SELECTING AND EVALUATING INDICATORS FOR HABITATS WITHIN THE CALIFORNIA CURRENT LARGE MARINE ECOSYSTEM

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Aquatic habitats are at the heart of science and management mandates for the National Marine Fisheries Service, the National Ocean Service, and other state and federal agencies charged with natural resource management. However, our lack of understanding of the condition of aquatic habitats and their importance for living resources often hinders decisions regarding effective habitat conservation. In the face of needs for better habitat monitoring, a critical starting point is addressing what indicators of habitat should be tracked to determine ecosystem health. This is the initial stage of Integrated Ecosystem Assessments (IEAs). In addition to indicator selection, IEAs examine status of trends of indicators, analysis of risk to ecosystem components, and management strategy evaluation of potential actions society can take to facilitate a sustainable ecosystem.

This document summarizes indicator selection for habitats in the California Current large marine ecosystem (CCLME). Indicator selection followed from a conceptual model that identifies four major habitat types (freshwater, estuary and nearshore, pelagic, and seafloor environments) in the CCLME and their links to other IEA components including environmental drivers, anthropogenic pressures, species-specific ecosystem components, and human wellbeing. Given contrasting habitat needs supporting the great diversity of species inhabiting the CCLME, we subdivided habitat indicators into these four habitat types, and for each type we identified indicators of habitat quantity, habitat quality, and the main anthropogenic pressures impacting them. We rated each indicator using 18 criteria encompassing 1) primary or scientific support considerations, 2) data limitations, and 3) other considerations related to the application of indicators by society (Levin & Schwing 2011). During the evaluation, we recognized that habitat data are often limited in time or across space, so we strove to identify indicators useful for either mapping or trend analysis for quantity or quality of each habitat type.

We identified 33 priority indicators for freshwater, estuary/nearshore, pelagic, and seafloor habitats, which are listed in Table H5 on page 66. In general, metrics related to estimating areal extents of substrate or biogenic habitat were identified as priority indicators of habitat quantity, while metrics of habitat quality often focused on well-measured attributes such as temperature, dissolved oxygen, and nutrients. Common pressures were urban and agricultural land cover and effects of fishing.

The suite of priority habitat indicators addressed many of the linkages we postulated in our conceptual model, although more attention to cross-habitat linkages and connections to human wellbeing is warranted. In addition, indicator selection also provided insight into monitoring gaps for potential indicators with strong scientific support, and

points to the need for better monitoring programs, data collection, and synthesis of these sources of habitat information. Our next steps will be to summarize data for priority indicators and thereby examine status (maps and summaries of current condition) and region-specific trends over time.

DETAILED REPORT

INTRODUCTION

Habitats are the interface through which climate drivers and human activities influence biota and the matrix through which ecosystem interactions occur. Aquatic habitats are therefore at the heart of science and management mandates (e.g., Essential Fish Habitat (EFH), Critical Habitat under the Endangered Species Act) for the National Marine Fisheries Service (NMFS). Unfortunately, we are still in the foundational stages of identifying important habitats for fish and other living resources at all life stages, the extent that people have affected these habitats and the benefits they receive from them, how natural resource managers can apply habitat information, and how habitat restoration and protection stand to improve the status of commercial fisheries and other trust resources.

The importance of improving habitat information for management has been laid out in the Habitat Assessment Improvement Plan (HAIP; NMFS 2010) and NOAA's Habitat Blueprint (NMFS 2012). The HAIP's primary goals are two-fold: 1) to improve habitat assessments so that EFH can progress from presence/absence to higher information levels, and 2) to integrate habitat information into stock assessments to better assist in stock management. As noted in the HAIP and NMFS' Our Living Oceans Habitat (NMFS 2014), the numerous unanswered scientific questions concerning species-habitat interactions and habitat status hamper our ability to effectively implement actions to benefit the living marine resources managed by NOAA. Following from these directives, building a comprehensive Habitat Component into Integrated Ecosystem Assessments (IEAs) should improve their applicability to NMFS's management and by extension their utility as tools for ecosystem management (Levin et al. 2009). This document lays the groundwork for integrating a habitat component into the California Current Integrated Ecosystem Assessment (CCIEA), specifically describing those indicators of habitat that should be characterized and monitored.

As described by Levin et al. (2009), IEAs synthesize information on ecosystem attributes and associated human dimensions in order to inform ecosystem management objectives. The framework of IEAs includes scoping, indicator selection, analysis of status and trends of indicators, risk analysis, management strategy evaluation, and feedbacks for adaptive management. The CCIEA is accomplishing these steps through integration of several socio-ecological components. Components include natural drivers and human activities influencing the ecosystem, as well as benefits people derive from the CCLME. Other components address the major groups of NOAA trust resources (e.g., salmon, groundfish, marine mammals) (see 2012 web report at http://www.noaa.gov/iea/CCIEA-

Report/index.html). Because habitats physically connect trust resources with most climate drivers and human activities, and because many of NMFS management actions concern habitat conservation measures, habitat constitutes an important additional component with unique indicators, risks, and management scenarios.

Habitats for NOAA trust resources on the Pacific Coast extend from the mountains (for Pacific salmon) to ocean depths greater than 1,000 m at the seaward edge of the Exclusive Economic Zone (EEZ). A broad set of indicators will therefore be needed to adequately characterize the habitats that support the rich diversity of aquatic life on the Pacific Coast. To that end, we have developed the Habitat Component of the CCIEA in four general groupings relevant to NMFS management – freshwater, estuarine/nearshore, pelagic, and seafloor habitats.

In this report, we provide a rationale for determining indicators of habitat quantity and quality and anthropogenic activities that can impact these four habitat types. We start with a conceptual model that frames the Habitat Component in the context of other components being examined in the CCIEA. Next we describe the process by which four teams of scientists selected indicators. Finally, we describe the priority indicators of habitat quantity and quality selected for future status and trends analysis. In the parlance of ecosystem management (Levin et al. 2009, Levin & Schwing 2011, Halpern et al. 2012), these indicator datasets can be used to determine the health of habitats in the California Current Ecosystem.

CONCEPTUAL MODEL OF HABITAT FOR THE CCIEA

The aquatic habitats of the California Current Ecosystem span the Pacific Coast from Northern Washington to Southern California. Spaulding et al. (2007) and others (Parrish et al. 1981, Allen et al. 2006) divide this region into two large marine ecosystem provinces, with the boundary at Point Conception. These have subsequently been divided into four ecoregions: the Salish Sea (Puget Sound and the Straits of Georgia and Juan de Fuca); the Washington, Oregon, and Northern California Coast; Central California, and the Southern California Bight (Sullivan-Sealey and Bustamante 1999, Spaulding et al. 2007, Parrish et al. 1981, Allen et al. 2006, Longhurst 1998, Pelc et al. 2009). The boundaries of these ecoregions are based on geomorphic, hydrodynamic, and biogeographic breaks at Cape Flattery, Cape Mendocino, and Point Conception, as well as on the political borders of the United States (i.e., those with Canada and Mexico). Freshwater systems entering the two provinces have been divided into six ecoregions based on the biogeography of associated fish (Abell et al. 2008). Nevertheless, these classification systems largely are consistent in encompassing habitats of the important freshwater and marine species in the CCIEA.

Aquatic habitats constitute essential links in the broader socio-ecological conceptual framework of the CCIEA. In this framework, habitat is the matrix for interactions of physical and anthropogenic activities with living marine resources, or in IEA terms, the 'components' of ecological integrity. Habitat is paralleled in this larger schema with social systems and governance as the matrix for interactions by broad social and economic forces with components of human wellbeing. Our conceptual model of the Habitat Component incorporates multiple drivers, interconnections among habitat types, the living marine resources using habitats, and the benefits of these habitats to people (Fig. H1).

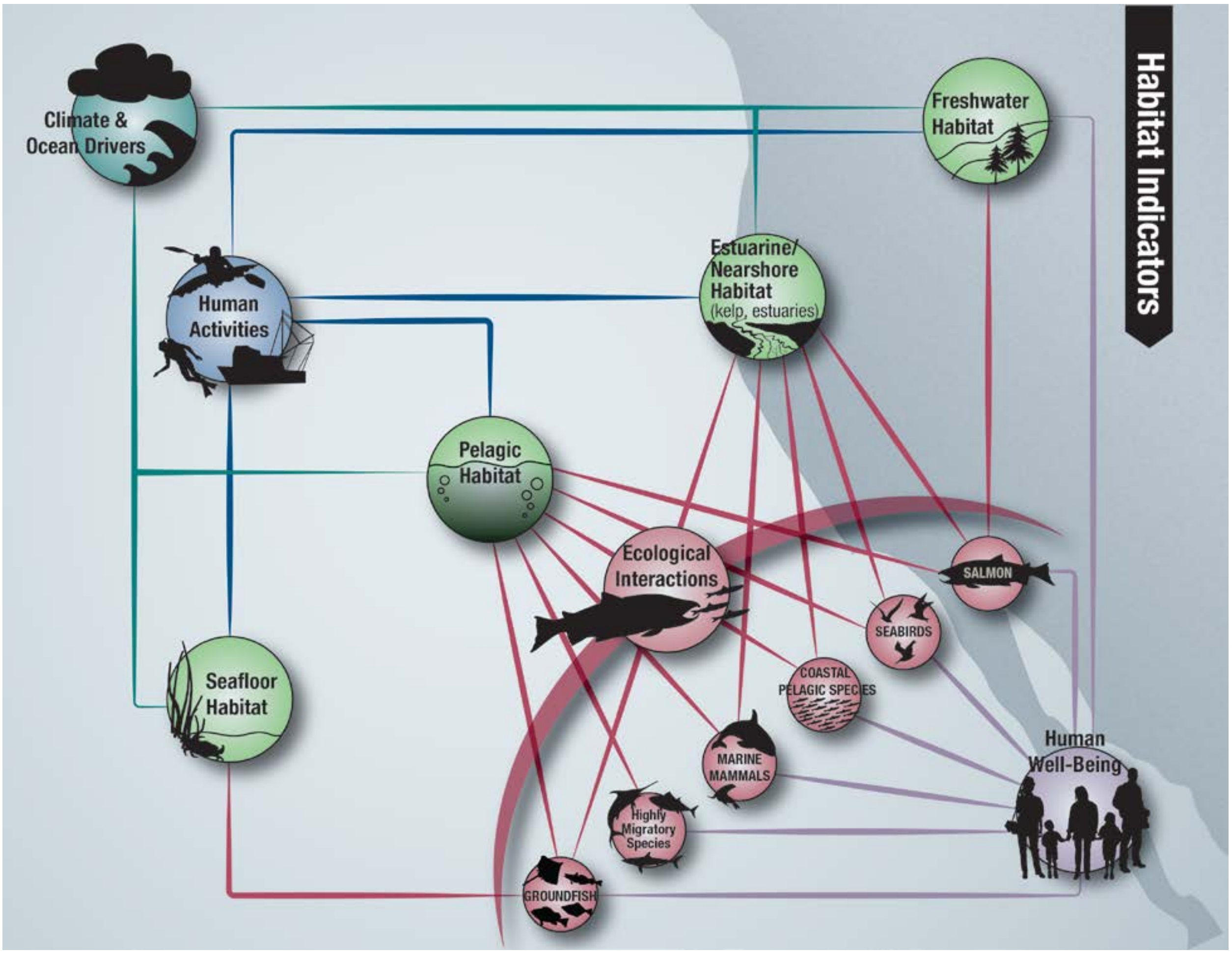

Figure H1. Conceptual model of the Habitat Component of the CCIEA. Freshwater, estuary/nearshore, pelagic, and seafloor habitats influence each other and provide the interface that affects associated organisms. Climate and ocean drivers directly affect habitats and associated organisms via the habitat interface. Human activities affect all habitats and, in turn, human wellbeing is influenced both by the habitats and the organisms (HMS = highly migratory species, CPS = coastal pelagic species) they influence. One main effect not illustrated is the direct effects of human activities on organisms via fishing.

Both freshwater and marine aquatic habitats in the California Current are the products of dynamic geologic, geomorphic, and climate processes with various time scales, many of which occur more slowly than annual rates of change. Habitat-forming processes influence the distribution of aquatic habitats, and processes interact in a manner largely following topography and bathymetry: freshwater systems influence estuary and nearshore environments, which in turn interact with pelagic environments, which subsequently influence seafloor habitats. Regional climate drivers shape temperature, precipitation, coastal storms, wind patterns, currents, and upwelling, and these natural drivers are now shifting as a result of anthropogenic climate change. In addition, people affect the quantity and quality of habitats through a number of activities occurring at more local levels. Different habitats support different complexes of species, which use multiple habitats during their life history. These species can be influenced directly by people through fisheries and indirectly by anthropogenic activities affecting habitats. People subsequently benefit from habitats directly, and indirectly from the fisheries they support. Hence, anthropogenic activities and species responses are the outcome of ecological interactions that occur in the context of habitat. This habitat context can modulate predator-prey interactions and interspecific competition, and influence the intensity of fisheries and other human activities upon NOAA trust resources.

Following from this conceptual model, fish and other species experience climate and most human activities (fisheries being a partial exception) through their interaction with multiple habitats. Consequently, efforts to rebuild imperiled stocks need to carefully consider the quantity and quality of habitats. To address the question "What is the state of the California Current Ecosystem?," we need indicators of habitat quality and quantity and to define the anthropogenic and climate pressures directly affecting them. Hence, we use a more detailed tier of conceptual models to describe the specific climate and ocean drivers and anthropogenic activities affecting specific habitat types, the consequential effects on different fisheries, and the benefits people gain from these habitats (Fig. H2).

FRESHWATER HABITAT

Freshwater habitats linked to the CCLME include river and lake systems connecting to the Pacific Ocean, spanning the West Coast of North America from the Fraser River in the north to the Tijuana River in the south. These habitats are intimately connected to their watersheds, and habitat conditions within rivers and lakes are strongly influenced by the landscapes that surround them (Fausch et al. 2002). Broadly speaking, freshwater habitat types include streams, rivers, floodplain channels, ponds, and lakes. Headwater streams are small and generally much steeper than rivers in the lower basins, and diversity of habitats generally increases in the downstream direction because the array of lentic and lotic habitat types grows as rivers and floodplains widen. However, this general trend is often interrupted by geologic controls, tributary junctions, and glacial features, which can create local variation in habitat types and diversity (e.g., Benda et al. 2004). This diverse array of habitats supports a large number of anadromous species, including salmon, sturgeon, lamprey and others. Rivers and their floodplains also support a wide range of ecosystem services to people, including water supply, land for agriculture or development, transportation, recreation, energy generation, cultural resources, and commercial, sport, and subsistence fisheries (Zedler & Kercher 2005, Nelson et al. 2009).

Freshwater habitat conditions are controlled by a hierarchical suite of climatic, geomorphic, and biological processes (e.g., Beechie et al. 2013). The spatial structure of the river network and locations of canyons, floodplains, and tributary junctions are controlled by geology and topography (which we refer to as landscape template). This template is relatively immutable over common management timeframes, meaning that land and water uses generally do not alter the structure of the drainage network, locations of canyon and valley reaches, or the slopes of valleys. The landscape template controls the range of potential habitat conditions that can be expressed within any particular reach. Conditions that are expressed at any point in time are then controlled by watershed-scale and reach-scale processes. The key watershed-scale processes are the runoff and erosion processes that produce stream flow and sediment supply to rivers. Hydrologic processes control the flow regime and sizes of streams and rivers, whereas sediment supply exerts strong controls on channel form and dynamics. Hence, these processes control basic channel patterns in the river network, including cascade, step-pool, plane-bed, and pool-riffle channels in small streams, and straight, meandering, island-braided, and braided channels in large rivers. Smaller scale habitat features such as pools and riffles, or habitat quality attributes such as food web structure and temperature regimes, are controlled by reach-scale riparian processes including root reinforcement of stream banks, supply of wood to channels, stream shading and nutrient supply.

Anthropogenic activities include direct modification of river channels and their floodplains, alteration of stream flow and erosion regimes, removal or altering riparian forests, and addition of pollutants or pesticides. Some of the earliest alterations to freshwater habitats in the California Current were channelization of rivers and draining water from floodplains for agriculture (e.g., Beechie et al. 1994). At the same time, most of the wood in rivers was removed to facilitate navigation (e.g., Collins et al. 2002). These early modifications to river floodplains dramatically reduced freshwater habitat availability and diversity throughout the region. Sediment supply from mountain regions was increased in some areas by logging practices or hydraulic mining, and sediment supply is locally decreased downstream of numerous dams in the region. In some rivers, flows are dramatically reduced by water extraction for irrigation or municipal water supplies. Riparian alteration is ubiquitous in the region.

