Conceptual models of six habitat types in Washington State marine spatial planning waters.

Graphics by: Su Kim, Office of the Science Director Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Blvd E., Seattle, WA 98112

Content developed by: Kelly S. Andrews and Chris J. Harvey, Conservation Biology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Blvd E., Seattle, WA 98112

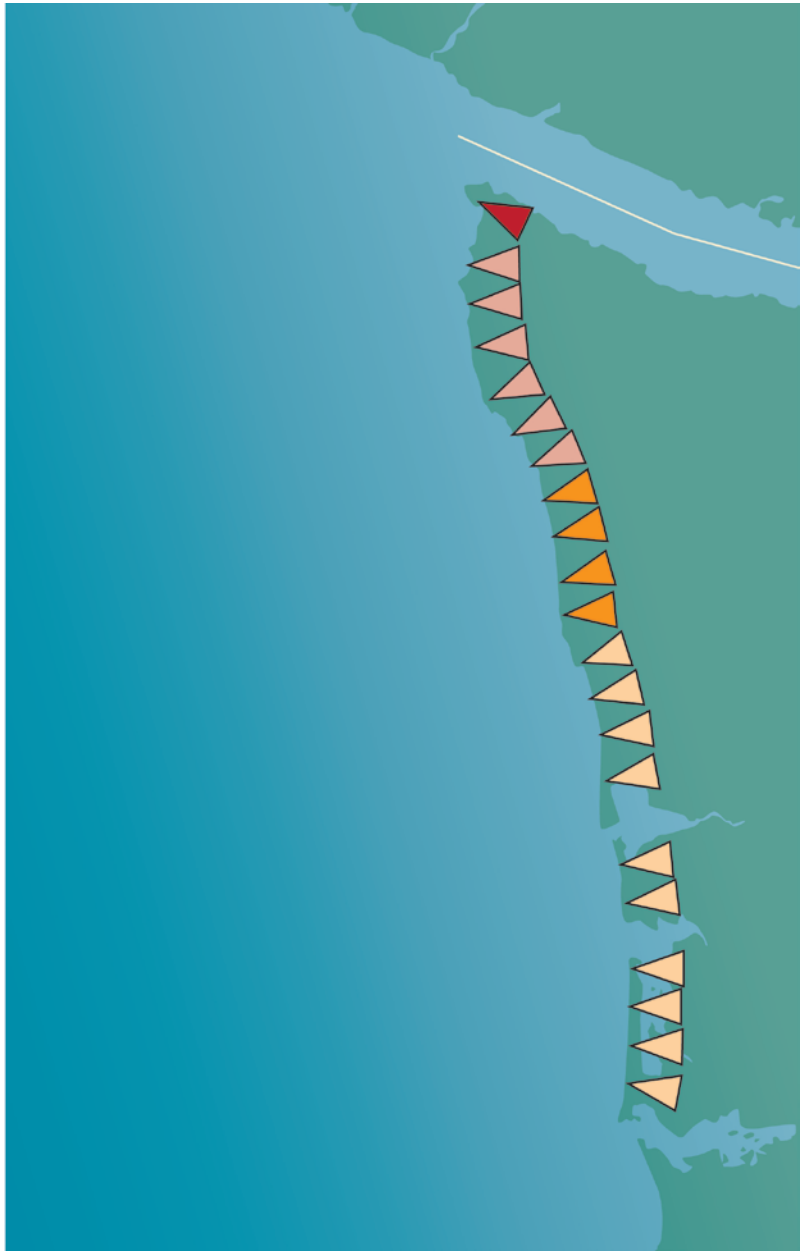
DOMINANT COASTAL FEATURES

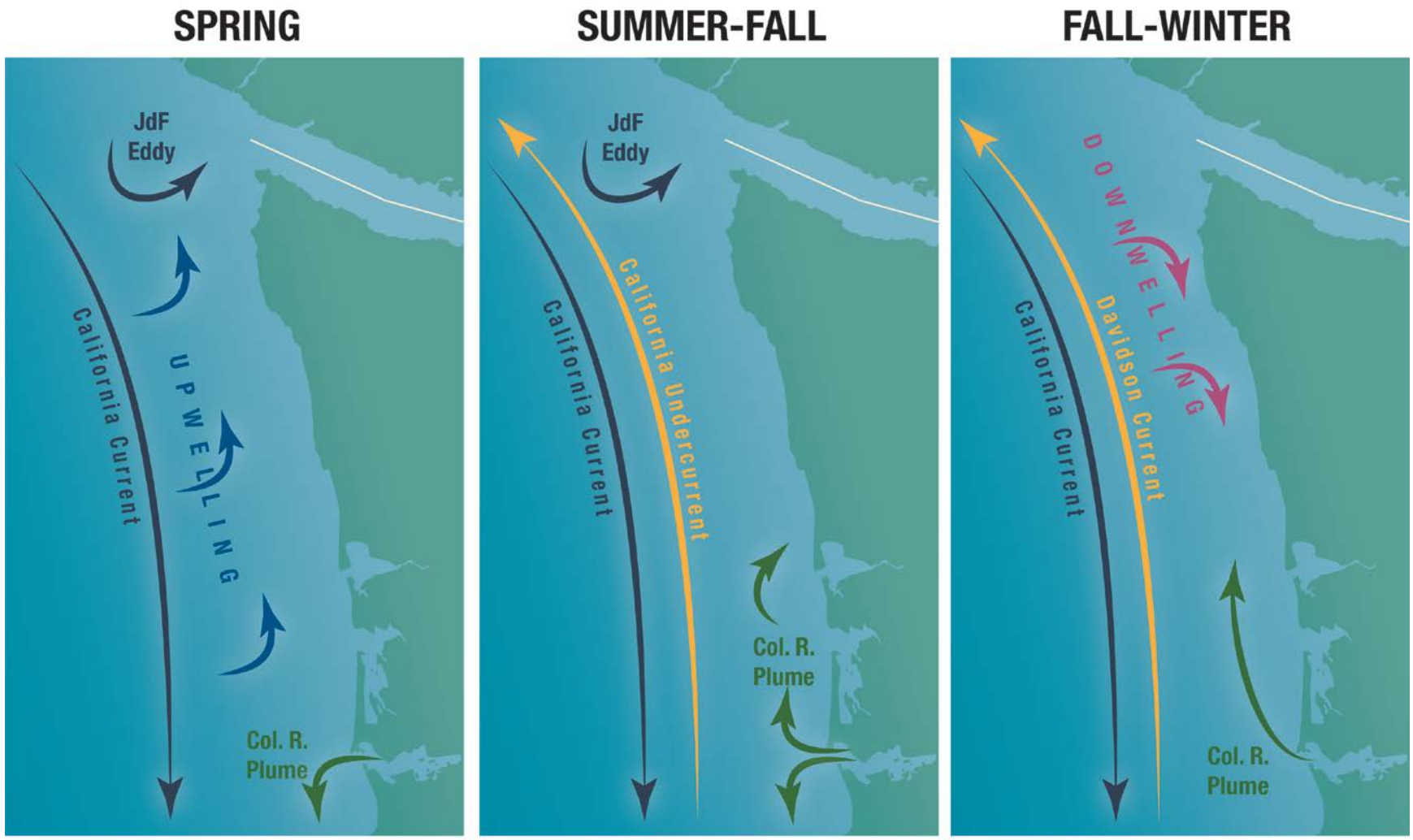
= rocky cliffs, bedrock benches

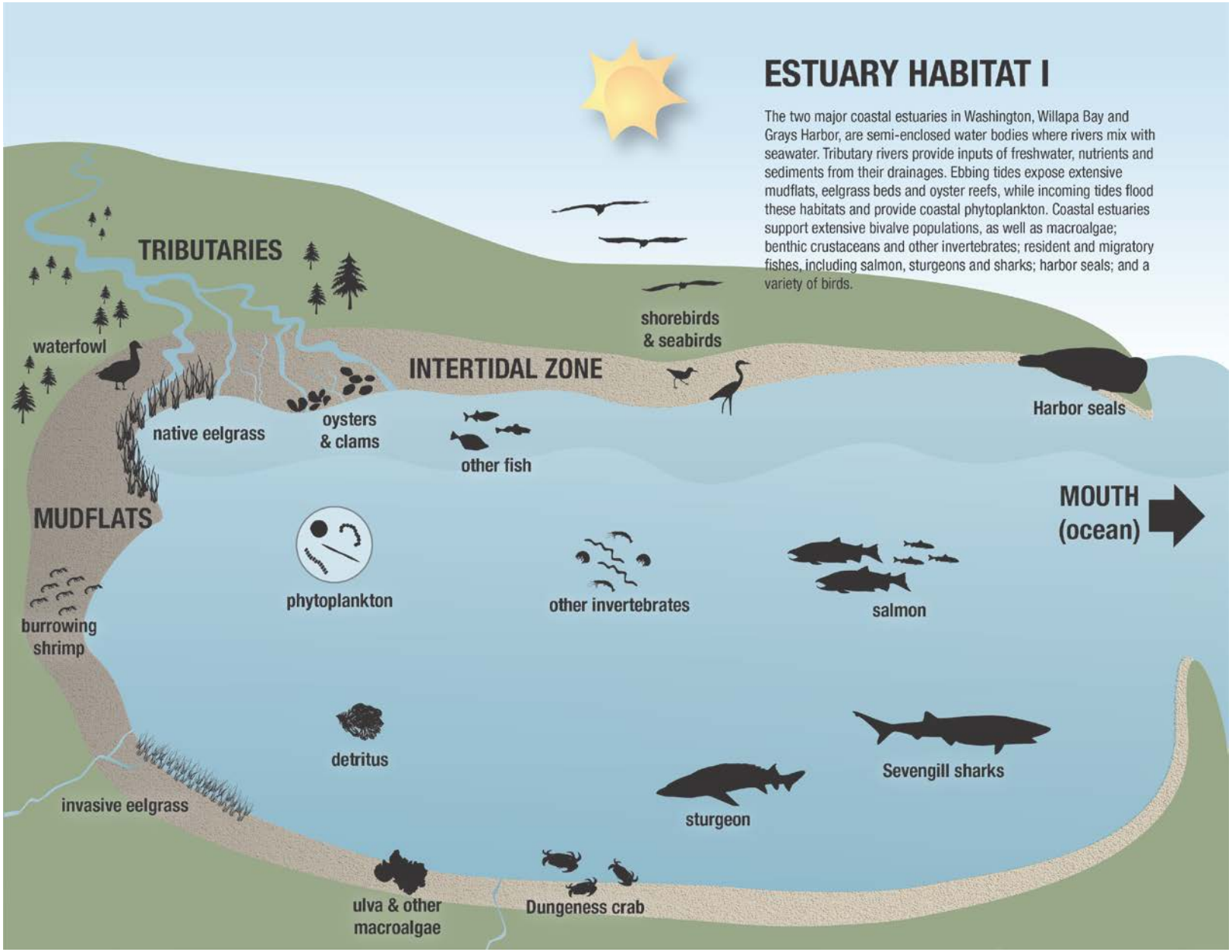
= mixed: rocky cliffs and benches with beach desposits; frequent offshore islands and sea stacks

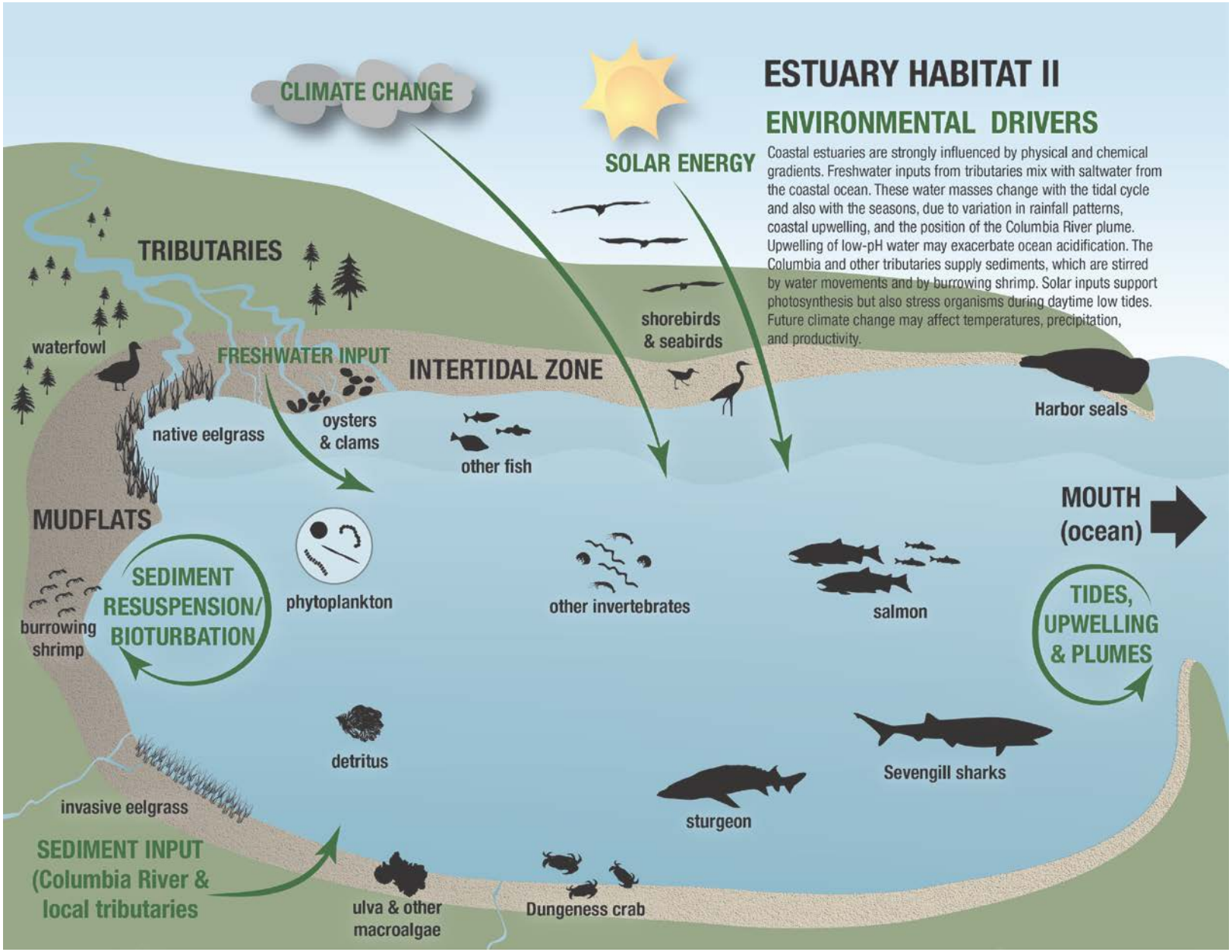
= mixed: sandy bluff and sand/gravel beach with some rocks, headlands, islands

