Point Blue Report

Ocean Research and Management Priorities off the U.S. West Coast

March 30, 2020

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EXECUTIVE SUMMARY

The marine environment along the west coast of the United States is known as the California Current Ecosystem; this eastern boundary system is highly productive due to coastal driven upwelling. In addition to hosting biologically important species, these waters also host important economies and an increasing human population. There is a need to understand the conservation priorities in the California Current, and how these priorities align or conflict with industrial activities and other threats.

In an effort to identify marine conservation priorities, we reviewed 33 documents that focused on ocean research and management issues along the U.S. West Coast. We identified the species, habitats, resources, and threats emphasized by different ocean stakeholders. Important species include fish (e.g., salmonids, Pacific sardine), invertebrates (e.g., Dungeness crab, Olympia oyster), birds (e.g., seabirds, western snowy plover), mammals (e.g., blue whale, Steller sea lion), and different marine vegetation species (e.g., kelp species, sea palm, eelgrass). Most habitats referenced in documents were considered a part of the Marine Nearshore system (e.g., beaches, rocky intertidal, kelp forest) or Estuarine system. In terms of resources, food production was emphasized the most, including fisheries, aquaculture, and other harvesting activities; recreational and cultural uses of the ocean were the second most emphasized resource, followed by commercial development (e.g., shipping), ecological/natural processes that the ocean provides (e.g., ocean circulation, upwelling), and energy (e.g., oil extraction, renewable energy projects).

The threats to the California Current Ecosystem are split into two categories: direct human impacts (threats attributable to direct human activities) and indirect human impacts (threats that are largely related to climate change). In the direct human impacts, we found the top threats emphasized are fishing, pollution (including urban, nonpoint, and industrial sources), and disturbance. The most important indirect human impacts that we found are changes in natural processes, ocean chemistry changes (acidification and hypoxia), sea level rise, increased temperatures (both sea surface and air), and invasive species.

The habitats enduring the most threats are shallow benthic, estuary, intertidal, and pelagic. Shallow benthic habitat is affected by both direct and indirect human impacts, and it is connected to the most number of species groups; however, this habitat is dominated by invertebrates and may not affect different levels of the marine food web as other habitats (e.g., estuary, pelagic). Habitats closest to human populations are considered the most vulnerable and less likely to be resilient to further stressors; the marine nearshore group contains most of these habitats, and the highest priority habitats identified are seagrass beds, beaches, dunes, and rocky intertidal.

INTRODUCTION

The West Coast of the United States is defined by the California Current, which is a current that moves southward from Vancouver to Baja California and contains strong upwelling zones, making this a nutrient-rich system. Like other highly-productive eastern boundary currents in the world, many biologically important species reside or migrate through the California Current System.

The U.S. West Coast also hosts large human population centers (e.g., Seattle, San Francisco, Los Angeles), with people operating in the California Current System for many different reasons; from fishing to oil extraction, the ocean along the U.S. West Coast has great economic value.

In the increasingly crowded waters of the California Current System, conflicts between industrial activities and conservation priorities are inevitable and must be addressed through a rigorous scientific, data-driven foundation. The first step of this process is presented in this report, which is a synthesis of the existing literature and marine prioritization efforts to help characterize the species and habitats that are most vulnerable in the California Current System.

In this report, we will:

1) Identify marine conservation priorities (species, habitats, and resources) in state and federal waters, guided by existing documents and input from ocean experts.

2) Identify the main threats (both direct human threats, as well as threats related to climate change) to habitats and species.

3) Identify the habitats and species most at risk from various human threats.

METHODS

We reviewed reports and peer-reviewed publications that focused on marine research and management issues along the U.S. West Coast. Most of the products we reviewed were the result of online searches (using "ocean prioritization" as our search text). We also solicited recommendations from marine experts (e.g., scientists at CeNCOOS) by having them review our publication list and make recommendations on other products that we should include. When reviewing each document, we identified several key aspects:

1. Goal – A description of the overall intended final outcome and use of the document.
2. Approach – How information and data were collected and synthesized.
3. Spatial scale – Spatial coverage and focus
4. Species – Species or species groups identified as important or of interest
5. Habitats – Specific or general habitat types identified as important or of interest
6. Threats – Human or natural threats to species or habitat types
7. Resources – Uses of natural resources for human consumption
8. Data gaps – Areas or ecological aspects where more research is needed

We recorded each individual habitat, species, threat, and resource identified in each document. For each of these categories, we then further grouped the lists into one or more broader categories for characterizing and highlighting important factors across the documents. We documented prioritization scores if a given document provided those. Once we had our lists of habitats, species, threats, and resources, we disseminated an online survey to marine experts to confirm our findings and request feedback.

To summarize the species, habitats, threats, and resources listed most often in the documents we reviewed, we created treemaps. A treemap is a data visualization technique which makes seeing data categories and their relative values easier. Hierarchical data are arranged into nested rectangles, with the size of each rectangle representing its quantitative value. In our case, the size of each data category indicates the number of times that an individual species, habitat, or threat was emphasized in the reports we reviewed.

In order to show how species, habitats, and threats are linked, we produced a Sankey graph. We produced this interactive tool by first identifying the top 3-5 threats for each habitat type listed for each report. For each species, we also identified the broad habitat group to which they belonged. Thus, this graph shows the connections between species (on the left) and habitat groups (in the middle) and connects these habitats to threats (on the right). Thicker connections indicate where there are more connections identified within the reports we summarized. Treemaps and the Sankey graph were produced with RStudio Team (2018).

RESULTS

Documents reviewed

We reviewed 33 ocean prioritization documents produced between 2007 and 2018 (Table 1; document number citations can also be found in this table). Most of these reports (1, 2, 4, 7, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 32) used either workshops, meetings, surveys, or interviews to gain expert input on different topics. Two reports (6, 17) were strictly literature review documents.

Previous prioritization efforts were led by a number of groups comprised of people from universities, agencies, research institutes, NGOs, consulting groups, native tribes, fishing industries, and politicians.

Each document or study focused on different aspects of marine management and/or resource protection. Each varied in spatial extent, with most of the documents covering some part of the California coast (2, 3, 4, 7, 12, 13, 16, 18, 21, 23, 24, 26, 28, 32, 33), five covering Washington (14, 15, 26, 27, 30), three covering Oregon (11, 17, 22), and the remaining covering the entire California Current (1, 5, 6, 8, 10, 19, 31) and beyond (9, 20).

Some reports were monitoring plans which focused more on the ecological communities and recommendations for monitoring them (11, 12, 13, 14, 23, 24). Other efforts focused more on identifying or cataloguing the many threats (mostly anthropogenic in origin) to the marine ecosystem, assessing their impacts, and prioritizing threats (1, 8, 9, 10, 20, 33). Fishing (5, 7, 16) and water quality (12) were the focus of a few reports, while others focused specifically on climate change and its many impacts to habitats and species (3, 17, 21, 22, 25, 26, 27, 29, 30) or to human infrastructure, health, and economies (15, 18, 19). One effort identified specific species or physical variables to monitor climate change impacts (4), while another report weighed the vulnerabilities of species and habitats to climate change (2). One paper focused only on threats to California marine protected areas (33) in an effort to examine areas that are receiving some protections from human activities yet still face many stressors.

Online survey results

An online survey was shared with scientists from CeNCOOS in October 2019 and with the West Coast Ocean Alliance in November 2019. A total of 27 people responded to our survey, most of whom were affiliated with CeNCOOS (10), followed by the Southern California Coastal Ocean Observing System (SCCOOS; 6), and the West Coast Ocean Alliance (7). Four respondents chose the “Other” category. The survey results for the species, habitats, resources, and threats will be discussed in their respective sections below.

Species

Species cited in the documents were grouped into ten categories of organisms: Algae, Bacteria, Birds, Fish, Foraminifera, Invertebrates, Mammals, Phytoplankton, Plants, Mammals, and Reptiles (Figure 1). Within each of these categories, species were further divided into groups based on taxonomy, habitat use, their harvest status by humans, and their protection status. The five most frequent categories of taxa were fish, invertebrates, birds, mammals, and algae; in addition, we will also discuss a few of the species in the plant category along with algae. Descriptions of each category are below.

Fish

For the fish category, the groups that received the most frequent recognition were groundfishes, pelagic forage fishes, and salmonids (Figure 1). The species highlighted the most frequently were Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), Pacific sardine (*Sardinops sagax caerulea*), California halibut (*Paralichthys californicus*), and northern anchovy (*Engraulis mordax*; Figure 1). We provide accounts of these species below. Most respondents agreed with the above species (Figure 2). Respondents who chose "other" indicated that forage fish (in general) should be included; rockfish (*Sebastes* spp., especially juvenile rockfish) and Pacific herring (*Clupea pallasii*) were specific examples of forage fish. Pacific bluefin tuna (*Thunnus orientalis*), great white shark (*Carcharodon carcharias*), fish species associated with kelp forest and deep seafloor habitats (e.g., sheephead (*Semicossyphus pulcher*), lingcod (*Ophiodon elongatus*), Pacific hake (*Merluccius productus*), and lamprey were other suggestions.

Chinook salmon

Chinook salmon is an anadromous fish, where adults spawn in freshwater and juveniles migrate to the ocean after a rearing period in freshwater habitat. National Oceanic and Atmospheric Administration (NOAA) fisheries recognizes seven different Chinook salmon species based on the spawning period and watershed they inhabit; two of these species are listed as endangered under the Endangered Species Act, and seven species are listed as threatened (*Chinook Salmon - Protected*). Main prey species for Chinook salmon during their life span are Pacific sardine, Pacific herring, northern anchovy, krill, and juvenile rockfish (1). This species has suffered from loss of or degraded habitat, overfishing, and human modifications (e.g. dams) to streams that have led to reduced fresh water flows and impeded access to spawning grounds (3, 23). Estuarine habitat is also important to Chinook salmon (particularly juveniles), and the continued loss and degradation of estuaries is also contributing to declines (1, 26). Shoreline armoring has also impacted beach habitat, which is important to juveniles (1). Due to these many stressors, this species is in decline, with most populations south of the Columbia River in sharp decline (1).

Chinook salmon experience lower survival when entering the ocean during weak upwelling years (3). This species favors cool ocean phases (16), with increased upwelling and productive ocean conditions leading to enhanced growth rates of this species, particularly in California (26).

This species is harvested for commercial, recreational, and tribal uses. Commercial landings are not remarkable in the California Current (ranks 14th out of 17 fisheries by landings, and 8th out of 21 fisheries by revenues; 1). There is a more popular recreational fishery for Chinook salmon (1). The Sacramento fall run of Chinook salmon is considered overfished (1). Poor ocean conditions can lead to closure of the Chinook salmon fishery, which occurred in 2008 (1, 23).

Climate change will influence this species in many ways. Lower freshwater flows in autumn will negatively impact juvenile survival (1). Increases in stream temperatures have been shown to decrease growth rates and make this species more vulnerable to predators (3). Changes in the timing of upwelling may also affect this species through a mismatch in primary production in the ocean, leading to reduced marine survival (26). Sea level rise is expected to change tidal wetlands which support juvenile Chinook salmon; in Puget Sound, a reduction in rearing capacity in tidal marshes is predicted for Chinook salmon with sea level rise (26).

Data gaps identified for this species include understanding more about marine survival, and more information about the temporal and spatial extent of how Chinook salmon use nearshore environments (11). Conservation efforts for this species have and should continue to include improving the condition of riparian habitat, continue ongoing restoration efforts, and support sustainable limits for this fishery (11). Restoring important wetland habitat, as is being done in the Nisqually Delta in Washington, will benefit juvenile Chinook salmon (and many other species; 26). There are efforts to increase Chinook salmon numbers through hatcheries, especially in California (23). There are management plans in the Snake River basin Endangered Species Act (ESA)-listed species (including spring/summer and fall Chinook salmon), and the Upper Klamath-Trinity Rivers Chinook Salmon evolutionarily significant unit (ESU) is being petitioned to be listed as threatened or endangered under the ESA (*Chinook Salmon - Protected*).

Coho salmon

Coho salmon is an anadromous fish, where spawning and rearing of juveniles occurs in freshwater, and adults live in the ocean before returning to freshwater to reproduce. Adults tend to stay on the continental shelf while juveniles use estuarine habitat before migrating to the marine environment (1). There are four ESUs identified by NOAA Fisheries, with varying statuses under the Endangered Species Act: the Central California coast ESU is endangered; and the Lower Columbia River ESU, Oregon coast ESU, and the Southern Oregon and Northern California coasts ESU are all threatened (*Coho Salmon - Protected*). Coho salmon depend on certain habitat characteristics for successful reproduction: cool, clear water, vegetative cover from riparian habitat, drowned logs, and gravel of a specific size for their redds (23).

Similar to Chinook salmon, this species faces many human (e.g., stream modifications, dams) and natural (e.g., increased stream temperatures, poor ocean conditions) changes to their habitats (3, 23). Drought has severely affected coho salmon populations in north-central

California (3). Climate change may change the timing of upwelling, which may lead to a timing mismatch between when coho salmon enter the ocean and when food is available, leading to decreased survival for this species (26). Climate indices are correlated with coho salmon returns; cool Pacific Decadal Oscillation (PDO) years leading to high returns of coho salmon in Oregon rivers; a late transition to the spring upwelling season leads to poor coho salmon survival in Oregon; and lower spring sea level anomalies (related to upwelling) are correlated with higher coho salmon survival in Oregon (26).

Coho salmon is harvested recreationally and commercially, although due to low population estimates in the 1990s, severe restrictions have been enacted (1). This species is a popular species among recreational fishermen in Oregon and Washington, and it is also frequently caught and released (1). Hatcheries in Oregon and California are being used to increase numbers (1).

Data gaps include monitoring to measure conservation effectiveness, and the mechanisms that affect coho salmon in the marine environment (11).

The different ESUs have plans in place to help steer specific management actions: for the Oregon coast ESU, there is the Oregon Coast Coho Conservation Plan, the Coastal Coho Assessment, and the Coastal Coho Stakeholder Team; the Lower Columbia River ESU has the Lower Columbia River Conservation and Recovery Plan; the Southern Oregon Northern California Coho Expert Panel developed a recovery plan for this ESU (11). All coho salmon ESUs would benefit from restoration of aquatic and riparian habitat, and harvesting in a sustainable way (11).

Pacific sardine

Pacific sardine is a coastal pelagic species occurring in nearshore and offshore waters from Baja California to southeastern Alaska (2); this species forms large schools that migrate north in early summer and then back south in the autumn (1). There are three subpopulations: the northern subpopulation (northern Baja California to Alaska), the southern subpopulation (outer coastal Baja California to southern California), and the Gulf of California subpopulation (Hill *et al.* 2014). Pacific sardine is an important forage species to many fish, bird, and mammal species (1, 2, 23, 28). The population of this species is cyclical, experiencing expansions and contractions on 20-50 year cycles (1, 23, 28). Ocean temperature and conditions (e.g., El Niño Southern Oscillation) are related to sardine population fluctuations, with warmer ocean phases favoring Pacific sardine (1, 16). Pacific sardine is a route for toxins (both natural (harmful algal blooms) and human-made (DDT)) to enter the marine food web (1).

With the expected increase in water temperature and warm water events with climate change, this species is anticipated to experience population growth and longer sardine regime periods (1, 2). Changes in upwelling frequency and intensity may allow for the separation of habitats for Pacific sardine and northern anchovy; sardine may occupy offshore habitats more (where upwelling influence will be weaker) and anchovy will stay in nearshore habitats (where upwelling influence will be stronger; 2). Lower dissolved oxygen levels and increased ocean acidification will also negatively impact Pacific sardine (2). However, the ability of this species to adapt to and exploit favorable conditions makes sardine a likely survivor with climate change (2), and poleward range expansion is likely (16).

This is a commercially important species, particularly in the northern portion of the California Current, and is managed by the Pacific Fisheries Management Council (1). Stocks of Pacific sardine are low (1, 5), and this fishery has been closed since July 2015 due to estimated biomass being below the 150,000 metric ton cutoff value (5). This is only one of two fisheries in California which incorporates a climate variable into its harvest control rule (16). Pacific sardine is targeted for bait (23). This species is the second most released species in Northern California and ninth most released species in Southern California; it is taken as bycatch in Pacific mackerel, squid, and anchovy fisheries, and this has complicated overfishing limits in some years (1). Fishermen may move to follow sardine migrations, or substitute by fishing for sardine when other target species are low in availability (16).

Better management of this species includes improved ways of incorporating predator needs into harvest guidelines, understanding the status of this species in northern Mexico, knowing more about the stock structure, and improving biomass estimates (which are highly uncertain; 1, 16). While temperature is an environmental variable used in setting harvest control rules for this species, natural variation in ocean conditions is complex, and temperature may not be the only factor that affects recruitment of this species; therefore, the incorporation of more environmental variables into stock assessments and forecast models may improve management of the Pacific sardine (16).

California halibut

California halibut is a flatfish species found in nearshore waters from Baja California to Washington (1, *California Halibut Identification*). The species prefers sandy/soft bottoms (1). California halibut use estuaries as nurseries for their young and feeding grounds (1, 3), and it favors warm ocean phases (16). While no fishery-independent state assessment of the population has been conducted, the California halibut's fast growth rate is thought to make it resilient against fishing pressure (1).

The loss and degradation of estuarine habitat has negatively affected California halibut spawning and nursery grounds. Eelgrass beds are also used by California halibut; the loss of eelgrass beds to invasive species (e.g., *Caulerpa taxifolia*) in southern California is another threat to this species (1).

In California, there is a commercial and recreational fishery for California halibut (7). This is a popular target species for recreational fishers in the Greater Farallones National Marine Sanctuary (23); it ranks as the second most landed recreational species in northern California, and the 8th recreational species in southern California (1). In an ecological risk assessment of fisheries in California, the commercial gill net and trawl fisheries for California halibut were determined to cause the greatest relative cumulative risk, due mainly to high bycatch and its negative impacts to nearshore soft bottom and habitat-forming marine invertebrates (7). The number of trawl fleets in California and Washington have been reduced, and specified California halibut trawling grounds in central and southern California have also been reduced due to closures in 2008 (1).