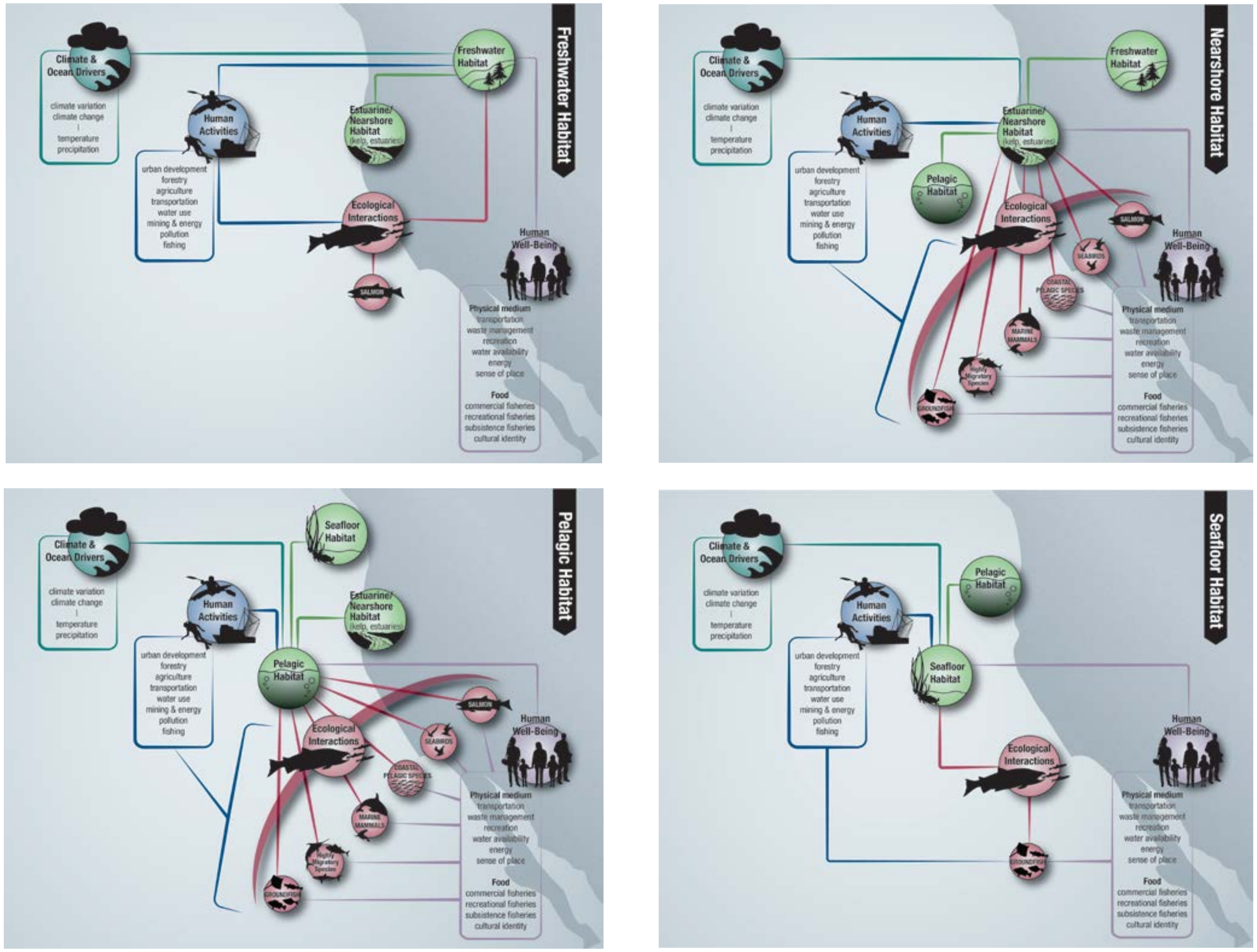

Figure H2. Application of the general conceptual model to each habitat type. The major differences among models are the between-habitat linkages, and the specific climate drivers, human activities, aspects of human wellbeing, and other ecosystem components affected.

ESTUARY AND NEARSHORE HABITAT

We define estuary and nearshore habitats as those systems that are strongly influenced by both marine and freshwater or terrestrial processes. On the Pacific Coast, the extent and variety of estuary and nearshore environments is limited by the steep topography of land and continental shelf. Estuaries include enclosed bodies of water – drowned river mouths, embayments, lagoons, and fjords – characterized by tidal influence such as water level fluctuations and daily to seasonal variation in salinity (Potter et al. 2010). Nearshore environments include rocky shores, beaches, and headlands directly adjacent to marine waters (Inman & Nordstrom 1971). The spatial extent of estuaries includes their floodplain from head of tide (the maximum upstream extent of tidal influence) to the marine shoreline, which has often been defined as the mean lower low water line (e.g., Wessel and Smith 1996) but can extend subtidally through distributary channel networks, deltaic formations, and hydrodynamic processes. Nearshore environments are intertidal and subtidal water column and benthic habitats as deep as 40 m (NMFS 2014), which define the bathymetric limit of kelp that play a key role in nearshore systems. Nearshore systems are defined laterally by littoral drift cells, which are discrete zones created by topography and longshore currents that define sediment sources (e.g., rivers, bluffs), transport, and deposition (e.g., beaches) (Inman & Nordstrom 1971). While estuary and nearshore systems on the Pacific Coast are strongly influenced by marine processes, they are differentiated from pelagic and seafloor environments by 1) the influence of terragenic geomorphic processes creating shallow and sheltered habitats, and 2) the presence of sunlight throughout the water column, creating opportunities for submerged aquatic vegetation such as eelgrass and kelp.

Estuary and nearshore habitat quality and quantity are shaped by large scale geomorphic and climate drivers as well as human activities at local spatial extents. Geomorphic processes such as river flow, tidal action, fetch, and currents (Uncles 2002) make estuary and nearshore systems highly dynamic and subject to a wide variety of climate forcings. Consequently, estuary and nearshore environments might be expected to be influenced by the gamut of climate processes affecting Pacific Coast systems, from changes in precipitation, river flow and water temperature, to variation in sea level and storm surges. In addition, estuary and nearshore environments are foci for human activities and therefore are at risk from a broad array of anthropogenic activities, including habitat loss, hardening of wetland and shoreline habitats, and water quality impairments from pollution and nutrient inputs. In addition to local drivers, estuary and nearshore habitats are expected to be influenced by freshwater processes, and to link with pelagic habitat processes.

The species benefiting from estuary and nearshore habitats include salmon, groundfish, coastal pelagics, seabirds, and marine mammals (NMFS 2014), as well as numerous other fish and invertebrates. Salmon and some groundfish and coastal pelagic stocks use estuaries and nearshore environments as rearing areas during juvenile life stages, and these consequently are hotspots for feeding by seabirds and marine mammals. All species are influenced indirectly by human activities that affect these habitats, but also directly via commercial and recreational fishing. Habitats can conceivably play a mediating role in the extent to which people can affect stocks by fishing. For example, higher habitat complexity or the remoteness of habitat areas might reduce fishing pressure. In addition to supporting fisheries and aquaculture, estuary and nearshore habitats provide a number of benefits to people as sites for transportation, alternative energy infrastructure, waste disposal and water diversions, and recreation. Additional benefits to human wellbeing include sense of place, local ecological knowledge, cultural heritage, and quality of life.

PELAGIC HABITAT

The pelagic habitat for the CCLME extends from the west coast of Vancouver Island south to the subtropical waters off Baja California, Mexico (20-25°N), offshore to the EEZ, and vertically in the water column where the bottom is deeper than 40 m. While the four ecoregions in the CCLME are based on relatively static boundaries, the resultant oceanography and pelagic habitat is a highly dynamic product of oceanic processes (e.g., frontal structure, thermocline depth). Vertically, pelagic habitat is defined as below the surface and above the bottom, but more specifically as the Epipelagic (0-200 m, euphotic), Mesopelagic (200-1000 m), and Bathypelagic (>1000 m bottom depth). The pelagic habitat is characterized by strong physical forcing at a suite of space and time scales, beginning with wind-driven upwelling, nutrient delivery to the photic zone, phytoplankton blooms and the commencement of the pelagic food-web. Bathymetric and topographical features such as capes, islands, rocky banks, and canyons and oceanographic features including eddies and fronts affect the quality of pelagic habitat and their resultant food webs. For two reviews of pelagic ecosystems, see Checkley and Barth (2009) and Bograd et al. (in press).

The base of the pelagic food web is the phytoplankton, which bloom seasonally as nutrients are upwelled into the photic zone (Kudela et al. 2008). The predominant phytoplankton groups within the California Current include diatoms, dinoflagellates (which commonly form harmful algal blooms (HABs)), and cyanobacteria. Secondary producers include microzooplankton, crustacean zooplankton, gelatinous zooplankton, euphausiids, ichthyoplankton, and small pelagic fish. Copepods serve as critical prey resources for a suite of predators. Gelatinous zooplankton have boom and bust cycles where they can serve as an important predators of zooplankton and ichthyoplankton, although the forcing of these blooms is not well understood. Euphausiids, primarily the species *Euphausia pacifica* and *Thysanoessa spinifera*, are another critical link in the food-web of the CCLME (Brinton & Townsend 2003). These species primarily eat diatoms and small zooplankton, and in turn are the food for many species of fish, birds, and marine mammals. Euphausiids often form large conspicuous schools and swarms that attract larger predators, including baleen whales (Croll et al. 2005). Due to their quick feeding rates, high growth rates, and role as a key prey resource for many species, euphausiids are a major node of energy flow in the CCLME (Field et al. 2006).

Forage fish are both iconic components of the CCLME as targets of historic fisheries, and important components of the CCLME pelagic food-web. Dominant species include northern anchovy (*Engraulis mordax*), Pacific sardine (*Sardinops sagax*), Pacific mackerel (*Scomber japonicus*), and jack mackerel (*Trachurus symmetricus*) and they feed almost exclusively on phytoplankton, zooplankton, and ichthyoplankton. The forage fish complex is prey for predatory fishes, seabirds, and marine mammals. Further offshore, particularly outside of the reach of the more productive upwelled waters, mesopelagic fish and invertebrates that vertically migrate daily (e.g. myctophids, penaeid shrimp, squids) serve as a key prey resource in the oligotrophic pelagic habitat (Brodeur & Yamamura 2005).

Many mobile species migrate seasonally throughout the CCLME (Horne and Smith, 1997; Agostini et al. 2008; Checkley & Barth, 2009; Block et al. 2011), while other species come from across the Pacific. The California Current is a hotspot for a high diversity and abundance of top predators as a result of the seasonal upwelling and nutrient-rich waters that result in an abundance of prey (Block et al. 2011). Large pelagic migratory fishes are abundant and support a number of fisheries, including hake, salmon, rockfishes, billfishes, sharks, and a few species of tuna (Field et al. 2010; Block et al. 2011; Glaser 2011; Preti et al. 2012; Wells et al. 2012). Seabird species include local breeders and oceanic migrants, both of which rely on the CCLME as their foraging grounds (Shaffer et al. 2006; Yen et al. 2006; Mills et al. 2007; Kappes et al. 2010). Six pinniped species breed on the coast of California, with many of these animals foraging in offshore waters (Antonelis & Fiscus 1980) alongside a high diversity of cetacean species (Barlow & Forney 2007). These predators have all evolved strategies to benefit from the seasonal productivity of the CCLME while minimizing interspecific competition.

Pelagic habitat is identified by predictable and persistent areas of productivity or aggregation of lower organisms at multiple trophic levels (Sydeman et al. 2006, Hazen et al. 2013). These persistent features, often called marine hotspots, are characterized by increased trophic exchange and often are of high ecosystem importance (Sydeman et al. 2006, Hazen et al. 2013). Bathymetric features such as seamounts, shelf breaks, or islands create hotspots by increasing upwelling or creating eddies (Reese & Brodeur 2006). Mesoscale features such as large eddies and fronts can entrain productivity or prey species that in turn result in increased productivity and aggregation (Logerwell and Smith 2001; Palacios et al. 2006; Yen et al. 2006). Persistent upwelling locations can result in greater productivity than surrounding areas, attracting forage species and top predators (Palacios et al. 2006 and references within). In the CCLME, three coastal hotspots of primary production are apparent via remotely sensed imagery: Cape Mendocino to Point Arena, Bodega Head to Point Sur, and Cape San Martin to Point Arguello (Palacios et al. 2006). Beyond the magnitude of chlorophyll *a* blooms, persistence indices identified similar hotspots in time and space that are productive regions for a large portion of the year, and provide reliable prey resources for seabirds in the area (Suryan et al. 2012). Much less is known about the vertical components of marine hotspots compared to the horizontal, but temperature ranges, light penetration, nutria-clines, and dissolved oxygen can all serve to define pelagic habitat. Shoaling oxyclines can lead to vertical displacement of organisms, mismatches in predator and prey based on oxygen tolerances of prey and predator (Chan et al. 2008, Stramma et al. 2011), and also create pathways for invasion by species such as for Humboldt squid, *Dosidicus gigas* (Stewart et al. 2012).

Marine hotspots are important economically, as aggregations of forage fishes and predatory fishes create reliable fishing spots. Some of the most valuable fisheries in the CCLME include forage fish (e.g. anchovies and sardines), salmon species, highly migratory fishes such as tunas and swordfish, and squids. These species are not only economically important, but they also support an associated suite of human wellbeing benefits, such as fishing heritage, sense of place and social networks within fishing communities. In addition, shipping vessels travel across the pelagic realm transporting goods to the western Pacific and beyond. In the pelagic realm, fisheries, shipping, and use by culturally important species are the primary ecosystem services. Anthropogenic pressures such as climate change, ocean acidification, ship strikes, pollution, and oil spills can affect living resources in the pelagic realm. For example, earth system models of climate change project widespread shifts in fish distribution and abundance through habitat change in the Pacific (Polovina et al. 2011, Hazen et al. 2013). There have been proposals and limited implementation of alternative energy sources including wind and tidal energy where installation could negatively impact habitat in the pelagic realm.

SEAFLOOR HABITAT

Seafloor habitats in the CCLME extend from the neritic zone (ca. 40 m water depth) to the abyssal plain (>3,000 m) at the seaward boundary of the U.S. EEZ. The geospatial framework for seafloor habitats follows on recent analyses by NMFS (2013) identifying four ecoregions and three depth zones. The three depth zones are the continental shelf, upper and lower slopes. The water depth of the continental shelf break in the region varies slightly, but is generally described to be ca. 200 m water depth. The boundary between the upper and lower continental slope was placed at 700 fathoms (1280 m) water depth, corresponding in general to the deepest extent of the groundfish fishery.

Seafloor habitats in the California Current are shaped by a diverse array of physical processes. The CCLME is located in an active tectonic region where the Pacific plate is subducting under the North American plate. Tectonic and seismic activity has transformed the continental margin in several ways over the past several millennia. The continental margin of the northern and central ecoregions is characterized by a relatively narrow (8-40 km) continental shelf and steep slope. Although the shelf is dotted with occasional rocky banks (e.g., Heceta, Cordell), it comprises mostly sandy and muddy sediments. Several large submarine canyons cut across the shelf, often ending in a sedimentary fan at the base of the slope. Other unique seafloor habitats in the northern and central ecoregions include slumps, landslides, and cold methane seeps. In the southern ecoregion, submerged islands and banks interspersed with deep basins characterize what is known as the southern California borderlands. These rocky banks support some of the most diverse assemblages of fishes and macroinvertebrates in the CCLME.

Seafloor habitats provide critical ecological services. Most importantly, the physical structure of seafloor habitat is necessary for sessile invertebrates to attach, and for sedentary invertebrates and fishes to forage and seek refuge. Habitat studies over the past few decades have greatly contributed to our knowledge of how demersal fishes and macroinvertebrates use seafloor habitats. One general conclusion from these analyses is that abundance and diversity of these organisms are influenced by primarily by physical attributes, and associations with biogenic habitat are much weaker or statistically undetectable (Tissot et al. 2006).

At a larger scale, climate and associated changes in seawater temperature and chemistry influence distribution of fishes and invertebrates. For example, Pacific hake, the most migratory species of groundfish in the CCLME, make large seasonal migrations between winter spawning and summer feeding grounds. The northern extent of these migrations is greatest during El Niño years. Other fishes, such as rockfishes and many marine macroinvertebrates are more closely associated with seafloor habitats and have much smaller home ranges. Nevertheless, these species may be affected by large-scale hypoxic events in the northern part of the CCLME.