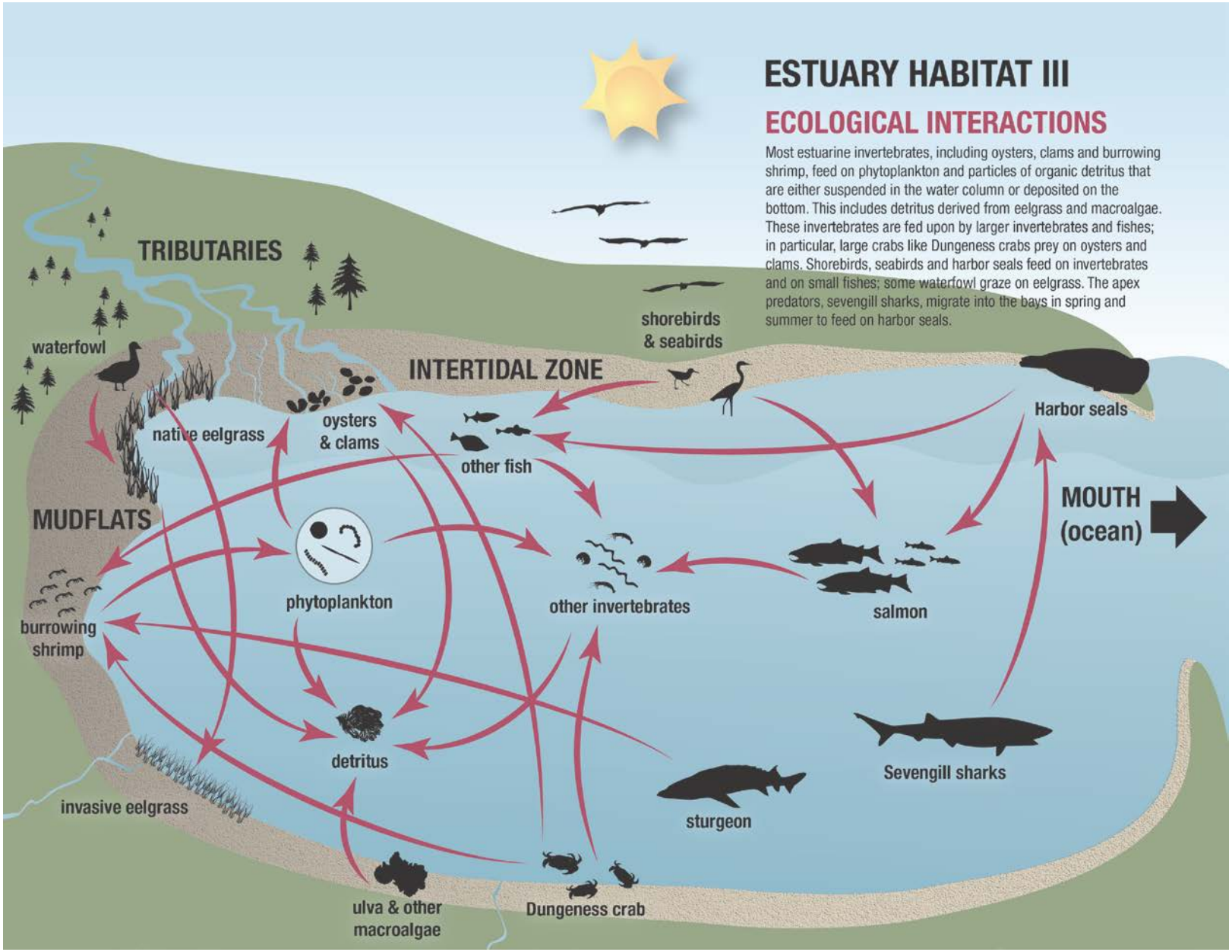
= sandy beach

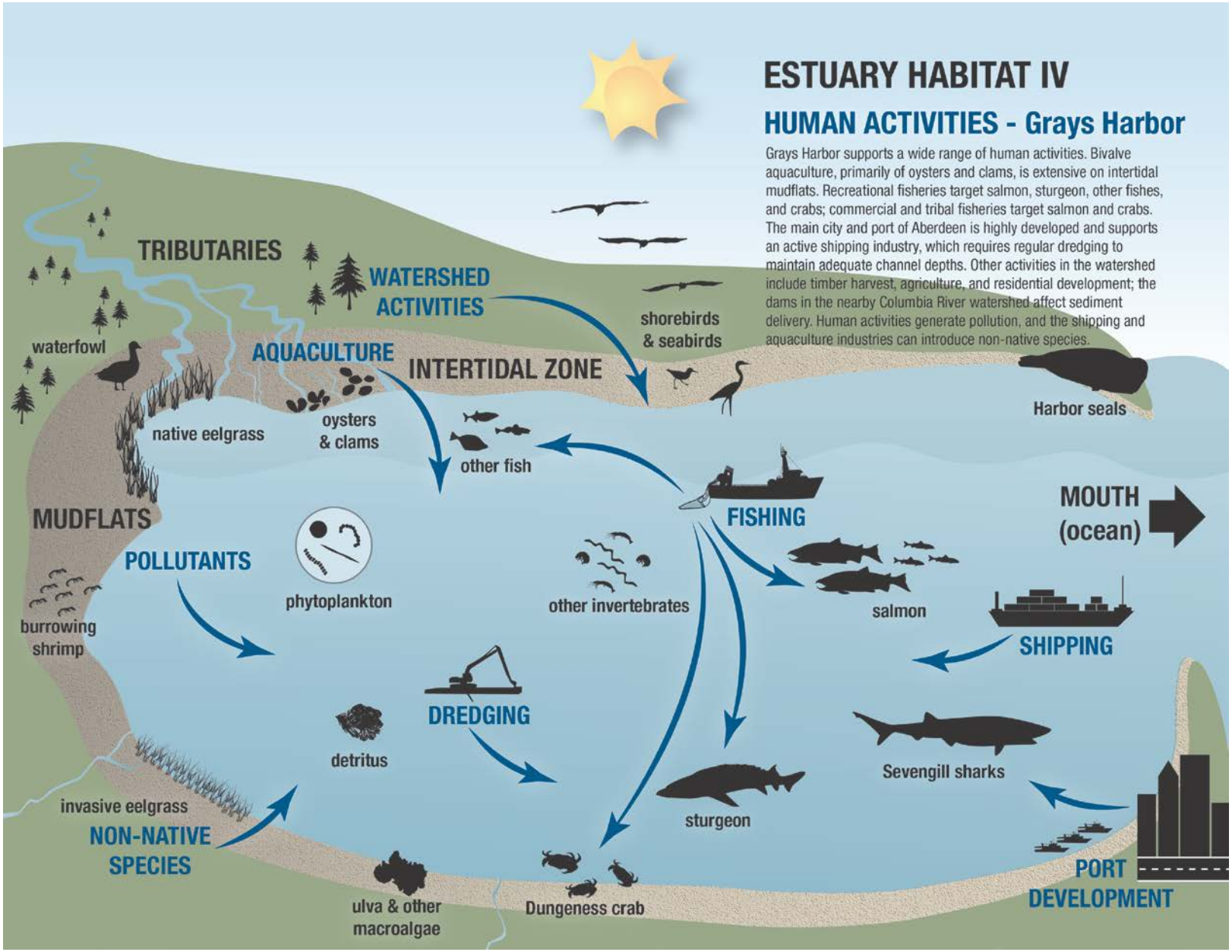


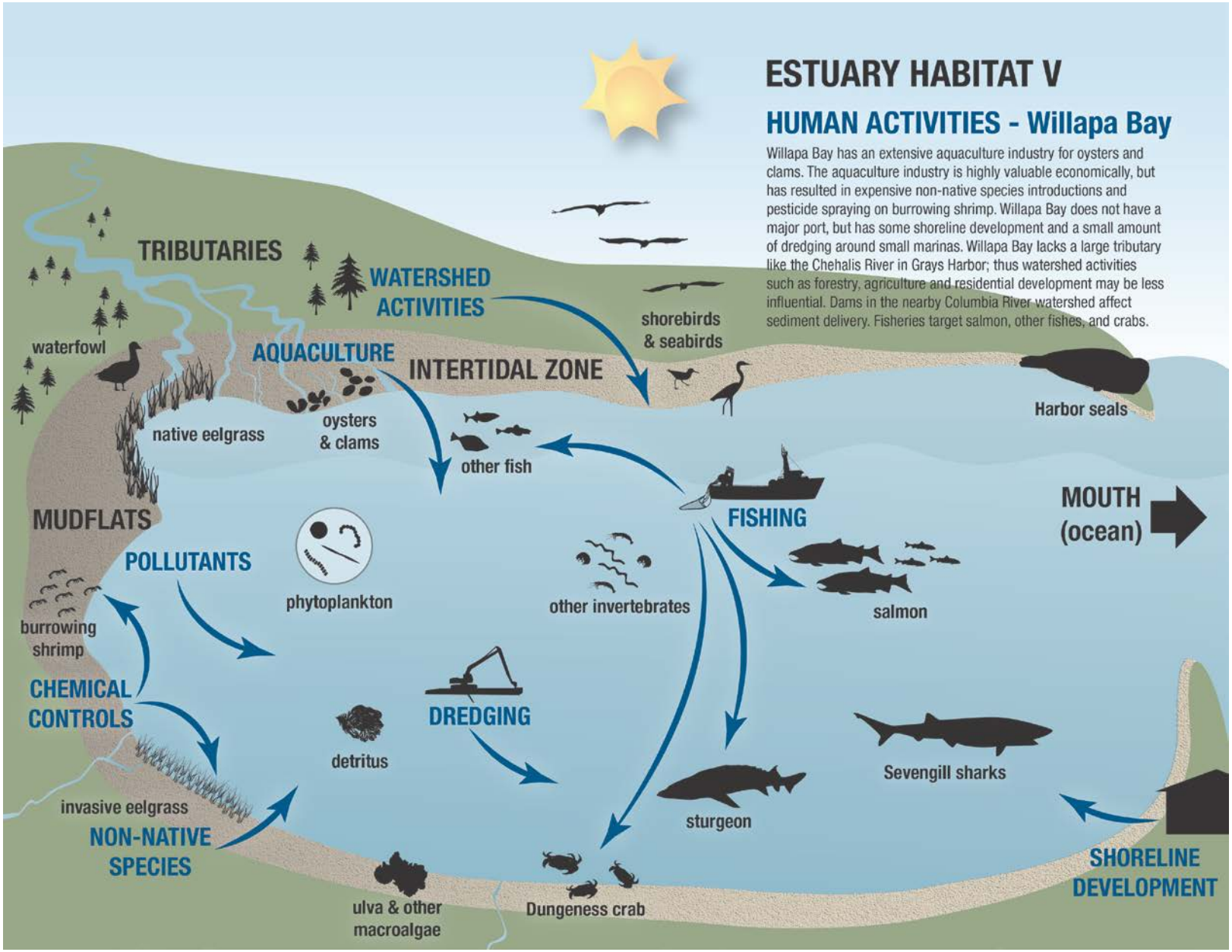

SPRING
JdF Eddy
UPWELLING
California Current
Col. R. Plume
SUMMER-FALL
JdF Eddy
California Undercurrent
California Current
Col. R. Plume
FALL-WINTER
DOWNWELLING
Davidson Current
California Current
Col. R. Plume

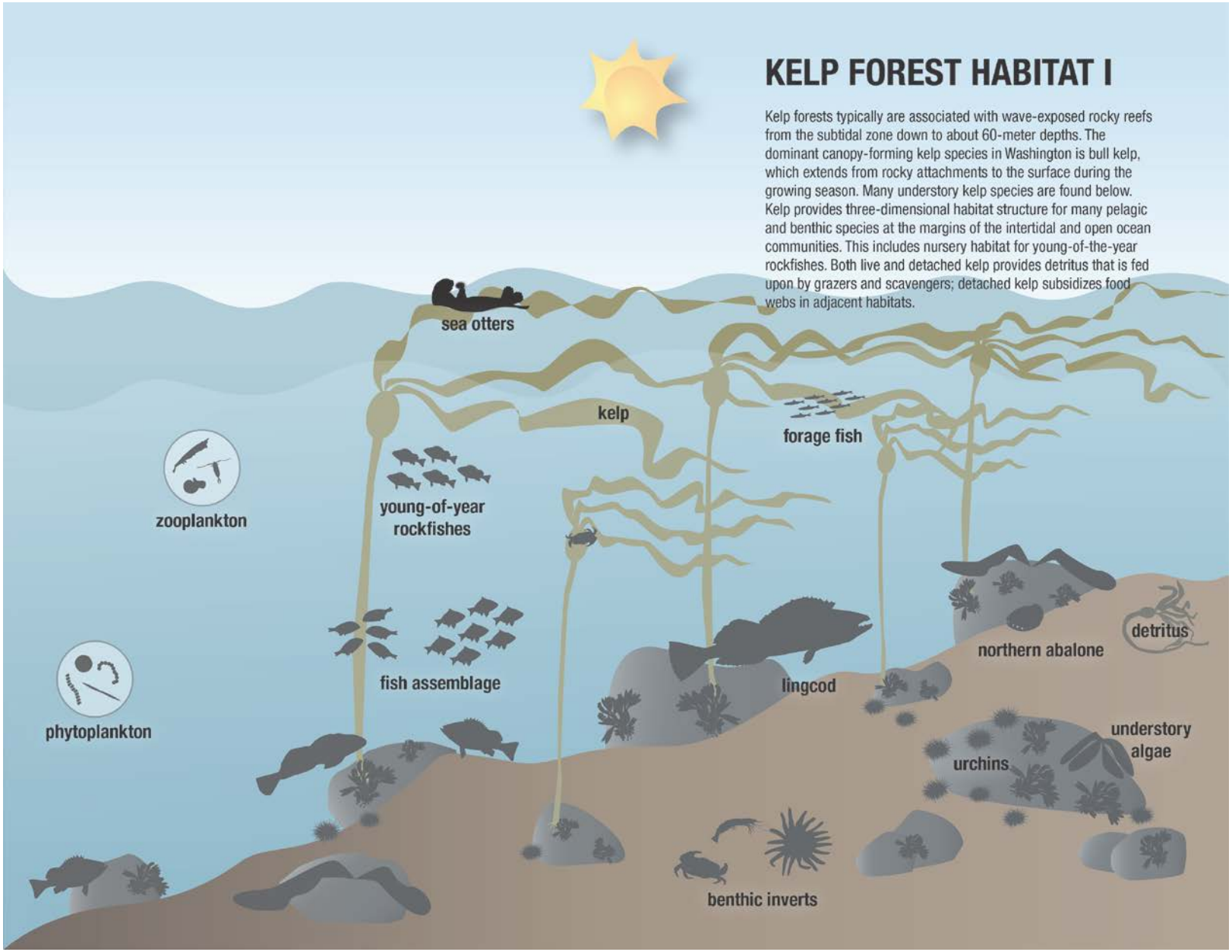

ESTUARY HABITAT I
The two major coastal estuaries in Washington, Willapa Bay and Grays Harbor, are semi-enclosed water bodies where rivers mix with seawater. Tributary rivers provide inputs of freshwater, nutrients and sediments from their drainages. Ebbing tides expose extensive mudflats, eelgrass beds and oyster reefs, while incoming tides flood these habitats and provide coastal phytoplankton. Coastal estuaries support extensive bivalve populations, as well as macroalgae; benthic crustaceans and other invertebrates; resident and migratory fishes, including salmon, sturgeons and sharks; harbor seals; and a variety of birds.
TRIBUTARIES
waterfowl
shorebirds & seabirds
INTERTIDAL ZONE
native eelgrass
oysters & clams
other fish
Harbor seals
MOUTH (ocean)
MUDFLATS
phytoplankton
other invertebrates
salmon
burrowing shrimp
detritus
Sevengill sharks
invasive eelgrass
sturgeon
ulva & other macroalgae
Dungeness crab

