fishes	Widow rockfish	*Sebastes entomelas*	Rockfish / Juvenile rockfish	CC	Y	Lamb & Edgell 2010	–	SeasketchC CIRA data	–	Gauthier et al. 2018	–	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Fishes	Wolfeel	*Anarrhichthys ocellatus*	Wolf eel	Additional	Y	–	–	–	–	Gauthier et al. 2018	–	–
Fishes	Yelloweye rockfish	*Sebastes ruberrimus*	Rockfish / Juvenile rockfish	NSB ESS, CC	Y	–	–	DFO 2017	–	Gauthier et al. 2018	–	–
Fishes	Yellowmouth rockfish	*Sebastes reedi*	Rockfish	CC	Y	COSEWIC 2010	–	–	–	Gauthier et al. 2018	–	–
Fishes	Yellowtail rockfish	*Sebastes flavidus*	Rockfish / Juvenile rockfish	CC	Y	Lamb & Edgell 2010	Rubidge et al. 2020	Marliave & Challenger 2009	–	Gauthier et al. 2018	–	–
Reptiles	Leatherback	*Dermochelys coriacea*		CC	N	Heise et al. 2006	–	–	–	DFO 2019	–	–
Birds	Albatross	e.g. *Phoebastria nigripes, P. immutabilis P. albatrus*	Albatross		Y	Gale et al. 2019	–	–	–	DFO 2019	–	–
Birds	American crow	*Corvus brachyrhynchos*	Crow		Y	–	Dethier 1990	–	–	–	–	–
Birds	Auklet	e.g. *Ptychoramphus aleuticus, Cerorhina*	Auklet		Y	Ban et al. 2016	Dethier 1990	–	–	DFO 2019	–	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
		monocerata, Fratercula cirrhata, & F. corniculata										
Birds	Bald eagle	*Haliaeetus leucocephalus*	Eagle		Y	–	Dethier 1990	Barry 2015	–	–	–	–
Birds	Black oystercatcher	*Haematopus bachmani*	Oystercatcher		Y	–	–	–	–	–	–	–
Birds	Bufflehead	*Bucephala albeola*	Bufflehead		Y	–	–	Vermeer 1982	–	–	–	–
Birds	Cormorant	*Phalacrocorax penicillatus, P. auritu, P. pelagicus*	Cormorant		Y	–	Dethier 1990	Hipfner 2015	–	–	–	–
Birds	Goose	e.g. *Branta canadensis*	Goose		Y	–	Dethier 1990	–	–	–	–	–
Birds	Great blue heron	*Ardea herodias*	Great blue heron		Y	–	Dethier 1990	–	–	–	–	–
Birds	Grebe	e.g. *Podiceps auritus, Aechmophorus occidentalis*	Grebe		Y	–	Dethier 1990	Vermeer et al. 1991	–	–	–	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Birds	Gull	e.g. *Larus glaucescens,L. argentatus smithsonianus, L. californicus*	Gull		Y	Siddle 2015	Dethier 1990	Siddle 2015	–	DFO 2019	–	–
Birds	Loon	*e.g. Gavia immer, G. pacifica, G. adamsi*	Loon		Y	Baney.al. 2016	Dethier 1990	Hearne 2015	–	–	–	–
Birds	Murrelets	*e.g. Brachyramphus marmoratus*	Murrelet / Marbled murrelet		Y	Ban et.al. 2016	–	Arimitsu et al. 2010	–	Gale et al. 2017	–	–
Birds	Peregrine falcon	*Falco peregrinus*	Peregrine falcon		Y	–	–	–	–	–	–	–
Birds	Sooty shearwater	*Puffinus griseus*	Shearwater / Sooty shearwater		Y	Gale et al. 2019	Cannings et al. 2016	–	–	DFO 2019	–	–
Birds	Surf scoter	*Melanitta perspicillata*	Surf scoter		Y	–	Dethier 1990	–	–	–	–	–
Birds	Western sandpiper	*Calidris mauri*	Sandpiper		Y	–	Dethier 1990	–	–	–	–	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Mammals	Black bear	*Ursus americanus*	Black bear		Y	–	Reimchen 2000	–	–	–	–	–
Mammals	Blue whale	*Balaenoptera musculus*		CC	N	Gale et al. 2019; Ford 2014	–	–	–	DFO 2019	–	–