Seafloor habitats in the CCLME support valuable fisheries, providing food, income and recreation to coastal economies. The Pacific Coast Groundfish fishery management plan of the Pacific Fishery Management Council includes 91 species, including rockfishes, flatfishes, sablefish, lingcod, hake and sharks. Most of these fishes are targeted either commercially or recreationally using bottom and pelagic trawls, traps, bottom-set longlines, and other hook-and-line gears.

Seafloor habitats in the CCLME are subject to several direct and indirect anthropogenic activities. Fishing and pollution are the most widespread stressors in the region, while dredge material disposal, undersea cable laying, mining, and offshore energy development and production have localized impacts. Fishing pressures due to bottom trawling are higher in the northern part of the CCLME. Offshore oil and gas production only occurs in the southern ecoregion, where 26 drilling platforms provide complex artificial habitats for a diverse assemblage of fishes and macroinvertebrates. Off Oregon, several sites are being proposed for offshore wave and wind energy facilities. Finally, in all parts of the CCLME, the impacts of human activities like pollution, ship traffic, and disposal of dredge material diminish with distance from shore or point source.

SELECTING INDICATORS FOR HABITAT

WHAT IS AN INDICATOR?

Indicators are quantitative biological, chemical, physical, social, or economic measurements that serve as proxies of the conditions of attributes of natural and socioeconomic systems (e.g., Landres et al. 1988, Kurtz et al. 2001, EPA 2008a, Fleishman & Murphy 2009). Ecosystem attributes are characteristics that define the structure, composition, and function of the ecosystem. These attributes are typically of scientific or management importance but insufficiently specific or logistically challenging to measure directly (e.g., Landres et al. 1988, Kurtz et al. 2001, EPA 2008, Fleishman & Murphy 2009). Thus, indicators provide a practical means to judge changes in ecosystem attributes related to the achievement of management objectives. They can also be used for predicting ecosystem change and assessing risk.

Indicators are often cast in the Driver-Pressure-State-Impact-Response (DPSIR) framework—an approach that has been broadly applied in environmental assessments of both terrestrial and aquatic ecosystems, including NOAA's IEA (Levin et al. 2009). Drivers are factors that result in pressures that cause changes in the system. Both natural and anthropogenic forcing factors are considered; an example of the former is climate conditions while the latter include human population size in the coastal zone and associated coastal development, the desire for recreational opportunities, etc. In principle, human driving forces can be assessed and managed. Natural environmental changes cannot be controlled but must be accounted for in management.

Pressures are factors that cause changes in state or condition. They can be mapped to specific drivers. Examples include coastal pollution, habitat loss and degradation, and fishing. Coastal development results in increased coastal armoring and the degradation of associated nearshore habitat. State variables describe the condition of the ecosystem (including physical, chemical, and biotic factors). Impacts comprise measures of the effect of change in these state variables such as loss of biodiversity, declines in productivity and yield, etc. Impacts are measured with respect to management objectives and the risks associated with exceeding or returning to below these targets and limits.

Responses are the actions (regulatory and otherwise) taken in response to predicted impacts. Forcing factors under human control trigger management responses when target values are not met as indicated by risk assessments. Natural drivers may require adaptive responses to minimize risk. For example, changes in climate conditions that in turn affect the basic productivity characteristics of a system may require modifications to ecosystem reference points that reflect the shifting environmental states.

Ideally, indicators should be identified for each step of the DPSIR framework such that the full portfolio of indicators can be used to assess ecosystem condition as well as the processes and mechanisms that drive ecosystem health. State and impact indicators are preferable for identifying the seriousness of an environmental problem, but pressure and response indicators are needed to know how best to control the problem (Niemeijer & de Groot 2008). Indicators can be used as measurement endpoints for examining alternative management scenarios in ecosystem models or in emerging analyses to predict or anticipate regime shifts.

CONCEPTUAL FRAMEWORK FOR INDICATOR SELECTION

Habitat is often the focus of management efforts because natural resources or ecosystem services are generally associated with specific types of habitat (e.g., designations of essential fish habitat or critical habitat). Conservation or restoration efforts for many species are often directed toward habitats needed to support specific life-history stages, making habitat a critical component of ecosystem assessments. At the scale of the California Current, it is a significant challenge to select a suite of indicators that accurately characterize important patterns and processes among the various habitat types while also being relevant to policy concerns. A straightforward approach to overcoming this challenge is to employ a framework that explicitly links indicators to policy goals (Harwell et al. 1999, EPA 2002). This type of framework organizes indicators in logical and meaningful ways in order to assess progress towards policy goals. We use the framework within the rest of the California Current IEA as guidance. Our framework begins with the conceptual models presented above using the set of four major habitat types: freshwater, estuarine/nearshore, pelagic, and seafloor. The key attributes of these habitats are characteristics that specifically describe management-relevant aspects of the habitat. They are characteristic of the health and functioning of each habitat, and they provide a clear and direct link with the indicators. For each habitat type, we identified the same key attributes: habitat quantity, habitat quality, and anthropogenic pressures on quantity and quality.

Habitat quantity. Understanding the distribution and/or abundance of specific types of physical or biogenic habitat is important for management actions. Habitat characteristics are often used to delineate spatial management boundaries that regulate specific activities. For example, rockfish conservation areas (RCAs) designate areas that prohibit bottom trawl fishing, primarily in areas along the continental shelf break that are the main habitat for several overfished rockfish species. Habitat quantity can also be used to describe the upper limits (carrying capacity) of population size or biomass that a system can support. While this idea has been applied to a great extent in freshwater (Reeves et al. 1989) and estuary systems (Beamer et al. submitted) and underlies much of the logic for habitat restoration, it has received less attention in pelagic and seafloor environments even though the concept of carrying capacity has long been accepted in stock assessment and modeling for diverse stocks (Ricker 1954, Beverton & Holt 1957).

Habitat quality. The quality of habitat available has been shown to influence physiology, growth, and behavior of individuals, and these translate into variation in demographic rates of many aquatic organisms. Indicators related to these processes are often important for identifying mechanisms responsible for changes in population size and condition of species-of-interest or changes in ecosystem health.

Anthropogenic pressures. The CCIEA previously developed indicators for a host of anthropogenic pressures, but at the time these did not necessarily include terrestrially based pressures (Andrews et al. 2013). We have updated the indicators of anthropogenic pressures upon habitats in the CCLME to include a wider range of such pressures.

Our goal was to summarize indicators into those supporting two sets of products: spatial analyses and temporal trends. Habitat indicators are often spatially rich but lack long time series, due to the slow pace of change or poor historical monitoring. For these, maps are very important tools even if they are often static and rarely updated. Some habitat indicators are temporally dynamic and amenable to analysis of temporal trends. Examination of trends should be done in the context of the spatial framework such that heterogeneity of habitat state across the California Current Ecosystem is quantified.

EVALUATING POTENTIAL INDICATORS FOR THE CALIFORNIA CURRENT

INITIAL SELECTION OF INDICATORS

The quantity and quality of habitat have been measured in numerous ways throughout the scientific literature. During reviews of the literature, we identified 131 potential indicators of quantity and quality across all four habitat types. Indicators of habitat quantity include the measurement and spatial mapping of various physical and biogenic habitats or population size of algae, corals, sponges and other biogenic habitats. Habitat quality indicators vary widely with measurements of water quality, structural complexity, and food availability.

EVALUATION FRAMEWORK

We follow the evaluation framework established by Kershner et al. (2011) and Levin & Schwing (2011). We divide indicator criteria into three categories: primary considerations, data considerations, and other considerations. Indicators should do more than simply document the decline or recovery of the habitat; they must also provide information that is meaningful to resource managers and policy makers (Orians & Policansky 2009). Because indicators serve as the primary vehicle for communicating habitat status to stakeholders, resource managers, and policy makers, they may be critical to the policy success of EBM efforts, where policy success can be measured by the relevance of laws, regulations, and governance institutions to ecosystem goals (Olsen 2003). Advances in public policy and improvements in management outcomes are most likely if indicators carry significant ecological information and resonate with the public (Levin et al. 2010).

PRIMARY CONSIDERATIONS

Primary considerations are essential criteria that should be fulfilled by an indicator in order for it to provide scientifically useful information about the status of the ecosystem in relation to key attributes of the defined goals. They are:

1. Theoretically sound: Scientific, peer-reviewed findings should demonstrate that indicators can act as reliable surrogates for ecosystem attributes.
2. Relevant to management concerns: Indicators should provide information related to specific management goals and strategies.
3. Predictably responsive and sufficiently sensitive to changes in specific ecosystem attributes: Indicators should respond unambiguously to variation in the ecosystem

attribute(s) they are intended to measure, in a theoretically expected or empirically expected direction.

4. Predictably responsive and sufficiently sensitive to changes in specific management actions or pressures: Management actions or other human-induced pressures should cause detectable changes in the indicators, in a theoretically expected or empirically expected direction, and it should be possible to distinguish the effects of other factors on the response.
5. Linkable to scientifically defined reference points and progress targets: It should be possible to link indicator values to quantitative or qualitative reference points and target reference points, which imply positive progress toward ecosystem goals.

DATA CONSIDERATIONS

Data considerations criteria relate to the actual measurement of the indicator. These criteria are listed separately to highlight ecosystem indicators that meet all or most of the primary considerations, but for which data are currently unavailable. They are:

1. Concrete and numerical: Indicators should be directly measureable. Quantitative measurements are preferred over qualitative, categorical measurements, which in turn are preferred over expert opinions and professional judgments.
2. Historical data or information available: Indicators should be supported by existing data to facilitate current status evaluation (relative to historic levels) and interpretation of future trends.
3. Operationally simple: The methods for sampling, measuring, processing, and analyzing the indicator data should be technically feasible.
4. Broad spatial coverage: Ideally, data for each indicator should be available across a broad range of the California Current.
5. Continuous time series: Indicators should have been sampled on multiple occasions, preferably without substantial time gaps between sampling.
6. Spatial and temporal variation understood: Diel, seasonal, annual, and decadal variability in the indicators should ideally be understood, as should spatial heterogeneity and patchiness in indicator values.
7. High signal-to-noise ratio: It should be possible to estimate measurement and process uncertainty associated with each indicator, and to ensure that variability in indicator values does not prevent detection of significant changes.

OTHER CONSIDERATIONS

Other considerations criteria may be important but not essential for indicator performance. Other considerations are meant to incorporate nonscientific information into the indicator evaluation process. They are:

1. Understood by the public and policy makers: Indicators should be simple to interpret, easy to communicate, and public understanding should be consistent with technical definitions.
2. Historically reported: Indicators already perceived by the public and policy makers as reliable and meaningful should be preferred over novel indicators.
3. Cost-effective: Sampling, measuring, processing, and analyzing the indicator data should make effective use of limited financial resources.
4. Anticipatory or leading indicator: A subset of indicators should signal changes in ecosystem attributes before they occur, and ideally with sufficient lead-time to allow for a management response.
5. Lagging indicator: Reveals evidence of a failure in or to the attribute.
6. Regionally, nationally, and internationally compatible: Indicators should be comparable to those used in other geographic locations, in order to contextualize ecosystem status and changes in status.

SCORING INDICATORS

Each indicator was evaluated independently according to these 18 evaluation criteria by reviewing peer-reviewed publications and reports. The result was a matrix of indicators and criteria that contained specific references and notes in each cell, which summarized the literature support for each indicator against the criteria. This matrix can be easily reevaluated and updated as new information becomes available. The matrix of habitat indicators and indicator evaluation criteria provided the basis for scoring the relative support in the literature for each indicator (Kershner et al. 2011, Levin & Schwing 2011). For each cell in the evaluation matrix, we assigned a literature-support value of 1.0, 0.5, or 0.0 depending on whether there was support in the literature for the indicator, whether the literature was ambiguous, or whether there was no support in the literature for the indicator, respectively.

However, scoring indicators also requires careful consideration of the relative importance of evaluation criteria. The importance of the criteria will certainly vary depending on the context within which the indicators are used and the people using them.

Thus, scoring requires that managers and scientists work together to weight criteria. Failure to weight criteria is, of course, a decision to weight all criteria equally.

To determine the weightings for each of the evaluation criteria, we used weightings calculated in Levin & Schwing (2011). Briefly, the weightings were calculated by asking 15 regional resource managers, policy analysts, and scientists to rate how important each of the evaluation criteria was to them on a scale of 0 to 1. This provided an average weighting for each criterion. Each criterion was then assigned to the quartile into which its average weighting fell (1^{st} = 0.25, 2^{nd} = 0.50, 3^{rd} = 0.75 or 4^{th} = 1.0) and this was used as the weighting for each criterion.

For each cell, the literature-support value was multiplied by the weighting for the respective criterion and then summed across each indicator to yield the final score for each indicator. For each key attribute of each EBM component, we then calculated the quartiles for the distribution of scores for each indicator. Indicators that scored in the top quartile (top 25%) for each attribute of each habitat type were considered to have good support in the literature as an indicator of the attribute they were evaluated against. We describe below the results of the evaluation for each indicator that scored in the top quartile.

RESULTS OF INDICATOR EVALUATIONS

The results of our evaluation of each indicator are summarized in the tables in this section. Following the framework outlined above, we organized the results of the evaluation by habitat type. The sum-of-scores within each criteria grouping (e.g., Primary considerations) in the tables are provided along with a brief summary of why the indicator is important and how it was evaluated. Indicators that ranked in the top quartile for each key attribute of each habitat type are described in more detail in the following sections. Potential indicators that scored poorly and are unlikely to be used in the IEA are listed in the tables but not discussed further in the text.

EVALUATION OF FRESHWATER HABITAT INDICATORS

HABITAT QUANTITY

We identified nine indicators of freshwater habitat quantity (Table H1). Given the long history of studies of freshwater systems and salmonid habitats, most potential metrics had a good scientific basis. However, many potential indicators suffered data limitations due to poor sampling over time and across systems, and due to lack of historical reference points. We highlight three indicators for which these spatial or temporal challenges can largely be overcome.

Discharge: spatial and temporal patterns. Discharge (or streamflow) is considered a "master variable" in riverine ecosystems, meaning that it strongly influences many habitat attributes of rivers (e.g., temperature, channel morphology, habitat diversity) and ultimately limits the distribution and abundance of riverine species (Poff et al. 2007). There are five key discharge attributes that comprise the streamflow regime: magnitude, frequency, duration, timing, and rate of change (Poff et al. 2007). Each of these attributes can be quantified from long-term discharge records, with a range of individual metrics that can be calculated for each attribute. One such set of metrics is the Indicators of Hydrologic Alteration (IHA; Richter et al. 1996). These metrics were selected for characterizing the influence of dams on the flow regime, and for identifying how those flow changes influence physical and biological processes and the health of biota downstream of dams (Poff et al. 2007, Poff et al. 2010). The IHA includes 33 individual flow metrics, 24 of which are measures of flow magnitude for high and low flows of various durations (e.g., 1-day average, 7-day average, monthly, annual), and 2-3 metrics each for flow timing, frequency, duration, and rate of change Richter et al. 1996). We note that at least 15 years of data are required for reasonable characterization of the flow regime; describing changes in the flow regime due to a dam therefore requires 15 years of data both before and after dam construction. In this report we do not select specific indicators, as the relevant indicators depend upon the species and pressures evaluated.

The primary data source for these discharge records is the set of long-term USGS gage records. Daily discharge data for all 26,000 active and inactive gages in the US are available at http://waterdata.usgs.gov/nwis/sw.

Available habitat length (% of historical stream habitat that is currently accessible). Available habitat length or area is one of the most important habitat variables controlling population sizes of anadromous fishes (e.g., Reeves et al. 1989, Beechie et al. 1994, Sharma & Hilborn 2001). Several studies indicate that more habitat generally produces more fish, and this general relationship holds across species and spatial extents (e.g., Beechie et al. 1994, Kim and LaPointe 2010). However, the type and arrangement of habitats also influences population size (Sharma & Hilborn 2001, Kim & LaPointe 2010). The simplest indicator of habitat quantity is the length of stream or river accessible to anadromous fish relative to the amount that was historically available. This indicates whether the overall habitat capacity is significantly reduced from its natural potential. The most difficult component of this metric to measure is the historical habitat length that has been blocked by dams, although there are methods available to do so. Where dams are large and large areas of habitat are blocked, existing maps can provide a reasonable measure of blocked habitat. However, smaller barriers are often not mapped, and the cumulative length of blocked habitat on small streams and rivers is generally not available.

Hence, this metric may currently be most useful in large river basins such as the Columbia River basin or the Central Valley in California, where the majority of blocked habitat is in relatively large rivers above major dams. In smaller basins with only small dams or with habitat blocked mainly by other structures such as culverts, this metric is less likely to be useful except where full barrier inventories have been completed.