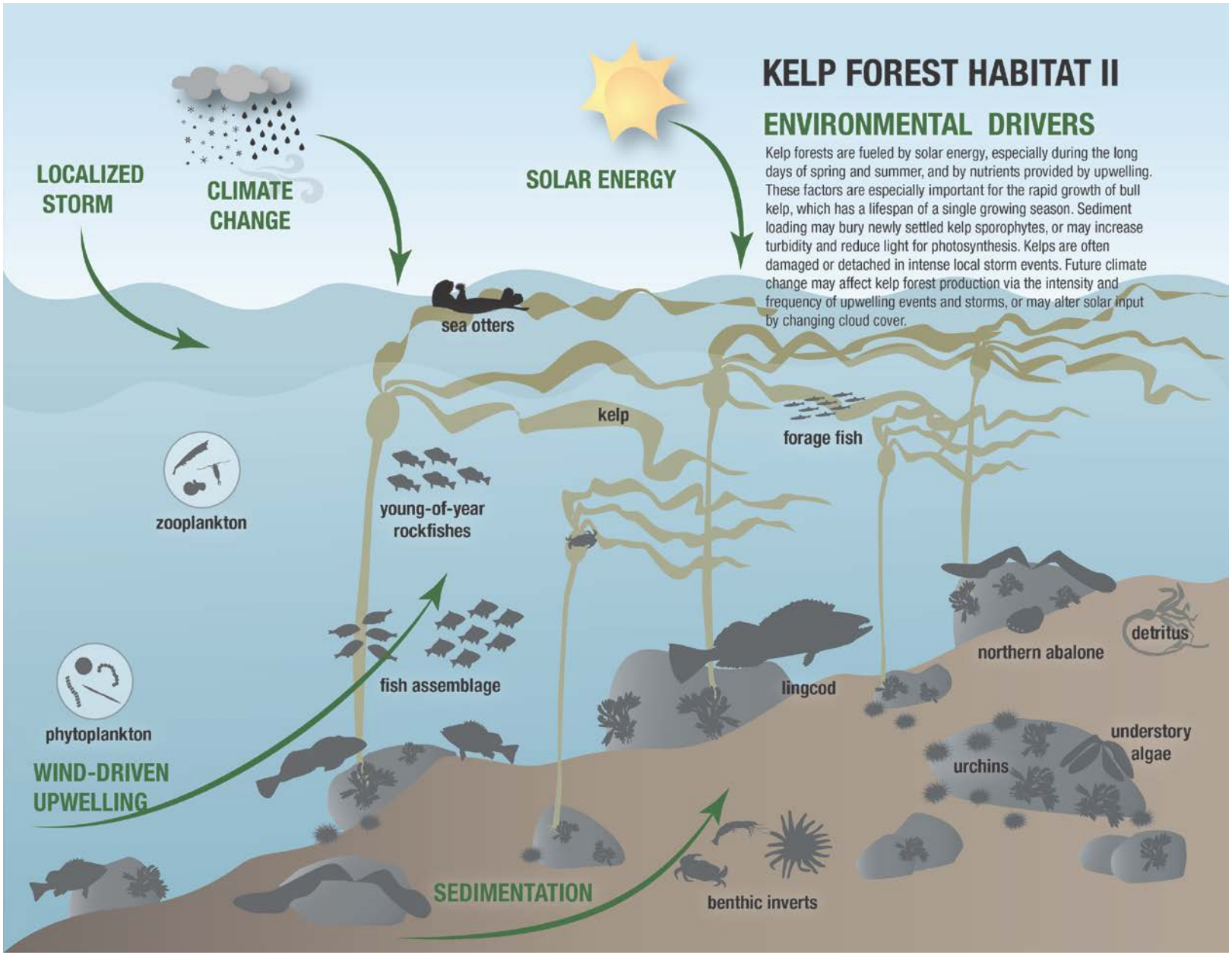

ESTUARY HABITAT II
ENVIRONMENTAL DRIVERS
Coastal estuaries are strongly influenced by physical and chemical gradients. Freshwater inputs from tributaries mix with saltwater from the coastal ocean. These water masses change with the tidal cycle and also with the seasons, due to variation in rainfall patterns, coastal upwelling, and the position of the Columbia River plume. Upwelling of low-pH water may exacerbate ocean acidification. The Columbia and other tributaries supply sediments, which are stirred by water movements and by burrowing shrimp. Solar inputs support photosynthesis but also stress organisms during daytime low tides. Future climate change may affect temperatures, precipitation, and productivity.
CLIMATE CHANGE
SOLAR ENERGY
TRIBUTARIES
waterfowl
FRESHWATER INPUT
INTERTIDAL ZONE
shorebirds & seabirds
Harbor seals
native eelgrass
oysters & clams
other fish
MUDFLATS
MOUTH (ocean)
SEDIMENT RESUSPENSION/ BIOTURBATION
phytoplankton
other invertebrates
salmon
TIDES, UPWELLING & PLUMES
burrowing shrimp
detritus
Sevengill sharks
invasive eelgrass
sturgeon
SEDIMENT INPUT (Columbia River & local tributaries
ulva & other macroalgae
Dungeness crab

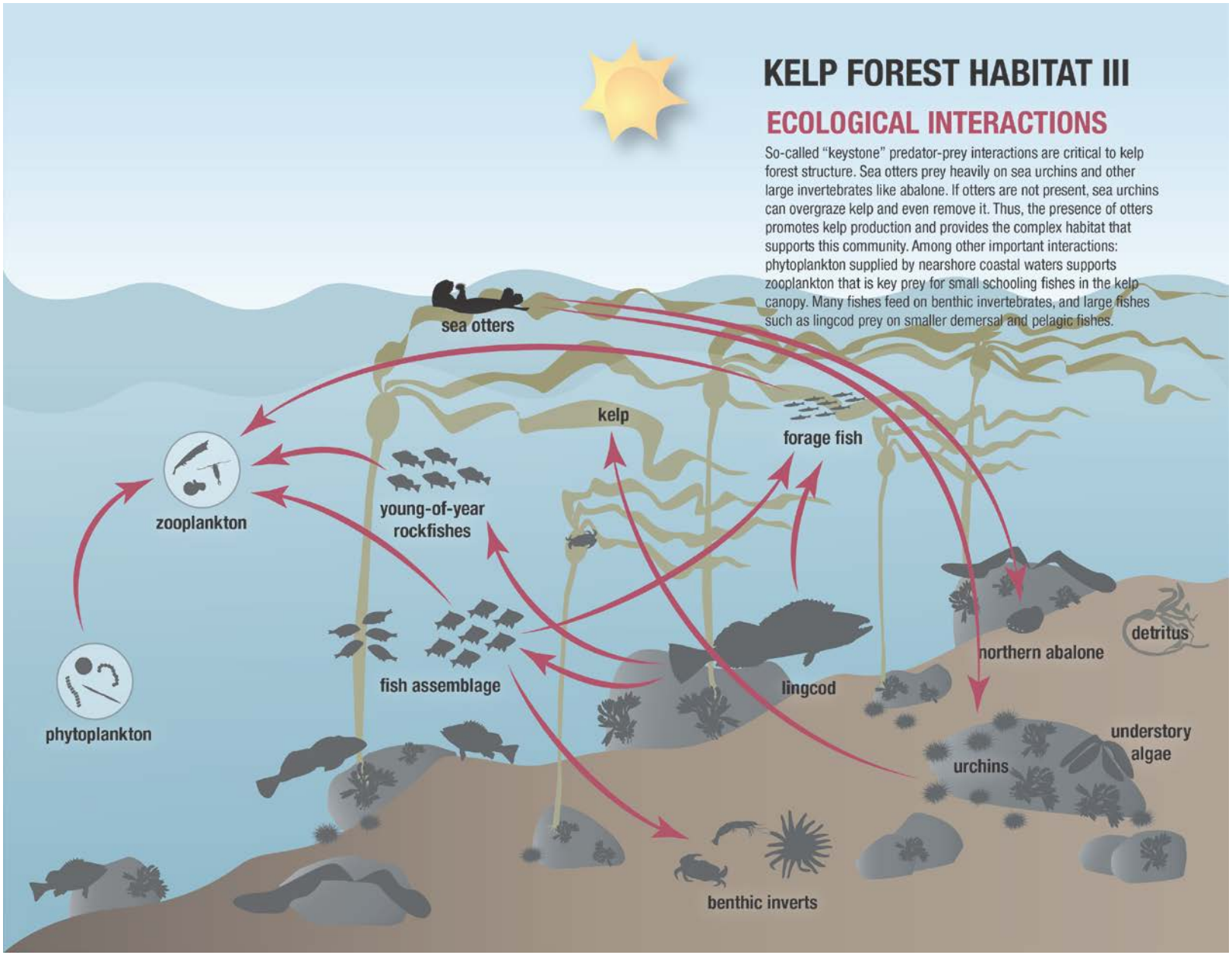

ESTUARY HABITAT III
ECOLOGICAL INTERACTIONS
Most estuarine invertebrates, including oysters, clams and burrowing shrimp, feed on phytoplankton and particles of organic detritus that are either suspended in the water column or deposited on the bottom. This includes detritus derived from eelgrass and macroalgae. These invertebrates are fed upon by larger invertebrates and fishes; in particular, large crabs like Dungeness crabs prey on oysters and clams. Shorebirds, seabirds and harbor seals feed on invertebrates and on small fishes; some waterfowl graze on eelgrass. The apex predators, sevengill sharks, migrate into the bays in spring and summer to feed on harbor seals.
TRIBUTARIES
waterfowl
shorebirds & seabirds
INTERTIDAL ZONE
native eelgrass
oysters & clams
other fish
Harbor seals
MOUTH (ocean)
MUDFLATS
phytoplankton
other invertebrates
salmon
burrowing shrimp
detritus
Sevengill sharks
sturgeon
invasive eelgrass
ulva & other macroalgae
Dungeness crab

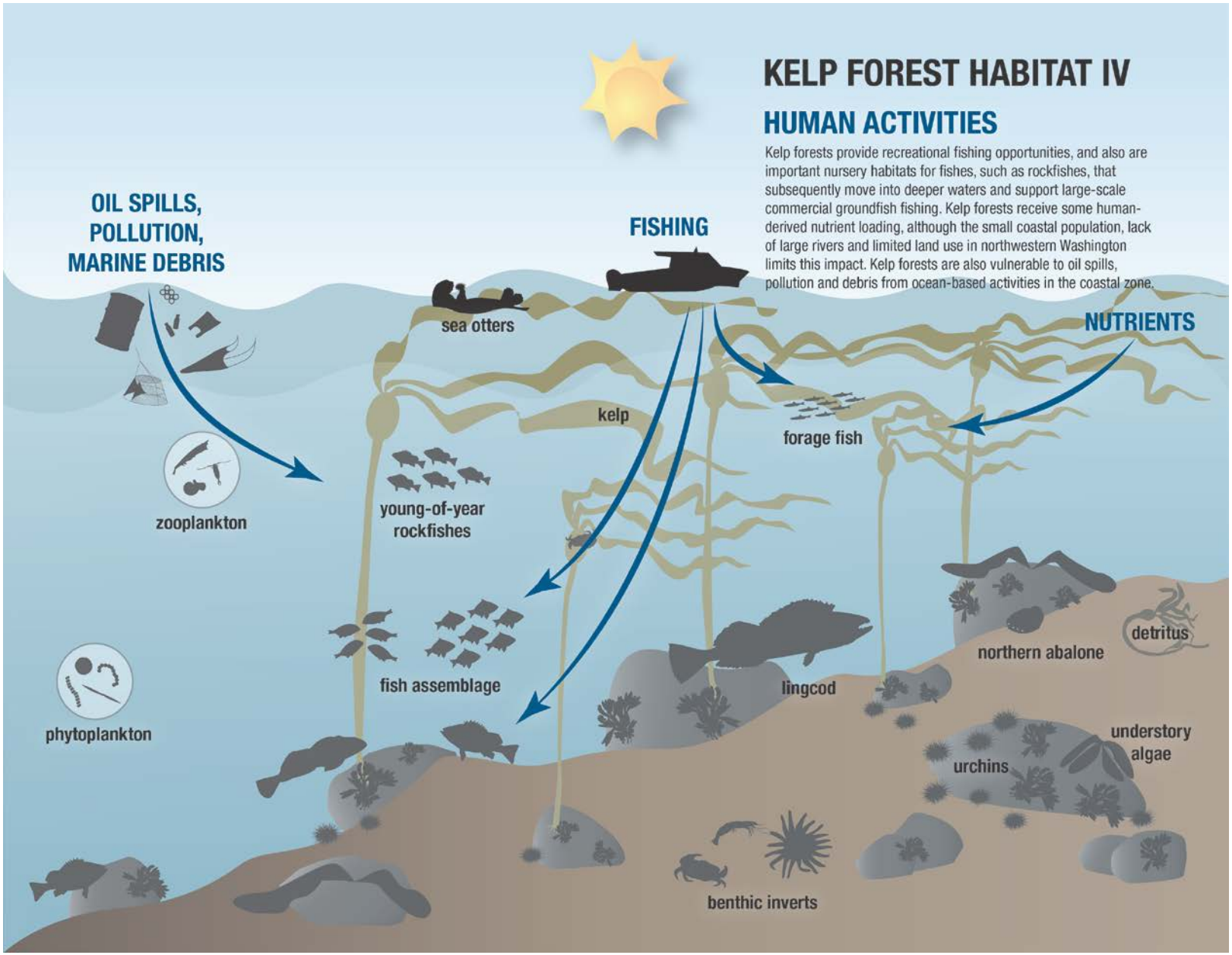

ESTUARY HABITAT IV
HUMAN ACTIVITIES - Grays Harbor
Grays Harbor supports a wide range of human activities. Bivalve aquaculture, primarily of oysters and clams, is extensive on intertidal mudflats. Recreational fisheries target salmon, sturgeon, other fishes, and crabs; commercial and tribal fisheries target salmon and crabs. The main city and port of Aberdeen is highly developed and supports an active shipping industry, which requires regular dredging to maintain adequate channel depths. Other activities in the watershed include timber harvest, agriculture, and residential development; the dams in the nearby Columbia River watershed affect sediment delivery. Human activities generate pollution, and the shipping and aquaculture industries can introduce non-native species.
TRIBUTARIES
WATERSHED ACTIVITIES
waterfowl
AQUACULTURE
INTERTIDAL ZONE
shorebirds & seabirds
Harbor seals
native eelgrass
oysters & clams
other fish
MUDFLATS
POLLUTANTS
FISHING
MOUTH (ocean)
phytoplankton
other invertebrates
salmon
burrowing shrimp
SHIPPING
DREDGING
detritus
Sevengill sharks
sturgeon
invasive eelgrass
NON-NATIVE SPECIES
PORT DEVELOPMENT
ulva & other macroalgae
Dungeness crab