Mammals	California sea lion	*Zalophus californianus*		NSB ESS	N	Ford 2014	–	–	–	–	–	–
Mammals	Common minke whale	*Balaenoptera acutorostrata*		NSB ESS, CC	N	Ford 2014	–	–	–	0	–	–
Mammals	Dall's porpoise	*Phocoenoides dalli*	Dolphin & Porpoise	NSB ESS	Y	Ford 2014	–	McDaniel 2018	–	DFO 2019	–	–
Mammals	Deer	*Odocoileus hemionus columbianus*	Deer		Y	–	Dethier 1990	–	–	–	–	–
Mammals	Fin whale	*Balaenoptera physalus*		CC	N	Williams et al. 2010	–	Keen et al. 2018	–	Koot 2015	–	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Mammals	Grey whale	*Eschrichtius robustus*	Grey whale	CC	Y	Ford 2014	Rubidge et al. 2020	–	–	–	–	–
Mammals	Harbour porpoise	*Phocoena phocoena*	Dolphin & Porpoise	NSB ESS, CC	Y	Ford 2014	Ford 2014	McDaniel 2018	–	–	–	–
Mammals	Harbour seal	*Phoca vitulina*	Harbour seal / Seal	NSB ESS	Y	Williams et al. 2010	Ford 2014	Ford 2014	–	–	–	–
Mammals	Humpback whale	*Megaptera novaeangliae*	Humpback whale	CC	Y	Williams et al. 2010	–	Ford 2014	–	DFO 2019	–	–
Mammals	Mink	*Neogale vison*	Mink		Y	–	Dethier 1990	–	–	–	–	–
Mammals	North Pacific right whale	*Eubalaena japonica*		CC	N	Ford 2014	–	–	–	0	–	–
Mammals	Northeast Pacific northern resident orca	*Orcinus orca*	Orca	NSB ESS, CC	Y	Ford 2014	–	Ford 2014	–	Canessa et al. 2003	–	–
Mammals	Northeast Pacific offshore orca	*Orcinus orca*	Orca	NSB ESS, CC	Y	Ford 2014	–	–	–	Canessa et al. 2003	–	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Mammals	Northeast Pacific southern resident orca	*Orcinus orca*	Orca	NSB ESS, CC	Y	Ford 2014	–	Ford 2014	–	–	–	–
Mammals	Northern elephant seal	*Mirounga angustirostris*		NSB ESS, CC	N	Williams et al. 2010	–	Ford 2014; Best et al. 2015	–	DFO 2019	–	–
Mammals	Northern fur seal	*Callorhinus ursinus*		NSB ESS, CC	N	Ford 2014	–	–	–	Newton & Devogelaere 2013	–	–
Mammals	Pacific whitesided dolphin	*Lagenorhynchus obliquidens*	Pacific whitesided dolphin	NSB ESS	Y	Williams et al. 2010	–	Ford 2014	–	Canessa et al. 2003	–	–
Mammals	Raccoon	*Procyon lotor*	Raccoon		Y	–	Dethier 1990	–	–	–	–	–
Mammals	River otter	*Lontra canadensis*	River otter		Y	–	Dethier 1990	–	–	–	–	–
Mammals	Sea otter	*Enhydra lutris*	Sea otter	NSB ESS, CC	Y	–	–	–	–	–	–	–
Mammals	Sei whale	*Balaenoptera borealis*		CC	N	DFO 2013	–	–	–	DFO 2013	–	–

Group	Common Name	Species	Conceptual model illustration label text	MSP List category	Listed as model component?	Pelagic	Estuary	Fjords Subtidal	Hydrothermal vents	Seamounts	Bathyal plains	Cold seeps
Mammals	Sperm whale	*Physeter macrocephalus*		NSB ESS, CC	N	Heise et al. 2006	–	–	–	Canessa et al. 2003	–	–
Mammals	Steller sea lion	*Eumetopias jubatus*	Steller sea lion	NSB ESS, CC	Y	Heise et al. 2006	–	McDaniel 2018	–	Canessa et al. 2003	–	–
Mammals	West coast transient orca	*Orcinus orca*	Orca	NSB ESS, CC	Y	Heise et al. 2006	–	Ford 2014	–	Canessa et al. 2003	–	–
Mammals	Wolf	*Canis lupus*	Wolf		Y	–	–	–	–	–	–	–

Table 2A References

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