Fish distribution data downstream of major barriers can be found on StreamNet (for Washington, Oregon, Idaho; https://www.streamnet.org/mapping_apps.cfm). Data on barriers that have been removed or modified to allow passage since the inception of the Pacific Coastal Salmon Recovery Fund can be found in the PCSRF restoration project database (https://www.webapps.nwfsc.noaa.gov/apex/f?p=309:13:). State salmon passage barrier databases are:

Washington: http://geography.wa.gov/GeospatialPortal/dataDownload.shtml

Oregon: https://nrimp.dfw.state.or.us/Oregonplan/default.aspx?p=134&XMLname=44.xml

California:
http://www.calfish.org/Programs/ProgramIndex/CaliforniaFishPassageAssessmentDatabase/tabid/189/Default.aspx

Area of disconnected floodplain (% of floodplain habitat accessible vs historical habitat). Just as stream length is an important control on population size of anadromous fishes, the availability of floodplain habitats strongly influences habitat capacity and population size (e.g., Beechie et al. 1994, Burnett et al. 2007). Floodplains are dynamic environments that produce abundant and diverse habitats for salmon and other aquatic organisms (Ward et al. 2002, Beechie et al. 2001, Beechie & Imaki 2014), as well as for riparian species diversity (Beechie et al. 2006, Naiman et al. 2010). Not surprisingly, human occupation of floodplains was one of the earliest impacts on salmon habitat (Beechie et al. 1994, Beechie et al. 2001), and those impacts are wide-spread in the region (Fullerton et al 2006, Hall et al. 2007). The main effect of human occupation was the separation of rivers from their floodplains by levees, and the elimination of floodplain channels and ponds that functioned as salmon spawning and rearing habitats (Beechie et al. 1994, Beechie et al. 2001). In much of the CCLME drainage area, floodplain habitats have been virtually eliminated, and loss of floodplain habitats is by far the largest habitat influence on salmon population declines. Hence, restoration of those habitats is a critical conservation need for successful recovery of important species (Hall et al. 2007, Beechie & Imaki 2014)

There are no readily available geospatial datasets that quantify this metric, although the necessary datasets and techniques exist. Floodplains can be mapped from existing topographic datasets (including readily available 10-m DEMs and locally available LiDAR) (Hall et al. 2007, Beechie & Imaki 2014, Nagel et al 2014). The 10-m data are likely not of high enough resolution to provide accurate data to quantify the proportion of floodplains disconnected from rivers region-wide, but are sufficient for identifying extent of historical floodplains (Beechie & Imaki 2014). The human impact on connectivity will require LIDAR data, which are increasingly available and can be used to identify patches of floodplain that are disconnected by roads and levees (e.g., Konrad unpublished data). Other satellite-based methods of identifying wetted area of the landscape may eventually be useful, though they currently appear to be incapable of measuring connectivity directly (e.g., Watts et al. 2012).

HABITAT QUALITY

We identified nine indicators of freshwater habitat quality (Table H1). Like freshwater quantity, some of these indicators have benefited from a long history of freshwater studies. However, many indicators lacked ability to directly link the metric to habitat condition, or sufficiently understand variation. Habitat quality metrics also suffered from large spatiotemporal gaps and public support for monitoring. We identified one indicator that could overcome these challenges:

Water temperature: temporal and spatial patterns. Temperature controls the rates of many biological processes, and is a key driver of ecological processes controlling population and community structure in aquatic ecosystems (Allan and Castillo 2007; Webb et al. 2008). For ectotherms, water temperature regulates rates of physiological, neurological, embryological and behavioral development (Brett 1971; Ficke et al. 2007). Water temperature can alter behavior (e.g., rates of movement), and through its influence on metabolic efficiency and growth, water temperature drives the timing of ontogenetic transitions from one life stage to the next (Ward & Stanford 1979; Beacham & Murray 1990). Pacific salmon are likely influenced by both spatial and temporal patterns in altered thermal regimes (McCullough et al. 2009). At broad spatial scales, stream temperature may define species distributions. At finer scales, stream temperature can define connectivity among habitats used during different life stages (e.g., foraging, breeding) (Schlosser 1995; Armstrong et al. 2013). Extreme temperatures may create barriers to movement but spatial heterogeneity in water temperature provides pockets of refuge from unfavorable temperatures (Poole & Berman 2001; Torgersen et al. 1999). Salmon may also be influenced by temporal variability in water temperature. Angilletta et al. (2008) and Crozier et al. (2008) suggested that alterations in the magnitude and timing of stream thermal regimes could induce mismatches between evolved life-histories and current environmental conditions that may reduce survival and fitness. Emergence by Chinook salmon alevins in a laboratory was delayed when fish experienced thermal regimes with extreme daily or seasonal variation (Steel et al. 2012).

Human activities such as operation of hydropower dams, development of land adjacent to streams, and water withdrawal for irrigation alter stream thermal regimes. For many regulated rivers, water below large dams is warmer in winter and cooler in summer than in unregulated rivers, and the amplitude of variation in water temperature at finer resolutions (hourly, daily, weekly) is dampened (Steel & Lange 2007; Olden & Naiman 2010). Land conversion and water withdrawal alter stream thermal regimes by increasing the amount of surface area exposed to solar radiation (e.g., from reduced forested buffers or stream widening) or by altering the hydrologic cycle, and therefore the rate of water exchange, both overland and via groundwater recharge (Bisson et al. 2009). Each of these impacts can intensify temporal trends in water temperature causing streams to be warmer during hot periods and cooler during cool periods. Anthropogenic climate change is predicted to alter thermal regimes in streams by increasing water temperatures and decreasing summer flows (Mote et al. 2003; IPCC 2007). Coupled with natural variability and uncertainty in projections, stream temperatures may increasingly stress stream organisms (Ficke et al. 2007). In the Pacific Northwest, summer stream temperatures are expected to reach or exceed thermal tolerances for salmonids by as early as the 2020s (Mantua et al. 2010; Isaak et al. 2013). Specific metrics for temperature are not identified here, but all rely on availability of continuously recorded data. Examples of specific metrics that may be useful in include number of days or weeks above some specified threshold (Mantua et al. 2010), or maximum weekly maximum temperature (Isaak et al. 2010).

Data are increasingly available to characterize both temporal and spatial patterns in water temperature at a variety of scales. Isaak et al. (2011) are compiling temporal data collected at many point locations across the region by various entities. They have developed a geostatistical model that uses these data to make spatially continuous predictions of water temperature for both current and future scenarios (Peterson et al. 2013). Predictions can be made for different time periods (e.g., seasons), but data collected during summers are most abundant. Spatially continuous data for maximum summer stream temperature are also available for hundreds of large rivers throughout the Pacific Northwest collected using remotely sensed airborne thermal infrared (TIR) sensing (R. Faux, Watershed Sciences Inc., pers. comm.; Handcock et al. 2012).

PRESSURES

We identified 14 indicators of anthropogenic pressures (Table H1). Many of these were summarized in the anthropogenic pressures report for the CCIEA (Andrews et al.

2013). Most pressure indicators suffer from insufficient reporting and spatial and temporal gaps, which was one reason Andrews et al. (2013) used population density as the main indicator for tracking anthropogenic pressures. We identified three indicators that could be synthesized either for mapping or for tracking trends:

Number of dams. Dams can block access of fish to upstream habitats or alter flow, sediment, and temperature regimes downstream (e.g., Sheer & Steel 2006, Poff et al. 2007). Therefore, this pressure is related to the quantity indicators of discharge and percent of historical habitat length accessible to anadromous fish, as well as the quality indicator of temperature. The primary dataset available is the National Inventory of Dams maintained by the US Army Corps of Engineers (http://geo.usace.army.mil/pgis/f?p=397:1:0). One problem with this database is that it does not consistently identify whether the dam is a passage barrier, and for which species (e.g., some dams are passable to salmon via fish ladders, but are still barriers to lamprey migration). Nonetheless, even in the near term the number of dams is a coarse indicator of human pressures on riverine habitats. It may also be possible to identify whether each dam in the database is passable or not, thereby restricting the dataset to more accurately reflect dams that affect upstream passage (for the 'length of habitat' indicator). The full dataset is more likely to be appropriate as an indicator of pressure on discharge and temperature regimes downstream of dams.

Riparian vegetation. Riparian (streamside) vegetation provides many benefits to freshwater biota, both directly and indirectly. Key functions include root reinforcement of banks, stream shading, sediment retention, nutrient supply, and large wood supply to stream, lake, and wetland ecosystems (Beechie et al. 2013). Nutrients and terrestrial invertebrates can enhance aquatic food webs, and large wood provides cover and helps to form habitat units such as pools and backwater areas. Functioning riparian areas also allow interactions between a water body and its floodplain, and access by fish to important off-channel rearing habitats (Ward et al. 2002, Naiman et al. 2010). Indirect benefits include contributions to water quality and maintenance of hydrologic processes (Beechie et al. 2013). Riparian vegetation can influence water temperature via shading (reduced solar input blocked by leaves) (Moore et al. 2005). Vegetation can filter excess sediment, nutrients, and pollutants and provide stable banks (via networks of roots) that prevent large inputs of sediment. Intact riparian areas also help to control the timing and amount of runoff from precipitation events and the maintenance of adequate water table heights.

Types of native vegetation differ among regions; areas with wetter climates tend to have dense forests often with thick understory, and arid regions tend to have sparser tree cover with mostly brush and grasses underneath. The types of vegetation present (both native and nonindigenous) and alterations to riparian characteristics can decrease riparian function. Removal or reduction in coverage of riparian vegetation can lead to stream widening, which may decrease shading and increase water temperature. Wood recruitment is also reduced, which may alter stream morphology (i.e., simplifying channel characteristics and reducing habitat diversity). Bank hardening associated with developed areas (rip rap, levees) and water withdrawal or diversion may lead to stream widening or incision which reduces access by fish to off-channel habitats. Primary mechanisms of altered riparian characteristics (reduction in vegetation cover or increased representation of nonindigenous species) are anthropogenic development (e.g., development, agriculture, and road building), forestry (timber harvest, road building), grazing, and mining. Climate change may alter the type of vegetation capable of growing in a region. Beavers are also agents of riparian change, and can be used to restore riparian processes along with active riparian planting or other restoration techniques.

Quantification of changes in vegetation can be accomplished by comparing land use and land cover from satellite and aerial imagery at different spatial resolutions (Fullerton et al. 2006). Data are not summarized very frequently but there are applications available for tracking change over time, such as LandTrendr. In certain locations (e.g., west of the Cascades), vegetation has been summarized at a finer resolution and includes variables such as tree size, percent cover, and type (conifer vs. deciduous) that may be more relevant for monitoring riparian areas (i.e., the Interagency Vegetation Mapping Project).

% Urban land cover. Urban land cover has been associated with degraded habitat quantity and quality for salmon and other aquatic organisms (Booth & Jackson 1997, Booth et al. 2002, Morley & Karr 2002, Pess et al. 2002). Urbanization results in increased impervious surface area, causing increased runoff and peak flows, runoff of metals and pesticides from roads and landscaping, reduced riparian functions via vegetation removal, and in some cases channel modifications that simplify or eliminate habitat (Beechie et al. 2013). Increased runoff and flood magnitudes due to impervious surfaces (mainly pavement and rooftops) in some areas cause channel incision (Booth & Jackson 1997, Booth et al. 2002). Runoff of pesticides and metals degrades ecosystem health and can also cause pre-spawning mortality of some salmon species (e.g., Morley & Karr 2002, Scholz et al. 2011). Percent developed land cover has also been correlated directly with coho salmon population sizes (Pess et al. 2002). Therefore, trends in developed land cover are potentially a useful indicator of large-scale trends in habitat quality.

A variety of land cover classifications, land cover, and land use data are available for the USA, and can be used to assess the proportion of land in urban areas (e.g., the Human Footprint, and NOAA's C-CAP land cover dataset). NOAA's C-CAP data is available for Pacific Coast, and spans 1985-2011 (https://www.csc.noaa.gov/digitalcoast/data/ccapregional).

Table H 1 Summary of evaluations of potential freshwater indicator across five primary considerations, seven data considerations, and six other criteria. Each criterion was scored 0, 0.5, or 1 depending on the level of literature support for that criterion. The numerical value that appears under each of the criteria groupings represents the sum of those values. For example, river discharge has peer-reviewed literature strongly supporting five out of five primary considerations criteria. *Indicators in the top quartile; **Promising indicators with gaps; unmarked indicators scored poorly and will not be considered further.

Indicator	Primary (5)	Data (7)	Other (6)	Summary comments
Quantity				
River discharge (e.g., 1-day average peak flow, 7-day average low flow)*	5	6	3	Good indicator of change in ecologically important flows (e.g., low flows, flood flows). Spatial and temporal patterns of river discharge well recorded with long-term USGS gaging stations on large rivers. Less consistent coverage of smaller streams.
% of network accessible vs historical*	5	6.5	5.5	Good indicator of habitat availability at large scales (e.g., amount of habitat blocked by dams). Time series can be reconstructed but will require some additional effort. Less useful for migration barriers on small streams because field inventories are rarely complete or consistent across states or watersheds.
% of floodplain vs historical**	5	4	4.5	Good indicator of habitat availability at reach scales (e.g., amount of habitat removed by levees and floodplain modification). Time series can be reconstructed but will require some additional effort. Where LIDAR is available this can be modeled in GIS, but accuracy needs to be evaluated.
Wood counts at index sites	5	3.5	3	Wood counts are inconsistently recorded both spatially and temporally. Historical records are rare and there are few monitoring programs in place to inventory wood in streams.
Spawning gravel availability	2.5	2.5	1.5	Spawning gravel is rarely measured, and inconsistently recorded both spatially and temporally. Criteria vary by species.
Intrinsic potential	3.5	3	2	Indirect indicator and not sensitive to land use or other impacts to habitat.
Node density (Whited et al.)	5	4	5	Indicator that can be linked to habitat availability but would need additional work to be a good indicator of change over time. Remote sensing methods are available to measure this on very large rivers (e.g., Yukon), but it has been well tested in smaller rivers such as those in the CC.
% watershed restored	2.5	4	2	Very little data available, and unlikely that this could be made into a useful metric even with considerable effort and expense.
Wetland area	4	5	4.5	Some data available but accuracy is low and time series not available.

Quality				
Riparian or floodplain condition*	5	4	4	Good indicator of habitat quality at reach scales, but time series must be reconstructed and will require some additional effort. There are no automated remote sensing methods developed yet; Land cover data from LandSAT are available but coarse resolution (30-30m cells). Finer resolution data not yet able to characterize riparian types.
Temperature **	4.5	5	4	Poorer time series data, but a good indicator where available. Time series available at selected sites, but not widespread.
Upland condition	2	3	2.5	Difficult to link directly to habitat condition in many cases. The indirect is indirect and mechanistic links to habitat vary widely; the meaning of the indicator is not clear except that more human influence generally means lower quality habitat.
IBI/BIBI scores	5	3	2.5	Good indicator of ecosystem health but poor spatial and temporal coverage.
303d lists	3	2	4	These are opportunistic designations of poor water quality under the Clean Water Act, but reaches are inconsistently identified where specific perceived problems are documented. Not a systematic dataset, so not a good indicator of water quality either temporally or spatially.
Grain size/fine sediment	4.5	2	3.5	In some cases this may be a good indicator of ecosystem health (not always); these are field measurements that have poor spatial and temporal coverage and methods vary among locations and studies.
Salmon production per km	2.5	2	1.5	This may be a good indicator of ecosystem health where hatchery and harvest influences are low, but is influenced by many factors besides habitat.
# listed species	1.5	3.5	2.5	Potentially a good indicator of ecosystem health, but may be influenced by factors other than habitat.
Predators (e.g., birds, fish)	4	0.5	3	Inconsistent data coverage; more predators not necessarily negative in natural settings.
Pressures				
% developed/impervious*	4	6	4	Good indicator of pressure influencing hydrologic effects on small streams in urban areas. Also related to poor water quality as measured by multi-metric biological indicators. Generally not a wide-spread habitat problem, but locally important.
% agriculture*	3.5	6	4	Good indicator of pressure influencing sediment effects on habitat may also be related to water quality and habitat quantity changes, but specific mechanisms not well documented.