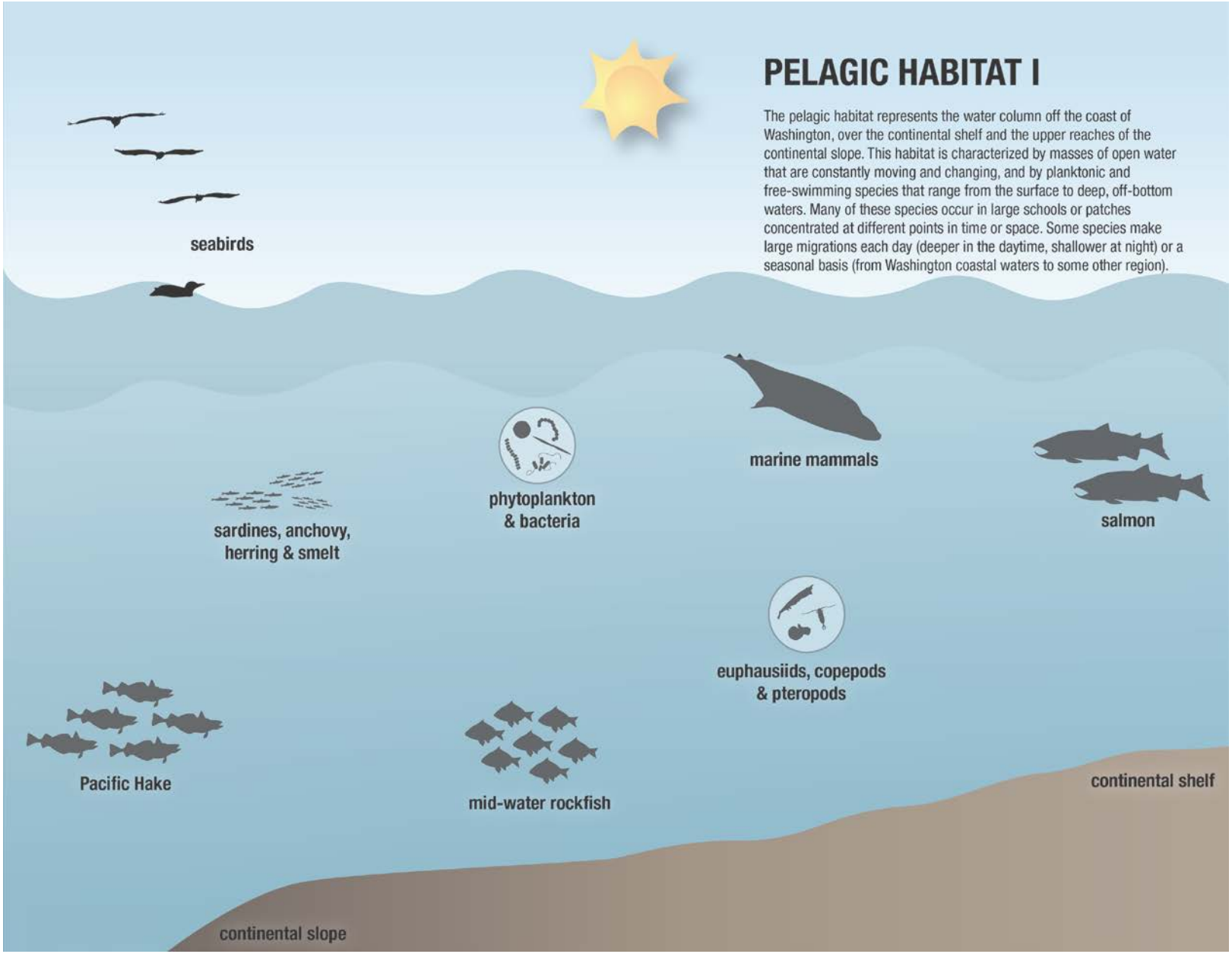

ESTUARY HABITAT V
HUMAN ACTIVITIES - Willapa Bay
Willapa Bay has an extensive aquaculture industry for oysters and clams. The aquaculture industry is highly valuable economically, but has resulted in expensive non-native species introductions and pesticide spraying on burrowing shrimp. Willapa Bay does not have a major port, but has some shoreline development and a small amount of dredging around small marinas. Willapa Bay lacks a large tributary like the Chehalis River in Grays Harbor; thus watershed activities such as forestry, agriculture and residential development may be less influential. Dams in the nearby Columbia River watershed affect sediment delivery. Fisheries target salmon, other fishes, and crabs.
TRIBUTARIES
WATERSHED ACTIVITIES
shorebirds & seabirds
waterfowl
AQUACULTURE
INTERTIDAL ZONE
Harbor seals
native eelgrass
oysters & clams
other fish
MUDFLATS
FISHING
MOUTH (ocean)
POLLUTANTS
phytoplankton
other invertebrates
salmon
burrowing shrimp
CHEMICAL CONTROLS
DREDGING
detritus
Sevengill sharks
invasive eelgrass
NON-NATIVE SPECIES
sturgeon
SHORELINE DEVELOPMENT
ulva & other macroalgae
Dungeness crab

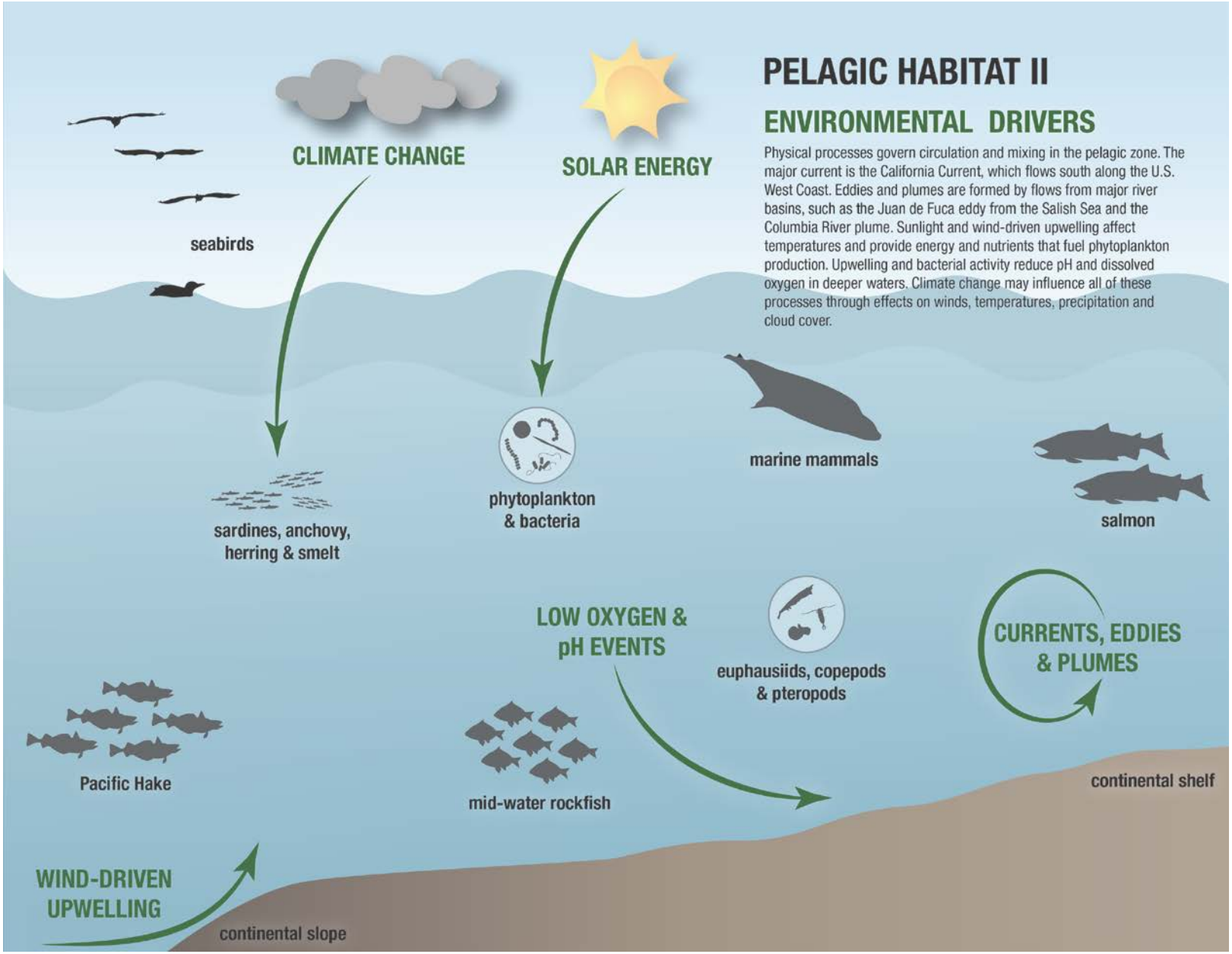

KELP FOREST HABITAT I
Kelp forests typically are associated with wave-exposed rocky reefs from the subtidal zone down to about 60-meter depths. The dominant canopy-forming kelp species in Washington is bull kelp, which extends from rocky attachments to the surface during the growing season. Many understory kelp species are found below. Kelp provides three-dimensional habitat structure for many pelagic and benthic species at the margins of the intertidal and open ocean communities. This includes nursery habitat for young-of-the-year rockfishes. Both live and detached kelp provides detritus that is fed upon by grazers and scavengers; detached kelp subsidizes food webs in adjacent habitats.
sea otters
kelp
forage fish
zooplankton
young-of-year rockfishes
fish assemblage
phytoplankton
lingcod
northern abalone
detritus
understory algae
urchins
benthic inverts

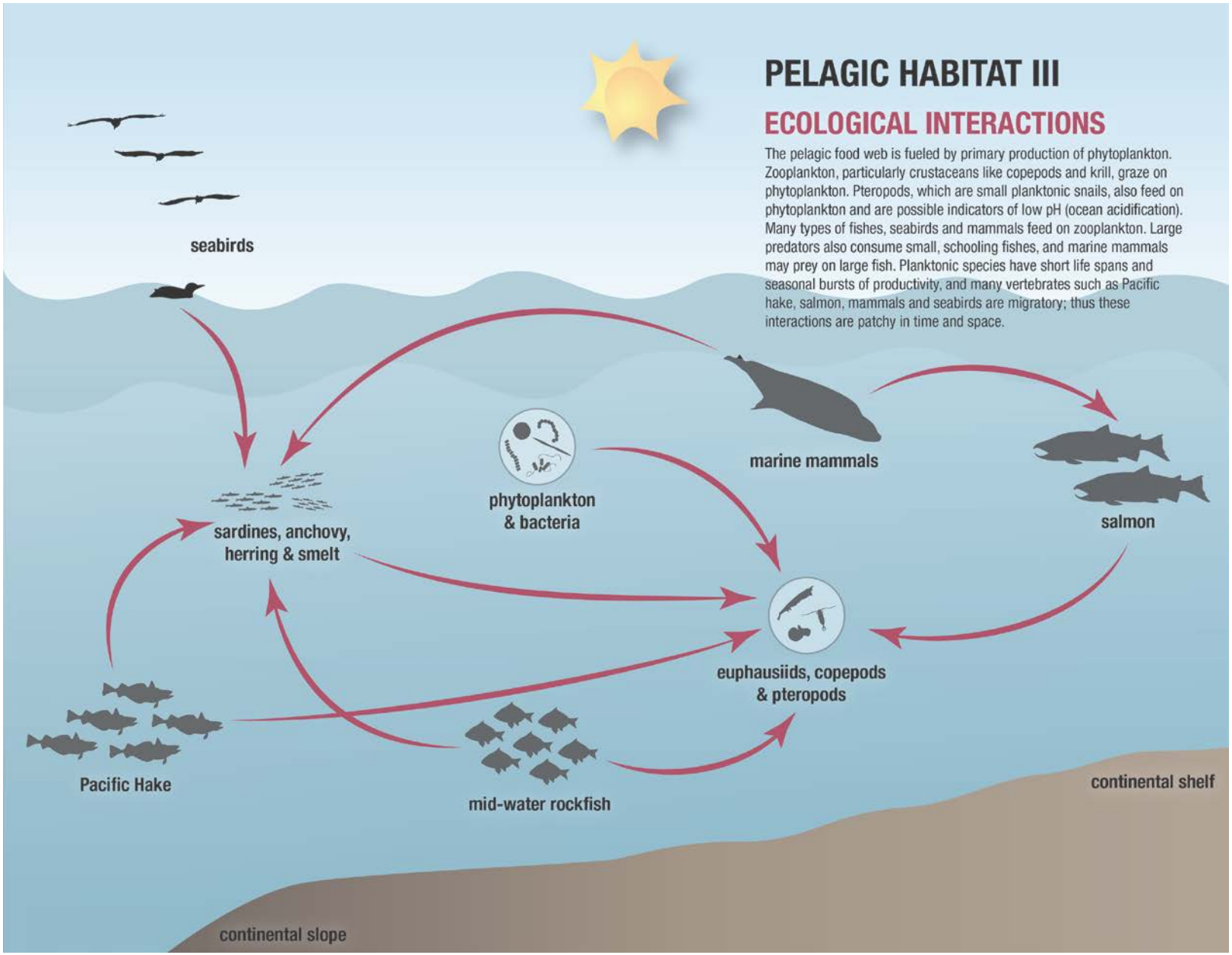

KELP FOREST HABITAT II
ENVIRONMENTAL DRIVERS
Kelp forests are fueled by solar energy, especially during the long days of spring and summer, and by nutrients provided by upwelling. These factors are especially important for the rapid growth of bull kelp, which has a lifespan of a single growing season. Sediment loading may bury newly settled kelp sporophytes, or may increase turbidity and reduce light for photosynthesis. Kelps are often damaged or detached in intense local storm events. Future climate change may affect kelp forest production via the intensity and frequency of upwelling events and storms, or may alter solar input by changing cloud cover.
LOCALIZED STORM
CLIMATE CHANGE
SOLAR ENERGY
sea otters
kelp
forage fish
zooplankton
young-of-year rockfishes
fish assemblage
lingcod
northern abalone
detritus
understory algae
urchins
phytoplankton
WIND-DRIVEN UPWELLING
SEDIMENTATION
benthic inverts