Northern anchovy

Northern anchovy is a small forage fish species that occurs from British Columbia to the Gulf of California (2). There are two sub-populations: the northern sub-population, occurring off Oregon and Washington; and the central sub-population, occurring from California to Baja California, Mexico (*Northern Anchovy*). This species inhabits pelagic waters in large schools (2, 11). Anchovy consume phytoplankton, and their life span rarely exceeds 4 years (2). Populations of northern anchovy can fluctuate greatly and is typically opposite of Pacific sardine trends (23); while anchovy tend to favor cool, productive ocean phases, sardine prefer warmer ocean conditions (16, 23). Northern anchovy is an important forage species to many marine species (2, 23).

There is a commercial fishery for northern anchovy in California (16), although the landings are low (2). Fishermen may switch to other species (e.g. squid, Pacific sardine) when anchovy becomes less available or market demand changes (16). Northern anchovy is managed under the Coastal Pelagic Species Fishery Management Plan by the Pacific Fisheries Management Council (2). The annual catch limit of 25,000 metric tons for northern anchovy set in California was challenged by Oceana in federal district court; in January 2018, the Court agreed and ruled that this annual catch limit was not based on the most recent scientific findings (5). There is also a recreational bait fishery for anchovy (2, 23).

Northern anchovy is considered a highly specialized species and depends on a certain temperature range to live and reproduce, making it more vulnerable to the increased ocean and climate variability predicted with climate change (2, 16). The availability of their plankton prey (e.g., euphausiids, copepods, decapod larvae) is expected to be the most significant impact from climate change; increased sea surface temperature, decreased oxygen, and decreased pH are also expected to negatively impact northern anchovy populations (2).

Gaps in the existing knowledge of this species include the abundance and status of the northern sub-population (as it has never been formally assessed; *Northern Anchovy*), and drivers behind population fluctuations (11). Areas for conservation attention include protecting critical habitat and managing for sustainable harvest (11).

Invertebrates

For the Invertebrates category, there were several documents that discussed the intertidal and benthic invertebrates that are harvested by people, including various species of crabs, oysters, sea urchins, and clams (Figure 1). The top five species in this category include Dungeness crab (*Metacarcinus magister*), Olympia oyster (*Ostrea lurida*), red abalone (*Haliotis rufescens*), California mussel (*Mytilus californianus*), and red sea urchin (*Mesocentrotus franciscanus*; Figure 1). Most respondents agreed with the above species (Figure 3). Deep-sea corals, sunflower sea star (*Pyconopodia helianthoidies*), black abalone (*Haliotis cracherodii*), market squid (*Doryteuthis opalescens*), copepods, krill, purple urchin (*Strongylocentrotus purpuratus*), ochre sea star (*Pisaster ochraceus*), and white abalone *(Haliotis sorenseni*) were suggestions made in the "other" category.

Dungeness crab

Dungeness crab is a commercially important species that lives in the subtidal zone, usually occurring on sandy substrate (11) and in estuaries (1). This species tends to favor cool water conditions (16, 18), and its distribution and abundance is impacted by larval supplies and variation in recruitment (11). Recruitment of this species is dependent on the release of larvae during the spring bloom, leaving it vulnerable to reduced recruitment if there is a temporal mismatch between nutrient availability and reproduction (16). Previous studies have documented that mortality of Dungeness crab is related to hypoxia and ocean acidification (for larval stages) and is expected to increase as these threats intensify (1, 18, 22, 26). Invasive species, such as the European green crab (*Carcinus maenas*), are a threat to Dungeness crab, although the impacts to the fishery in central California are unknown (23).

There is a very valuable fishery for Dungeness crab, and fortunately, the population appears to be stable (1). In years 2001-2010, the commercial Dungeness crab fishery in the California Current was the fourth highest fishery in terms of landings (metric tons), and the first fishery in revenue (1). Commercial and recreational fisheries for this species are common in the California Current north of Point Conception, and a Tri-State Dungeness Crab Committee was established in 1996 to better coordinate management of this fishery along the west coast (16). All three states follow similar regulations in regards to the size, sex, and season: a minimum carapace size requirement, only male crabs (ban on female crabs), and an open fishery from winter (November/December) through summer (June) to protect the species during the molting period (16). In the Greater Farallones National Marine Sanctuary, there are no limits on the number of traps (23). While not targeted, females and younger age classes are also caught and not retained; understanding the mortality estimates of these non-target sex and age classes was highlighted as a data gap (11). Fluctuations in the activity of the Dungeness crab fishery can lead to fishermen switching to other fisheries or professions when activity is low, or to on-the-water conflicts and unsafe work conditions when activity is high (16).

The North Pacific marine heat wave of 2015-2016 led to harmful algal blooms off the coast of California, and this prompted the Dungeness crab fishery to be closed or delayed to protect public health (16, 18). This heat wave also led to other prey species moving to nearshore waters, causing whales to follow them and become entangled in crab pot gear; a California Dungeness Crab Fishing Gear Working Group was established in 2015 (convened by California Department of Fish and Wildlife, in partnership with Ocean Protection Council and the National Marine Fisheries Service) to address this problem (16). Tribes are also negatively impacted by harmful algal blooms, with some tribes in Washington losing 50% of their Dungeness crab income during a 1998-99 harmful algal bloom event (18). Scientists recommend developing improved climate and ocean chemistry projections to help managers and fishery participants better predict and plan for these scenarios (16, 18). Ecosystem vulnerability assessments, as well as the associated adaptation and resilience strategies for key species (like Dungeness crab), are also recommended (22). Dungeness crab behavior may also be disrupted by electromagnetic fields produced from wave and tidal energy projects (1).

Olympia oyster

Olympia oyster is a bivalve filter-feeder inhabiting estuaries and low tidelines (2). This species ranges from northern British Columbia to Baja California. Olympia oyster spawn in mid-summer; larvae have high dispersal capabilities, traveling 5-25 km (2). It takes approximately one year for this species to reach sexual maturity (2). Firm, rocky substrate is the preferred habitat for settled individuals (11).

Climate change will negatively impact this species through ocean acidification and changes in salinity and precipitation (2, 18). However, many threats to Olympia oyster are from human activities (e.g., dredging, introduction of invasive species, pollution, and toxins; 2). Paper mills in Washington discharge sulfite waste, which is filtered out by Olympia oysters and other filter-feeding organisms (2). Large, non-native oysters (e.g., Pacific oyster *Miyagi oyster*) can displace Olympia oysters (2). Available habitat is a limiting factor for this species (11). Removal of shell accumulations has limited Olympia oyster recovery (14).

Olympia oyster has suffered historic overharvest from the 1800s and early 1900s (2). Spatial extent of habitat has declined 64% and biomass has declined by 88% over the last 100 years (2). By the 1930s, commercial harvest of this species ceased in Washington (14).

Conservation of this species depends on managing the human-caused stressors and restoring habitat (2). Protecting mature Olympia oyster beds is one way to provide habitat to promote self-sustaining populations (25). The use of conservation hatchery methods will help protect these populations from ocean acidification (25). Studies currently conducted by the National Estuarine Research Reserve will help produce restoration planning tools to best manage restoration efforts for the Olympia oyster (2). It is a State Candidate species subject to reintroduction throughout the state of Washington (14).

Red abalone

Red abalone is a marine gastropod mollusc, inhabiting low rocky intertidal habitat and subtidal habitat from Sunset Bay, Oregon to Baja California (2, 11). It is also an important kelp forest species (28). This species is the largest abalone species in North America; it breeds in the spring (February-April) and reaches sexual maturity in about four years (2). This species is a broadcast spawner, so there must be a sufficient density for successful reproduction (11). It is a common prey item of sea otters (2). This species is best adapted to cold ocean phases (16).

Red abalone faces several threats related to climate change, including lower dissolved oxygen levels, ocean acidification, increased air and sea temperatures, changes in salinity, and increased harmful algal bloom events (2, 26, Benefield 2011). Increased storm frequency and intensity is of particular concern for red abalone, as extreme storm events will dislodge this species from intertidal surfaces (2). Increased water temperatures will result in slower growth rates, reduced sperm production, and an increased susceptibility to disease (e.g., withering foot syndrome; 2). However, red abalone appear to exhibit plasticity to some factors (e.g., low pH and low oxygen), which may make them only moderately vulnerable to these threats (2). A combination of disease (sea star wasting disease) and warm-water, low productivity conditions off the coast of northern California has led to the explosion of the purple sea urchin (prey of sea stars) and a decline in bull kelp (*Nereocystis luetkeana*) in recent years; purple sea urchins are eating the bull kelp, the main food of the red abalone, causing red abalone populations to plummet (Fox 2017).

This species is harvested for its meat and iridescent shells; it has experienced historic overharvesting and may suffer from lower genetic diversity (2). The fishery peaked in the late 1960s, then experienced declines until it was closed in 1997 (2). A recreational fishery still exists in northern California, from Marin County to the north (23). The California Department of Fish and Wildlife is currently working on a red abalone fishery management plan for northern California which will incorporate environmental indicators and allow for catch adjustment in future seasons (16).

The spatial distribution and abundance of this species in shallow subtidal habitat is a knowledge gap in Oregon (11). Focused monitoring efforts in Monterey Bay National Marine Sanctuary are showing an increase in red abalone (28). Continued monitoring, as well as managing for sustainable harvest, are important conservation actions for red abalone (11).

California mussel

California mussel is a filter-feeding bivalve species common to the rocky intertidal zone from Alaska to Baja California (2). This species is the primary prey of the ochre sea star, and the interactions between these two species dictates the community composition in the rocky intertidal (2). California mussel is also the main prey for the black oystercatcher (2). Sea palm is a competitor for space with the California mussel (2).

Increased air temperature, changes in salinity, lower pH, increased wave action, and erosion are climate-related threats for the California mussel (2). Salinity extremes result in embryonic mortality and reduced adult aerobic performance in this species (2). The byssal threads of the California mussel are weaker in lower pH waters, making it more difficult for this species to stay attached to rocky intertidal surfaces (2). Human-related stressors include shoreline armoring, pollution and poisons, recreation, and non-native species (2). Scientists predict increased wave action will be a benefit to the California mussel, as it will negatively affect their primary predator, the ochre sea star; there is a similar prediction for disease (e.g., sea star wasting syndrome) and its indirect benefits to the California mussel (2). Episodic recruitment and larval supplies are the main factors limiting the abundance and distribution of the California mussel (11). Volcano barnacles (*Tetraclita rubescens*), a native species that has significantly expanded its range, is now becoming a competitor for space with California mussels (2). Metals and other pollutants can accumulate in their tissues, which can have negative impacts on their predators (2). This species is recreationally harvested.

Understanding the relationships between ocean variables and California mussel settlement and recruitment has been identified as a data gap (11). Conservation actions for California mussel include improved management of tidepool site to decrease disturbance, protection of upland rocky habitat (for future migration), monitoring, and sustainable harvest (2, 11). California mussel may be a species used as a bio-indicator of ocean acidification in California; its wide distribution that can be easily monitored makes it an effective indicator (4, 18).

Red sea urchin

Red sea urchin is a rocky intertidal invertebrate, ranging from Alaska to Baja California (11, *Red sea urchin*). This species is long-lived, often exceeding 30 years; spawning peaks in summer (June-September; *Red sea urchin*). The abundance and distribution of red sea urchin is affected by larval supplies and variable recruitment (11). Sea otters feed on red sea urchin (1). This species is a key species in the Greater Farallones, Monterey Bay, and Channel Islands National Marine Sanctuaries, and research of red sea urchin impacts on kelp forest communities are ongoing (23, 28, 32).

There is a commercial fishery for red sea urchin in California, and it has been fully exploited (1). The northern California fishery is more productive than the southern California fishery in recent years (1). Since the fishery peaked in the late 1980s, the California Department of Fish and Game reduced the number of permits allowed and instituted a size limit and a limit on fishing days (1). In Oregon, red sea urchin is the main target of the dive fishery; this is a limited access fishery with only 30 permits, a minimum size limit, and depth restrictions (1).

Lower ocean pH is anticipated to negatively impact red sea urchin, as will disease (2). In recent years, harmful algal blooms, sea star wasting disease, purple sea urchin explosion, and warm water episodes have worked to significantly reduce bull kelp biomass (explained in the red abalone section, above); this has also led to declines in red sea urchin populations (Hohman 2018).

Understanding the role of red sea urchins in bull kelp beds and population dynamics of the species are areas that need further research (11). The Kelp Recovery Working Group of the Greater Farallones National Marine Sanctuary Advisory Council has developed research, education/outreach, and management recommendations for the recovery of bull kelp, which will help the red sea urchin (Kelp Recovery Recommendations 2018). Monitoring and managing for sustainable harvest are keys to conservation of red sea urchin (11).

Birds

For the Birds category, there are a number of seabirds, shorebirds, and waterfowl mentioned in the documents, particularly those with a protected or special status. The top five species in this category are Cassin's auklet (*Ptychoramphus aleuticus*), western snowy plover (*Charadrius alexandrinusj nivosus*), common murre (*Uria aalge*), black oystercatcher (*Haematopus bachmani*), and Brandt's cormorant (*Phalacrocorax penicillatus*). Agreement with these species was high among respondents (Figure 4). Migratory species (e.g., northern fulmar (*Fulmarus* *glacialis*), sooty shearwater (*Ardenna grisea*), western grebe (*Aechmophorus occidentalis*), Clark's grebe (*Aechmophorus clarkii*), surf scoter (*Melanitta perspicillata*) and black-footed albatross (*Phoebastria nigripes*)) were also recommended for inclusion. One respondent suggested albatross and puffin but did not mention particular species; the tufted puffin (*Fratercula cirrhata*) is the only puffin species found in the California Current.

Cassin's auklet

The Cassin's auklet is a seabird found along much of the western coast of North America. It breeds in crevices or burrows on offshore islands and forages in a relatively diverse set of offshore habitats in association with upwelling where it finds its primary food, copepods and krill (2).

Non-climate change related threats include oil spills near their breeding or foraging sites and invasive rodents which can disturb nesting habitat or prey on eggs or chicks (2, 23). Cassin's auklets are sensitive to changes in oceanographic conditions and their impacts on the food resources on which they depend. Changes in these conditions can be brought about by natural cycles which affect factors like sea surface temperature, winds and upwelling, salinity, and as a consequence, changes in timing and availability of prey. For example, complete breeding failure has been documented for the Cassin's auklet in 2005 when seasonal upwelling was shifted much later (26). Climate change will impact these cycles and conditions and, if they occur more regularly, may make population recoveries much more difficult (2, 26).

Western snowy plover

The western snowy plover is a small shorebird found year round along much of the west coast of the United States (2). The Pacific coast population of snowy plovers nests along beaches of the Pacific Ocean and is listed as threatened under both the federal Endangered Species Act and by the Oregon Fish and Wildlife Commission, and it is listed as endangered by the Washington Department of Game. It breeds above the high tide line on coastal beaches, sand spits, dune-backed beaches, sparsely vegetated dunes, beaches at creek and river mouths, and salt pans at lagoons and estuaries (USFWS 2007). During the winter, other populations breeding inland may migrate to the Pacific coast to overwinter and forage along beaches, salt ponds, and estuarine sand and mud flats (USFWS 2007). This species feeds on taltrid amphipods (*Megalorchestia* spp.) that live in the macroalgae wrack on beaches (3).

Snowy plovers face several threats historically, currently, and into the future due to climate change. Primary threats historically and currently include habitat degradation and loss due to human disturbance, urban development, and introduced non-native European beachgrass (*Ammophila* spp.). Non-invasive predators such as gulls, ravens, foxes, and dogs are linked to human activity and are threats to nesting and non-nesting plovers (2, 11, 28). Human disturbance related threats include sand removal or mining (e.g. along Monterey Bay), driftwood removal for firewood, beach camping and associated disturbances, and water diversion impacting river and creek mouths habitat (USFWS 2007).

Sea level rise is the major climate change related threat for snowy plovers and will exacerbate the impacts of human disturbance and human related habitat loss for nesting and foraging. Sea level rise can inundate beach and dune habitat and increase coastal erosion and wave action. Without upland space to retreat to (e.g., in cliff backed beaches vs dune backed beaches), beaches and dune habitat can be reduced by rising seas. Sea level rise can alter ecosystem dynamics by changing the proportions of different sub-habitats within beaches and by disrupting successional dynamics (2)

Due to its conservation status, this species is closely studied, monitored, and highly managed. Conservation efforts have had mixed success and sea level rise will further challenge the ability of managers to maintain population numbers (2).

Common murre

The common murre is a seabird found along much of the west coast of North America from southern California to Alaska. Along this range it is both migratory and a permanent resident. Its diet can vary regionally and consists largely of fish such as herring, sandlance, smelt, anchovy, and rockfish, but also euphausiids, large copepods and squid. It forages near its breeding colony (~40km) where its prey is concentrated by oceanographic, upwelling, density, and shelf break fronts, but can be found closer to shore when upwelling is limited (Ainley *et al*. 2002). They breed on open surfaces of offshore islands and rocks, and coastal cliffs. During the winter, it can be found within sheltered bays away from breeding colonies.

Historically, gill-netting had been a threat to common murres (23) and entanglement of individuals in marine debris continues to be a threat (28). Murres can also be very sensitive to oil spills (2, 23, 28). The main prey items of the common murre are rockfish, anchovies, and squid; these species are also recreationally and commercially harvested, which can lead to reduced food availability (2, 23). Human related disturbance of nesting colonies via aircraft, boats, and hikers can adversely impact nest success via flushing adults off nests resulting in increased predation of nests or nest abandonment (2).

Common murres are sensitive to changes in oceanographic conditions and their impacts on the food resources on which they depend (2, 23, 28). Changes in these conditions can be brought about by natural cycles and trends defined by sea surface temperature, winds, upwelling, salinity, and, as a consequence, changes in nutrient delivery, ocean primary productivity, and in timing and availability of prey (23). Climate change will impact these conditions, cycles, and their timing which can lead to mismatches between food availability and the murres breeding cycle (phenological decoupling), when food demands are greatest (23, 26).

Black oystercatcher

The black oystercatcher is a non-migratory shorebird found within rocky intertidal shorelines and offshore islands along the western coast of North America. They can also be found within coastal mudflats largely during the winter. Oystercatcher feed on aquatic invertebrates such as mussels, limpets, crabs, and marine worms.