# of dams (length of habitat blocked)*	5	6.5	5.5	Good indicator of pressure that drives length of habitat accessible. Databases exist for medium to large dams.
Riparian veg condition**	5	4	4	Good indicator of pressure on stream habitat condition and stream temperature. There are no automated remote sensing methods developed yet; Land cover data from LandSAT are available but coarse resolution (30-30m cells). Finer resolution data not yet able to characterize riparian types.
Erosion rate (function of land use)	2.5	6	3	See land use pressures below (%ag land cover and forest road density). Mechanistic linkages are known but datasets are sometimes inaccurately represented in existing data (e.g., forest road data are of poor quality).
# of flow diversions	3.5	2	1.5	Indicator of pressure on stream flow, but poor spatial and temporal data availability.
% high Intrinsic potential modified by land use	4	3.5	2	Indirect indicator of pressure on habitat condition; indicator will change with land cover change.
Levees/dikes (% of bank)	4.5	3.5	3.5	Good indicator of pressure on stream habitat condition, but poor temporal and spatial coverage.
Shoreline armoring (% of bank)	4.5	3.5	3.5	Good indicator of pressure on stream habitat condition, but poor temporal and spatial coverage.
Human foot print metrics	4	5	4	Indirect indicators of pressure on habitat condition, but poor temporal coverage.
Forest road density	5	5	4.5	Data quality is inconsistent spatially and temporally, but important indicator of erosion pressure.
Point sources of pollution	3.5	4	3	Good indicator of pressure on stream habitat condition, but poor temporal and spatial coverage.
Nonpoint sources of pollution	3.5	3.5	2.5	Good indicator of pressure on stream habitat condition, but poor temporal and spatial coverage.
Non-indigenous species	4.5	0.5	2	Indirect indicator of pressure on habitat condition, but poor temporal coverage.

EVALUATION OF ESTUARINE/NEARSHORE HABITAT INDICATORS

HABITAT QUANTITY

We evaluated 16 indicators of estuary and nearshore habitat quantity (Table H2). These indicators were related to the quantification of physical and biogenic habitat types. They include indices of the areal extent of selected habitat types (e.g., areal inundated wetland coverage); indicators of energy flow and transport processes (e.g., sediment deposition); and landscape-scale metrics of drainage-basin and habitat characteristics (e.g., estuary surface area: drainage area). Among the highest ranked indicators were habitat metrics for which satellite data are available to map annual changes in extent and distribution over large areas (e.g., areal extent of macrophytes). Salinity and other physical measurements (e.g., isohaline position) also hold some promise because such metrics are routinely monitored in many systems. Landscape-scale metrics depicting the relative size or complexity of river basins, estuaries, and nearshore environments were deemed relatively insensitive to interannual variations and ranked relatively low in our assessment. We identified eight promising indicators of estuarine and nearshore habitat quantity.

River Flow. Alteration of hydrology in estuaries resulting from changes to freshwater flow can have substantial effects on tidal inundation, material delivery, degree of mixing between salt and freshwater, water residence time, and temperature. Such changes can lead to impacts to water quality, reduced connectivity, and marsh subsidence (MBNEP 2002a,b). Rivers supply an estuary with freshwater, sediment, and other materials, all of which are important for the continued functioning of estuarine processes. Like freshwater habitats, discharge (or streamflow) therefore strongly influences many habitat attributes of rivers (e.g., temperature, channel morphology, habitat diversity) and limits the distribution and abundance of estuarine species. As noted in the Freshwater indicators, the magnitude, frequency, duration, timing, and rate of change (Poff et al. 2007) of flow metrics can be quantified from long-term discharge records, and one such set of metrics that have been commonly used is the Indicators of Hydrologic Alteration (IHA; Richter et al. 1996). These metrics were developed for characterizing the influence of dams on the flow regime, and for identifying how those flow changes influence physical and biological processes and the health of biota downstream of dams (Poff et al. 2007, Poff et al. 2010). Recently, IHA metrics were used to examine impacts to estuaries on all coasts of the contiguous United States (Greene et al. in press). This analysis utilized long time series of flow records at USGS gages (http://waterdata.usgs.gov/nwis/sw) upstream of estuaries. Numerous gaps were observed across the US, although the Pacific Coast had relatively fewer gaps than other coasts.

Areal inundated wetland coverage. Tidal wetlands in estuaries provide a variety of ecosystem services, including flood and erosion control, water purification, energy production and nutrient cycling, and cover and structure for a diversity of species (Barbier et al. 2011; Zedler and Kercher 2005; Visintainer et al. 2006). Tidal wetlands produce large quantities of organic matter and prey that can be exported far from local production sites to the larger ecosystem (Ramirez 2008; Eaton 2010). For example, wetland vascular plants are a primary source supporting the estuarine food webs of juvenile salmon, conveyed through production of insect and other prey taxa (Gray et al. 2002; Maier & Simenstad 2009). Various salmon-performance metrics have been linked directly to the extent of available estuarine wetlands, including salmon rearing capacity (Greene and Beamer 2012; Beamer et al. 2013), survival (Magnusson & Hilborn 2003), life-history diversity (Bottom et al. 2005; Jones et al. 2014), and adult returns (Jones et al. 2014).

Coarse scale mapping of land cover and wetland classes is available across the United States from the National Wetland Inventory (http://www.fws.gov/wetlands/Data/) and the national land cover database (http://www.mrlc.gov/) . Satellite imagery provides data to quantify annual changes in herbaceous and woody wetland cover classes (http://www.mrlc.gov/; http://www.csc.noaa.gov/digitalcoast/data/ccapregional). Historical land and hydrological survey data also have been analyzed for selected Pacific Coast estuaries, establishing a baseline for long-term changes in the composition and distribution of wetland habitat types (e.g., Collins & Sheik 2005; Marcoe & Pilson 2013).

Historical wetland losses have been substantial in most Pacific Coast estuaries (Good 2000; Collins & Sheik 2005; Cereghino et al. 2012), and wetland restoration is now recognized as a priority of various ecosystem and salmon recovery strategies (e.g., Cereghino et al. 2012; Thom et al. 2013). Thus, the areal extent of wetland habitat is not only a useful indicator of habitat quality or the potential nursery function of estuaries. It is also a useful benchmark for measuring the progress of ecosystem restoration and salmon recovery efforts.

Area of salinity zones. The composition and distribution of fish, invertebrate, and plant assemblages in estuaries have been linked to variations in salinity distribution as determined by interactions between tides and river flow in each basin (Allen 1982; Bottom & Jones 1990; Emmett et al. 1991). Salinity tolerances vary among species, and the estuary distributions of sessile plants and invertebrates may be constrained by salinity (e.g., Kentula & DeWitt 2003). In contrast, nektonic species can adjust to the physical environment, and the horizontal distribution and composition of estuarine fish assemblages has been linked to seasonal fluctuations in the salinity gradient (Allen 1982; Bottom et al. 1984; Bottom & Jones 1990). The mean areal extent of salinity zones within an estuary (e.g., oligohaline, mesohaline, euryhaline) could be a useful indicator of habitat quantity based on the tolerances or preferences of individual species and assemblages.

Salinity is recorded in many estuaries, although existing monitoring programs do not routinely report the average areal extent of particular estuary salinity zones. Several studies have reported fish assemblage or species distributions relative to broad salinity ranges (Bottom et al. 1984, Bottom & Jones 1990; Beamer et al. 2007) but different salinity classes have been chosen for these comparisons. NOAA uses a digital geographic information system (GIS) to report average annual salinity of US estuaries for three broad salinity classes: Tidal Fresh (0 - 0.5 parts per thousand), Mixing Zone (0.5 - 25 parts per thousand), and Seawater Zone (25 parts per thousand or greater; see http://catalog.data.gov/harvest/object/8ff3b448-7128-4414-a5d4-7268df7ba140/html). These same zones were used by Monaco et al. (1990) and Emmett et al. (1991) to organize general species distribution data for each estuary in the NEI Data Atlas (NOAA 1985).

Salinity is a common parameter of many ongoing estuary monitoring programs and is readily understood by the public. Yet in some estuaries short-term (i.e., tidal) salinity variations may equal or exceed seasonal fluctuations, complicating efforts to distinguish anthropogenic effects from natural variations. Salinity could be a useful indicator of estuary response to future climate changes that will likely alter hydrology, increase sea level, and thereby modify estuary circulation and salinity patterns. However, such changes also could shift fundamental relationships of species to salinity indicators (Cloern & Jassby 2012). While salinity zones may be a promising indicator, additional analysis may be needed to define the appropriate zones, estimate their areas in Pacific Coast estuaries, and evaluate their sensitivity as an indicator of ecosystem change.

Isohaline position. Some studies have used the near-bottom isohaline position as an indicator of potential physical and biotic responses to changes in salinity intrusion. In San Francisco Bay the 2 parts per thousand salinity isohaline has been related to annual measures for a variety of variables including phytoplankton supply, benthic macroinvertebrates, mysids and shrimp, larval fishes, and fish abundance (Jassby et al. 1995; Dege & Brown 2004). The position of the low-salinity isohaline has been widely used in San Francisco Bay as an indicator of the effects of flow variation and water withdrawals. Linkages between water diversion and native fish mortality, including imperiled species such as longfin and delta smelt, are now recognized in management policies for the San Francisco Bay-Delta (Cloern & Jassby 2012).

Jassby et al (1995) note that "the 2‰ value may not have special ecological significance for other estuaries…but the concept of using near-bottom isohaline position as a habitat indicator should be widely applicable." For example, salinity intrusion length similarly has been used as an indicator of effects of flow regulation in the Columbia River estuary (Jay & Naik 2011).

The data needed to depict distribution of a particular salinity isohaline are available from a variety of monitoring programs but isohaline position is not now routinely reported for many Pacific Coast estuaries. Salinity monitoring data at multiple scales are available for Puget Sound (Moore et al. 2008a,b) and the Columbia River estuary (http://www.stccmop.org/datamart/virtualcolumbiariver). The data are less consistent for small coastal estuaries, although some long-term salinity records are available from the Oregon Department of Environmental Quality (http://deq12.deq.state.or.us/lasar2/ ; see Lee and Brown 2009).

As noted for salinity-zone metrics, isohaline position is a promising indicator of potential hydrological and biotic responses to climate or other changes. The indicator is straightforward and readily understood, and data needed to define isohaline position are available for many areas. However, further analyses may be needed to determine the isohaline value(s) that are most biologically relevant and to estimate isohaline position in each estuary.

Areal extent of physical habitat. Area of physical habitat did not evaluate in the top quartile primarily due to limitations in the amount of historical data available but did evaluate highly in four out of five primary considerations criteria. Moreover, area of physical habitat (e.g., rocky intertidal, sandy beaches) is an obvious indicator to evaluate the status and trends of quantity of nearshore habitat. Physical habitat is relevant to management concerns as boundaries of various habitat types have often been used to delineate management actions such as spatial closures or regulations associated with shoreline modification. Physical habitat on land can be quantified using remote sensing, although this will require lots of processing time to calculate across the CCLME. Subtidal physical habitat can be measured with multi-beam sonar surveys, but typically these surveys occur in offshore habitats where large ships can operate. Small-boat based surveys could map nearshore habitats, but funding to map these areas along the Pacific Coast has been an obstacle. The amount of physical habitat is easily understood by the public and often used by policymakers.

Areal extent of macrophytes. In the California Current ecosystem, the two most important submerged macrophytes are eelgrass and kelp. Eelgrass is an important structural component of subtidal and intertidal communities in shallow coastal bays, estuaries, and semi-protected soft-bottom areas of the open coast (Bernstein et al. 2011). Native eelgrass provides habitat for young-of-the-year Dungeness crab (McMillan et al. 1995), produces epibenthic prey species favored by juvenile chum salmon (Fresh 2006), and serves as spawning substrate for Pacific herring (Plummer et al. 2012). Eelgrass beds also can provide key rearing habitats for coastal cutthroat trout (Krentz 2007) and juvenile coho and Chinook salmon (Bottom et al. 2005, Jones et al 2014). Subtidal eelgrass beds adjacent to intertidal flats offer complex low-tide refugia that may support higher fish densities than other non-vegetated channels (Bottom et al. 1988).

Areal extent of eelgrass is commonly monitored in many estuaries and coastal bays as an indicator of ecosystem condition and change. Underwater surveys have been useful in deeper habitats that are not well represented in photo imagery. For example, underwater videography has been used in Puget Sound to estimate changes in areal cover of eelgrass beds at site and regional scales (Norris et al. 1997; Gaeckle et al. 2008). Aerial photography and digital mapping (GIS) have been used successfully to quantify coarse-scale changes in eelgrass coverage (Short and Burdick 1996; Robbins 1997). A combination of side-scan sonar and aerial imagery is now widely used for system-wide surveys conducted in southern California (Morro Bay in the north to Tijuana Estuary) (Bernstein et al. 2011). Use of satellite imagery should reduce future field sampling of eelgrass extent and allow for regional and national comparisons.

Historical eelgrass data are available for selected regions, including southern California Bays (Bernstein et al. 2011). Coarse resolution habitat maps produced for coastal planners in the late 1970s may provide a satisfactory baseline for monitoring changes in eelgrass extent among 16 Oregon estuaries (e.g., Bottom et al. 1979; maps available online: http://www.coastalatlas.net/index.php/tools/planners/63-estuary-data-viewer). Eelgrass monitoring data for Puget Sound is also available since 2000 (Gaeckle et al. 2009). Eelgrass extent has wide application to estuary management programs including its designation as Essential Fish Habitat (Sustainable Fisheries Act) and a Habitat Area of Particular Concern (HAPC); as an ecosystem indicator for measuring the progress of Puget Sound restoration (Puget Sound Vital Signs, http://www.psp.wa.gov/vitalsigns/); and in mitigation policies enacted in California (Southern California Eelgrass Mitigation Plan) and Oregon (Oregon Administrative Rules governing removal-fill authorizations, e.g., http://arcweb.sos.state.or.us/pages/rules/oars_100/oar_141/141_085.html).

Kelp forests are ecologically and economically important, as they are the foundational structure for diverse communities in most coastal waters of the CCLME (Dayton 1985, Graham 2004). The persistence of many biologically and commercially important species of algae, invertebrates, fish, and marine mammals are directly coupled to the production of energy from kelp (Foster & Schiel 1985, Steneck et al. 2002). Kelp forests may also serve functional roles in cycling carbon between coastal marine, littoral (Polis & Hurd 1996, Dugan et al. 2003), and continental shelf (Harrold et al. 1998, Vetter & Dayton

1999) ecosystems. Most kelp forests exist in waters less than 60 m deep, but because of its importance as essential fish habitat for many species of concern, including young-of-year (Carr 1991), understanding the temporal variation and spatial heterogeneity (Jones 1992, Bustamante & Branch 1996) of kelp forest coverage in the CCLME should be a useful indicator of the quantity of important nearshore habitat. Following the framework of Link (2005), reference points related to percent change in areal coverage of canopy-forming kelp could be established.

The distribution of kelp forests has been measured historically in numerous ways. Many historical datasets include scuba diving surveys (e.g., Partnership for Interdisciplinary Studies of Coastal Oceans [PISCO] at http://www.piscoweb.org/, U.S. National Park Service at http://www.nps.gov/chis/contacts.htm), but these are generally over small spatial and short temporal scales. Recent advances in satellite and infrared photography should allow researchers to measure areal canopy cover and biomass of kelps along much of the U.S. Pacific Coast (Deysher 1993, Cavanaugh et al. 2010).

Extent of kelp coverage along the coastline is easily understood by the public and has been used by policy makers to develop guidelines related to provisions of the Magnuson Stevens Act to identify essential fish habitat (16 U. S. C. §1855b). Changes in the extent of kelp cover affects recruitment of invertebrates and other species (e.g., Carr 1991), such that kelp coverage could anticipate recruitment of older life stages into offshore populations and into various fisheries; thus kelp coverage may not only be a good indicator for the quantity of nearshore habitat, but could also be a leading indicator for community-level attributes of the CCLME.

Macrophyte density. Whereas areal extent of macrophytes measures their exterior boundary across a large area, eelgrass density provides an index of the relative condition of eelgrass or kelp within a bed. Two types of condition indicators often have been used. Percent eelgrass coverage estimates the proportion of eelgrass patches that compose the area of a bed (e.g., 0-25%, 26 to 50%, etc.) (Bernstein et al. 2011). Eelgrass coverage at multiple scales has been estimated based on diver surveys, underwater videography, and side-scan sonar (Norris et al. 1997; Bernstein et al. 2011). Permanent plots have been established in some areas to assess rates of expansion and mortality of patches within an eelgrass meadow (Oleson and Sand-Jensen 1994).

Eelgrass condition within a defined patch is often indicated by the mean density of leaf shoots m^{-2}. Shoot density has proven a useful indicator of productivity response to environmental change and is sensitive to a wide variety of anthropogenic disturbances, including effects of commercial mussel harvest (Neckles et al. 2005), boat docks and other light-limiting obstructions (Burdick and Short 1999), eutrophication and associated macroalgal cover (Hauxwell et al. 2001; Hessing-Lewis et al. 2011), and climate change (Short & Neckles 1999). In situ measurements at representative reference and disturbed sites have been used to compare eelgrass shoot density and to quantify the extent and intensity of disturbance over larger areas (Neckles et al. 2005).