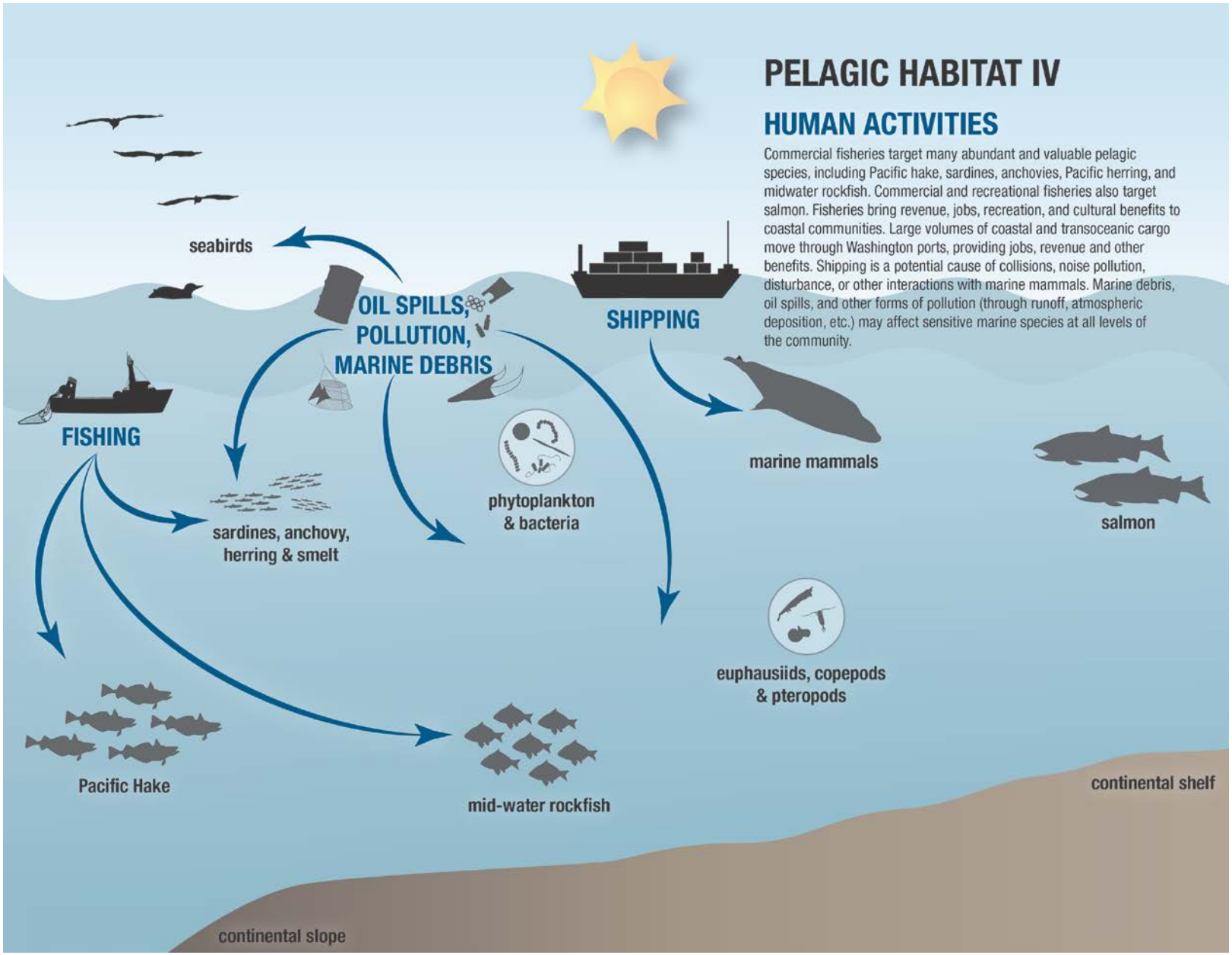

KELP FOREST HABITAT III
ECOLOGICAL INTERACTIONS
So-called "keystone" predator-prey interactions are critical to kelp forest structure. Sea otters prey heavily on sea urchins and other large invertebrates like abalone. If otters are not present, sea urchins can overgraze kelp and even remove it. Thus, the presence of otters promotes kelp production and provides the complex habitat that supports this community. Among other important interactions: phytoplankton supplied by nearshore coastal waters supports zooplankton that is key prey for small schooling fishes in the kelp canopy. Many fishes feed on benthic invertebrates, and large fishes such as lingcod prey on smaller demersal and pelagic fishes.
sea otters
kelp
forage fish
zooplankton
young-of-year rockfishes
fish assemblage
lingcod
northern abalone
detritus
phytoplankton
understory algae
urchins
benthic inverts

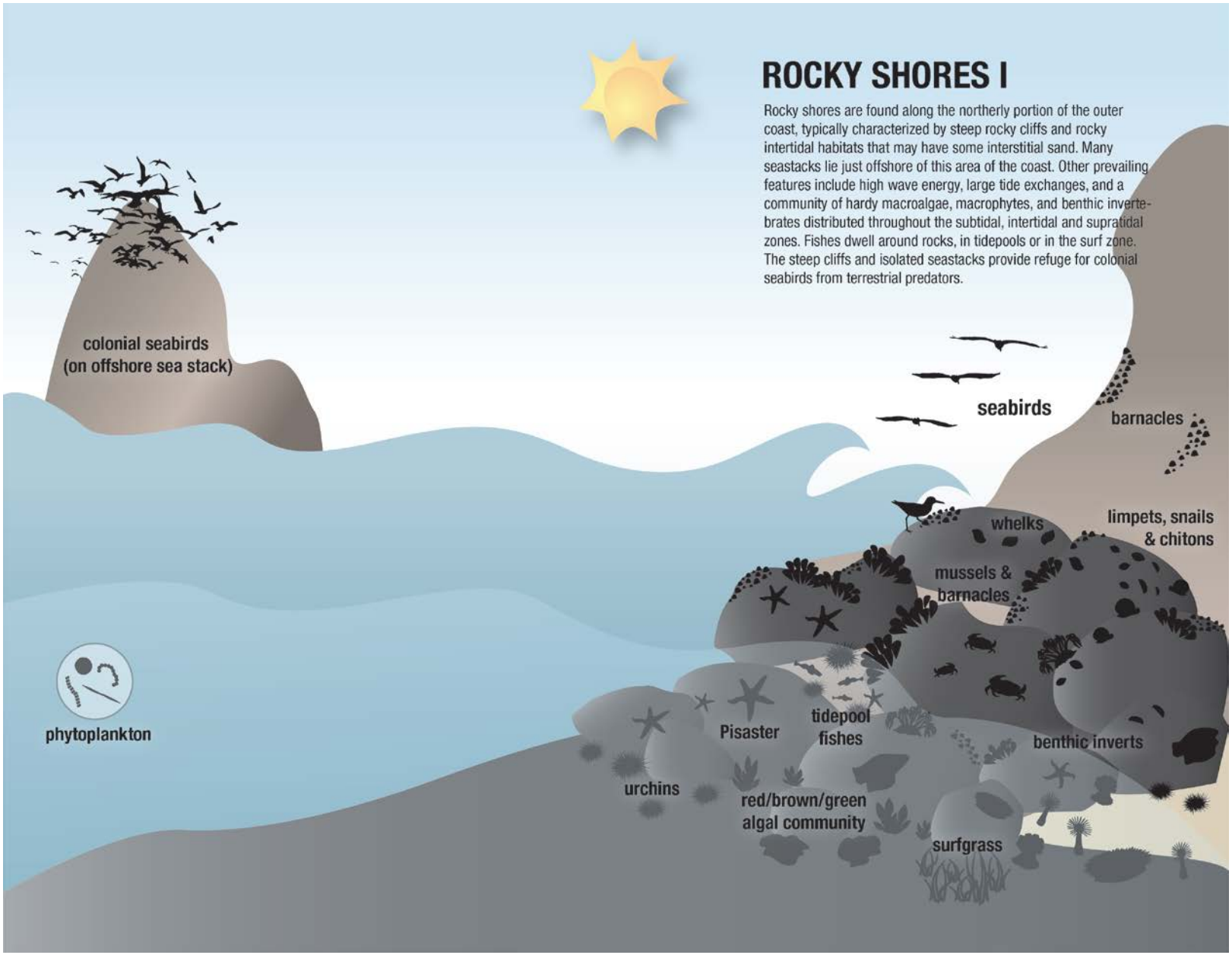

KELP FOREST HABITAT IV
HUMAN ACTIVITIES
Kelp forests provide recreational fishing opportunities, and also are important nursery habitats for fishes, such as rockfishes, that subsequently move into deeper waters and support large-scale commercial groundfish fishing. Kelp forests receive some human-derived nutrient loading, although the small coastal population, lack of large rivers and limited land use in northwestern Washington limits this impact. Kelp forests are also vulnerable to oil spills, pollution and debris from ocean-based activities in the coastal zone.
OIL SPILLS, POLLUTION, MARINE DEBRIS
FISHING
NUTRIENTS
sea otters
kelp
forage fish
zooplankton
young-of-year rockfishes
fish assemblage
lingcod
northern abalone
detritus
phytoplankton
understory algae
urchins
benthic inverts

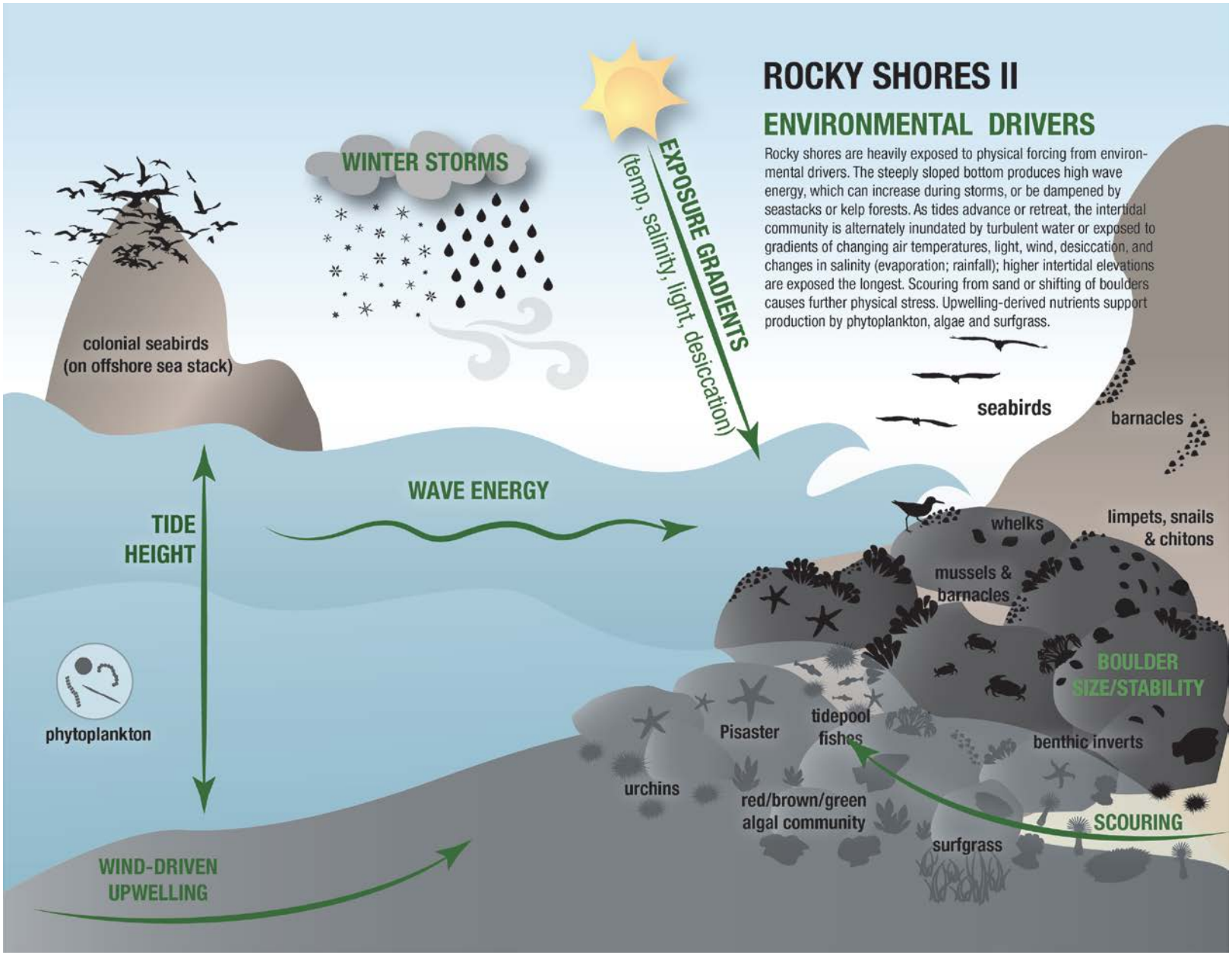

PELAGIC HABITAT I
The pelagic habitat represents the water column off the coast of Washington, over the continental shelf and the upper reaches of the continental slope. This habitat is characterized by masses of open water that are constantly moving and changing, and by planktonic and free-swimming species that range from the surface to deep, off-bottom waters. Many of these species occur in large schools or patches concentrated at different points in time or space. Some species make large migrations each day (deeper in the daytime, shallower at night) or a seasonal basis (from Washington coastal waters to some other region).
seabirds
marine mammals
phytoplankton & bacteria
salmon
sardines, anchovy, herring & smelt
euphausiids, copepods & pteropods
Pacific Hake
mid-water rockfish
continental shelf
continental slope

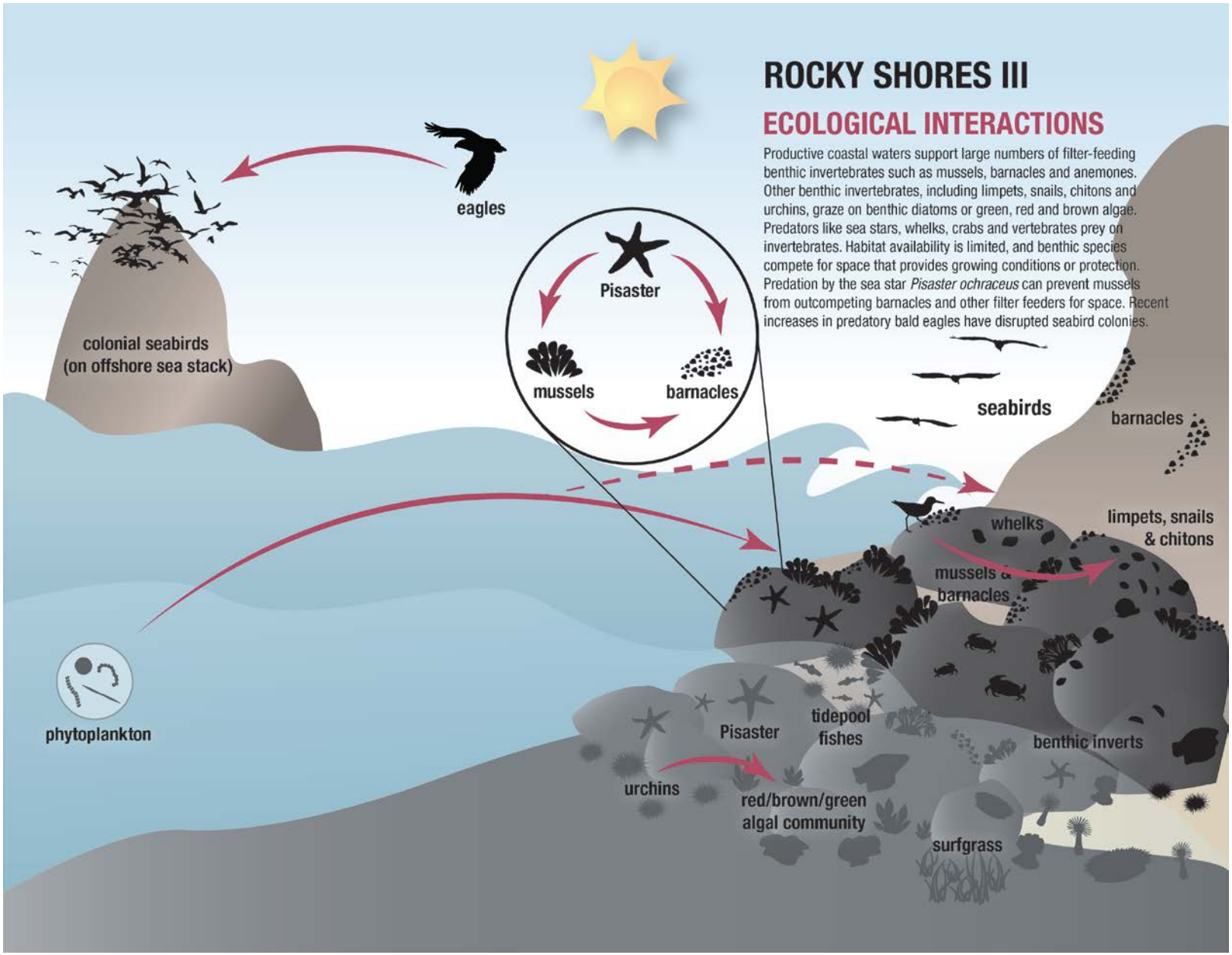

PELAGIC HABITAT II
ENVIRONMENTAL DRIVERS
Physical processes govern circulation and mixing in the pelagic zone. The major current is the California Current, which flows south along the U.S. West Coast. Eddies and plumes are formed by flows from major river basins, such as the Juan de Fuca eddy from the Salish Sea and the Columbia River plume. Sunlight and wind-driven upwelling affect temperatures and provide energy and nutrients that fuel phytoplankton production. Upwelling and bacterial activity reduce pH and dissolved oxygen in deeper waters. Climate change may influence all of these processes through effects on winds, temperatures, precipitation and cloud cover.
CLIMATE CHANGE
SOLAR ENERGY
seabirds
marine mammals
salmon
phytoplankton & bacteria
sardines, anchovy, herring & smelt
LOW OXYGEN & pH EVENTS
euphausiids, copepods & pteropods
CURRENTS, EDDIES & PLUMES
Pacific Hake
mid-water rockfish
continental shelf
WIND-DRIVEN UPWELLING
continental slope