Because of its dependence on a narrow band of coastal habitat for nesting and feeding, climate change is considered a significant threat via sea level rise, and increases in wave action, storm severity, precipitation, and coastal erosion. All of these can lead to habitat loss or degradation and can also lead to nest loss due to flooding events or indirectly by inhibiting adult feeding patterns (2, 26, 28).

Non-climate related threats include disturbance by humans both directly and indirectly. Direct impacts can include trampling of nests or flooding of nests via boat wakes. Indirect impacts include increased nest predation via the flushing of adults on nests or by the attraction of dogs or nest predators such as ravens (2, 28). Other threats include pollution (and their impact on their filter-feeding prey), oil spills, and changes in land use (26).

Brandt's cormorant

Brandt's cormorant is a seabird endemic to North America. Found along almost the entire west coast, it is closely tied to upwelling of the California Current and found mostly along inshore coastal waters (>10km from shore) in association with kelp and in sheltered inlets or near the coast >1 km from shore during winter (Wallace & Wallace 1998). They breed on open surfaces of offshore islands and rocks and coastal cliffs. Its diet varies regionally but consists mainly of fish such as rockfish, herring, anchovies, and sanddabs but also squid, shrimp, and crabs (2).

Historically, gill-netting had been a threat to Brandt's cormorants (23) and entanglement of individuals in marine debris is a continuing threat (28). This species is also highly susceptible to oil spills (2, 28). The main prey items of this species are rockfish species; rockfish are also recreationally and commercially harvested, which can lead to reduced food availability (2, 23). Human related disturbance of nesting colonies via aircraft, boats, and hikers can adversely impact nest success via flushing adults off nests resulting in increased predation of nests, damage to eggs when flushing, or desertion (2, Wallace & Wallace 1998).

Similar to common murres, Brandt's cormorants are sensitive to changes in oceanographic conditions and their impacts on the food resources on which they depend (2, 23, 28). Changes in these conditions can be brought about by natural cycles and trends defined by sea surface temperature, winds, upwelling, salinity, and, as a consequence, changes in nutrient delivery, ocean primary productivity, and in timing and availability of prey (23). Climate change will impact these conditions, cycles, and their timing which can lead to mismatches between food availability and the cormorant breeding cycle (phenological decoupling), when food demands are greatest (23, 26). On the other hand, changes in ocean conditions can increase the availability of prey or counteract increased sea surface temperatures.

Mammals

For the Mammals category, these include cetaceans, pinnipeds, and an otter species. The top five mammal species cited in our synthesis include blue whale (*Balaenoptera musculus*), Steller sea lion (*Eumetopias jubatus*), humpback whale (*Megaptera novaeangliae*), California sea lion (*Zalophus californianus*), and southern sea otter (*Enhydra lutris nereis*). Again, there was agreement with these species among survey respondents (Figure 5). Harbor porpoise (*Phocoena phocoena*), gray whale (*Eschrichtius robustus*), and beaked whales (family Ziphiidae) were cited as missing.

Blue whale

The blue whale is a filter-feeding baleen whale which consumes krill and is distributed globally. Along the west coast of North America, the Eastern North Pacific stock is found from the Gulf of Alaska to Southern California in the summer and fall. In the winter and spring, this population migrates south to Mexico and Panama to breed (2). Its distribution is closely tied to its foraging needs where krill can be concentrated such as near areas of upwelling. Between April and November, it is estimated that 1,700 - 2,500 individuals can be found along California, Oregon, and Washington (1, 23). It is listed as endangered by both the Endangered Species Act and the IUCN Red List (1,2, Cooke 2018) and surveys have not shown an increase in this population (1) but it may be recovering globally.

Because the blue whale is dependent on krill, factors that drive ocean productivity and the abundance and distribution of krill will likely impact blue whale presence and abundance, but more study is needed (2). Factors such as sea surface temperature, salinity, chlorophyll, and thermocline depth, described by indices such as the Pacific Decadal Oscillation, for example, have been linked to lower blue whale sightings during periods of weaker upwelling (2). Climate change will have an impact on these ocean processes.

Historically, blue whales were commercially hunted and harvested and their population numbers severely reduced by the hundreds of thousands. Blue whale hunting was globally banned in the 1960s and the management and recovery of their populations are underway. Today, injury and death by ship strikes and entanglement in fishing gear are a threat. Anywhere from 0.2 to 4 blue whale deaths per year have been reported due to ship strikes, with as many as 40 blue whale deaths per year due to strikes (Rockwood *et al.* 2017), and this has been identified as a threat to their recovery (2, 24). Other human interactions such as whale watching and fisheries operations can be problematic (2). Moreover, human-caused noise pollution from ships, as well as industrial and military activities, can disrupt communication between individuals, affect prey detection, disrupt normal behavior, and cause direct physiological damage (2). Increasing commercial fleets has made this an increasing threat of interest and also highlighted it as a data gap where more study is needed in terms of impact to populations. Overall, whale recovery from past depletion remains poorly understood, especially in the context of newly emerging stressors (1).

Steller sea lion

The Steller sea lion is a marine mammal found along coastal waters of the North Pacific Ocean from Japan, ranging west to North America and then as far south as central California. The eastern distinct population segment (DPS, which includes California, Oregon, and Washington) was listed as threatened in 1997, but was considered recovered and delisted in 2013 (*Steller sea lion*). This species breeds at rookeries found on beaches and rocky reefs near the coast. They feed primarily on fishes and invertebrates such as squid and octopus. During the breeding season they typically feed in coastal waters on the continental shelf but can also use the continental shelf slope and pelagic waters. Foraging habitat may vary between the breeding and non-breeding seasons and between individuals, but females are restricted to foraging near the rookery during breeding.

The Steller sea lion was historically hunted for meat and fur; culling of their population due to perceived competition for fish was another reason for declines (23). Other causes of this decline include entanglement in fishing gear, declines in sardine populations, and nonpoint source pollution (e.g., DDT, PCBs), which may be tied to a decline in pupping rates for this species (23). While the western DPS of Steller sea lion (western Gulf of Alaska, Aleutian Islands, and Russian coastal waters) continues to be listed as endangered, the eastern DPS of the Steller sea lion has experienced dramatic population increases through the 1980s and 1990s, which was likely driven by shifts in ocean climate (Trites *et al.* 2007). Determining age-specific survival rates is identified as a data gap (11).

Humpback whale

The humpback whale is a filter feeding baleen whale which consumes krill and is distributed globally. It is found along the coasts of California, Oregon, and Washington in the spring, summer, and fall, migrating to tropical waters (Hawaii, Central America, Mexico) in the winter to mate and calve. It can travel long distances during this migration with some individuals recorded as travelling over 5,000 miles, the longest known migration for a mammal. In 2016, the listing of the humpback whale changed, with the description of 14 DPSs: the Mexico (now listed as threatened) and the Central America (now listed as endangered) are the DPSs found along the U.S. West Coast (*Endangered and Threatened Species*). The population of the U.S. West Coast is estimated at ~2,000 individuals (down from ~15,000 before 1905) with an estimated population growth rate of 7.5% annually (1).

Historic commercial whaling reduced humpback whale numbers to a fraction of its former population. A moratorium on whaling has allowed for recovery efforts to begin but it is a significant challenge given the sheer reduction in the size of the population. Similar to blue whales, current threats to humpbacks include danger from ship strikes and entanglement in fishing gear. More than 40 ship strikes to humpback whales each year have been estimated (Rockwood *et al.* 2017). Noise pollution, disturbance from whale watching ships, commercial fisheries and shipping, and recreational boats may also be problematic by disrupting normal behavior and increasing stress levels. Anthropogenic noise pollution may cause multiple problems such as disrupting communication and prey detection or potentially even direct physiological damage or mortality, although more study is needed (2). Pollution and bioaccumulation of toxins (e.g., DDT, PCBs) also pose a threat but their impacts are not well understood (1). As with blue whales, humpback whale recovery from past depletion remains poorly understood, especially in the context of newly emerging stressors (1).

California sea lion

California sea lion is a pinniped species found from Vancouver Island, British Columbia to the southern tip of Baja California, Mexico. This species breeds on offshore islands (e.g., Channel

Islands, Farallon Islands), with most pups born in the summer (*California Sea Lion*). Main prey species include northern anchovy, market squid *Doryteuthis opalescens*, Pacific hake *Merluccius productus*, jack mackerel *Trachurus symmetricus*, and shortbelly rockfish *Sebastes jordani* (1). This species appears to be increasing rapidly and expanding its range, and possibly reaching environmental carrying capacity (1, 3).

Threats to the California sea lion include human-produced toxins (e.g., DDT, PCBs), natural toxins (e.g., domoic acid produced by harmful algal blooms), diseases (some originating on land and transferred via freshwater runoff), and marine debris (1, 3). Malnutrition is another stressor to this species (1); the abundance and distribution of California sea lions and their prey will likely be impacted by the many changes to natural ocean processes expected with climate change (24, 28). However, California sea lion numbers increased during some warm water events (e.g., El Niño; 3), so it is possible this species may benefit from warmer waters in the future. Conservation and American Indian groups have sued the National Marine Fisheries Service in 2012 for failing to protect sea lions and other marine wildlife from Navy training exercises along the coasts of California, Oregon, and Washington (1). The effects of noise pollution on marine mammals (including California sea lions) were observed and documented, with likely victims of "seal bombs" (incendiary devices used in California to deter pinnipeds and other marine mammals from fishing operations) being injured (e.g., broken bones, soft tissue burns, prolapsed eye balls) or killed; a call for research and tighter regulation is needed (Kerr and Scorse 2018).

Southern sea otter

The southern sea otter is a member of the weasel family that inhabits nearshore marine habitats, especially kelp forests, bays, estuaries, and the exposed outer coast (2). The southern sea otter once ranged from Mexico to Oregon, but after overhunting for their fur in the 1700s and 1800s, this species currently ranges from Half Moon Bay to Point Conception in California (2). Females can give birth at any time of year, but most pups are born between January and March. This species exhibits low dispersal and low genetic diversity from overharvesting (2). The sea otter is one of a few animal species known to use tools, as it uses stones to break open clams and abalone to eat (*Sea Otter*). They are currently listed as threatened in California (1) and an endangered species with the IUCN (Doroff & Burdin 2015). The population of this species is growing ~6% annually (1). This is a keystone species, eating benthic invertebrates (e.g. sea urchins), allowing kelp forests to grow and photosynthesize, and thereby indirectly mitigating the effects of climate change.

Threats to the southern sea otter include disease (including *Toxoplasma gondii*, originating from domesticated cats), toxins from harmful algal blooms, bioaccumulation of contaminants (e.g., DDT, PCBs), oil spills, marine debris, and recent losses in bull kelp caused by a variety of factors (described previously for red abalone and red sea urchin; 1, 2, CDFW 2016). Gillnet fisheries once posed a threat to this species, but gear restrictions have eliminated this danger (1). Climate change sensitivities include changes in precipitation (which is also related to disease transfer), ocean acidification (by reducing their prey source), and wave action (by negatively impacting their kelp habitat; 2, 3).

Algae and Plants

The Algae and Plants category is represented mostly by macroalgae species (e.g., kelps), which provide important habitat for many marine species, and some of which are harvested by people. Important species in this category are bull kelp (*Nereocystis* species), sea palm (*Postelsia palmaeformis*), and coralline algae. For the Plants category, eelgrass (*Zostera marina*) and surf grass (*Phyllospadix* spp.) were cited frequently, both of which provide habitat for marine wildlife and will become important species in mitigating climate change. Most people agreed with these species (Figure 6). One respondent questioned singling out bull kelp and recommended kelp forests in general, and others advocated for including giant kelp (*Macrocystis pyrifera*), crustose coralline algae, brown algae (order Fucales), and red algae (*Neorhodomela species*).

Macroalgae – Bull kelp and coralline algae

Macroalgae are benthic and canopy forming subtidal marine vegetation, including kelps and calcareous algae (3, 27). Kelp forests provide refuge and nursery habitat for many marine organisms, including microbes, algae, invertebrates, and fishes (21). Macroalgae improve water quality and protect coastlines from other climate change threats (e.g., storm surge, erosion, sea level rise; 21). Kelp is an important food source for urchins (25). While kelp forests in Oregon and Washington are in good condition, California kelp forests are in decline (1). As kelp dies and becomes dislodged from the kelp forest, it becomes wrack on beach and hosts terrestrial taltrid amphipods, an important prey item for the protected western snowy plover and other shorebirds (3).

Kelp harvest is prohibited in Washington, and it is now prohibited in southern Oregon (1). Bull kelp is harvested in California, with management measures enacted by the California Fish and Game Commission in 2001 and permits managed through the Department of Fish and Wildlife (1). During 2001-2010, kelp was the fifth highest commercial fishery by landings along the west coast of North America (1). Since its regulation in California, bull kelp has become more abundant and become essential habitat for heavily-exploited species such as sea urchins and abalones (1).

Macroalgae may be impacted by climate change through increased sea surface temperatures, sea level rise (reducing availability of light and attachment surfaces), changes in upwelling (affecting nutrient availability and increased dispersion of larvae and spores), and, most importantly, increased waves and turbulence (which will detach algae from its substrates; 3, 25, 27). The increased occurrence and intensity of El Niño events in the future will harm kelp forests (21). Calcified algae (corallines) are particularly vulnerable to ocean acidification, with increased acidity reducing their ability to construct their calcium carbonate skeletons (3, 27). The invasive kelp *Undaria pinnatifida* is also of concern, as it may be expanding its range to northern California and competing with native kelp for habitat (3).

Giant kelp (*Macrocystic pyifera*), bull kelp, and other submerged aquatic vegetation are being researched for their abilities to ameliorate ocean acidification by removing carbon dioxide from the water, particularly in the canopy (21, 27). Research in Monterey Bay shows the ability of kelp to increase ocean pH (21). Kelp farming is being explored as a way to extract CO_2 from seawater in Puget Sound (21).

Conservation actions for macroalgae include restoring lost kelp forests, protecting current kelp forests, and reducing urchin populations (21, 25, Kelp Recovery Recommendations 2018). Data gaps include current kelp forest abundance, distribution, and condition (21).

Sea palm

Sea palm is a kelp species inhabiting the rocky intertidal zone; it ranges from British Columbia to San Luis Obispo County, California (2). This species has a low dispersal capability; it releases spores just once during its annual life cycle (2, 11). The California mussel is the main competitor of sea palm for space in the intertidal (2).

Sea palm is a commercially harvested species in California, but harvesting is illegal in Oregon and Washington (*Postelsia*).

This species was characterized as being very vulnerable to climate change, due mainly to its high exposure and sensitivity and lower adaptive capacity (2). The most significant climate change factors include changes to air temperature, salinity, wave action, pH, and coastal erosion (2). Increased air temperatures will likely affect microscopic stages of sea palm more so than old life stages, as these are already adapted to being exposed (2). Wave action effects on this species are unclear: it may benefit sea palm as it may remove California mussels; however, increased wave action may also damage fronds of the sea palm and lead to lower reproductive output (2). Lower pH conditions will have mixed, indirect effects on sea palm through negative impacts on California mussel (a competitor for space) and negative impacts on coralline algae (important habitat for zoospores of sea palm; 2). Human-related stressors include harvest (2). Sea star wasting disease may indirectly harm sea palm by removing sea stars, a major predator of the California mussel and a competitor with sea palm for space in the intertidal (2).

Conservation actions include managing this species to protect it from overexploitation (2). Understanding its spatial distribution, seasonal variability in biomass, and ecological role are all areas needing further research (11).

Eelgrass

Eelgrass is a flowering subtidal marine plant and an important species in estuarine habitats (11, 14, 23, 26). This habitat-forming species forms beds across mudflats, which aids in trapping sediments, slowing water currents and waves, and stabilizing sediments with their roots (4, 14). Eelgrass is an ecologically important species, providing primary production to the nearshore food webs, creating habitat for algae and invertebrates (including commercially-important species such as Dungeness crab, Pacific herring, salmon, and California spiny lobster *Panulirus interruptus*), sequestering nutrients, stabilizing soil, and capturing pollutants (4, 14, 23, 26).

Eelgrass is a food source for many species, including the Brant goose *Branta bernicla* and other waterfowl that migrate along the Pacific flyway (14, 26).

Climate change may negatively impact eelgrass through increased water temperatures and sea level rise; potential benefits of climate change include increased dissolved carbon dioxide concentrations (which may enhance photosynthesis; 11, 14, 26). This species is sensitive to water quality changes (14). Introduced species of eelgrass (e.g., Japanese eelgrass *Zostera japonica*) may not be a competitor for habitat and may actually benefit native eelgrass (14). Eelgrass beds in southern California are being threatened by an invasive species of alga (*Caulerpa taxifolia)* native to the Indian Ocean, which was introduced through ballast water; it has been largely eradicated and is being monitored for regrowth (1). Human activities such as water diversion projects (leading to increased sedimentation and decreased freshwater inputs), submarine cables, and pollution from multiple sources (e.g., heavy metals from abandoned mines, dairy ranches) have led to the decline in eelgrass habitat (1, 23). Increased sedimentation and declines in water quality has multiple negative impacts to eelgrass, including reduced ability to photosynthesize (due to turbid waters and epiphytes weighing down their leaves) and exposure to higher temperatures (due to growing closer to surface waters; 23).

Complicated interactions have been observed between eelgrass and bivalves (e.g., oysters, mussels): in some studies, certain densities of bivalves increased nutrient availability to eelgrass and led to higher growth rates for eelgrass; other studies have shown high oyster densities have led to eelgrass declines (14). Loss of eelgrass beds in Bolinas Lagoon has resulted in changes in species diversity, including the abundance of the native tidewater goby (23). Black brant have shifted their winter distributions to northern areas as eelgrass in the southern extent of their range have declined (26).

Conservation actions include restoration activities, improved vessel management plans to reduce destruction to eelgrass habitat, minimizing impacts from dredging and other development projects, and reducing impacts from shellfish mariculture operations (11, 23). Research on the use of eelgrass to ameliorate the effects of ocean acidification (through the removal of carbon from seawater) is being explored, making protections of current eelgrass habitat and expansions to new habitats a key tool to fighting ocean acidification (21). Having improved models on sea level rise impacts is an area for further study (11).