On the Pacific Coast, eelgrass coverage and density indicators have been used primarily in southern California bays (Bernstein et al. 2011) and in National Estuarine Research Reserves (e.g., Rumrill & Sowers 2008). Unlike estimates of eelgrass extent, which rely on indirect methods (i.e., imagery) to map areal distribution over large regions, monitoring protocols for eelgrass density typically involve surveying permanent plots within a bed to quantify short-term changes representative of a larger area. SeagrassNet has established standard monitoring protocols for vegetative parameters and environmental variables that allow regional and world-wide comparisons of seagrass changes through time (Short et al. 2006).

Areal coverage of biogenic species. Biogenic species other than macrophytes, such as structure-forming invertebrates, provide habitat for diverse subtidal communities (Dayton 1985, Syms & Jones 2000, Tissot et al. 2006). These communities often consist of biologically and commercially-important species of algae, invertebrates, fish, and marine mammals (Foster & Schiel 1985, Steneck et al. 2002, Tissot et al. 2006). Thus, understanding the spatial and temporal variation in the quantity of this habitat will be a useful measure of the quantity of nearshore habitat. Following the framework of Link (2005), reference points related to percent change in areal coverage of biogenic species could be established.

The distribution of biogenic species has been measured historically in numerous ways. Many historical datasets include scuba diving surveys (e.g., Partnership for Interdisciplinary Studies of Coastal Oceans [PISCO] at http://www.piscoweb.org/, U.S. National Park Service at http://www.nps.gov/chis/contacts.htm), but these are generally over small spatial and short temporal scales. Recent advances in satellite and infrared photography should allow researchers to measure areal canopy cover and biomass of kelps along much of the U.S. Pacific Coast (Deysher 1993, Cavanaugh et al. 2010), but measuring the coverage of structure-forming invertebrates will only be possible in specific areas such as oyster flats, which can be surveyed when they are exposed, or areas where long-term monitoring occurs using scuba surveys or hydroacoustic sonar methods (e.g., multi-beam, side-scan).

The areal coverage of biogenic species is easily understood by the public and has been used by policymakers to delineate essential fish habitat (e.g., Habitat Areas of Particular Concern). Changes in the coverage of biogenic species can affect recruitment of invertebrates and other species (Zimmerman et al. 1989, Carr 1991, Lenihan et al. 2001, Peterson et al. 2003), such that areal coverage of biogenic species could anticipate recruitment of older life stages into offshore populations and into various fisheries; thus areal coverage of biogenic species may not only be a good indicator for the quantity of nearshore habitat, but could also be a leading indicator for community-level attributes of the CCLME.

HABITAT QUALITY

We evaluated 14 indicators for estuarine and nearshore habitat quality (Table H2). These indicators were related to the quantification of factors affecting system productivity (e.g., dissolved oxygen and temperature) and growth of organisms inhabiting estuaries. Growth indicators had limitations with respect to primary criteria, and in terms of spatial and temporal data limitations. We identified six promising indicators of estuarine habitat quality with high spatial or temporal resolution.

Water temperature. Water temperature is an important habitat quality metric because most aquatic species exhibit temperature-dependent growth windows (e.g., Buckley et al. 2004, Hinke et al. 2005). At low temperatures metabolism is slowed, resulting in low growth rates. At higher temperatures, ectothermic aquatic organisms have a higher metabolism, and so must consume more food (Portner 2002). At physiologically stressful temperatures, organisms are unable to keep up with metabolic demands. In addition, dissolved oxygen concentrations decline at high temperatures following Boyle's Law, and organisms can expire from heart failure due to lack of aerobic scope (Farrell et al. 2008).

Water temperature has a long record of measurement across the Pacific Coast and is one of the most commonly measured water quality variables. Data varies in terms of spatial and bathymetric coverage, frequency and methods employed. Methods vary from spot surface or benthic measurements during other sampling events, monthly or other consistent periodic measurements across the water column, continuous measurements at particular depths using automated loggers, and nearly continuous water column sampling at automated buoys. Satellite datasets in the infrared spectrum also can be used to interpret surface temperature in coastal environments (Thomas et al. 2002, Franz et al. 2006, Thomas and Weatherbee 2006).

Dissolved oxygen. Dissolved oxygen in estuarine and nearshore areas has been widely acknowledged as an important indicator of habitat quality for fish. Dissolved oxygen is required for aerobic respiration, so all fish and shellfish species are sensitive to low dissolved oxygen, although some species are more sensitive to declines than others. Standards for hypoxic (< 2 mg/l) and stressful conditions (< 5 mg/l) have been long established, based on laboratory studies and documented fish kills in the field. In addition the seasonal conditions associated with low dissolved oxygen are now well understood – in the California Current, low dissolved oxygen is associated with upwelling events in the spring. However, hypoxia in some nearshore environments and deep estuary systems like Puget Sound is often most acute in the late summer and early fall, when near-bottom hypoxic water created as a consequence of microbial respiration in stratified waters undergoes mixing and affects a larger portion of the water column. In shallower systems, hypoxia can occur as a result of eutrophication and subsequent bacterial activity. Hypoxia has been linked with low pH and high carbonic acid levels; hence where these other metrics are unavailable, low dissolved oxygen has been used as an indicator of ocean acidification. As a consequence of all these factors, dissolved oxygen has been routinely measured in water quality surveys within estuaries and nearshore areas by state, federal, and other groups. In some cases, these datasets are readily accessible, but even these have key spatial and temporal gaps.

Turbidity. Turbidity is a consequence of suspended solids in the water column and is an important indicator of habitat quality for a number of species. Turbidity influences light diffusion and attenuation and hence the ability of phytoplankton and macrophytes to perform photosynthesis. Moderate levels of turbidity may reduce predation risk of planktivorous fish without impacting their ability to feed, while high levels of turbidity can clog gills. Extremely high turbidity levels can abrade tissues like eyes and gills, although these events are rare and occur primarily in freshwater under high run-off conditions. Turbidity is associated with riverine inputs, particularly during run-off events. For example, the Columbia River is well known for the relatively high turbidity levels in its plume, and fish utilization of the plume is associated with turbidity level and spatial variation. In addition to riverine inputs, high primary productivity by phytoplankton can elevate turbidity, resulting in negative feedback on primary producers such phytoplankton and submerged aquatic vegetation.

Turbidity has had a long history of being measured in estuary and nearshore environments with a Secchi disk. Increasingly turbidity is measured with optical sensors that calculate light scattering properties based on nephelometric turbidity units (NTUs). Like many other metrics measured in estuary and nearshore environments, turbidity measurements have many spatial and temporal gaps. Over the last 16 years, turbidity has been measured using NASA's SEAWIFS remote sensing data. These measurements, based on surface optical properties of turbid waters, are sensitive to reflectance and other noise created by coastal activities, and the spatial resolution is relatively coarse for estuary systems. Hence, remotely sensed turbidity measurements must be considered carefully in the context of estuary and nearshore systems.

Chlorophyll *a*. The concentration of chlorophyll *a* is a direct measure of primary production by phytoplankton and therefore a useful indicator for basal elements of food availability in aquatic environments including estuary and nearshore environments. As such, chlorophyll *a* is a leading indicator of ecosystem function, and is sensitive to anthropogenic alterations in coastal waters such as nutrient additions. However, a number of different microbes including diatoms and dinoflagellates produce chlorophyll *a*. Hence, overall concentrations of chlorophyll may not be informative for groups of species that consume specific microbes or are dependent on these consumers.

Chlorophyll production has been measured in several ways, including lab assays of concentration in water samples, fluorometric readings in automated water column profilers, and satellite-based measurements. Lab assays have the highest precision but data collection is often temporally or spatially patchy. In contrast, satellite methods have broad spatial and temporal coverage over the last 16 years, but the precision of measurements can be reduced for estuary and nearshore datasets due to reflectance and other issues. Calibrating satellite-based measurements along the coast with lab assays is currently an active area of research.

Nitrogen: Phosphorus ratio. The N:P ratio describes the ratio of two important nutrients in aquatic systems – total inorganic nitrogen (ammonium, nitrates, and nitrites), and phosphate ions (PO_4). Theoretical and experimental work has examined departures of this ratio from the ratio that primary producers uptake these nutrients (Redfield et al. 1963), the effects of anthropogenic nutrients upon this ratio (Cloern 2001), and the relationship of these nutrients with eutrophication. These nutrients are routinely measured in estuary environments, and a number of studies have documented trends in N:P in particular estuaries. They are also a component of the National Eutrophication Assessment's suite of indicators (Bricker et al. 2007) and the EPA's National Coastal Condition index. However, systematic spatiotemporally extensive measurements are much spottier (Greene et al. in press), so a fair amount of data synthesis may be required for systems not covered by previous national and state-wide assessments.

Silicate: Nitrogen ratio. The Si:N ratio describes the ratio of two important inorganic nutrients in aquatic systems – silicilic acid ($Si0_4$ ions) and total inorganic nitrogen (ammonium, nitrates, and nitrites). Like the N:P ratio, the benchmark for the Si:N ratio is the rate at which phytoplankton requiring Si (diatoms, most notably) optimally consume these nutrients (Redfield et al. 1963, Cloern 2001). Departures from this ratio indicate whether Si or N is limiting in a particular environment (Cloern 2001). Consequently this metric is sensitive to anthropogenic changes such as nutrient additions, water storage, and run-off. Unlike chlorophyll *a*, Si:N is particularly reflective of potential primary production by diatoms and is therefore a good potential leading indicator of primary productivity in estuaries and nearshore systems. Si and total N are very commonly measured inorganic nutrients. However, sampling programs vary temporally and spatially; Si:N measurements therefore suffer from spatiotemporal gaps.

PRESSURES

We evaluated 17 potential indicators of anthropogenic pressures in estuarine and nearshore environments (Table H2). In the California Current, estuaries tend to be subject to greater pressures than nearshore environments, and include threats that were outlined in the Freshwater Habitat section (upland environments). Hence, the indicators of pressures we outline below are in addition to those outlined earlier, and most focus on indicators measured within estuary and nearshore environments. The best indicators as noted below outperformed others due to extensive previous research on primary, the spatial and temporal breadth of sampling, and emerging importance. Conversely, we identified a number of potential indicators of pressures that lacked good scientific backing or lacked spatiotemporally extensive data. We identified eight promising indicators of pressures on estuarine and nearshore habitat.

Eustatic sea level rise. Sea level rise from climate change is expected to accelerate in the next century. The International Panel on Climate Change (IPCC) estimates that the global average sea level will rise further between 0.6 and 2 feet (0.18 to 0.59 meters) in the next century (IPCC 2007) as a result of natural processes and anthropogenic global warming. Across the Pacific Coast, the ranges of estimated sea level rise are between 10 and 167 cm by 2100, with strong latitudinal clines (NRC 2012). At its simplest, sea level rise is due to the thermal expansion of seawater (Domingues et al. 2008) and increased freshwater inputs from melting polar and glacier ice from the continents (Radić & Hock 2011). To best estimate the rate of sea level rise, vertical movements of the land such as post-glacial rebound need to be considered to get an adequate rate (Douglas 1991). Multiple time scales are associated with sea level rise. On multidecadal timescales, steric changes in the density field are often attributed to climate variability, while seasonal to interannual time scales variations are due to atmospheric and oceanic effects that can result in geostrophic readjustments.

Records of sea level rise must be multiple decades in length to distinguish changes over naturally occurring low-frequency signals that derive from atmospheric and oceanic forcing (Parker 1991). Three tidal gauge locations within the California Current ecosystem achieve the criteria of being exceptionally long in length. They are: San Diego, CA (1906-present), San Francisco, CA (1897-present), and South Beach, OR (1967-present).

Combining coastal tide gauges with satellite altimetry (Saraceno et al. 2008) can provide a direct measure of sea level rise, although time series are limited by satellite altimetry availability.

Organic pollutants in fish and shellfish. Organic pollutants measured in fish and shellfish tissue include industrial pollutants such as polychlorinated biphenyls (PCBs), organochlorine pesticides such as DDTs, chlordane, and dieldrin, and more recently, the flame retardants, polybrominated diphenyl ethers (PBDEs). Polycyclic aromatic hydrocarbons are also organic pollutants of concern, which bioaccumulate in shellfish, but to a lesser extent in fish (Varanasi et al. 1989). Exposure to these compounds can be monitored by measuring their metabolites in fish bile (Beyer et al. 2010). Most organic pollutants are not extensively metabolized by fish and shellfish, and generally there are good correlations between levels of organic pollutants in sediments and other environmental media and concentrations in fish and shellfish from the corresponding areas. This may, however, be influenced by how resident the target fish species is at the site of collection, as well as the lipid content of the target fish species. Fish with higher lipid content generally accumulate higher concentrations of organic contaminants.

Concentrations of organic pollutants are typically measured by gas chromatography and mass spectroscopy (GC/MS) using standard protocols common to all laboratories, with some minor modifications (e.g., Sloan et al. 2004; EPA 2007a, 2007b, 2008). For classes of compounds that include multiple congeners or isomers (e.g. DDTs, PCBs, PBDEs), there may be some variability in the specific chemical congeners or isomers measured, with larger number of compounds generally being measured in more recent analyses. There may also be variation in detection limits, with higher detection limits in older data. However, total concentrations of these chemicals are often comparable, as the most commonly occurring and abundant congeners and isomers are consistently measured.

Data on concentrations of organic contaminants in fish and shellfish from Pacific Coast estuarine and nearshore environments are available from a variety of sources, including the EPA's Coastal Condition and EMAP programs (EPA 2005; Hayslip et al. 2006, 2007; EPA 2012); NOAA's Mussel Watch program (Kimbrough et al. 2008); NOAA's National Benthic Surveillance program (Brown et al, 1998; McCain et al. 2000); the California Water Resources Control Board California Surface Water Ambient Monitoring Program, SWAMP (Davis et al. 2007, 2012) and the Puget Sound Ecosystem Monitoring Program, PSEMP (West et al. 2001; PSAT 2007; West et al. 2011). Monitoring has also been conducted in the Lower Columbia River and Estuary (e.g., LCREP 2007; Nilsen et al. 2014). While the most extensive datasets are available for major urban estuaries such as Puget Sound and San Francisco Bay, there is broad coverage, with the EMAP program, for example, providing data on 410 estuaries and bays and 3,940 square miles of coastal area (EPA 2012). Some datasets include information collected as long ago as the 1970s (Davis et al. 2007).

Concentrations of contaminants in fish and shellfish are easily understood by the public and have been used by policymakers to develop fish consumption advisories, to identify impaired water bodies, and for resource damage assessment and remediation at contaminated sites. Elevated concentrations of organic contaminants in fish and shellfish pose a threat not only to the affected fish themselves but to the wildlife and humans that consume them. Moreover, the effects of contaminants on the health and productivity of estuarine species may affect fish recruitment and populations of fisheries.

Sediment quality index. Various types of sediment quality indices are widely used in estuarine and nearshore environments along the Pacific Coast. Most of these indices include three components: concentrations of chemical contaminants in sediments, sediment toxicity to benthic organisms in bioassays, and benthic community condition, evaluated by metrics such as invertebrate species diversity, or proportions of sensitive and tolerant species (Borja & Dauer 2008; Long et al. 2006; Chapman et al. 2013).

Chemical concentrations in samples are generally compared with sediment guidelines associated with the likelihood of toxicity or injury to benthic organisms. Various guidelines are used, such as the effects range low (ERL) and effects range moderate (ERM) of Long and colleagues (1995; 2006) which is used in the EPA's Coastal Condition Assessment (EPA 2012) and related assessments performed as part of the Pacific Coast EMAP program (Hayslip et al. 2006, 2007), as well as some assessments performed by the State of Washington's Department of Ecology (Dutch et al. 2009). The State of California uses two sets of guidelines (Bay and Weisberg 2012): the California Logistic Regression Model (CA LRM), a logistic regression modeling approach that estimates the probability of acute toxicity in sediments based on the chemical concentration; and the Chemical Score Indicator (CSI), which is based on the association of chemical concentration with benthic community disturbance. Based on comparison with these guidelines, areas are classified into categories such as minimally exposure, low exposure, moderate, exposure, or high exposure.

Sediment toxicity is evaluated with invertebrate bioassays. The State of California, the EPA Coastal Condition Assessment Program, and the State of Washington all use a marine amphipod survival bioassay (EPA 2012; Bay et al. 2007). Responses are assigned to categories of non-toxic, low toxicity, moderate toxicity and high toxicity, depending on how they compare with responses on uncontaminated control sediments.