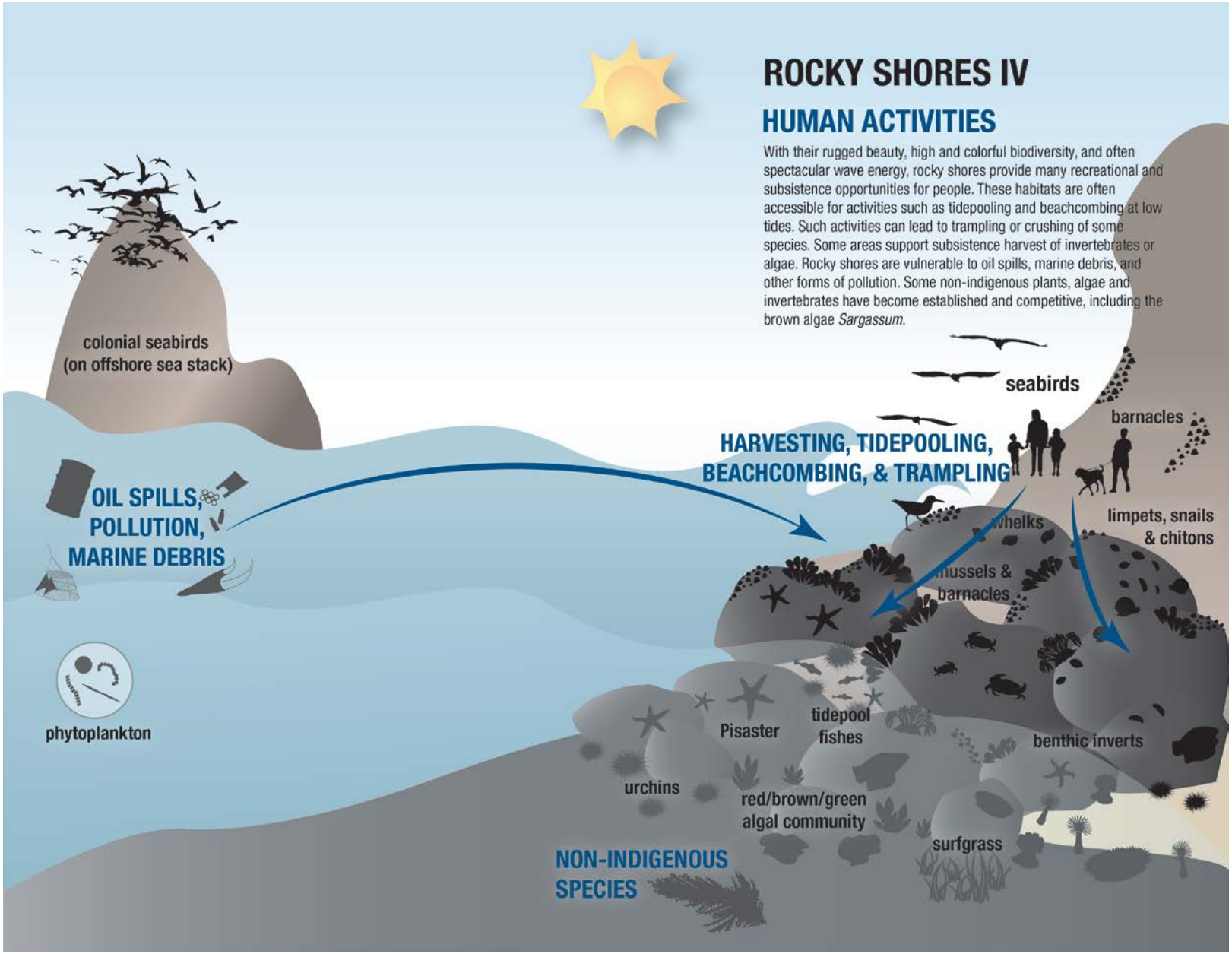

PELAGIC HABITAT III
ECOLOGICAL INTERACTIONS
The pelagic food web is fueled by primary production of phytoplankton. Zooplankton, particularly crustaceans like copepods and krill, graze on phytoplankton. Pteropods, which are small planktonic snails, also feed on phytoplankton and are possible indicators of low pH (ocean acidification). Many types of fishes, seabirds and mammals feed on zooplankton. Large predators also consume small, schooling fishes, and marine mammals may prey on large fish. Planktonic species have short life spans and seasonal bursts of productivity, and many vertebrates such as Pacific hake, salmon, mammals and seabirds are migratory; thus these interactions are patchy in time and space.
seabirds
marine mammals
salmon
phytoplankton & bacteria
sardines, anchovy, herring & smelt
euphausiids, copepods & pteropods
Pacific Hake
mid-water rockfish
continental shelf
continental slope


PELAGIC HABITAT IV
HUMAN ACTIVITIES
Commercial fisheries target many abundant and valuable pelagic species, including Pacific hake, sardines, anchovies, Pacific herring, and midwater rockfish. Commercial and recreational fisheries also target salmon. Fisheries bring revenue, jobs, recreation, and cultural benefits to coastal communities. Large volumes of coastal and transoceanic cargo move through Washington ports, providing jobs, revenue and other benefits. Shipping is a potential cause of collisions, noise pollution, disturbance, or other interactions with marine mammals. Marine debris, oil spills, and other forms of pollution (through runoff, atmospheric deposition, etc.) may affect sensitive marine species at all levels of the community.
seabirds
OIL SPILLS, POLLUTION, MARINE DEBRIS
SHIPPING
FISHING
marine mammals
salmon
phytoplankton & bacteria
sardines, anchovy, herring & smelt
euphausiids, copepods & pteropods
Pacific Hake
mid-water rockfish
continental shelf
continental slope


ROCKY SHORES I
Rocky shores are found along the northerly portion of the outer coast, typically characterized by steep rocky cliffs and rocky intertidal habitats that may have some interstitial sand. Many seastacks lie just offshore of this area of the coast. Other prevailing features include high wave energy, large tide exchanges, and a community of hardy macroalgae, macrophytes, and benthic invertebrates distributed throughout the subtidal, intertidal and supratidal zones. Fishes dwell around rocks, in tidepools or in the surf zone. The steep cliffs and isolated seastacks provide refuge for colonial seabirds from terrestrial predators.
colonial seabirds
(on offshore sea stack)
seabirds
barnacles
whelks
limpets, snails
& chitons
mussels &
barnacles
phytoplankton
Pisaster
tidepool
fishes
benthic inverts
urchins
red/brown/green
algal community
surfgrass

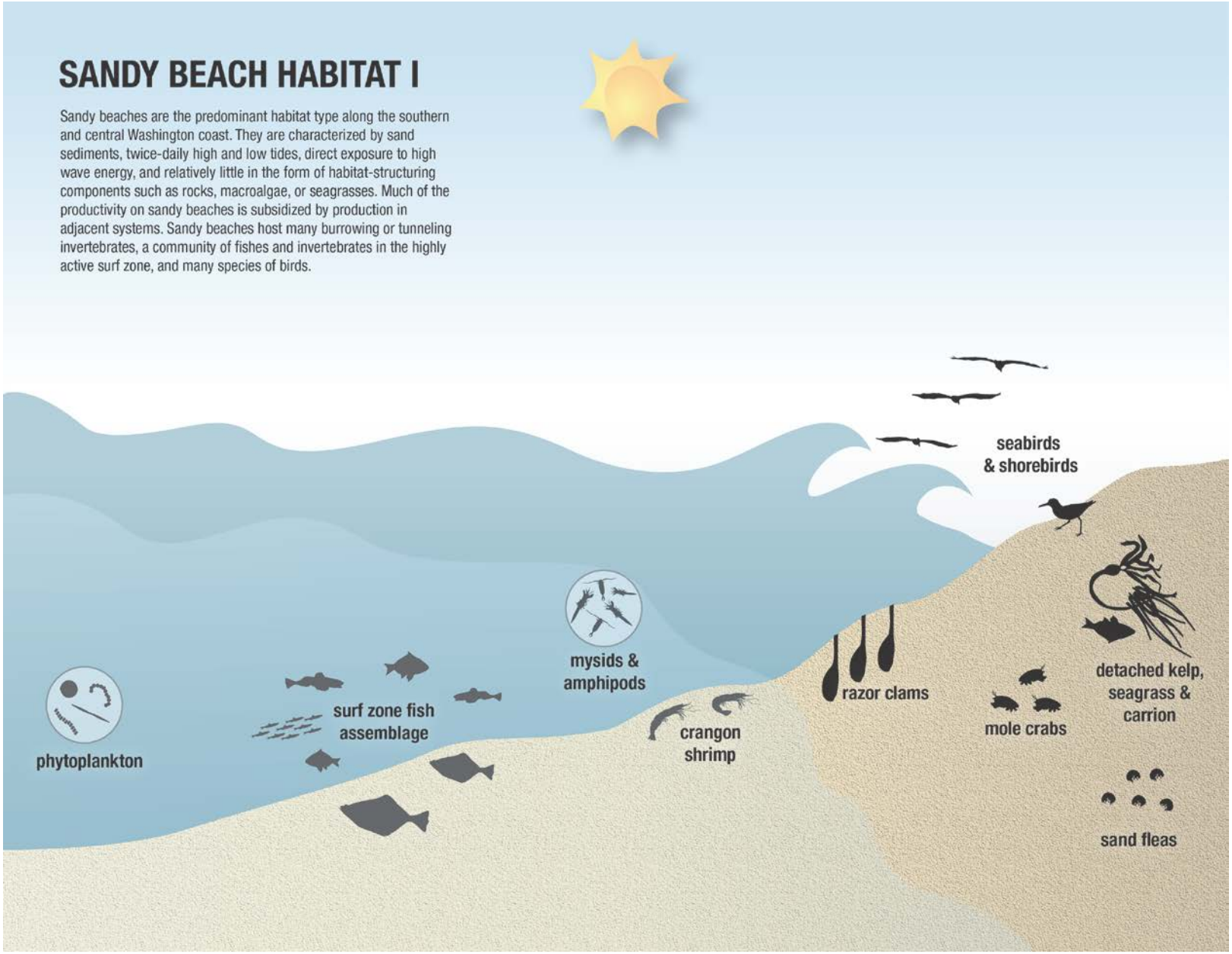

ROCKY SHORES II
ENVIRONMENTAL DRIVERS
Rocky shores are heavily exposed to physical forcing from environmental drivers. The steeply sloped bottom produces high wave energy, which can increase during storms, or be dampened by seastacks or kelp forests. As tides advance or retreat, the intertidal community is alternately inundated by turbulent water or exposed to gradients of changing air temperatures, light, wind, desiccation, and changes in salinity (evaporation; rainfall); higher intertidal elevations are exposed the longest. Scouring from sand or shifting of boulders causes further physical stress. Upwelling-derived nutrients support production by phytoplankton, algae and surfgrass.
WINTER STORMS
EXPOSURE GRADIENTS
(temp, salinity, light, desiccation)
colonial seabirds
(on offshore sea stack)
seabirds
barnacles
WAVE ENERGY
TIDE
HEIGHT
whelks
limpets, snails
& chitons
mussels &
barnacles
BOULDER
SIZE/STABILITY
phytoplankton
Pisaster
tidepool
fishes
benthic inverts
urchins
red/brown/green
algal community
SCOURING
surfgrass
WIND-DRIVEN
UPWELLING

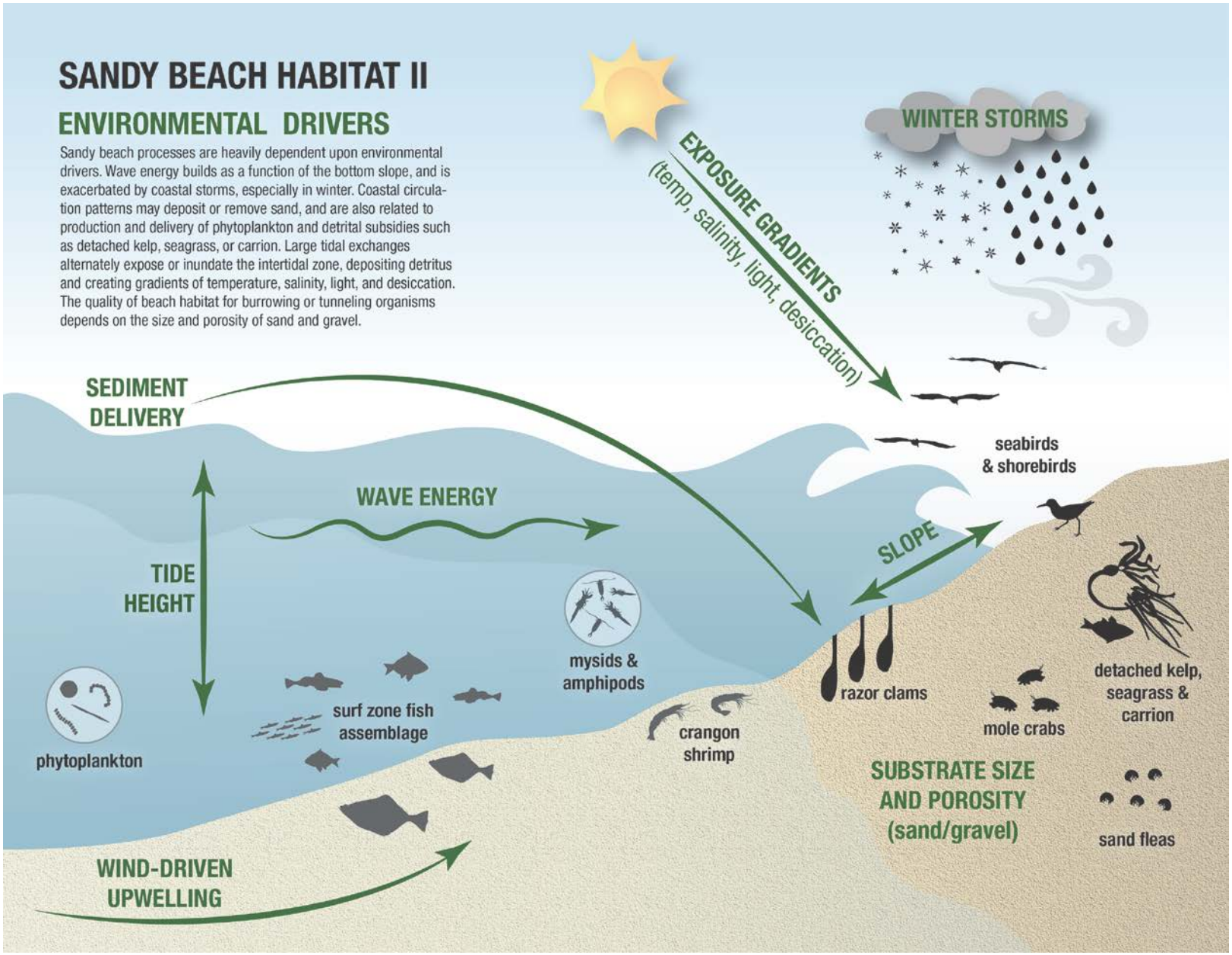

ROCKY SHORES III
ECOLOGICAL INTERACTIONS
Productive coastal waters support large numbers of filter-feeding benthic invertebrates such as mussels, barnacles and anemones. Other benthic invertebrates, including limpets, snails, chitons and urchins, graze on benthic diatoms or green, red and brown algae. Predators like sea stars, whelks, crabs and vertebrates prey on invertebrates. Habitat availability is limited, and benthic species compete for space that provides growing conditions or protection. Predation by the sea star *Pisaster ochraceus* can prevent mussels from outcompeting barnacles and other filter feeders for space. Recent increases in predatory bald eagles have disrupted seabird colonies.
eagles
colonial seabirds
(on offshore sea stack)
Pisaster
mussels
barnacles
seabirds
barnacles
whelks
limpets, snails
& chitons
mussels &
barnacles
phytoplankton
Pisaster
tidepool
fishes
benthic inverts
urchins
red/brown/green
algal community
surfgrass