Surf grass

Surf grass are habitat-forming species occurring in rocky intertidal and shallow subtidal habitat (11). *Phyllospadix scouleri* and *P. torreyi* are two species identified as species to monitor for climate change impacts in central California (4). They are flowering plants that can pollinate underwater and at the water's surface; they also improve water clarity, trap and stabilize sediments, dampen waves, and provide refuge for many species of invertebrates and algae (*Phyllospadix*). Seed dispersal and available substrate for attachment are factors limiting surf grass distribution (11).

Climate change stressors include increased temperatures; however, many of the stressors to surf grass are directly human-caused, including coastal development, introduction/invasion of non-natives (e.g., *Caulerpa taxifolia*), power plants (causing thermal pollution), and dislodging from substrate by anchors (*Phyllospadix*).

Information about the spatial and seasonal variability in biomass, as well as the ecological role of surfgrass beds in Oregon, have been identified as data gaps (11).

Conservation actions include continued restrictions on harvest, and monitoring surf grass at previously monitored sites (11). Surf grass currently receives protection from the Environmental Protection Agency under the Clean Water Act and the Rivers and Harbors Act (*Phyllospadix*).

Habitats

Each habitat type cited in the documents was assigned to standardized habitats outlined in the Coastal and Marine Ecological Classification Standard, or CMECS (FGDC 2012). CMECS provides a way of classifying and organizing the marine environment. Using the CMECS Systems and Subsystems as our guide, we had four systems and their corresponding subsystems:

- **<u>Lacustrine</u>**: This system includes freshwater habitats, which is not the focus of this report. However, freshwater systems are connected to estuarine and coastal systems.
- **<u>Estuarine</u>**: This system is tidally influenced, has an open-surface connection to the ocean, has freshwater input from land, and has some land enclosing it. For this system, we had two subsystems:
  - ***Estuarine Tidal Riverine Coastal***: This is the most upstream region of the estuary, is regularly influenced by tides, contains water with salinity <0.5 psu (practical salinity units), and includes areas between MHHW (mean higher high water) to the 4 m depth contour below MLLW (mean lower low water). An example habitat in this subsystem would be riverine tidal (29).
  - ***Estuarine Coastal***: This region incorporates the supratidal zone (or splash zone) at the land margin up to the 4 m depth contour in waters with salinity >0.5 psu. Examples of these habitats include tidal marsh, mud flats, and estuarine beaches.
- **<u>Marine</u>**: This system has little or no significant freshwater input, except from estuaries and rivers. Salinity is typically 35 psu, and it can range from the supratidal zone to the central ocean. There were three main subsystems identified in our synthesis:
  - ***Marine Nearshore***: This area covers the landward limit to the 30 m depth contour. Habitats that fall in this category include beaches, rocky intertidal, rocky reefs, and seagrass beds.
  - ***Marine Offshore***: This encompasses the region from the 30 m depth contour to the continental shelf break. Examples of these habitats are coral reefs, offshore rocky banks, and any habitat described as being on the continental shelf.

- ***Marine Oceanic***: This is the open ocean, from the continental shelf break to the deep ocean, and these waters can have higher salinity values (>36 psu). Habitats described as being on the continental slope, seamounts, and deep waters would be categorized in this subsystem.

- **Cross-habitat**: For habitats that encompassed multiple habitats or did not have sufficient information to assign them to a single system or subsystem would be classified as cross-habitat. Refuges are an example of cross-habitat.

Based on our classifications, most habitats (76%) referenced in the documents belonged to the Marine system, with a little more than half of these habitats fitting into the Marine Nearshore subsystem (Figure 7). Beaches (including sandy and gravel beaches) was the most frequently cited habitat, followed by rocky intertidal, kelp forest, rocky reefs, and seagrass habitat. The Estuaries subsystem (under the Estuarine system) also received many citations.

Overall, survey results showed most people agreed with these habitats (Figure 8). Tidal marshes and dunes (for upland connectivity and upshore retreat habitats), benthic habitats (citing the Marine Life Protection Act approach), water habitats/features (e,g., upwelling regions, upwelling shadows, etc.), continental shelf, estuaries and their specific habitats (e.g., mudflats, marshes, neretic zones), open ocean, pelagic habitats (or water column), and sediment habitats were cited by respondents as important. One respondent pointed out that the nearshore habitats were cited the most because there is more information on them, and deeper, more remote habitats should not be left out due to lack of data.

Beaches

Beaches provide spawning habitat for certain forage fish species (e.g., Pacific herring, surf smelt *Hypomesus pretiosus*, sand lance, California grunion *Leuresthes tenuis*), haul-out and pupping areas for pinnipeds (e.g., harbor seal *Phoca vitulina*, elephant seal *Mirounga angustirostris*), and nesting and foraging habitat for shorebirds and seabirds (e.g., western snowy plover, California least tern *Sternula antillarum browni*; 3, 14, 29, 32). Invertebrates, including razor clams (a species harvested by tribes), are found on sandy beaches (14). This habitat is constantly changing as waves and wind transport sediments (3, 4, 11, 23, 32). While beaches are popular recreation destinations for people, this habitat is damaged by people through trampling, disturbance, and introduction of non-native species (11, 23). Beaches have also become degraded through accumulations of contaminants and pollutants (e.g., oil, marine debris, sewage), beach wrack removal, sand replenishment, and shoreline armoring (3, 32). It is one of the habitats most impacted by human activities (10). Beaches are projected to be negatively impacted by climate change through sea level rise, increased storm intensity, flooding, and coastal erosion (3, 4, 14, 23, 29). Harmful algal blooms may become more frequent near beaches, where nutrient inputs originate from wastewater treatment plants or residential septic tanks (3, 14). Loss of beach habitat may also have large economic impacts on the communities that rely on beaches for tourism dollars (3). Keeping invasive species in check and protecting sensitive areas from human disturbance are current conservation actions (11). A gap in knowledge identified was knowing more about the keystone and foundation species in beaches in the Channel Islands National Marine Sanctuary (32).

Rocky intertidal

The rocky intertidal is rocky substrate found between high and low tide water levels, and it is subject to wave action, changing tide levels, and temperature changes; it is home to sea palm, shorebirds (e.g., black oystercatcher), and many species of invertebrates, including the ochre sea star and California mussel (2, 3, 4, 24). This habitat was identified as one being most vulnerable to climate change impacts (2); like most nearshore habitats, it is a habitat that has high overall impact scores (8), particularly from human activities (10). Climate change will negatively impact the rocky intertidal zone through increased air and water temperatures, ocean acidification (which will prevent shell formation in some invertebrates), sea level rise, increased storm intensity and frequency, and coastal erosion (2, 3). Invasive species and salinity changes are other concerns (2). Human-related threats to the intertidal include shoreline armoring, pollution (including oil spills), trampling (2, 3); wave energy conversion devices, which are anticipated to reduce wave energy to the intertidal and influence species zonation, is a future stressor and requires more study (3).

Kelp forest

The kelp forest is iconic to the California coast and important for ecological, recreational, and commercial reasons (18, 32). Kelps are known as a habitat-forming species, as they provide habitat for many fish species (e.g., kelp bass *Paralabrax clathratus*, rockfishes, California sheephead), and kelp forests within marine protected areas (MPAs) are helping to bolster depressed fish populations (1, 32). Invertebrates such as sea urchins live in kelp forests and graze on kelp; the resurgence of the southern sea otter, a key predator of sea urchins, has led to the increase in kelp forest biomass and distribution in California (32); however, in recent years, this has reversed and kelp forests (particularly bull kelp) are significantly reduced (Benefield 2011, CDFW 2016, Fox 2017, Hohman 2018, Kelp Recovery Recommendations 2018). Kelp that is dislodged and deposited on beaches becomes critical habitat for invertebrates, thereby becoming food for shorebirds (32). Bull and giant kelp are common canopy-forming species, while other species (e.g., feather boa kelp *Egregia menziesii*) make up the understory (1, 2). There has been significant loss of kelp forests, particularly in southern California (1). Similar to the rocky intertidal and other nearshore habitat types, kelp forest habitat has one of the higher impact scores of cumulative human impacts (8). Non-native species such as *Sargassum horneri* poses a threat to native kelp species (32). Kelp forest habitat was deemed to be one of the least vulnerable habitats to climate change threats, mainly due to the kelp forest's high adaptive capacity (2). The key climate sensitivities of this habitat are dissolved oxygen, salinity, wave action, sea surface temperature, and the changes to ocean currents and upwelling that is anticipated to happen (2). Kelp is harvested by people in California, although restrictions have been implemented (1). Disease among invertebrate grazers may indirectly affect this habitat (2). Kelp forests and other submerged aquatic vegetation are of interest in sequestering carbon dioxide and helping to mitigate the effects of climate change and ameliorate ocean acidification at local levels (18, 25, 32). Protecting kelp forest habitat has been identified as a conservation action for both its carbon sequestration abilities and its refuge qualities (18, 25, 32).

Rocky reefs

Rocky reef habitat are submerged rocky outcrops that provide a physical structure for many species to find refuge or places to attach themselves (*Rocky Reef on the West Coast*). Rocky reefs can range anywhere from the rocky intertidal zone (at the shoreline) to seamounts (in the deep sea; *Rocky Reef on the West Coast*). For the purposes of this project, rocky reefs will refer to rocky outcroppings in the marine nearshore and offshore areas, but not the rocky intertidal or seamounts found in the marine oceanic zone. Depending on the depth of the rocky reef, they can support algae (if close enough to the surface for sunlight), invertebrate filter feeders (if too deep for sunlight), and a number of groundfish species, including commercially and recreationally important rockfish species (1, 32, *Rocky Reef on the West Coast*). Rocky reefs are important recreational habitat for SCUBA divers (32).

This habitat is highly impacted by human activities (8, 9). Fishing activities are the biggest threat to this habitat (5, 32); bottom trawls destroy the reef structure, and fishing gear that is caught on the reef can continue to kill animals for many years (called "ghost fishing"; *Rocky Reef on the West Coast*). Removing too many individuals from a reef can disrupt the ecosystem structure and make it less productive (*Rocky Reef on the West Coast*). Bottom trawling practices can destroy the habitat, and the Pacific Fishery Management Council has enacted limits to this damaging fishing practice, which applies to more than 90% of the U.S. West Coast's Exclusive Economic Zone (3-200 miles from shore; 5). Introduced species (e.g., Japanese brown alga *Undaria pinnatifida*) threatens this habitat (32). Climate change will affect this habitat through increased water temperatures and ocean acidification, which will negatively impact the invertebrate communities here (*Rocky Reef on the West Coast*).

Seagrass

Seagrass habitat is composed of submerged aquatic flowering plants. There are 60 species of seagrass (including eelgrass); seagrass meadows offer habitat to fish, macroalgae, microalgae, and various invertebrates. Seagrass also feeds turtles, fish, birds, and crabs, and this habitat is important for stabilizing sediments and reducing coastal erosion (*Seagrass*). Seagrass habitat is highly impacted by human activities; there are almost no seagrass beds in the world that have remained untouched by humans (9, 10). Underwater structures, vessel propellers, and increased sedimentation negatively impact seagrass habitat (2). Increased water temperatures with climate change may actually benefit seagrasses (2). Similar to kelp forest habitat, seagrass meadows capture carbon dioxide from the water and may reduce (on a local level) ocean acidification effects (18). Seagrasses also have the ability to store carbon for long periods of time, making them great carbon sponges, but also making them release substantial amounts of carbon into the atmosphere when destroyed (18).

Estuaries

Estuaries offer refuge and nursery habitat to many fish species (including commercially important salmonid species), and shorebirds utilize estuaries during their migrations (29). Sea level rise and changes in precipitation (and resulting freshwater runoff) are expected to have significant impacts on estuarine habitat (3). The morphology of estuaries will also be impacted by changes in sediment delivery, which may impact on the mouths of estuaries, circulation patterns within estuaries, and salinity levels (3). Sea surface temperature and wave action are other climate sensitivities (2). Other threats to estuaries are land use change (leading to increased sedimentation and delivery of contaminants), overwater/underwater structures, roads and other shoreline armoring, and invasive species (2). Estuarine habitat is one of the most vulnerable habitats identified in climate assessments (2).

Resources

We grouped resources mentioned in the documents into 8 larger categories (Figure 9). In order of greater to lesser importance, they are as follows:

1. **Food production**: This category includes fisheries, aquaculture, or other food harvesting activities.
2. **Recreation/cultural**: Recreational opportunities, natural heritage, and archaeological resources fall into this category.
3. **Commercial development**: Coastal development and industrial uses of the ocean (e.g., shipping) are covered in this group.
4. **Ecology/natural processes**: Some documents highlighted the natural resources and processes (e.g., upwelling, ocean circulation) as an important resource.
5. **Energy**: Resources related to energy projects on the coast (e.g., power plants) or in the ocean (e.g., oil extraction, renewable energy projects) are highlighted here.
6. **Health and safety**: This category encapsulates some of the resources that relate to public health and safety. Flood and erosion protection, shoreline armoring, and green infrastructure are examples.
7. **Water**: These reports talked about the importance of water resources in the ocean. One example includes the ability of some habitats to purify water.
8. **Other**: This category mainly includes military resources that we did not see fitting with other resource categories.

Fisheries and aquaculture were the top resources in the food production category. Shipping, under commercial development, was the next largest resource. There was a five-way tie with the next most mentioned resource: two belonged to recreational/cultural resources (archaeological resources and recreation), two belonged to ecology/natural processes (habitat and living resources), and one belonged to energy (oil); for these, we chose to describe recreation and oil.

Survey respondents agreed with these categories (Figure 10). Non-fossil fuel power generation from ocean processes (e.g., wind, wave, tidal) and desalination were cited by respondents as missing.

Fisheries

The ocean is a source of food for people; from finfish to groundfish to invertebrates, species from various habitats are exploited for human consumption. Commercial fisheries abound in the California Current Ecosystem. Pacific hake, market squid, and Pacific sardine are the top species in overall landings by weight (1). While salmon and rockfish are still fished, they have declined significantly in the last 30 years (1). During the 2001-2010 period, California landed the most amount of fish by weight (37%), followed by Oregon (22%), then Washington (17%); another 24% of fish by weight were processed at sea (1). The Dungeness crab fishery is the most valuable fishery on the U.S. West Coast (1). Recreational fisheries are also popular, with black rockfish *Sebastes melanops*, California halibut, albacore *Thunnus alalunga*, lingcod *Ophiodon elongatus*, coho salmon, and Chinook salmon, with salmon species caught more frequently in Washington and Oregon than California (1). Recreational fishing was the second most common stressor in the California Current, and commercial fishing was a top stressor in most offshore environments (10). Tribal fisheries are co-managed by the tribes and states; salmon, steelhead, groundfish, Dungeness crab, and razor clams are examples of tribal fisheries (14).

The topic of fisheries appears to receive moderate attention in the literature, with California (particularly southern California) having more peer-reviewed articles than other areas of the California Current; Oregon has the fewest fisheries-related publications (6). Quantifying the impacts of fisheries, in terms of bycatch and destruction of habitat, have been summarized in a few studies (8, 9, 10). Fishermen value local knowledge of the ocean; they also expressed frustration that their opinions are not being heard by scientists and policymakers (20).

With several fisheries in decline, there are efforts by non-profit organizations to keep fisheries in check by stopping overfishing, reducing bycatch, protecting habitat, increasing transparency in fisheries, and curbing pollution (5). Climate change is anticipated to change the distribution range of certain fished species, or negatively impact their populations through temperature changes, ocean acidification, lower dissolved oxygen levels, and toxins produced by harmful algal blooms (16, 18, 26). Implementing sustainable management of fisheries, protecting habitat for important species, and providing job training for people who fish for a living are ways to deal with the negative impacts of climate change to fisheries (18, 26). Others recommend a more holistic approach to ensure fisheries endure with climate change, including managing for ecological resilience, social resilience, and increasing management adaptability (16).

Aquaculture

Aquaculture is farming in the ocean. It can include the cultivation of fish, invertebrates (mainly oysters, clams, and mussels), or marine plants for human consumption. This industry provides jobs and food to local economies and is helping to meet future seafood demand (2). Based on data from the early 2010s, this industry on the U.S. West Coast does not appear to be growing due to international competition and regulations (1); however, more recent data (2012-2016) show the finfish and shellfish aquaculture industries in the California Current Ecosystem to be increasing (31). Most shellfish aquaculture and salmon mariculture on the U.S. West Coast is located in Washington (1, 25); Oregon has mostly shellfish aquaculture; and California has a small amount of oyster production, but most aquaculture here is for freshwater species (1). During the 2000-2010 period, oyster and salmon aquaculture industries on the U.S. West Coast appear to be declining, but the Pacific geoduck *Panopea generosa* industry is on the rise (1).

Aquaculture is considered a non-climate stressor to marine and estuarine environments; shellfish operations displace or alter seagrass beds, facilitate disease transmission (especially to farmed abalone), introduce non-native species, and alter water quality and turbidity (1, 2, 26). Concerns with finfish aquaculture include: using wild fish to feed the farmed fish, thereby reducing these populations in the ocean; using of drugs and chemicals and their effects on the surrounding environment; producing excess fish waste and its impacts on the local ecosystem; escaping fish and their impacts on the health of wild populations; and entangling predators in fish pens (1). Salmon mariculture risks introducing sea lice and disease to wild salmon populations (1). Out of four different aquaculture types (finfish (herbivores), finfish (predators), marine plant, and shellfish), shellfish aquaculture had the greatest stressor score (10). Shellfish aquaculture impacts multiple habitats, including seagrass, suspension-feeding reefs, mud flats, rocky intertidal, and salt marsh (10). The effects of aquaculture, particularly in regards to disease transmission, rated high in concerns among scientists and ocean resource users (20).