Benthic community measures are also included in most sediment quality indices. The EPA Coastal Condition Assessment, for example, uses a benthic index that compares invertebrate species diversity at each site to the expected diversity for the specific salinity representative of the site (EPA 2012). In the State of California, up to four benthic community condition indices are used to determine the magnitude of disturbance to the benthos at each site (Bay & Weisberg 2012). These include the Benthic Response Index (BRI) based on the pollution tolerance of the organisms present; the Index of Benthic Biotic Integrity (IBI), which identifies community measures that have values outside a reference range of estuaries; the Relative Benthic Index (RBI), which incorporates several community metrics as well as presence or absence of both positive and negative indicators species; and the River Invertebrate Prediction and Classification System (RIVPACS), which calculates the number of reference taxa present in the test sample and compares it to the number expected to be present in a reference sample from the same habitat. The results are combined to provide an overall benthos level of effect category, with four levels ranging from reference to high disturbance. In Washington State, a benthic community condition is also assessed from a suite of indices, including total abundance, major taxa abundances, taxa richness, evenness, species dominance, and abundance of stress-sensitive and -tolerant species. These indices are compared to median values for all of Puget Sound to determine whether the invertebrate assemblages appeared to be adversely affected or unaffected by natural and/or human-caused stressors (Dutch et al 2012).

Finally, the sediment chemistry, toxicity, and benthos data are typically integrated into an overall assessment of site condition. Both the State of California and the State of Washington classify sediment quality into six categories of impact ranging from unimpacted to clearly impacted, plus an inconclusive category for cases in which the three lines of evidence conflict (Bay & Weisberg, 2012; Dutch et al., 2012). The EPA Coastal condition assessment uses good, fair and poor ratings (EPA 2012).

As the discussion above indicates, sediment quality index data are available from nearshore and estuarine sites all along the Pacific Coast. Time series data are also available for some sites and estuaries. In Puget Sound, for example, sediment quality index data are available from 1997 to the present (Dutch et al. 2012). Sediment quality indices present some challenges as indicators because the exact components included in them and their methods of calculation vary from program to program and state to state. Also, indicator reporting is often limited to proportions of samples classified as unimpacted or in good condition, possibly impacted or in fair condition, and clearly impacted or in poor condition. However, similar data are collected for all the indices, and underlying data are usually available, so a consistent methodology could be applied to generate a uniform index or classification scheme for all nearshore and estuarine sites. Indeed, the EPAs Coastal

Condition assessment has applied their index to sites from Washington, Oregon, and California.

While sediment quality indices can appear complex, their basic components of sediment contaminant concentrations, toxicity to benthic organisms, and changes to benthic communities are easily understood by the public. Sediment quality indices are used by policymakers to evaluate dredged material, to identify impaired water bodies, and for resource damage assessment and remediation at contaminated sites. Elevated concentrations of contaminants in sediments and injury to benthic communities are in themselves a concern, but have wider implications for incorporation of contaminants into estuarine and nearshore food webs, as well as potential indirect effects on fish and other aquatic organisms that use benthic invertebrates as a food source through reductions in prey quality and availability.

Eutrophic state. Eutrophication is defined as "the enrichment of water by nutrients causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned, and therefor refers to the undesirable effects resulting from anthropogenic enrichment by nutrients (OSPAR 1998). Eutrophication can lead to increases in hypoxia, fish kills, and the occurrence of harmful algae (e.g. Boesch, 2002). Various indicators of eutrophic state have been developed in Europe and the United States but common components include chlorophyll *a* as a measure of phytoplankton biomass; and several physiochemical indicators including total phosphorus (TP), total nitrogen (TN), dissolved inorganic nitrogen (DIN), and dissolved inorganic phosphorus (DIP) as indicators of nutrient levels, as well as dissolved oxygen (DO) as an indicator of potential hypoxia and water quality degradation (Ferreira et al. 2011).

Many of these parameters are routinely measured in Pacific Coast estuarine and nearshore environments as part of water quality assessments required by the EPA. However, some indices have also been developed and applied that deal specifically with eutrophication. For example, the EPA's Coastal Condition Assessment Water Quality Index includes all of these indicators and uses them to assess the extent of eutrophication in coastal estuaries (EPA 2012). Some states have components of their water quality assessment program that deal specifically with eutrophication. For example, as part of the Oregon Water Quality Index, a eutrophication sub-index is calculated based on ammonia-nitrate nitrogen and phosphorus (Cude 2001). The Puget Sound Marine Water Condition Index (Krembs 2012) also includes a Eutrophication Index which incorporates ambient changes in levels of nutrients (concentrations of nitrate, nitrate:DIN, and phosphate); nutrient enrichment (changes in ammonium, phosphate, and nitrate concentrations in estuarine or nearshore waters compared to ocean conditions); and the impact (changes in the balance of nutrients and algal biomass, as indicated by DIN:phosphate, silicate:DIN, and chlorophyll *a*).

Some coast-wide assessments of eutrophic state are available for Pacific Coast estuarine and nearshore sites. As mentioned above, eutrophication is assessed as part of EPA's National Coastal Condition Assessment (EPA 2012). Additionally, NOAA conducted a nationwide assessment of eutrophication in coastal water, including 29 estuarine and nearshore sites on the Pacific Coast in 1999, and updated in 2007 (Bricker et al. 2007). This assessment provides a rating of eutrophic condition based on common symptoms of eutrophication, including increased chlorophyll *a*, epiphytes, and macrophytes, low dissolved oxygen, loss of submerged aquatic vegetation, and increased frequency of nuisance and/or toxic algal blooms. Embayments were ranked high, moderate and low for eutrophic condition. At the state level, information on components of the Oregon Water Quality Index related to eutrophication are available in Oregon water quality index annual reports (e.g. Merrick & Hubler 2013), which date from 2001. The Puget Sound Marine Water Eutrophic Index was adopted only in 2012, but has been evaluated as far back as 1999 from previously collected data (Krembs 2012). Additionally, information on variables related to eutrophic state is widely available as part of state, federal, and local water quality assessment programs but these data are not integrated into an index or comparable comprehensive evaluation of eutrophic status.

The general concept of eutrophic state and the overall findings of evaluations using eutrophication indices are easily understood by the public and policy makers (i.e., the eutrophic condition or index score of a particular area is good or poor, high or low) but the details of index calculation and differences among indices with different components may be less clear. Since these indices measure current water quality conditions, they generally provide an assessment of changes that have already taken place (i.e., nutrient enrichment, increased algal growth, hypoxia) so this is generally a lagging indicator. Trends in some parameters, such as nutrient levels, however, may be indications of developing problems even if currently measured values would not be indicative of impaired waters.

Beach closures. Beach closures are a simple indicator relating to fecal coliform or other bacterial outbreaks or at estuarine and nearshore sites. Human activities including sewer treatment plants, failing septic systems, improper handling of boat waste, combined sewer outfalls, agricultural activities, and animal waste are major sources of bacterial contamination of aquatic environments. These microbial contaminants may include disease-carrying organisms that pose a risk to public health. For example, use of swimming beaches that do not meet water quality standards for bacterial contamination can result in gastrointestinal illnesses, respiratory illnesses, and skin infections. This is problematic not only for infected individuals, but for the economies of coastal towns that are dependent on income from tourism at coastal beaches.

Beach closures, as well an indicators related to closure, such as levels of microbial contaminants, are tracked and used as a habitat quality indicator in estuaries throughout the Pacific Coast. Much of this data is generated by states and counties in conjunction with EPA's Beaches Environmental Assessment and Coastal Health (BEACH) Program, initiated in 1999 to reduce the risk of disease to users of marine recreational beaches. The EPA provides national guidance on beach monitoring as part of its Environmental Monitoring for Public Access and Community Tracking (EMPACT) Program (EPA 2003), which is incorporated into programs administered by the states. The California beach program is the most extensive in the nation, annually sampling 656 monitoring stations at 291 beaches. The Oregon Department of Environmental Quality and Oregon Health Authority also have a program that monitors recreational water quality at ocean beaches (ODEQ 2006). The State of Washington BEACH Program (WDOE 2002; Schneider 2004) led jointly by the Washington State Departments of Ecology and Health, is comparable. In Washington, the condition of swimming beaches is a Vital Signs indicator in the Healthy Human Population component of the Puget Sound Ecosystem Monitoring Program, in which the number of beaches not meeting the EPA water quality standards for the fecal bacteria enterococcus is tracked.

Data on beach closures are available from a number of sources. The EPA releases an annual report on beach closures by state (e.g. EPA 2013b; see http://water.epa.gov/type/oceb/beaches/summarylist.cfm). Data are available as far back as 1999, though information by state may not be available prior to 2006. Beach closures are also used as an indicator in EPA's Coastal Condition Assessment reports (EPA 2012). In California, beach closure reports are issued by the counties and by the Southern California Water Resources Control Board (e.g., SCWRB 2002). California is also developing a statewide California Beachwatch database to collect all state beach water quality information. Data on beach closures are also available through the Oregon and Washington BEACH programs. In Washington, the condition of swimming beaches is an indicator in the Healthy Human Population component of the Puget Sound Ecosystem Monitoring Program. This indicator tracks the number of beaches not meeting the EPA water quality standards for the fecal bacteria enterococcus. Heal the Bay (www.healthybay.org), a non-profit organization based in Southern California, also compiles data on beach closures and other measures of beach quality, and issues a yearly beach report card. Information has been compiled for California beaches since the 1990s

(Heal the Bay 2000), and the more recent reports include Oregon and Washington (Heal the Bay 2011).

Recreational water quality standards associated with beach closures may vary somewhat from state to state. Most are based on the EPA guideline of less than 104 enterococcus bacteria per 100 ml saltwater, but some states like California have additional sampling criteria, so conditions for closures may be more stringent.

This indicator is easily understood by public and policy makers, and generally could be expected to respond in a predictable way to management actions directed toward reducing bacterial contamination. Beach closures and proportions of beaches meeting water quality standards for fecal coliform are used by policy makers and managers to regulate water quality for the protection of human health. As discussed above, these measures are also used as habitat quality indicators nationally and in state and local programs in specific estuaries, including Puget Sound.

Fish disease. Fish disease has been used as an indicator of environmental quality in a number of studies worldwide (Au et al. 2004). In some cases, as in EPA's EMAP program, assessments are made by collecting gross pathology data on parasites, visible tumors in liver, fin erosion, abrasions, and other lesions (EPA 2001). In other cases, fish tissues are examined microscopically to diagnose disease conditions based on histopathology (e.g., Murchelano 1990; Myers et al. 1998, Schwaiger et al. 2003; PSAMP 2007; Stentiford et al. 2009). The latter studies document a range of lesions in fish liver tissue, including neoplasms and pre-neoplasms that are highly correlated with exposure to carcinogenic polycyclic aromatic hydrocarbons in field studies, and that have also been induced with controlled exposure to similar chemicals in laboratory settings (Myers et al. 2003).

Fish disease monitoring with gross pathology can be somewhat problematic as an indicator of estuarine and nearshore habitat quality, as its relationship with chemical contamination and habitat degradation can be inconclusive. However, it has been used successfully in some East and Gulf Coast estuaries sampled in EPA's EMAP program (Fournie et al. 1996; Landsberg et al. 1998). Fish liver disease, on the other hand, shows a much more consistent relationship with chemical contamination, especially with exposure to PAHs (Myers et al. 2003; Logan 2007), and has been used successfully to monitor improvements in fish health and ecological condition of PAH-contaminated sites following cleanup and remediation (PSAMP 2007; Myers et al. 2008). However, this indicator also has some limitations, as there is variation in the susceptibility of different fish species to liver disease, due to differences in diet and migratory patterns that affect exposure, as well as to differences in metabolism and detoxification of PAHs (Logan 2007). The risk of liver disease also increases with age (Stentiford et al. 2010), so this factor must be taken into account in comparing lesions prevalences.

Data on gross pathology in fish have been collected along the Pacific Coast as part of EPA's EMAP program (Hayslip et al. 2006, 2007) though its relationship with other measures of environmental degradation has not been comprehensively analyzed. Histopathological data on lesions in benthic fish were collected as part of NOAA's NBSP (Myers et al. 1998). Extensive data are also available for Puget Sound, collected as part of the PSEMP program, in which liver lesions in English sole *Parophrys vetulus* are a key indicator for PAH exposure and injury (PSAT 2007). Several studies have also been conducted in specific embayments in California (e.g., Basmadiian et al. 2008).

Fish disease, including fish cancer, is easily understood by the public and has been used by policymakers to identify impaired water bodies. Fish liver disease, on the other hand, shows a much more consistent relationship with chemical contamination, especially with exposure to PAHs (Myers et al. 2003; Logan 2007), and has been used successfully to monitor improvements in fish health.

Fish vitellogenin (VTG) induction. Since the 1990s, there have been many reports of releases of synthetic and natural estrogens into river systems and marine waters (Ramirez et al. 2009), including into nearshore and estuarine sites on the Pacific Coast (Alvarez et al. 2014; Sengupta et al. 2014). Exposure to these chemicals has been associated with a number of health effects on aquatic organisms, including altered reproductive development and behavior, reduced fertility, intersex, and feminization of males (Kime 1996; Goksyr 2006).

Among the actions of estrogens in fish is the induction of the yolk protein, vitellogenin, which is incorporated into the developing egg (Tyler et al. 1990). In female fish this is a natural occurrence induced by increased levels of endogenous estrogens during the reproductive cycle. However, abnormal induction of vitellogenin may also occur in male and juvenile fish when they are exposed to estrogens or estrogen-like compounds from an exogenous source. Accordingly, the induction of vitellogenin in male or juvenile fish has become a useful environmental indicator for the presence of and exposure to environmental estrogens in aquatic life (Sumpter & Joblins 1995; Kime et al. 1999).

Vitellogenin can be measured in fish through a variety of methods (Sumpter & Jobling 1995; Jones et al. 2000). One of the most widely used in the enzyme-linked immunoassay (ELISA). Alternatively, exposure to environmental estrogens has been detected by monitoring increased expression of estrogen responsive genes, including those associated with the production of vitellogenin and zona pellucida (egg shell) proteins

(Arukwe & Goksyr 2003; Filby et al. 2007; Baker et al. 2013). One drawback of the indicator is that assays must often be developed for target species of concern (Sumpter and Jobling 1995; Tyler et al. 1996), although assay kits are increasingly available for a range of fish species, and some universal assays can be applied across species (Heppell et al. 1995; Van Veld et al. 2005). However, studies suggest that while relative levels and trends are generally consistent, there may be substantial interlaboratory variability in VTG concentrations measured by ELISA (Batelle 2003). Finally, as this indicator has been applied only relatively recently to environmental monitoring programs, long-term trends data are generally lacking.

Vitellogenin induction has been used as an indicator of xenoestrogen exposure in several Pacific Coast estuarine and nearshore sites, including Puget Sound (Johnson et al. 2008; Peck et al. 2011), San Diego, Orange County and Los Angeles (Rempel et al. 2006; Deng et al. 2007; Baker et al. 2013), and the Lower Columbia River and Estuary (Hinck et al. 2006; LCREP 2007; Jenkins et al. 2014). Results indicate widespread exposure of fish to environmental estrogens, with especially high proportions of fish affected in areas near industrial and municipal outfalls. The chemicals responsible have not always been identified, although in Puget Sound, analyses of fish bile suggest important sources of estrogen activity may be the plasticizer bisphenol A, and natural and synthetic estrogens (17-beta estradiol, estrone) often present in sewage (da Silva et al. 2013).

Fish vitellogenin induction is readily understood by the general public when explained as abnormal production of egg yolk proteins in male or juvenile fish. It is included as one of the recommended assays is EPAs endocrine disruptor screening program (EPA 2009) and is being used as an indicator in environmental monitoring programs in Puget Sound and southern California. It can also be a useful indicator to evaluate the effectiveness of toxics reduction activities, including changes in sewage treatment to reduce estrogenic compounds (Vidal-Dorsch et al. 2014).

Table H 2. Summary of estuary/nearshore indicator evaluations across five primary considerations, seven data considerations, and six other criteria. Each criterion was scored 0, 0.5, or 1 depending on the level of literature support for that criterion. The numerical value that appears under each of the criteria groupings represents the number of evaluation criteria supported by peer-reviewed literature. For example, areal extent of salinity zones has peer-reviewed literature supporting five out of five primary considerations criteria. *Indicators in the top quartile; ** Promising indicators with gaps; unmarked indicators scored poorly and will not be considered further.