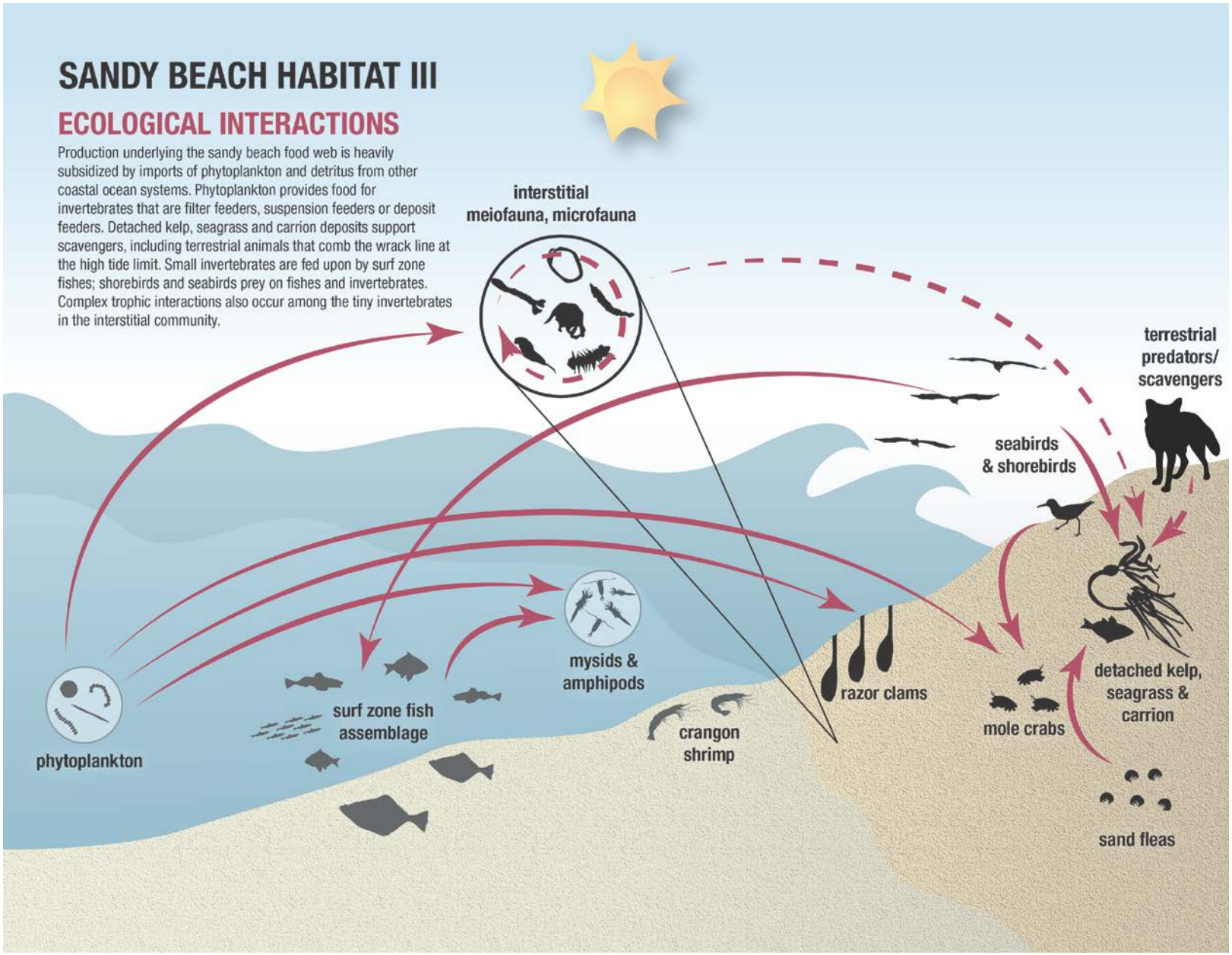

ROCKY SHORES IV
HUMAN ACTIVITIES
With their rugged beauty, high and colorful biodiversity, and often spectacular wave energy, rocky shores provide many recreational and subsistence opportunities for people. These habitats are often accessible for activities such as tidepooling and beachcombing at low tides. Such activities can lead to trampling or crushing of some species. Some areas support subsistence harvest of invertebrates or algae. Rocky shores are vulnerable to oil spills, marine debris, and other forms of pollution. Some non-indigenous plants, algae and invertebrates have become established and competitive, including the brown algae Sargassum.
colonial seabirds (on offshore sea stack)
seabirds
barnacles
HARVESTING, TIDEPOOLING, BEACHCOMBING, & TRAMPLING
OIL SPILLS, POLLUTION, MARINE DEBRIS
whelks
limpets, snails & chitons
mussels & barnacles
phytoplankton
Pisaster
tidepool fishes
benthic inverts
urchins
red/brown/green algal community
surfgrass
NON-INDIGENOUS SPECIES

SANDY BEACH HABITAT I

Sandy beaches are the predominant habitat type along the southern and central Washington coast. They are characterized by sand sediments, twice-daily high and low tides, direct exposure to high wave energy, and relatively little in the form of habitat-structuring components such as rocks, macroalgae, or seagrasses. Much of the productivity on sandy beaches is subsidized by production in adjacent systems. Sandy beaches host many burrowing or tunneling invertebrates, a community of fishes and invertebrates in the highly active surf zone, and many species of birds.



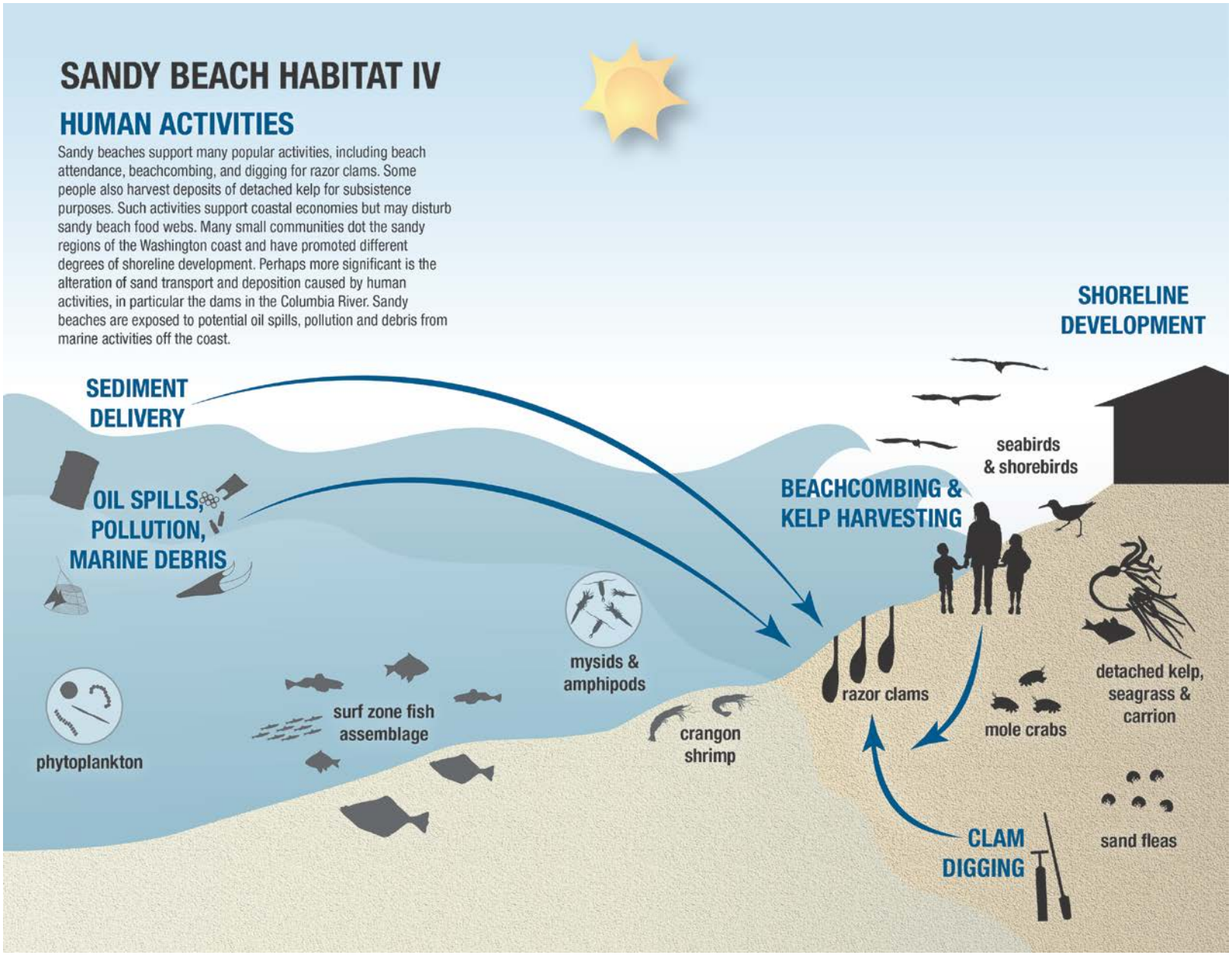

SANDY BEACH HABITAT II
ENVIRONMENTAL DRIVERS
Sandy beach processes are heavily dependent upon environmental drivers. Wave energy builds as a function of the bottom slope, and is exacerbated by coastal storms, especially in winter. Coastal circulation patterns may deposit or remove sand, and are also related to production and delivery of phytoplankton and detrital subsidies such as detached kelp, seagrass, or carrion. Large tidal exchanges alternately expose or inundate the intertidal zone, depositing detritus and creating gradients of temperature, salinity, light, and desiccation. The quality of beach habitat for burrowing or tunneling organisms depends on the size and porosity of sand and gravel.
EXPOSURE GRADIENTS
(temp, salinity, light, desiccation)
WINTER STORMS
SEDIMENT DELIVERY
WAVE ENERGY
TIDE HEIGHT
SLOPE
seabirds & shorebirds
mysids & amphipods
phytoplankton
surf zone fish assemblage
crangon shrimp
razor clams
mole crabs
detached kelp, seagrass & carrion
SUBSTRATE SIZE AND POROSITY (sand/gravel)
sand fleas
WIND-DRIVEN UPWELLING

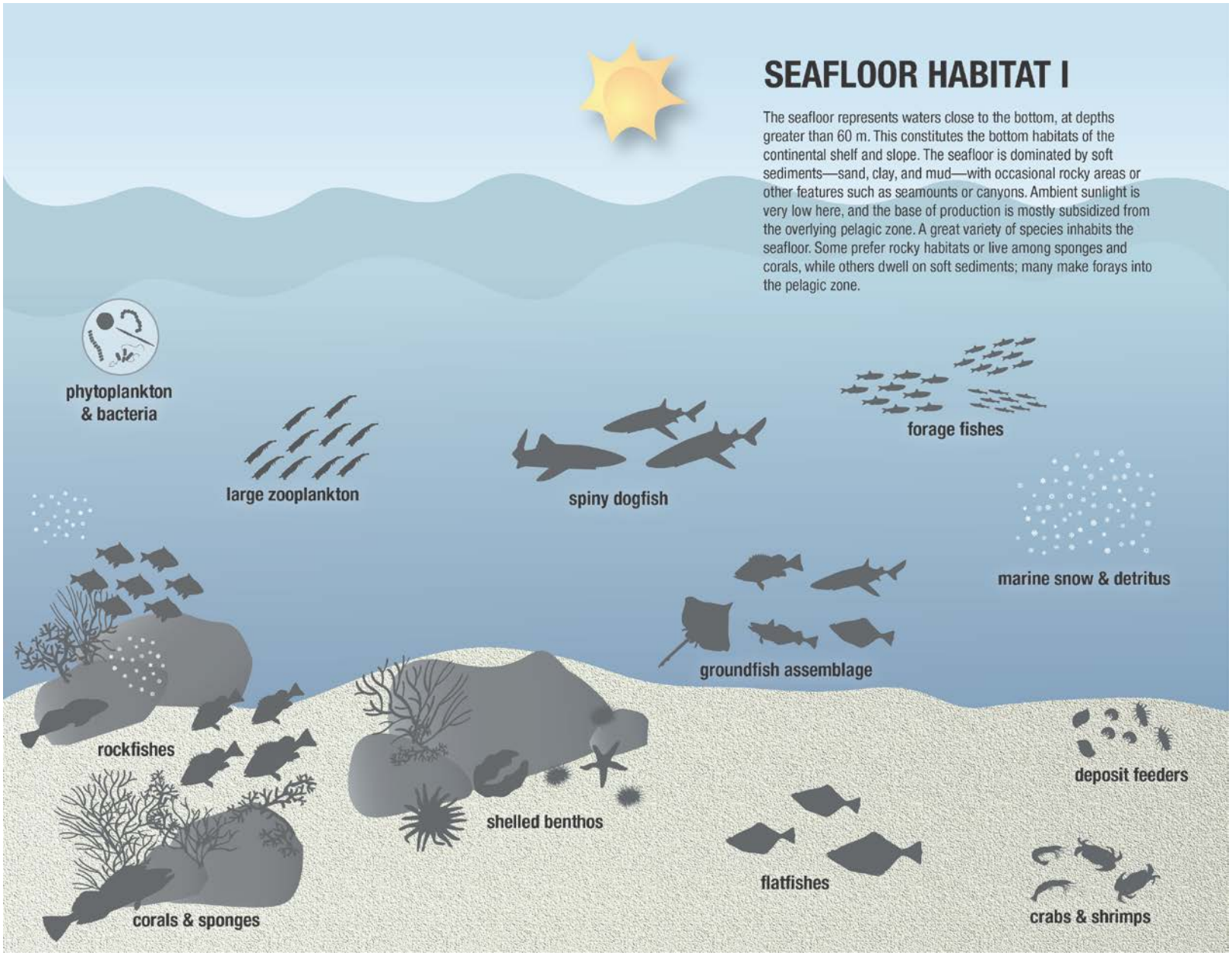

SANDY BEACH HABITAT III
ECOLOGICAL INTERACTIONS
Production underlying the sandy beach food web is heavily subsidized by imports of phytoplankton and detritus from other coastal ocean systems. Phytoplankton provides food for invertebrates that are filter feeders, suspension feeders or deposit feeders. Detached kelp, seagrass and carrion deposits support scavengers, including terrestrial animals that comb the wrack line at the high tide limit. Small invertebrates are fed upon by surf zone fishes; shorebirds and seabirds prey on fishes and invertebrates. Complex trophic interactions also occur among the tiny invertebrates in the interstitial community.
interstitial meiofauna, microfauna
terrestrial predators/ scavengers
seabirds & shorebirds
mysids & amphipods
surf zone fish assemblage
phytoplankton
crangon shrimp
razor clams
mole crabs
detached kelp, seagrass & carrion
sand fleas