Aquaculture also suffers from climate change impacts, with ocean acidification, increased ocean temperatures, sea level rise, and changes to ocean currents having the biggest impacts on this industry (15, 17, 18, 27). More frequent harmful algal blooms are also of concern to the industry (15, 27). Having a flexible monitoring program, developing predictive models of climate change impacts, improving our understanding of the biology and ecology of aquaculture organisms, and improving our understanding of biotoxins and their movements through the food web will help the aquaculture industry thrive (17, 18, 25). Photoremediation (i.e., planting submerged vegetation near and in shellfish aquaculture operations to reduce carbon dioxide and nutrient loads) can help protect shellfish from local acidification and hypoxia (25). Property rights issues are also likely to emerge for this industry with sea level rise, as shoreline property lines will be pushed as the mean high water mark moves inland (15). New job training for people who work in the aquaculture industry is another option (26).

Shipping

The movements of goods and people across the world is dependent on shipping. Shipping can include commercial shipping, cruise, passenger ships, and any other vessel traffic. Shipping can also encompass ports, terminals, and shore-based equipment (e.g., cranes used to move containers) associated with shipping (15). Data on distance traveled by commercial vessels during transit within the California Current shows almost no change in the last 5 years (31).

Shipping is the only major industrial activity having an impact on the offshore environment, and transpacific shipping (cargo traffic in particular) is growing (1). Commercial shipping poses several threats to the marine environment; some of these include ship strikes to large animals (e.g., whales), noise pollution, oil pollution, possible groundings or sinkings, and marine debris (1, 8, 9). Commercial shipping is the main source of underwater anthropogenic noise; these ships emit low frequency noise which has significant impacts on baleen whales (1). Shipping is also the main method of introducing invasive species (via ballast water) to estuaries throughout the California Current (1).

Shipping has not received much attention in the literature, so more studies are needed, particularly in Oregon (6). A recent study indicates that the number of blue, humpback, and fin whales estimated to be struck by ships is underestimated and are causing an impediment to recovery (Rockwood *et al*. 2017). As with any other shoreline structures, ports and marinas must consider sea level rise and how this may affect their functioning in future years (15). New quieting technologies (e.g., propeller modifications) and designating critical habitat as "quiet areas" may help reduce noise pollution and lessen disturbance to whales (1). Reducing ship speeds and shifting shipping lanes may be avenues to reducing ship strikes to whales (1, Rockwood *et al.* 2017).

Recreation

Recreation encompasses a large variety of activities which bring humans in close contact with the natural environment. These activities include wildlife viewing, boating, kayaking, hiking, camping, recreational fishing and diving, and surfing. Many of these activities are encouraged or promoted, even within protected areas, since they provide educational and outreach opportunities for the general public, in turn fostering a desire to keep these areas protected (22,32). While these activities can be considered non-commercial in nature, commercial industries have formed to support them and recreation can be a key economic driver, especially at the local level (2).

Climate change may have a mixed set of positive and negative impacts on recreational opportunities. Increased sea surface temperatures, for example, may increase recreational swimming opportunities in waters that were historically too cold for much of the year. Changes in sea level and increased storm intensities can result in the direct loss of beach areas for recreation through flooding and erosion or indirectly through increased armoring and flood protection infrastructure (2). Impact of climate change on habitats and wildlife can also drive changes in recreational opportunities and intensity. For example, changes in disturbance regimes or other environmental conditions can cause the loss or shifting of species that draw in people for wildlife viewing opportunities (2). Overall, however, there are relatively few studies focusing on the connections between climate change and recreation and tourism (2, 6).

Recreational activities can have a direct impact on habitats and wildlife and are considered an important non-climate stressor (2, 6, 10, 32). General impacts include pollution and littering, trampling of habitat, disturbance to wildlife, and the disruption of ecosystem processes (32). For example, recreational use of beaches can lead to disturbance of nesting snowy plovers and nest abandonment (2, USFWS 2007). Within dune ecosystems, trampling can hamper the regeneration of native habitat and facilitate invasion by non-native species such as European beachgrass (2). Resources can be directed towards minimizing these impacts through the development of best practices, policies and recommendations, and by education, raising the awareness, and enforcement of these.

Oil

This resource includes oil and gas development projects, which are currently limited to Southern California (1). National Marine Sanctuaries prohibit oil and gas development, and oil and gas extraction activities are prohibited in California state waters; however, Oregon and Washington state waters have no prohibitions, and the moratorium that once covered the outer continental shelf off the U.S. West Coast expired in 2017 (1). The Trump administration is now seeking to expand offshore oil and gas drilling in nearly all U.S. waters (Friedman 2018). Oil and gas are extracted from offshore marine environments using oil extraction rigs, then transferred to facilities on land through pipelines for refining (8, 9).

The main concerns with oil and gas developments are oil spills, seismic testing (and its associated acoustic impacts to marine wildlife), and minor leaks (1). An assessment of cumulative impacts from multiple stressors on Marine Protected Areas in California scored oil platforms as having little to no impact (33). An assessment of oil and gas activity and production across the coast of California since 1974 showed a clearly declining trend over the last 20 years with peaks in the mid-1980s and mid-1990s (31).

The largest threat from oil spills may come from its transportation. In Washington State in 2006 an estimated 5.7 billion liters of oil were transported through the Strait of Juan de Fuca (14).

Oil spills can impact different habitats in different ways and magnitudes due to the different sensitivities and species within those habitats (2,14). NOAA has classified estuaries (including marshes and sheltered tidal flats) as the most sensitive to oil among shoreline habitats (14) partly because of the persistence of oil within the anaerobic subsurface of these habitats. However, even within rocky shores where cleaning through natural wave action and mechanical cleaning is possible, the effects of oil spills on the ecological community can persist for years or decades (14). One benefit from oil and gas development is the artificial habitat created by oil rigs; however, fish that use this habitat may be exposed to a host of toxic compounds (e.g., mercury, lead, benzene; 1).

More research is needed on how oil spills behave and how they can be cleaned up. For example, the Olympic Coast National Marine Sanctuary has prioritized a need to research the effective use of oil dispersants (14). The sub-lethal effects of oil spills (e.g., trophic cascades, impacts on habitat forming species, impacts on reproduction) and dispersants used to clean them up have received more attention recently and it is thought that their impacts are currently underestimated (14).

Threats

We split the threats to the marine environment into two broad groups: **Direct Human Impacts** and **Indirect Human Impacts** (Figure 11). The Direct Human Impacts groups encompasses the threats that are directly attributed to human activities, while Indirect Human Impacts includes those threats more related to climate change. While we acknowledge climate change is related to human activities, we recognize these threats as being indirectly related to human activities and more directly related to the changes in the ocean that occur with more carbon dioxide being released into our atmosphere.

For example, high nutrient input in nearshore areas (which is usually a result of human activities) can lead to harmful algal blooms; in addition, these blooms produce neurotoxins, which are a hazard to human and wildlife health. We are currently showing harmful algal blooms in the Indirect Human Impacts group.

Direct Human Impacts

Fishing, pollution (from a variety of sources), and disturbance are the main human-related threats to the California Current Ecosystem. Most respondents agreed with the categories of direct threats (Figure 12), although some advocated for more emphasis on coastal armoring, benthic habitat destruction and entanglement (from fishing activities), and the inclusion of salinity change/increased freshwater flows, increased sedimentation, and nutrification under the Pollution or Habitat destruction category. The term “ghost gear” was mentioned by one respondent as a specific focus under the Fishing threat. One respondent suggested looking at the cumulative impacts of all the direct human impacts would be valuable. The categories of threats receiving the most citations are:

Fishing

This includes overfishing, high bycatch, destruction to habitat (connected with demersal fishing practices), impacts to biodiversity, and a lack in transparency in fisheries. Both recreational and commercial fisheries were mentioned, as well as artisanal fishing (which was cited only once) and illegal harvest. The California halibut fisheries (commercial gill net and trawl) were highlighted as destroying habitat and having high bycatch. Common murres, Brandt’s cormorants, and other seabirds were historically caught in gill-nets; seabirds also compete with humans for similar fish species, making them susceptible to reduced food availability through human overfishing. Steller sea lions also get caught in fishing gear.

Urban pollution

This category includes many different forms of pollution from high human population centers on land. Marine debris, trash, and plastic tops this list, but other forms of urban pollution include light pollution, noise pollution, nutrient input from land, and urban runoff. Seabirds (e.g., common murre, Brandt’s cormorant) and marine mammals (e.g., California sea lion, southern sea otter) are at risk from being entangled in and consuming marine debris. Surf grass and other submerged aquatic vegetation is harmed by sewage.

Nonpoint source pollution

This category includes the many other forms of pollution that do not necessarily originate from urban centers. Pollutants deposited in the ocean from the atmosphere, inorganic pollutants, ocean dumping, sediment pollution, and toxics are examples. Steller sea lions may have experienced declines in pupping rates due to persistent organic pollutants; California sea lions and southern sea otters are also at risk from these compounds.

Disturbance

Direct human disturbance to wildlife and their habitats are the focus of this category. Examples include human trampling, disturbance to wildlife, and aircraft and vessel traffic near important habitats. Rocky intertidal inhabitants (e.g., California mussel) are at risk of being trampled by recreational users, researchers, and harvesters. Beachgoers risk disturbing protected species like the western snowy plover. Aircraft and boats can disturb seabird nesting colonies (e.g., common murre, Brandt's cormorant), leading to predation events and nest abandonment. Black oystercatchers are at risk from direct human disturbance (e.g., nest trampling, flooding nests by boat wakes) or indirect human disturbance (e.g., flushing adults from nests, attracting nest predators). Whale watching operations can be a disturbance to blue whales and humpback whales. Noise produced by ships can disrupt communication among whales and inhibit their ability to find prey. "Seal bombs" can cause injury and death in marine mammals.

Industrial pollution

This category is specific to industrial activities and the pollution that results from these activities. For instance, oil spills, ocean-based marine debris, ocean dumping (e.g., toxic materials, ship wrecks, fishing gear), coastal industrial facilities, radioactive waste, and aquaculture pollution are all industrial pollution threats. Paper mills discharge sulfite waste, which is then taken up by filter feeders (e.g., Olympia oyster). Filter feeders (e.g., California mussel) also accumulate heavy metals and organic pollutants, passing these on to their predators. Oil spills are a threat to the southern sea otter and seabirds like the Cassin's auklet, common murre, and Brandt's cormorant. Eelgrass habitat has also declined from this type of pollution. Thermal pollution from coastal power plants is a threat to surf grass.

Indirect Human Impacts

These threats are connected to climate change and the many alterations to the marine environment it is expected to bring. Overall, respondents agreed with our indirect human impact categories (Figure 13), although there was some confusion as to what defines an indirect impact (e.g., ocean acidification, sea level rise, and increased temperatures could be considered direct). "Storminess" (i.e., increase in storm frequency and severity) was recommended as its own category or called out in the "Changes in natural processes" category. The top five categories are:

Changes in natural processes

Climate change is bringing many changes to how the ocean normally functions. Changes in upwelling will be the biggest threat, as it is expected to be stronger, more persistent, and last into the fall months, which will have variable results for phytoplankton, the base of the marine food web (3). The timing of upwelling, when nutrients are delivered to surface waters, and when phytoplankton are available can also have big implications for many marine species, including zooplanktivores (e.g., endangered salmon species, Cassin's auklets, blue whales), kelp forests, and piscivores (e.g., common murre, Brandt's cormorant, California sea lion). Also, as upwelling becomes more intense and frequent, this could change the habitats and distributions of species; Pacific sardine may become an offshore species (where the influences of upwelling are weaker) and northern anchovy may stay in nearshore areas (where upwelling influences are stronger; 2). Changes in freshwater flow into estuarine and coastal habitats is the second most significant threat. While freshwater flows have already declined due to human water diversions (e.g., dams), there could be further declines in freshwater flows in the summer (due to lower summer precipitation) and increased freshwater flows in winter and fall (due to increased storm intensity and frequency; 1, 3). As previously mentioned, species like Chinook salmon and coho salmon may benefit in places where freshwater flows are increased during juvenile migration to the ocean (1); however, if freshwater flows are low during this time, this may lead to increased water temperatures, decreased growth rates, and higher vulnerability to predation (3). Increased freshwater flows could deliver disease to southern sea otters. Flooding and salinity changes are also associated with altered freshwater flows (1, 3), with lower salinity levels leading to higher mortality and lower food intake by Olympia oysters (2). Rocky intertidal species (e.g., California mussel, sea palm) will also suffer from salinity extremes. Black oystercatcher nesting habitat will also be impacted by flooding. The third most significant threat is changes in ocean circulation. While many factors affect the circulation of the ocean (e.g., temperature, salinity, winds, atmospheric pressure gradients), changes to the currents off the U.S. West Coast will impact the abundance and distribution of different marine organisms (3).

Ocean chemistry changes

Changes to the chemistry of the ocean are a significant stressor to the California Current Ecosystem. Ocean acidification is at the top of this list, which will negatively impact shellfish (e.g., Olympia oyster, California mussel) and other organisms with calcium carbonate structures (e.g., red sea urchin, corallines). Both positive and negative effects are expected with lower pH for some species (e.g., sea palm), while increased acidity (and increased aqueous carbon dioxide concentrations) may benefit others (e.g., eelgrass). The second biggest threat is hypoxia, or a decline in dissolved oxygen levels. Hypoxia has already been observed in deep waters (affecting offshore benthic communities), causing large mortality events (3); however, this oxygen minimum zone, common to deep waters, may be shoaling and causing mortality events in more places and in shallower waters (3). Both increased acidification and lower dissolved oxygen levels will negatively impact forage species (e.g., Pacific sardine, northern anchovy), species with high commercial value (e.g., Dungeness crab), and species popular in recreational fisheries (e.g., red abalone; 2, 16).

Sea level rise

Rising sea levels will affect habitats at the land-sea interface, particularly in estuaries. Beaches, dunes, the rocky intertidal zone, salt marshes, mud flats, and seagrass meadows – and the organisms associated with each of these habitats (including western snowy plover, black oystercatcher, juvenile Chinook salmon, kelp forests, and eelgrass beds) – are all at risk to being reduced, damaged, or lost with rising seas. Human infrastructure near sea level is in danger of flooding, as well as aquaculture operations. Coastal aquifers that provide fresh drinking water for people are in jeopardy of being inundated with seawater (15).

Increased temperatures

Increased surface ocean temperatures has significant impacts on the water column structure, mainly stratification, which has implications for vertical mixing of the water and how effectively nutrients are delivered to phytoplankton in surface waters (3). For organisms that can only tolerate certain temperature ranges, this can cause shifts in distribution to more favorable conditions. For example, Pacific sardine, a warm-water tolerant species, may experience a population expansion; however, northern anchovy, a cold-water species, may shift its distribution to northern latitudes. However, for those species that cannot endure warmer waters, this will negatively impact their populations. Red abalone, macroalgae, and eelgrass will also be harmed by increased sea surface temperatures. Increased air temperatures are also included in this category, with thermal constraints of organisms dictating where they will be able to live. Exposed habitats (e.g., dunes, beaches, rocky intertidal) will be under more pressure from increased air temperature, affecting species like California mussel, sea palm, and surf grass. People may also spend more time at coastal locations to get relief from extremely hot temperatures, which may lead to increased disturbance (a top threat in Direct Human Impacts, above).

Invasive species

A changing climate will also enable invasive species to spread, making it more challenging for native species to survive and remain in their habitat. While some species may be introduced to the California Current by people (i.e., ballast water from ships), other invasive species expansions are likely due to changing ocean conditions by climate change. Invasive species are of bigger concern to coastal habitats (10). The Olympia oyster, which is recovering from overharvest in past centuries, is impacted by invasive species on many levels: invasive gastropods prey upon them; they experience greater mortality in habitats dominated by invasive crabs and whelks; and they are displaced by non-native oysters (2). The invasive kelp *Undaria pinnatifida* is threatening native kelp forests. Native eelgrass beds and surf grass, used by various species (including the commercially important California halibut) for nurseries or spawning grounds, are at risk to invasive alga. Beach and dune habitat, home to the threatened western snowy plover, are being degraded by European beachgrass. Introduced species can also hybridize with native species, creating an even more invasive hybrid (1). Invasive species also have the potential to bring pathogens, changed hydrology, and altered nutrient cycling (1). Invasive species sometimes include native species that have significantly expanded their distribution and are edging out other native species (e.g., California mussel) for space. While invasive species may be a large issue for the California Current, this is a threat that managers may have some measurable impact upon at regional and local levels (33).

Connecting the dots: Species, Habitats, and Threats

The interactive Sankey figure can be accessed here: http://rpubs.com/pointblue/marinethreats

Hovering over one of the species, habitats, or threats highlights the connections (i.e. citations linking one group to another). Hovering over one of the connecting lines will show the number of papers or reports that linked the two groups.

When hovering the cursor over the different habitat types (in the middle), the shallow benthic habitat is connected to 18 species groups (to the left); most of the species represented are invertebrates (e.g., Dungeness crab, red abalone), but some vegetation (e.g., bull kelp, sea palm), fishes (e.g., California halibut), and birds (e.g., Brandt's cormorant, Cassin's auklet) also use this habitat.

The pelagic habitat group has 12 links to species groups and covers a greater spread of taxonomic groups, from the base of the food web (e.g., phytoplankton) to marine mammals (e.g., blue whale, humpback whale). Estuary habitat is next in number of species connections (11 species groups); eelgrass, Pacific herring, and southern sea otter are key species here.

When considering threats (to the right), the threat that has the greatest number of links to different habitats is acidification, connected to all but one habitat type. Food production also has extensive reach to different habitat types (8 habitats). Sea level rise is connected to five different habitats with many documents citing connections to intertidal and estuary habitats.

The habitat that has the most threats connected to it is estuary, connected to 13 different threats in both the direct human impacts and indirect human impacts groups. The 11 species groups linked to estuary and affected by these threats covers different levels of the food web (e.g., plants, invertebrates, fishes, birds, mammals).

The next habitat with the most threats connected to it is shallow benthic, connected to 10 different threats in both direct human impacts and indirect human impacts. As mentioned above, some key species of commercial and ecological importance are impacted.

Intertidal (8 threat groups, 8 species groups) and pelagic (6 threat groups, 12 species groups) were the next two habitats with extensive connections. Intertidal is connected mainly to indirect human impacts (i.e., climate change impacts), which will affect mainly algae, invertebrates and birds in this habitat. Pelagic has a mixture of direct human impacts and indirect human impacts, and the most trophic levels of the marine food web are connected to it, even species with protected status.