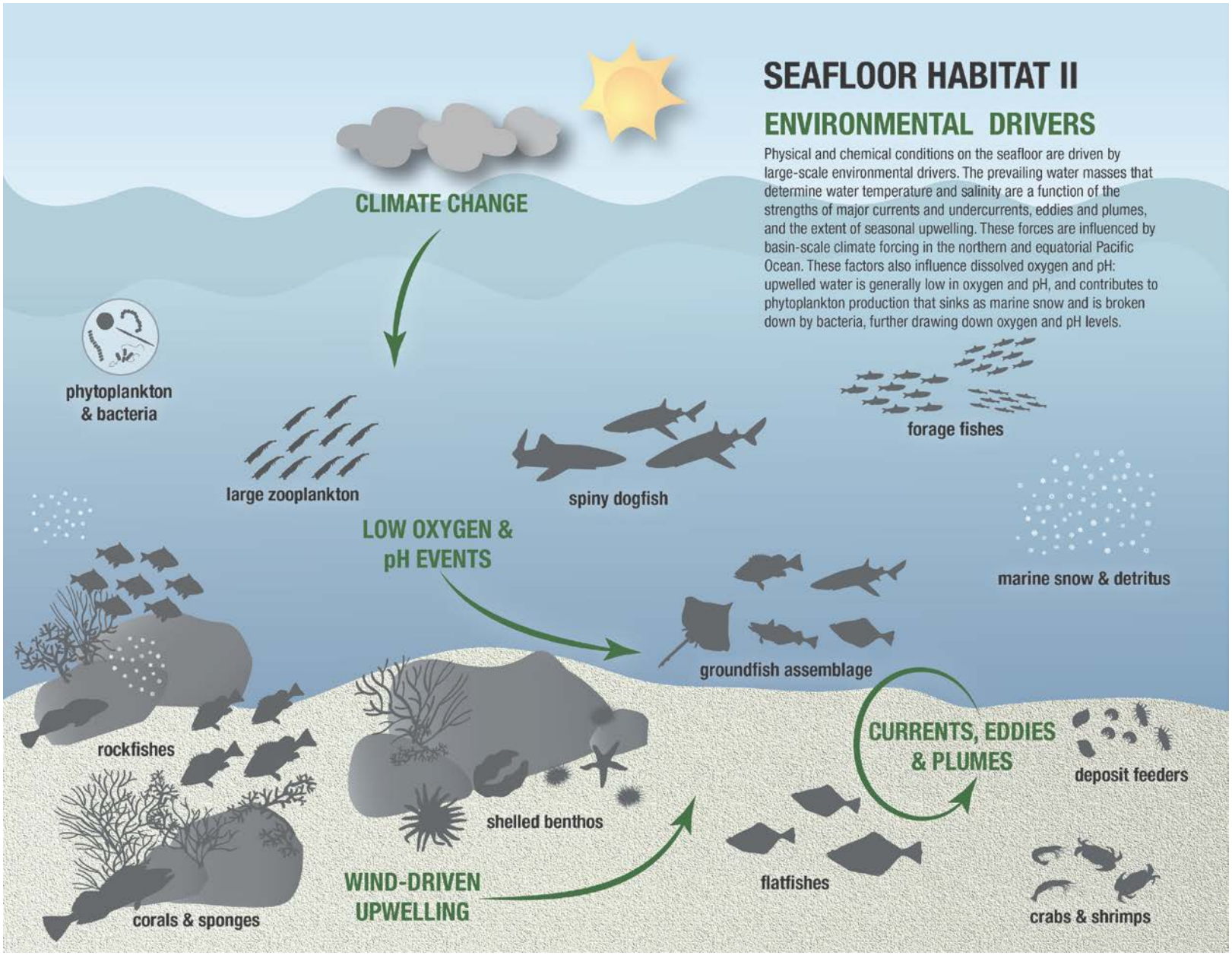
SANDY BEACH HABITAT IV

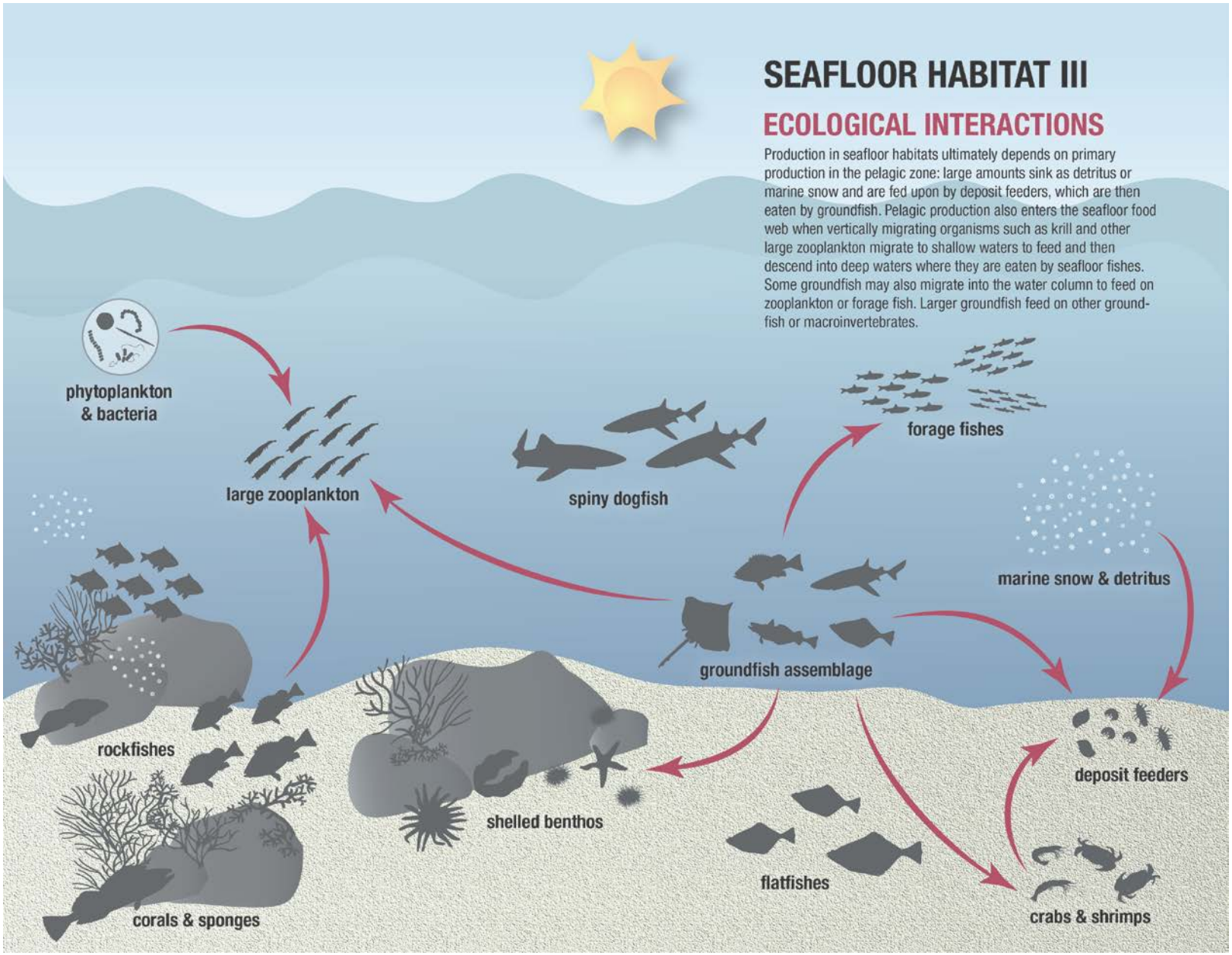
HUMAN ACTIVITIES

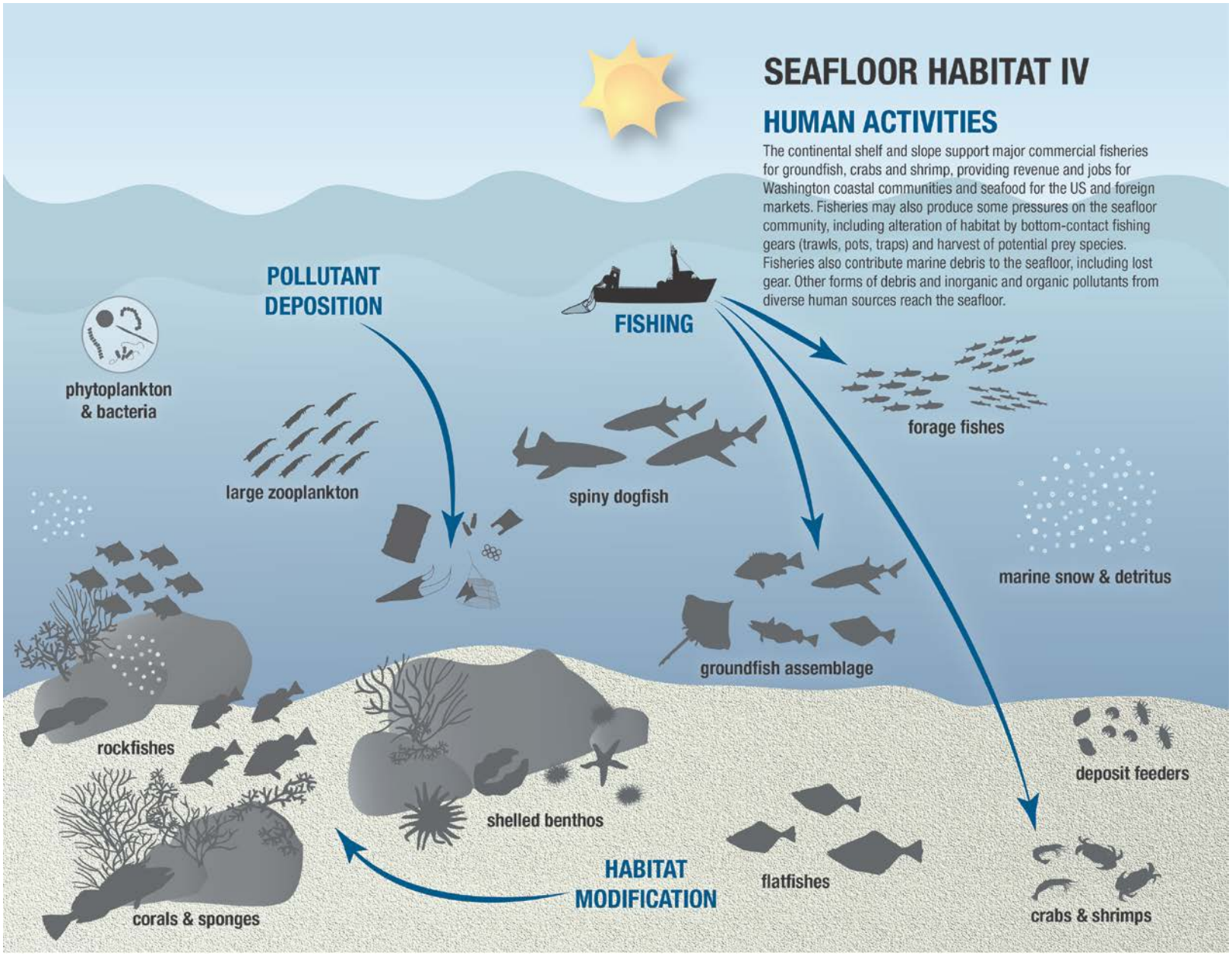
Sandy beaches support many popular activities, including beach attendance, beachcombing, and digging for razor clams. Some people also harvest deposits of detached kelp for subsistence purposes. Such activities support coastal economies but may disturb sandy beach food webs. Many small communities dot the sandy regions of the Washington coast and have promoted different degrees of shoreline development. Perhaps more significant is the alteration of sand transport and deposition caused by human activities, in particular the dams in the Columbia River. Sandy beaches are exposed to potential oil spills, pollution and debris from marine activities off the coast.




SEAFLOOR HABITAT I
The seafloor represents waters close to the bottom, at depths greater than 60 m. This constitutes the bottom habitats of the continental shelf and slope. The seafloor is dominated by soft sediments—sand, clay, and mud—with occasional rocky areas or other features such as seamounts or canyons. Ambient sunlight is very low here, and the base of production is mostly subsidized from the overlying pelagic zone. A great variety of species inhabits the seafloor. Some prefer rocky habitats or live among sponges and corals, while others dwell on soft sediments; many make forays into the pelagic zone.
phytoplankton & bacteria
large zooplankton
spiny dogfish
forage fishes
marine snow & detritus
groundfish assemblage
rockfishes
shelled benthos
deposit feeders
flatfishes
crabs & shrimps
corals & sponges


SEAFLOOR HABITAT II
ENVIRONMENTAL DRIVERS
Physical and chemical conditions on the seafloor are driven by large-scale environmental drivers. The prevailing water masses that determine water temperature and salinity are a function of the strengths of major currents and undercurrents, eddies and plumes, and the extent of seasonal upwelling. These forces are influenced by basin-scale climate forcing in the northern and equatorial Pacific Ocean. These factors also influence dissolved oxygen and pH: upwelled water is generally low in oxygen and pH, and contributes to phytoplankton production that sinks as marine snow and is broken down by bacteria, further drawing down oxygen and pH levels.
CLIMATE CHANGE
phytoplankton & bacteria
large zooplankton
spiny dogfish
forage fishes
LOW OXYGEN & pH EVENTS
marine snow & detritus
groundfish assemblage
rockfishes
shelled benthos
CURRENTS, EDDIES & PLUMES
deposit feeders
corals & sponges
WIND-DRIVEN UPWELLING
flatfishes
crabs & shrimps


SEAFLOOR HABITAT III
ECOLOGICAL INTERACTIONS
Production in seafloor habitats ultimately depends on primary production in the pelagic zone: large amounts sink as detritus or marine snow and are fed upon by deposit feeders, which are then eaten by groundfish. Pelagic production also enters the seafloor food web when vertically migrating organisms such as krill and other large zooplankton migrate to shallow waters to feed and then descend into deep waters where they are eaten by seafloor fishes. Some groundfish may also migrate into the water column to feed on zooplankton or forage fish. Larger groundfish feed on other groundfish or macroinvertebrates.
phytoplankton & bacteria
large zooplankton
spiny dogfish
forage fishes
marine snow & detritus
groundfish assemblage
rockfishes
corals & sponges
shelled benthos
flatfishes
deposit feeders
crabs & shrimps


SEAFLOOR HABITAT IV
HUMAN ACTIVITIES
The continental shelf and slope support major commercial fisheries for groundfish, crabs and shrimp, providing revenue and jobs for Washington coastal communities and seafood for the US and foreign markets. Fisheries may also produce some pressures on the seafloor community, including alteration of habitat by bottom-contact fishing gears (trawls, pots, traps) and harvest of potential prey species. Fisheries also contribute marine debris to the seafloor, including lost gear. Other forms of debris and inorganic and organic pollutants from diverse human sources reach the seafloor.
POLLUTANT DEPOSITION
FISHING
phytoplankton & bacteria
large zooplankton
spiny dogfish
forage fishes
marine snow & detritus
groundfish assemblage
rockfishes
shelled benthos
deposit feeders
HABITAT MODIFICATION
flatfishes
corals & sponges
crabs & shrimps