Resilience vs. vulnerability

Walker *et al.* (2004) was cited for a definition of resilience, which is defined as follows: "Resilience is the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks."

Walker *et al.* (2004) also further describes the four crucial aspects of resilience:

1. Latitude: the maximum amount a system can be changed before losing its ability to recover (before crossing a threshold which, if breached, makes recovery difficult or impossible).
2. Resistance: the ease or difficulty of changing the system; how "resistant" it is to being changed.
3. Precariousness: how close the current state of the system is to a limit or "threshold".
4. Panarchy: because of cross-scale interactions, the resilience of a system at a particular focal scale will depend on the influences from states and dynamics at scales above and below. For example, external oppressive politics, invasions, market shifts, or global climate change can trigger local surprises and regime shifts.

Most of the documents we reviewed did not address resilience directly; however, some reports did address the vulnerability or sensitivity of certain habitats, which we can use to consider the habitats least likely to be resilient in the face of more stressors. For this exercise, we have focused on five reports (2, 7, 8, 10, 33) that have done some type of scoring or quantitative assessment vulnerability.

As might be expected, the closer the habitat is to human populations, the more vulnerable it is and less likely to be resilient to further stressors. The marine nearshore group is the most vulnerable to various threats. Seagrass beds were identified as high priority habitat and received the most citations as a high priority habitat. Beaches, dunes, and rocky intertidal were also labeled as high priority habitats.

In line with the marine nearshore group, estuarine habitat is the next most vulnerable. Estuaries are close to large human populations and suffer from many human-related activities; now they are enduring the added stressors of climate change.

There were a few habitats in the marine offshore group that were identified as priority habitats; these include hard shelf and soft shelf. Coral reefs (also in the marine offshore group) was another important habitat, although this was from a study of global marine impacts and may not refer to coral reefs in the California Current, specifically.

In the cross-habitat group, existing refuges were classified as a habitat of significance, mainly as places where species can survive with reduced threats.

Recommendations

Many of the documents we reviewed had management, conservation, or research recommendations for different species and habitats.

Management

There were many recommendations related to sustainable fisheries and harvest. Improving harvest control rules for forage species were recommended. While the Pacific sardine is only one of two California fisheries that uses a climate variable in making harvest decisions, recommendations to use more environmental data in making harvest guidelines were expressed. In the case of northern anchovy, a stock assessment of the northern sub-population needs to be done. Managing for sustainable harvest, including calculating predator needs into management plans, was endorsed. Other recommendations included improving our knowledge of stock structure, improving biomass estimates, and protecting critical habitat. People supported sustainable harvest and continued restrictions on harvest of many species, including protected salmon species (Chinook and coho), California mussel, surf grass, and sea palm. Monitoring for sustainable harvest is also imperative, particularly for recent declines in the recreationally-popular red abalone due to combined effects of disease and El Niño-like conditions.

Management of vessel traffic was another priority identified. Modifying ship traffic (e.g., slowing ships down, modifying shipping lanes) and modifying vessels (making them less noisy) will help whales.

Improved vessel management plans, and minimizing dredging and other development projects can help reduce eelgrass destruction. Proper management of shellfish mariculture operations can also help reduce impacts to eelgrass habitat.

The abilities of kelp and eelgrass to ameliorate ocean acidification have been established; using these species in strategic areas can help lessen (at a local level) and manage for the effects of ocean acidification.

Conservation

Managing the human-caused threats and protecting (or restoring) habitat was a common recommendation. Continuing restoration efforts in riparian habitat to enhance spawning habitat was endorsed for Chinook and coho salmon; there are several management plans for both species to find recommendations on this. For the Olympia oyster, this means protecting mature oyster beds from human disturbance and harvest. With guidance from the National Estuarine Research Reserve, restoration planning tools can be used to increase the success of restoration efforts. For the California mussel (and other species of the rocky intertidal), reducing human disturbance and trampling will help. The western snowy plover would benefit from less human disturbance to their nesting habitat on beaches and dunes. Eelgrass habitat is in need of restoration. Protecting upland habitat for future migration of species (e.g., California mussel, western snowy plover) with sea level rise was a goal for some agencies and working groups. Restoring and protecting kelp forests was endorsed through reducing sea urchin populations.

Research

There is considerable support for developing or improving predictions for species using climate and ocean chemistry projections; this is particularly true for species of high commercial or recreational importance, as knowing what to expect in different scenarios will help fisheries prepare. From the North Pacific marine heat wave and the increase in whale entanglements in Dungeness crab pot gear, to the loss of Dungeness crab income to tribes in Washington from harmful algal blooms, fishermen and fisheries agencies can develop predictions of what will happen to fisheries in different scenarios and adapt accordingly. Monitoring for sustainable harvest is also imperative, particularly for recent declines in the recreationally-popular red abalone due to combined effects of disease and El Niño-like conditions. Research on coho salmon and how different ocean/climate indices correlate to different survival and return numbers could be a good starting point for developing something similar for Chinook salmon. Identifying relationships between ocean variables and settlement and recruitment of invertebrates (e.g., California mussel) can also help predict the range and distribution of species in the future.

For protected species like Chinook salmon, understanding the marine portion of their life cycle was recommended. Much of the current focus on this species is centered on their freshwater habitat, which is easier to restore and research than what happens in the ocean; however, the years this species spends in the marine environment is crucial to understanding their survival and population trajectories.

Understanding the role of red sea urchins in bull kelp beds and population dynamics of the species are areas that need further research. The recommendations from the Kelp Recovery Working Group will guide this (Kelp Recovery Recommendations 2018).

Having more data of noise pollution and its effects on marine organisms was voiced. Scientists expressed interest in knowing what the ambient noise levels are in the ocean, as well as the impacts to marine mammals.

Sea level rise will impact species that inhabit shoreline habitats. Understanding the impacts of sea level rise on eelgrass habitat, beaches and dunes, and rocky intertidal habitats are key to conserving upland habitat for retreat.

For recovering species (e.g., Steller sea lion), scientists wanted to determine age-specific survival rates in Steller sea lions.

Monitoring was endorsed for all habitats and species. For certain widespread species like the California mussel, monitoring would provide a good indicator of ecosystem health.

LITERATURE CITED

Ainley DG, Nettleship DN, Carter HR, Storey AE. 2002. Common Murre (*Uria aalge*), version 2.0. In *The Birds of North America* (A.F. Poole and F.B. Gill, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bna.666

Benefield, K. 2011, September 1. Red abalone die-off along the Sonoma Coast. *The Press Democrat*. Retrieved from https://www.pressdemocrat.com/news/2291446-181/red-abalone-die-off-along-the?sba=AAS.

"California Halibut Identification." California Department of Fish and Wildlife, https://www.wildlife.ca.gov/Conservation/Marine/NCCFRMP/Halibut-ID.

"California Sea Lion." The Marine Mammal Center, http://www.marinemammalcenter.org/education/marine-mammal-information/pinnipeds/california-sea-lion/.

CDFW. 2016, March 30. "Perfect Storm" Decimates Northern California Kelp Forests. CDFW Marine Management News. Retrieved from https://cdfwmarine.wordpress.com/2016/03/30/perfect-storm-decimates-kelp/.

"Chinook Salmon – Protected." NOAA Fisheries, U.S. Department of Commerce, https://www.fisheries.noaa.gov/species/chinook-salmon-protected.

"Coho Salmon – Protected." NOAA Fisheries, U.S. Department of Commerce, https://www.fisheries.noaa.gov/species/coho-salmon-protected.

Cooke JG. 2018. *Balaenoptera musculus*. *The IUCN Red List of Threatened Species* 2018: e. T2477A50226195. http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T2477A50226195.en. Downloaded on 05 March 2019.

Doroff A, Burdin A. 2015. *Enhydra lutris*. *The IUCN Red List of Threatened Species* 2015: e.T7750A21939518. http://dx.doi.org/10.2305/IUCN.UK.2015-2.RLTS.T7750A21939518.en. Downloaded on 05 March 2019.

"Endangered and Threatened Species; Identification of 14 Distinct Population Segments of the Humpback Whale (*Megaptera novaeangliae*) and Revision of Species-Wide Listing." A Rule by the National Oceanic and Atmospheric Administration on 9/8/2016, Federal Register, National Archives, https://www.federalregister.gov/documents/2016/09/08/2016-21276/endangered-and-threatened-species-identification-of-14-distinct-population-segments-of-the-humpback.

Federal Geographic Data Committee (FGDC). 2012. Coastal and Marine Ecological Classification Standard. https://www.fgdc.gov/standards/projects/cmecs-folder/CMECS_Version_06-2012_FINAL.pdf

Fox, A. 2017, December 6. Northern California abalone numbers crashing, recreational season may shutter. *The Mercury News*. Retrieved from https://www.mercurynews.com/2017/12/06/northern-california-abalone-numbers-crashing-recreational-season-may-shutter/.

Friedman, L., 2018, January 4. Trump moves to open nearly all offshore waters to drilling. The New York Times. Retrieved from https://www.nytimes.com/2018/01/04/climate/trump-offshore-drilling.html.

Hill KT, Crone PR, Demer DA, Zwolinski J, Dorval E, Macewicz BJ. 2014. Assessment of the Pacific sardine resource in 2014 for U.S.A. Management in 2014-15. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-531.

Hohman, R. 2018. North Coast Kelp Recovery Project: Improving Resilience of Vulnerable Bull Kelp Ecosystems in the Greater Farallones National Marine Sanctuary. Presentation to the Greater Farallones National Marine Sanctuary Advisory Council. Retrieved at https://nmsfarallones.blob.core.windows.net/farallones-prod/media/docs/20180110-kelpsacpresentation.pdf.

Kelp Recovery Recommendations. 2018. Retrieved at http://farallones.org/wp-content/uploads/2019/01/Kelp-Recovery-Recommendations_Clean_Sanctuary-Advisory-Council.pdf.

Kerr A, Scorse J. 2018. The use of seal bombs in California fisheries: Unknown impacts point to an urgent need for more research. Center for the Blue Economy. Retrieved from https://www.middlebury.edu/institute/sites/www.middlebury.edu.institute/files/2018-12/Seal%20Bombs%20in%20CA-%20Final.pdf.

"Northern Anchovy". NOAA Fisheries, U.S. Department of Commerce, https://www.fisheries.noaa.gov/species/northern-anchovy.

"*Phyllospadix*." Multi-Agency Rocky Intertidal Network (MARINe), https://www.eeb.ucsc.edu/pacificrockyintertidal/target/target-species-phyllospadix.html. Last modified 30 October 2018.

"*Postelsia*." Wikipedia, https://en.wikipedia.org/wiki/Postelsia.

"Red sea urchin". Wikipedia, https://en.wikipedia.org/wiki/Red_sea_urchin.

Rockwood RC, Calambokidis J, Jahncke J. 2017. High mortality of blue, humpback and fin whales from modeling of vessel collisions on the U.S. West Coast suggests population impacts and insufficient protection. *PLoS ONE* 12(8): e0183052. https://doi.org/10.1371/journal.pone.0183052

"Rocky Reef on the West Coast." NOAA Fisheries, U.S. Department of Commerce, https://www.fisheries.noaa.gov/west-coast/habitat-conservation/rocky-reef-west-coast

RStudio Team (2018). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA. http://www.rstudio.com/

"Seagrass." Wikipedia, https://en.wikipedia.org/wiki/Seagrass.

"Sea Otter." The Marine Mammal Center, http://www.marinemammalcenter.org/education/marine-mammal-information/sea-otter.html.

"Steller Sea Lion: Conservation and Management." NOAA Fisheries, U.S. Department of Commerce, https://www.fisheries.noaa.gov/species/steller-sea-lion#management.

Trites AW, Miller AJ, Maschner HDG, Alexander MA, Bograd SJ, et al. 2007. Bottom-up forcing and the decline of Steller sea lions (*Eumetopias jubatus*) in Alaska: assessing the ocean climate hypothesis. Fisheries Oceanography 16 (1): 46-67. doi:10.1111/j.1365-2419.2006.00408.x

U.S. Fish and Wildlife Service (USFWS). 2007. Recovery Plan for the Pacific Coast Population of the Western Snowy Plover (*Charadrius alexandrines nivosus*). In 2 volumes. Sacramento, California. xiv +751 pages.

Walker B, Holling CS, Carpenter SR, Kinzig A. 2004. Resilience, adaptability, and transformability in social-ecological systems. *Ecology and Society* **9**(2): 5. http://www.ecologyandsociety.org/vol9/iss2/art5

Wallace EA, Wallace GE. 1998. Brandt's Cormorant (*Phalacrocorax penicillatus*), version 2.0. In *The Birds of North America* (A.F. Poole and F. B. Gill, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bna.362.

FIGURES AND TABLES

Figure 1. Species treemap.
The size of each box corresponds to the number of documents that referenced it. For example, Dungeness crab was cited in 8 documents, while pink salmon was cited in only one document.

Figure 2. Agreement of survey respondents on fish species.

Figure 3. Agreement of survey respondents on invertebrate species.

Figure 4. Agreement of survey respondents on bird species.

Figure 5. Agreement of survey respondents on mammal species.

Figure 6. Agreement of survey respondents on algae and plant species.

Figure 7. Habitat treemap.
The size of each box corresponds to the number of documents that referenced it. For example, Estuaries was cited in 14 documents, while Fresh Marsh was cited in only one document.

Figure 8. Agreement of survey respondents on habitats.

Figure 9. Resources treemap.
The size of each box corresponds to the number of documents that referenced it. For example, Fisheries was cited in 12 documents, while Coastal Tourism Industry was cited in only one document.

Figure 10. Agreement of survey respondents on resources.

Figure 11. Threats treemap.
The size of each box corresponds to the number of documents that referenced it. For example, Acidification was cited in 22 documents, while Subsea Cables was cited in only one document.

Figure 12. Agreement of survey respondents on direct human impacts.

Figure 13. Agreement of survey respondents on indirect human impacts.

Figure 1. Species treemap.

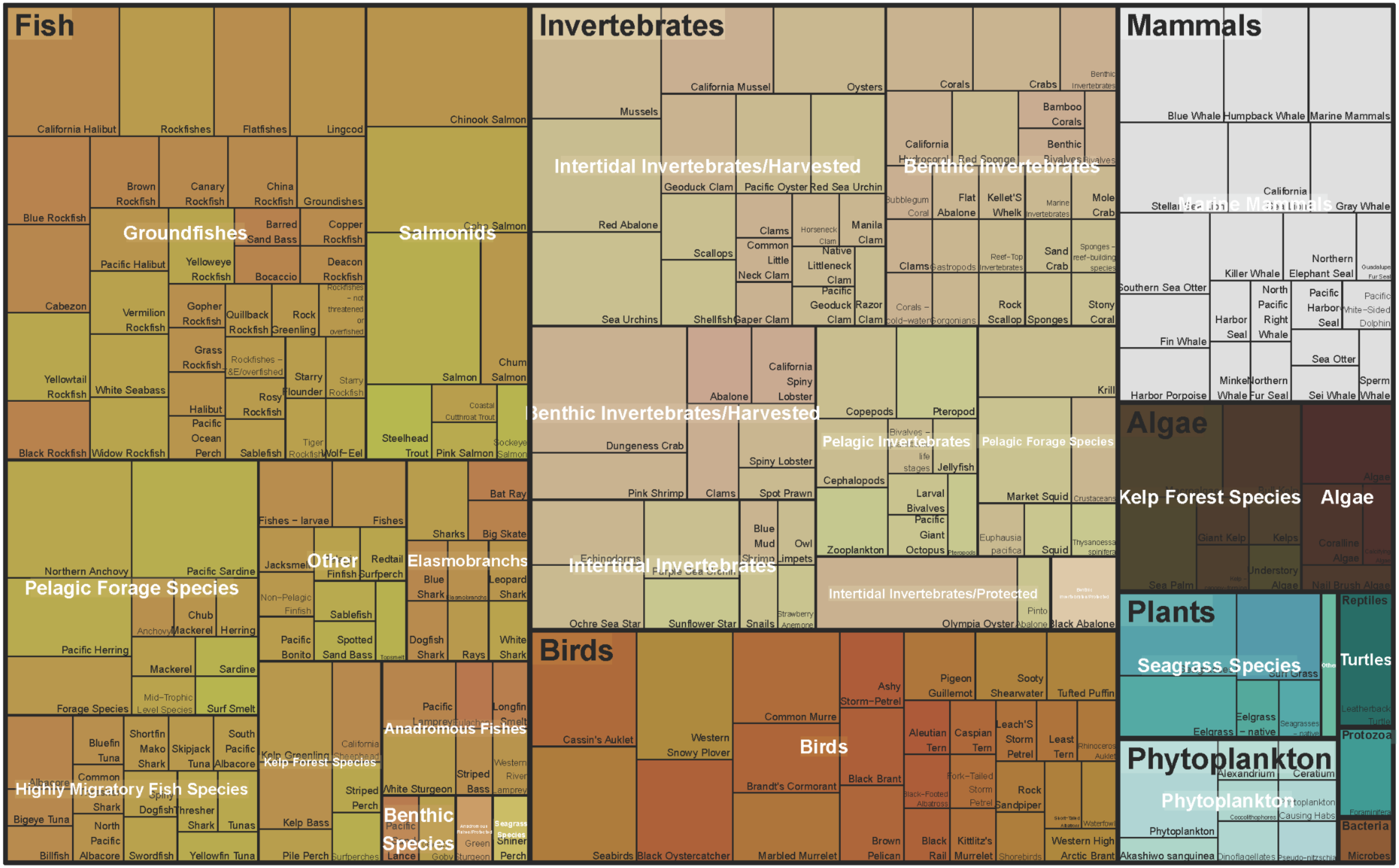

Figure 2. Agreement of survey respondents on fish species.

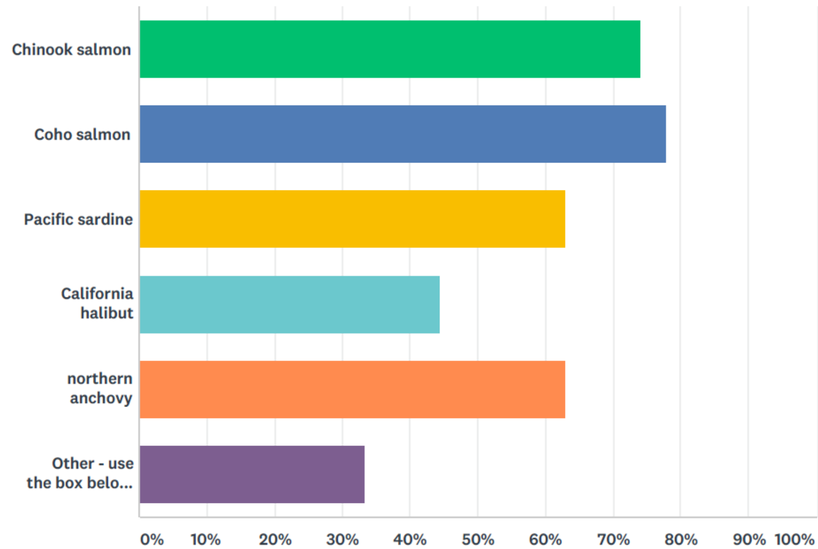

Figure 3. Agreement of survey respondents on invertebrate species.

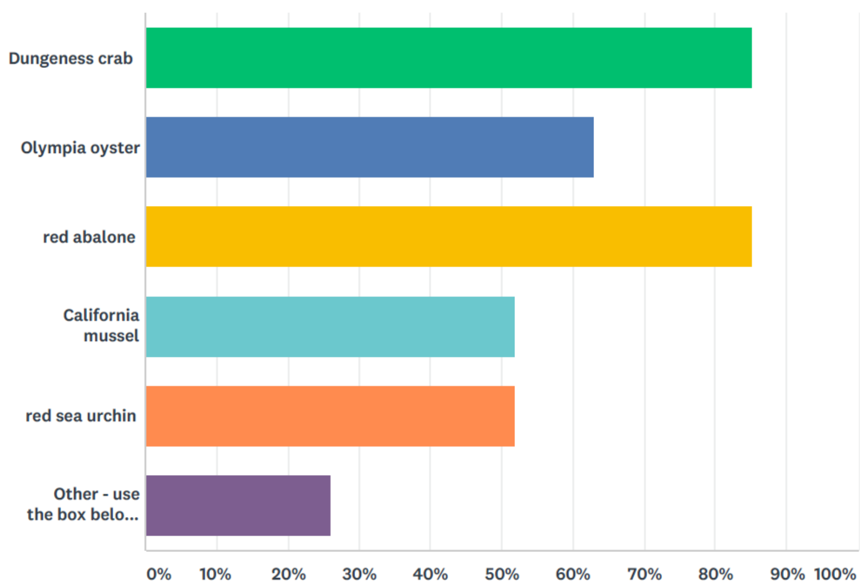

Figure 4. Agreement of survey respondents on bird species.

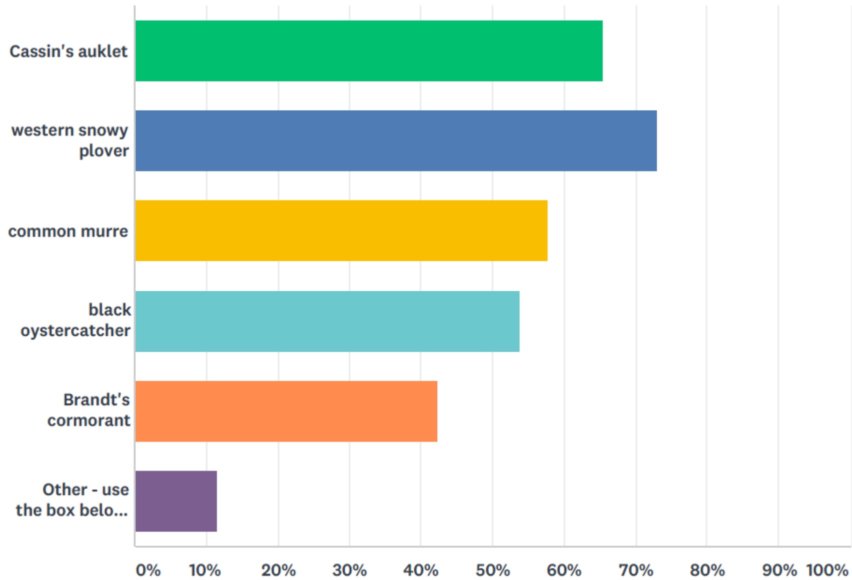

Figure 5. Agreement of survey respondents on mammal species.

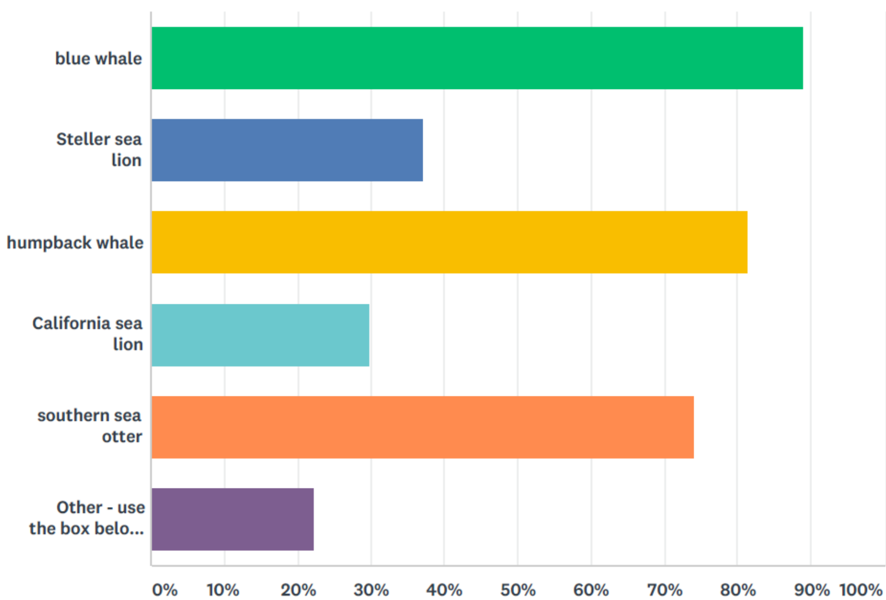

Figure 6. Agreement of survey respondents on algae and plant species.

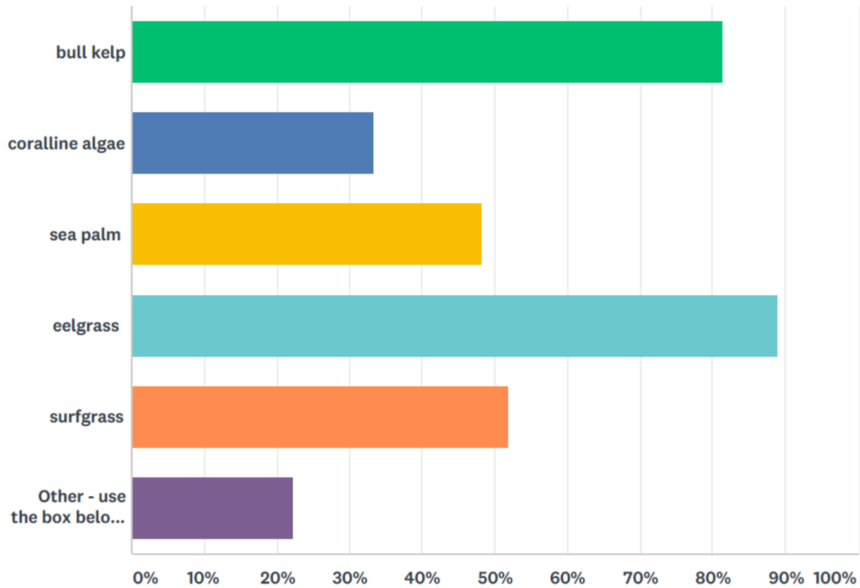

Figure 7. Habitat treemap.

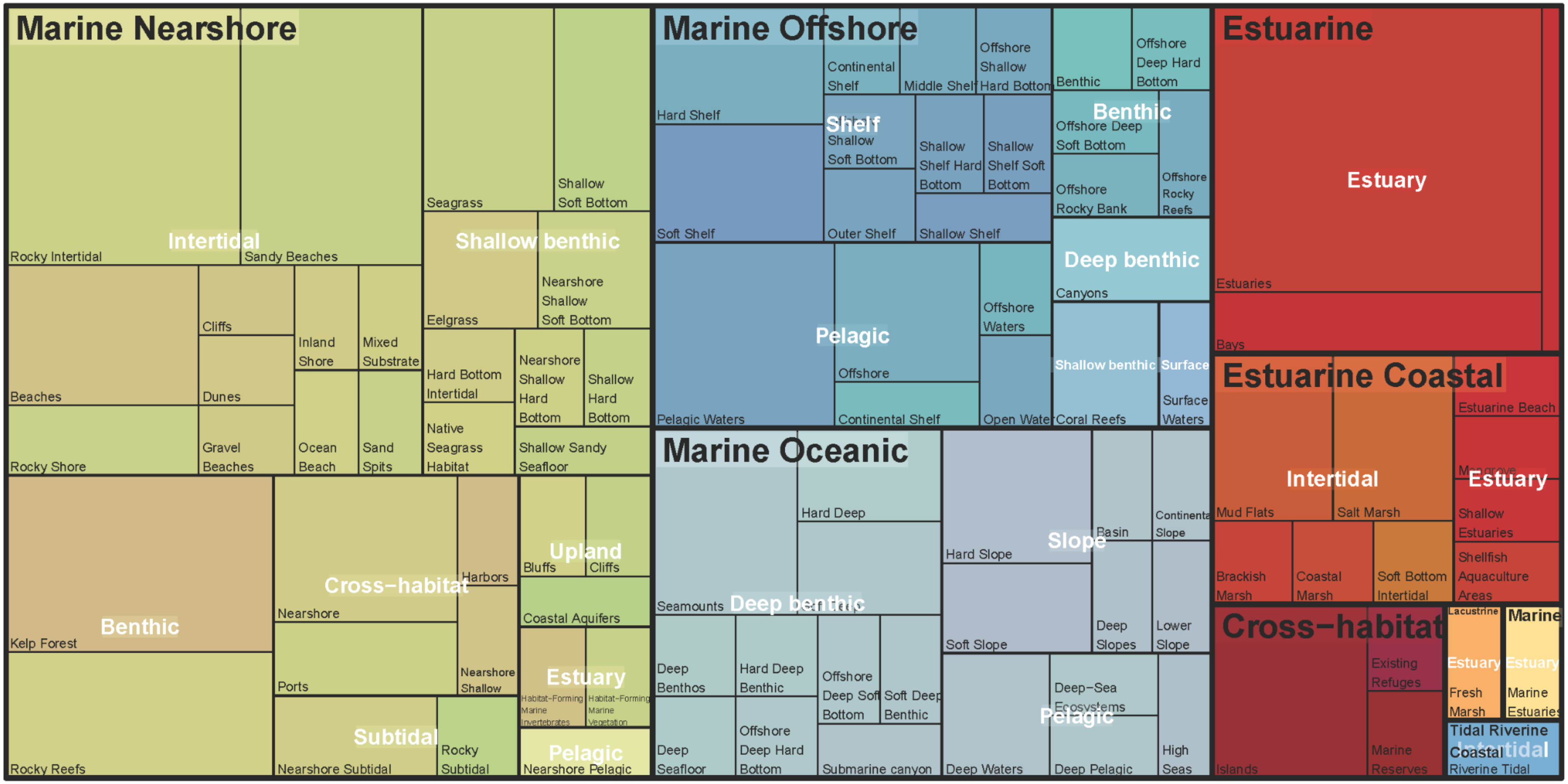

Figure 8. Agreement of survey respondents on habitats.

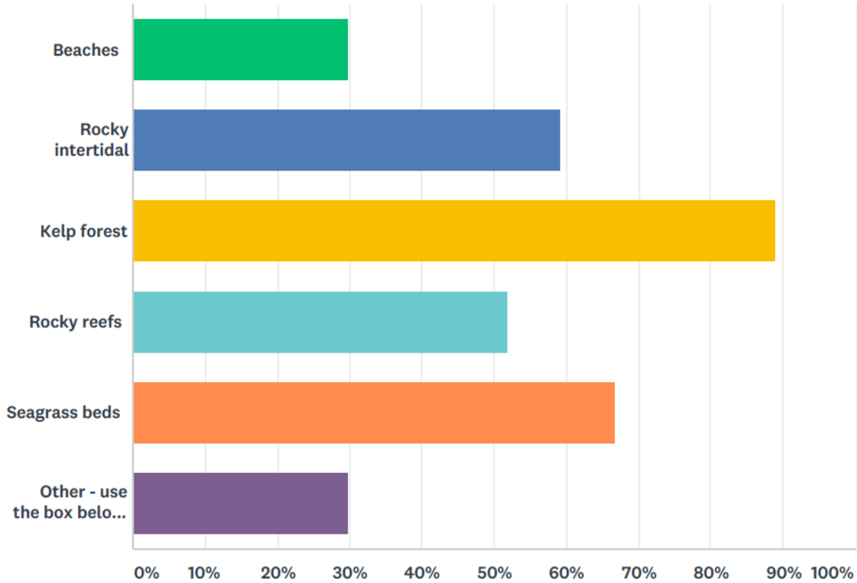

Figure 9. Resources treemap.

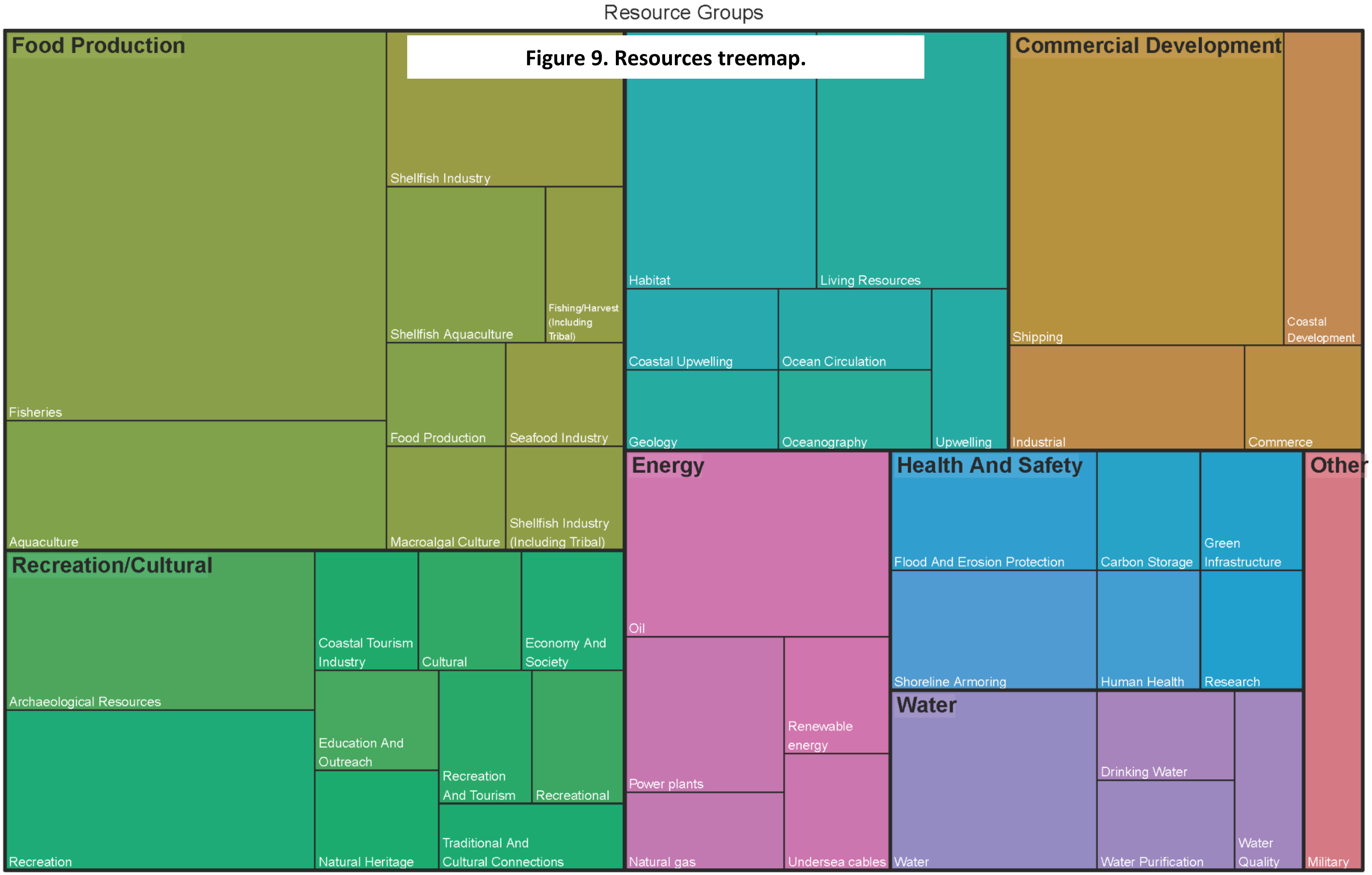

Figure 10. Agreement of survey respondents on resources.

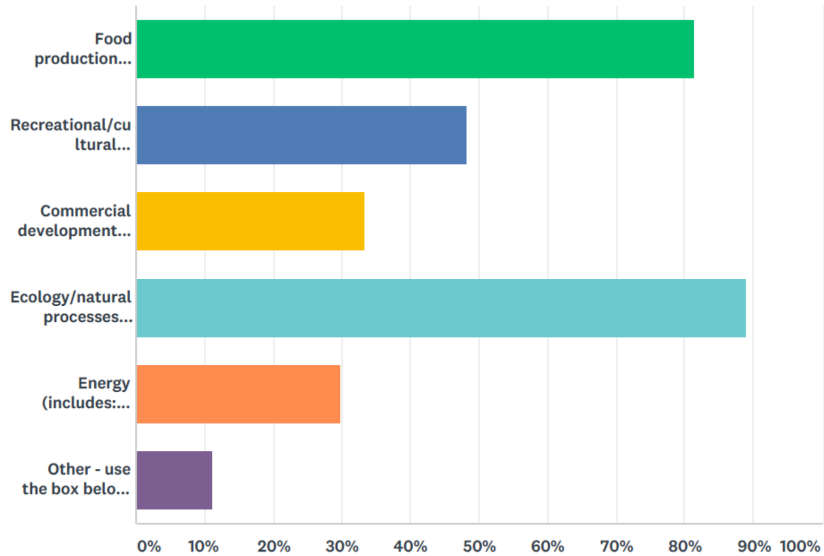

Figure 11. Threats treemap.

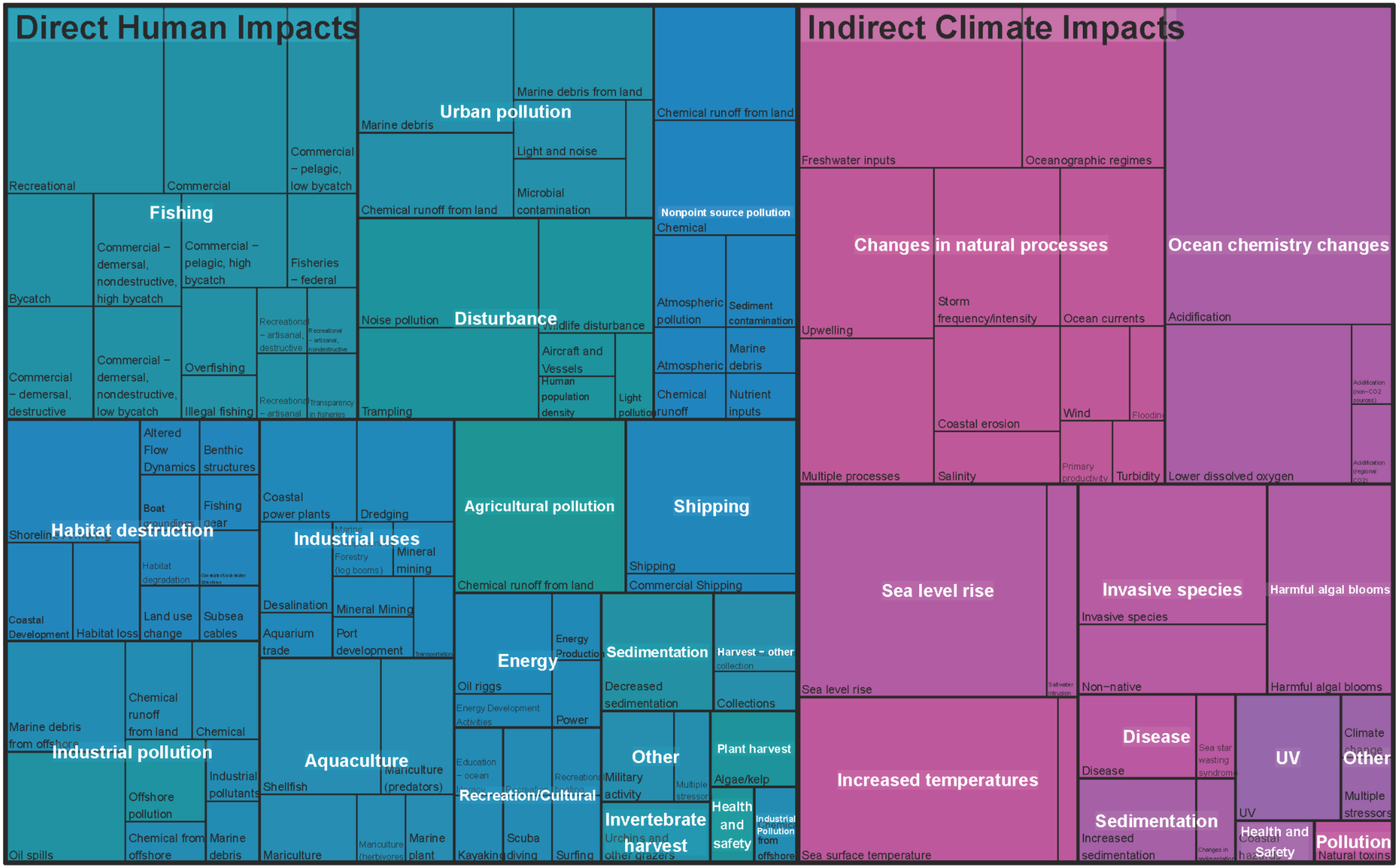

Figure 12. Agreement of survey respondents on direct human impacts.

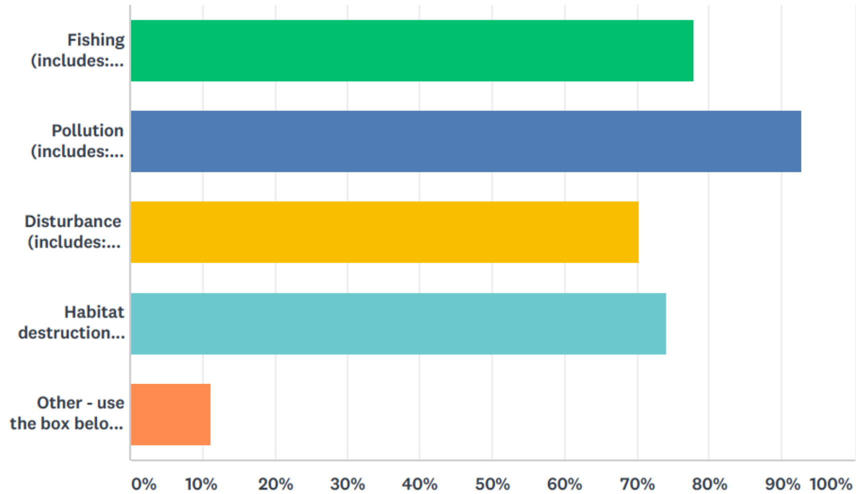

Figure 13. Agreement of survey respondents on indirect human impacts.

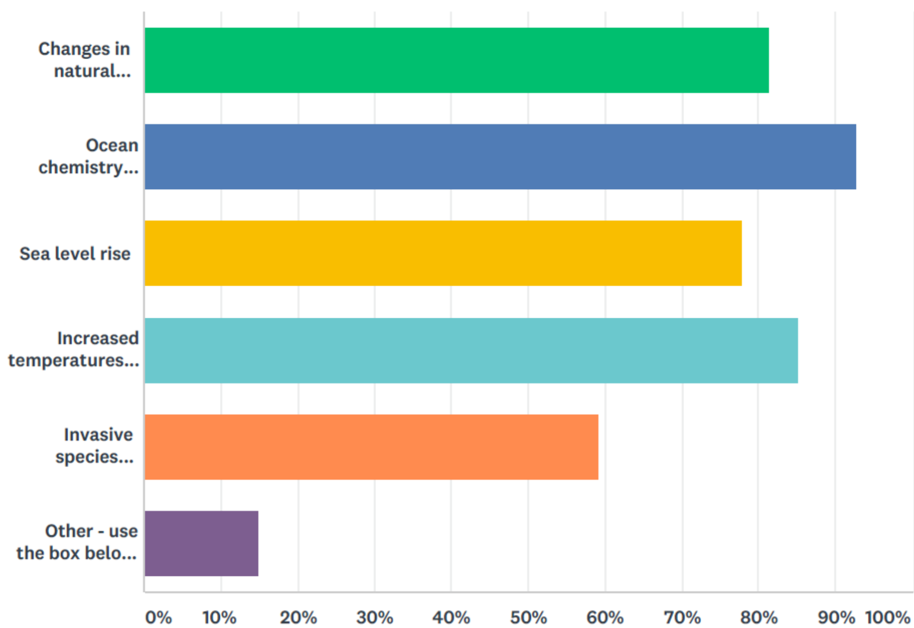

Table 1. Titles, Authors, and Descriptions of Products Reviewed.

Doc.#	Title (Authors and Year)	Description
1	California Current Ecosystem Assessment (California Environmental Associates 2012)	This effort compiled and synthesized information and expert input on the status of the California Current, and conservation opportunities were identified.
2	Climate Change Vulnerability Assessment for the North-Central California Coast and Ocean (Hutto *et al*. 2015)	This report focused on the Gulf of the Farallones (now Greater Farallones) National Marine Sanctuary (GFNMS) and how focal resources were going to be affected by future climate conditions. The vulnerabilities of species and habitats were identified.
3	Climate Change Impacts: Gulf of the Farallones and Cordell Bank National Marine Sanctuaries (Largier *et al.* 2010)	Through literature review and expert input, this report highlights the potential climate change impacts to habitats and biological communities in GFNMS and Cordell Bank National Marine Sanctuary (CBNMS).
4	Climate Change Indicators: A Monitoring Inventory and Plan for Tracking Climate Change in the North-Central California Coast and Ocean Region (Duncan *et al*. 2013)	Through working groups and literature review, indicators to monitor climate change were developed for GFNMS and CBNMS. Monitoring goals, objectives, strategies, and activities were also created for these indicators.
5	Oceana: Annual Report 2017-2018 (Oceana 2018)	This recent annual report highlights the organization's five strategies to restoring healthy oceans, and includes highlights on progress made on their global campaigns (including work in the California Current).
6	West Coast Ocean Assessment: Summary Document (West Coast Regional Planning Body 2017)	Through a literature review of marine research on the West Coast, this document identifies where we have knowledge gaps, and where future research could be prioritized for regional and sub-regional ocean planning efforts.
7	Ecological Risk Assessment as a Prioritization Tool to Support California Fisheries Management (Ramanujam *et al*. 2017)	Experts were asked to score the risk to certain fisheries in California, thereby creating ecological risk assessments. Results from this will help develop an ecosystem-based approach to fisheries management.

8	Mapping cumulative human impacts to California Current marine ecosystems (Halpern *et al*. 2009)	Spatial data in the California Current were used to map threats to the marine environment and help identify where protection and mitigation are needed the most.
9	A global map of human impact on marine ecosystems (Halpern *et al*. 2008)	Similar to Halpern's 2009 effort in the California Current, this paper takes global spatial data to provide tools to identify and prioritize marine conservation, inform marine spatial planning, and institute an ecosystem-based approach to ocean management.
10	Using expert judgment to estimate marine ecosystem vulnerability in the California Current (Teck *et al.* 2010)	Marine experts were asked to score different stressors to the California Current ecosystem. Results can help prioritize management actions, evaluate how people evaluate criteria of stressors, and identify knowledge gaps.
11	Oregon Nearshore Strategy (Oregon Department of Fish and Wildlife 2015)	Through stakeholder and expert input, this product aims to support actions to conserve ecological functions and resources in the nearshore environment of Oregon. Habitats, species, and threats are discussed.
12	Southern California Coastal Water Research Project Authority FY 2018-2019 Research Plan (SCCWRP 2018)	This research plan focuses on coastal waters of Southern California and how human activities are affecting the water quality and biological communities in these waters.
13	Southern California Bight 2018 Regional Monitoring Program (SCCWRP 2018)	This Southern California monitoring program is updated every 5 years. Research focuses on sediment quality, ocean acidification, harmful algal blooms, trash, and microbiology.
14	State of the Washington Coast: Ecology, Management, and Research Priorities (Skewgar and Pearson 2011)	Ecological communities of Washington's outer coast are characterized through literature review and expert input. A better understanding of these ecological communities can help in oil spill prevention and response efforts, as well as help prioritize research, monitoring, and management efforts.
15	Washington Climate Change Impacts Assessment (The Climate Impacts Group, University of Washington 2009)	Through literature review, expert input, and modeling work, this document focuses on climate change impacts on human structures and coastal economies.
16	Readying California Fisheries for Climate Change (Chavez *et al*. 2017)	The California Ocean Protection Council Science Advisory Team summarized feedback from scientists on the impacts of climate change to California fisheries. This document is intended to make climate-ready options for fisheries managers and policy makers accessible.
17	The Third Oregon Climate Assessment Report (Dalton *et al.* 2017)	The Oregon Climate Change Research Institute (associated with Oregon State University) summarized published literature (2013-2016) on climate change and its

		impacts to Oregon. A chapter on coastal issues provide a synopsis of impacts to coastal communities, as well as habitats and biological communities.
18	California's Coast and Ocean Summary Report (Sievanen *et al*. 2018)	The Ocean Protection Council Science Advisory Team gathered input, technical reports, and datasets and tools (for scenario planning) to produce this document. Intended for policy and decision-makers, the document highlights ways to address climate change impacts through coastal adaptation and mitigation.
19	The West Coast Ocean Acidification and Hypoxia Science Panel: Major Findings, Recommendations, and Actions (Chan *et al*. 2016)	The West Coast Ocean Acidification and Hypoxia Science Panel, California Ocean Science Trust, Ocean Protection Council, and the Institute of Natural Resources condensed the scientific findings on ocean acidification and hypoxia, and provided recommendations on management options to address these threats.
20	Ocean research priorities: similarities and differences among scientists, policymakers, and fishermen in the United States (Mason *et al*. 2017)	This peer-reviewed paper summarizes survey results from various ocean stakeholders (managers, policymakers, and ocean resource uses). Comparisons of priorities among the different groups is presented. While it covers ocean users in the United States, most respondents were from the west coast.
21	Emerging Understanding of Seagrass and Kelp as an Ocean Acidification Management Tool in California (Nielsen *et al*. 2018)	The Ocean Protection Council and California Ocean Science Trust used expert input and workshops to gather information on seagrasses and macroalgae (kelps), and how these can be used to remove carbon and ameliorate ocean acidification in California. Data gaps and recommendations were also provided.
22	The Oregon Coordinating Council on Ocean Acidification and Hypoxia (Barth *et al.* 2018)	The Ocean Acidification and Hypoxia Council held meetings to develop recommendations and an action plan on ocean acidification and hypoxia for Oregon. This report summarizes the recommendations to the State Legislature.
23	Gulf of the Farallones National Marine Sanctuary Condition Report 2010 (Office of National Marine Sanctuaries 2010)	The Office of National Marine Sanctuaries produced this report, which summarizes the resources in NOAA's Gulf of the Farallones National Marine Sanctuary, pressures on those resources, current conditions and trends, and management responses to the pressures that threaten the integrity of the marine environment.
24	Cordell Bank National Marine Sanctuary Condition Report 2009 (Office of National Marine Sanctuaries 2009)	The Office of National Marine Sanctuaries produced this report, which summarizes the resources in NOAA's Cordell Bank National Marine Sanctuary, pressures on those resources, current conditions and trends, and management responses to the pressures that threaten the integrity of the marine environment.
25	Ocean Acidification: From Knowledge to Action, Washington State's Strategic	The Washington State Blue Ribbon Panel on Ocean Acidification reviewed literature and solicited stakeholder input to summarize the current knowledge of ocean

	Response (Washington State Blue Ribbon Panel on Ocean Acidification 2012)	acidification, identify research and monitoring needs, develop recommendations on how to respond to ocean acidification, and identify opportunities to enhance public knowledge on acidification.
26	Climate Change Effects and Adaptation Approaches in Marine and Coastal Ecosystems of the North Pacific Landscape Conservation Cooperative Region (Tillman & Siemann 2011)	The National Wildlife Federation, with guidance from the University of Washington's Climate Impacts Group, conducted interviews and an extensive literature review to compile what is known (as well as information gaps) about climate change effects on the marine and coastal ecosystems in the North Pacific Landscape Conservation Cooperative (from southcentral Alaska to northern California).
27	Scientific Summary of Ocean Acidification in Washington State Marine Waters (Washington State Blue Ribbon Panel on Ocean Acidification 2012)	The Washington State Blue Ribbon Panel on Ocean Acidification, along with NOAA's Office of Oceanic and Atmospheric Research, produced this report for the Washington Shellfish Initiative Blue Ribbon Panel on Ocean Acidification. The report summarizes what is known and expected in regards to ocean acidification in coastal waters of Washington. Knowledge gaps and research opportunities are also identified. While declining pH is related to acidification, it is not covered in this document.
28	Monterey Bay National Marine Sanctuary Condition Report Partial Update: A New Assessment of the State of Sanctuary Resources 2015 (Office of National Marine Sanctuaries 2015)	The Office of National Marine Sanctuaries produced this partial report, which updates the 2009 condition report (the State of the Sanctuary Resources section, in particular) on the resources in NOAA's Monterey Bay National Marine Sanctuary, pressures on those resources, current conditions and trends, and management responses to the pressures that threaten the integrity of the marine environment.
29	Sea-level Rise and Coastal Habitats in the Pacific Northwest (National Wildlife Federation 2007)	The National Wildlife Federation used a modeling approach to look at sea level rise along the coast of Washington and Oregon. Potential impacts on sea level rise on key coastal habitats are investigated, and results can assist coastal managers and other relevant decision-makers to identify and implement strategies to minimize risks.
30	State of the Knowledge: Climate Change in Puget Sound (Mauger *et al.* 2015)	The Climate Impacts Group, University of Washington produced this document to serve as a reference for people interested in understanding the effects of climate change within the Puget Sound region. This synthesis of the peer reviewed literature is organized into 13 sections, which each section focusing on a different topic area.
31	California Current Integrated Ecosystem Assessment (NOAA 2018)	U.S. West Coast NOAA scientists have created a framework for organizing the science support needed to inform ecosystem based decisions in the California Current. This website houses data on the ecosystem (including ecosystem integrity, coastal

		communities, fisheries, protected species, and habitat), as well as threats (e.g. climate and ocean drivers, and human activities).
32	Channel Islands National Marine Sanctuary Report Volume I (Office of National Marine Sanctuaries 2016)	The Office of National Marine Sanctuaries produced this update to the 2009 condition report, which summarizes the resources in NOAA's Channel Islands National Marine Sanctuary, pressures on those resources, current conditions and trends, and management responses to the pressures that threaten the integrity of the marine environment. There are two volumes in this update; Volume I covers the state of the sanctuary from 2009-2016, and Volume II focuses on ecosystem services and gaps in current monitoring efforts.
33	Assessment and management of cumulative impacts in California's network of marine protected areas (Mach *et al.* 2017)	This peer reviewed paper uses spatial data to quantify the cumulative impacts of multiple stressors to California marine protected areas. Climate, land, and ocean threats are analyzed. Results may help marine managers make better decisions about California MPAs and improve their efficacy.