Indicator	Primary (5)	Data (7)	Other (6)	Summary Comments
Quantity				
River flow *	5	6.5	6	River flow is an important component of water quantity in estuaries and influences dynamics in estuaries and nearshore areas. Many USGS gages facilitate measurement of river flow, but coverage is spotty and time series are often not extensive.
Areal inundated wetland coverage*	4.5	4	5	Areal wetland coverage is an important measure of habitat quantity for all species that are resident in estuaries. Extent can be measured using remote sensing, although the extent of freshwater tidal zones requires additional analysis and groundtruthing.
Area of salinity zones**	5	3.5	3	Salinity zones are important transitions for a number of species and drive what marsh vegetation will grow. Salinity zones are temporally dynamic, fluctuating daily and seasonally. Measures of the average extent are possible but analysis requires extensive groundtruthing over time.
Isohaline position**	5	4	4	This metric may be useful for large estuaries influenced by water diversions or storage. It is currently quantified only for the Sacramento-San Joaquin Delta, but is useful for understanding habitat available for ESA listed species there.
Area of physical habitat	4.5	4	3.5	Management protects physical habitat that may otherwise be modified or disturbed by fishing or other industrial activities; however, increases in physical habitat, such as rock are not likely possible unless sediments are scoured away, but further loss of habitat may be possible. Nearshore, subtidal estimates can be difficult as multi-beam sonar surveys are less prevalent than in offshore habitats.
Areal macrophyte extent*	5	5.5	4	Macrophytes (e.g., eelgrass and kelp) provide habitat to diverse marine communities. Extent and coverage could anticipate recruitment of fish. Recent advances in satellite imagery and algorithms can help quantify extent and biomass efficiently.
Macrophyte density*	5	5	4	Macrophytes provide habitat to diverse marine communities. Density estimates are difficult to get from satellite imagery, so diver surveys along the coast are required.
Floodplain area: drainage area	2.5	4.5	2	Facilitates comparison of floodplain area among river systems. However, it is not expected to greatly change inter- or inter-annually.
Network complexity (number of nodes)	4	5	3	Network complexity provides insight into the existing estuary distributary network. However, it is not expected to greatly change inter- or inter-annually.
Estuary surface area:drainage area	3	4.5	2.5	This metric facilitates comparison of estuarine area among river systems. However, it is not expected to greatly change inter- or inter-annually.
Detritral production	2.5	4	3	Detrital production is one variable influencing accretion in estuaries and some nearshore environments. However, it is sporadically measured with many temporal gaps, and poorly

				understood as an indicator by the public.
Sediment deposition (mm)	3.5	4.5	3	Sediment deposition is one variable influencing accretion in estuaries and nearshore environments. However, it is sporadically measured with many temporal gaps.
Structure forming invertebrate extent	4.5	4.5	4	Benthic communities are highly diverse in habitats created by sessile invertebrates. Surveys of subtidal communities exist, but at small spatial scales.
Areal coverage of biogenic species*	5	6.5	5	Biogenic species provide habitat to highly diverse communities. Mapping of kelps, seagrasses, and sessile invertebrates can be combined to develop broad calculations of habitat quantity across nearshore habitat in the CCLME.
Density of biogenic species	4.5	6	5	Biogenic species provide habitat to highly diverse communities. Similar to macrophytes, density of biogenic species will be more difficult to quantify across the entire CCLME as most estimates are at small spatial scales and the difficulty in using satellite imagery.
Un-impounded shoreline extent	4.5	4.5	2.5	Shoreline modification alters nearshore currents and coastal sediment delivery processes which can interfere with the recruitment and survival of biogenic habitat. Satellite imagery could potentially measure changes in impoundment of shoreline.
Quality				
Temperature*	5	7	5	Important indicator of growth potential in estuary and nearshore environments and of impacts of global warming in these habitats. Data collection efforts are by many different agencies.
Dissolved O2*	5	7	5	Important indicator of growth potential in estuary and nearshore environments and of hypoxic conditions. In some places, data may be limited in time or space. Some historical conditions are known through sediment cores.
Turbidity*	5	7	5	Turbidity is important in estuary and nearshore environments as an indicator of phytoplankton production, and sediment delivery. This metric is spatially and temporally patchy, although satellite data exists that may be useful in estuary and nearshore habitat if well-calibrated to field conditions.
Chl a*	4.5	6	5	Good indicator of phytoplankton biomass and amount of energy fueling the ecosystem, satellite remotely sensed chlorophyll concentration data available system wide. However, satellite data are biased for nearshore areas and ground-based methods are therefore more accurate.
N:P*	5	7	5	Important indicator of nutrients for phytoplankton production, nutrient inputs by people, and eutrophication. Data is spatially and temporally patchy.
Si:N*	5	4	3.5	Important indicator of nutrients for production by diatoms, nutrient inputs by people, and eutrophication. Data is spatially and temporally patchy.
Water quality index	5	5	4.5	This type of metric has been used to summarize multiple physical water properties. The time series is just over a decade and currently limited to Puget Sound.
fish size and growth	3.5	4	2.5	These metrics have been used to infer growth benefits to key fisheries species. However, different species have different growth controls, and measurements have many spatial and temporal gaps.
Diversity of sediment grain size	2.5	2.5	4	Variation in sediment grain size in estuaries and nearshore environments provides one metric of habitat complexity. However, it is unclear how this metric informs habitat science, particularly when variation in this metric is not well understood and poor records existing across multiple

				systems and years. Annual variation in this metric is expected to be low.
Invertebrate density (benthic core, insect fallout, bongo net)	4	6.5	4	These metrics summarize food available for fisheries at early life stages. Very few systems use multiple sampling techniques even though all sample types are relevant, and the cost of taxonomic identification is high. Detailed time series are lacking for most systems.
Rugosity of substrate	4.5	5	4	Sampling of rugosity by multi-beam sonar can be useful in nearshore systems to examine structural complexity. However, post-processing of data can be expensive, and many spatial gaps exist, most without repeated measurements over time.
Habitat connectivity/ fragmentation	3.5	4.5	3.5	Habitat fragmentation and connectivity has been widely used in terrestrial contexts but much less so in aquatic areas. Measurements have many spatial and temporal gaps and poorly estimated historic condition.
Growth of biogenic habitat (kelps, sponges, corals, oysters)	3.5	4.5	2	Growth estimates from biogenic habitat provide one possible way to infer productivity during historical periods lacking direct monitoring. They also provide estimates of recovery rate of perturbation However, this metric needs additional calibration and data collection efforts to make it an effective metric across the California Current.
Pressures				
Eustatic sea level rise*	4	6	6	Sea level rise (SLR) is an important threat to estuary and nearshore systems. Several measurements are required to estimate SLR, so many systems lack adequate data to estimate affects and to monitor continuously.
Ocean acidification (pCO2, TCO2, alkalinity, calcite & aragonite saturation state)**	4	3.5	2.5	The frequency of corrosive waters has been increasing in the Pacific Northwest, and have directly impacted aquaculture facilities. Many data gaps exist across the coast due to the challenges of measuring carbonate chemistry, although national efforts may soon improve the technology and opportunity for long-term measurements.
Impoundment releases/hydrograph changes*	4	6	5.5	Changes in patterns of flow due to water storage and releases can be used to infer impacts to estuary habitats. Records have spatial and temporal gaps and often historical reference points do not exist.
Dam/Reservoir storage volume (acre-ft)*	4.5	6.5	3.5	Data series associated with water use and storage provide some of the best indicators of human impacts to freshwater input into estuaries. Freshwater storage data are available from state agency databases, which include information on construction date and impoundment area/volume for all dams.
Organic pollutants in shellfish & fish*	5	6	4.5	Data on concentrations of organic contaminants in fish and shellfish from Pacific Coast estuarine and nearshore environments are available from a variety of state and federal sources going back as far as the 1970s. However many spatial gaps exist.
Sediment quality index (pollutants, inverts)*	5	6	4.5	Provides information on sediment toxicity and invertebrate diversity and measured by state and federal agencies. Data are available in some systems from 1997 to the present, but time series may be limited for many systems. Sediment quality indices may be qualitatively estimated.
Eutrophic state **	5	3	4.5	This multi-metric index summarizes risk of an estuary to eutrophication. While this is a useful

				metric, many systems are not included, and updating has occurred every five years and may be discontinued.
Beach closures*	5	7	5	Beach closures provide a measure of the impacts of sewage, harmful algal blooms, and other impacts to recreational beach use. This measure can be tracked over time through state alerts, at relatively local levels.
Fish disease*	5	6	5	Fish diseases are easily understood by the public and policymakers, and has been used to assess effectiveness of toxics reduction and cleanup activities. Spatial and temporal data gaps exist.
Fish VTG induction*	5	5	5	Vitellogenin induction is an indicator of xenoestrogen exposure. It has been measured in several Pacific Coast estuarine and nearshore sites, including Puget Sound, Los Angeles, and the Columbia River, but large spatial and temporal gaps exist.
Shoreline armoring (dikes, hardening)	3	4	2	Shoreline armoring datasets have been completed for the Pacific Coast of North America by a variety of federal, state, and local agencies. Most, however, provide a baseline indication of current or recent conditions and are generally unavailable coastwide or over time.
Dredging	3	7	4	The amount of material (in cubic yards - CY) dredged from all waterways off the US Pacific Coast is a concrete, spatially explicit indicator that concisely tracks the magnitude of this human activity throughout the California Current region.
Aquaculture facilities (pounds produced)	3	6	4	Production is limited to the state of WA. Production will correlate with certain aspects of the pressures (e.g., escapement, disease, nutrient input, waste, fishmeal) on the ecosystem, but specific impacts may not increase/decrease with production as new technology is used to mitigate impacts on water quality or interactions with wild stocks.
Aquaculture facilities (acreage, number)	2.5	5	3	The amount of habitat used is relevant to determine impacts on the ecosystem. However, this metric may not account for advances in technology or growing capabilities. Data are limited to net-pen dimensions of the current year's permit, so there is little temporal data.
Nonnative macrophytes and invertebrates	5	3	5	A global assessment scored and ranked invasive species impacts (http://conserveonline.org/workspaces/global.invasive.assessment/). This database serves as a baseline for invasion, is spatially coarse, and has not been updated since its creation.
Inorganic pollutants in shellfish & fish	3	5.5	4.5	Measuring concentrations of inorganic pollutants in organisms assesses the severity and potential impacts of pollutants released. However, variation in other variables will still limit the correlation between these land-based pollutants and observations in the CCLME.
Organic pollutants (point and nonpoint sources)	5	6	5	Data are collected as part of various federal monitoring programs, so data will continue to be collected using standardized methods that will be useful for temporal and spatial analyses in the future.
Dissolved organic carbon, Particulate organic matter	4	4	3.5	Poorly characterized in CCLME; however, high POM usually linked to hypoxia and dead zones.

EVALUATION OF PELAGIC HABITAT INDICATORS

HABITAT QUANTITY

We identified four indicators of pelagic habitat quantity (Table H3). Of these, two indicators – euphotic depth and thermocline depth – were selected as high priority indicators. The other two indicators are plume and eddy size. Plumes from large rivers (most notably the Columbia River and the Fraser River in the Salish Sea) create areas of lower salinity and elevated turbidity. Eddies created by currents interacting with local topography create areas of longer water residence time. The direct impacts of these eddies on ocean life are poorly known but may represent unique habitat for some marine animals (Loggerwell and Smith 2001,Trainer et al. 2002, Burger 2003, Yen et al. 2006, Pool et al. 2008). Both plume environments and eddies are spatially restricted and are not extensively characterized for the entire CCLME (especially for smaller systems), but may be important elements of pelagic habitat quantity as additional data becomes available.

Euphotic depth and **Thermocline depth.** The euphotic or epipelagic zone is defined as the uppermost layer of the pelagic zone, where solar radiation can penetrate and therefore drive primary production. The lower boundary of this zone occurs around 200 m depth, where light radiation levels reach 1% of surface radiation (Checkley & Barth 2009). The thermocline is defined as the depth of maximum change in temperature and defines the bottom depth of the mesopelagic zone, below which water ceases to be mixed regularly (Checkley & Barth 2009). The depth of both the photic zone and the mixed water layer, and its temperature and solar irradiation play a key role on the productivity of pelagic ecosystems. In the California Current, the above attributes are subject to seasonal and interannual variability. Seasonal physical forcing is determinant to replenish nutrients to the euphotic zone, which in turn dictate the condition for primary production in the following spring (Mantyla et al., 2008, Ianson & Allen, 2002) and consequently the recruitment success of many fish species. The upwelling communities appear thus to be affected by the timing and intensity of both upwelling and downwelling, several times in advanced of the spawning and recruitment seasons. Epipelagic species, in particular those with planktonic early life stages seem to be extremely dependent on the conditions of the upper mixed layer (Lasker, 1978, Parrish et al., 1981). For example temperature is known to dictate the rate of development of eggs (Zwiefel & Lasker, 1976) and hence the duration of exposure to predators. Also, turbulence can modulate the feeding ability of larvae (Lasker, 1981), and upwelling generating-winds are known to disperse and transport the eggs and larvae, onto or beyond their suitable habitat (Bakun & Parrish, 1982). Therefore monitoring of the upper water column characteristics is essential for understanding trends in recruitment and planning sustainable exploitation plans for many commercial and ecologically important species in the California Current (McClatchie, 2014).

Euphotic depth and thermocline depth are routinely measured via water column measurements of photosynthetically active radiation and temperature in the CCLME. The longest time series of water column measurements encompassing physical and biological parameters is found on the California Cooperative Fisheries Investigations (CalCOFI) surveys (McClatchie, 2014). Although the surveys originally spanned the entire California Current (Hewitt, 1988), the current survey design encompasses four surveys per year focusing on Southern California waters, from the coastline to more than 200 miles offshore. Waters off Central California to the north are surveyed on a semi-periodical basis during fisheries-oriented surveys, for example the combined Hake/Sardine survey (http://www.nmfs.noaa.gov/stories/2012/11/11_26_12sake_survey.html). Partial sampling of the California Current is performed during many other surveys, for example the Annual midwater trawl survey for juvenile rockfish (Baltz et al., 2006), acoustic trawl method surveys for coastal pelagic species (Zwolinski et al., 2012) or meso-scale midwater multi-species trawls surveys (Suchman et al., 2012) Although the combination of the above and other fisheries surveys collectively survey the physical and biological characteristics of the upper mixed layer of a large proportion of the California Current, there is not an ongoing comprehensive and synoptic survey.

HABITAT QUALITY

We evaluated 12 indicators of pelagic habitat quality (Table H3). Most indicators have been previously examined in previous indicator assessments for the IEA (Levin & Schwing 2011, Hazen et al. 2013 Williams et al. 2012), and summaries of some of these are repeated below or reframed in a habitat context. Many were theoretically sound, relevant to management, and predictably responsive tended to meet many of our data criteria (e.g., chlorophyll *a*). Those potential indicators that did not score highly either did not meet primary criteria or were not well characterized in space or time. For example, salinity is well measured and may be an important indicator for river plume environments; however, other environmental variables (oxygen, temperature) have greater direct effects on organisms in the majority of the pelagic realm. Topographic upwelling is an emerging metric of importance (Genin 2004, Santora et al. 2011), that may create biological hotspots, but the extent and dynamics of these water mass boundaries is still poorly understood.

Temperature. Water temperature is a key driver of the rates for metabolism for both primary producers and ectothermic heterotrophs, including most fish. Not surprisingly, water temperature has a long record of measurement across pelagic areas of the Pacific coast and is one of the most commonly physically measured variables. Data varies in terms of spatial and bathymetric coverage, frequency and methods employed but most pelagic measurements come from water column measurements during periodic surveys, from fixed buoys, or from satellite-based measurements. Due to latitudinal differences, weather, currents, upwelling, and mixing, temperature can exhibit strong dynamic variation across the CCLME, so not all temperature variation is readily interpretable.

Turbidity. Turbidity is generally related to riverine or estuarine outflow (see plume size and volume) and is highest in the ocean immediately offshore of river mouths. However, even episodic storm events can create turbid plumes in such generally clear coastal areas such as in the Southern California Bight (Lahet & Stramski 2010). Terragenic sediments are likely to be the major contributor to the suspended material but during major phytoplankton blooms, biogenic particles (phytoplankton and zooplankton) are also likely to increase turbidity. The Columbia River Plume transports a great amount of suspended material directly offshore and in summer, along the coast of Oregon (Banas et al. 2009). The plume has well defined lateral boundaries separating turbid plume water from clearer coastal or oceanic water and may be an important localized high abundance area for plankton and fish (De Robertis et al. 2005, Morgan et al. 2005). It has been hypothesized that the Columbia River plume may serve as a refuge from predation for juvenile salmon and small forage fishes (Emmett et al. 2005), since experimental studies have shown that planktivores are still able to feed under relatively high turbidity levels whereas piscivores are generally prevented from feeding there due to the poor visibility (De Robertis et al. 2003).

Dissolved Oxygen. Low dissolved oxygen concentrations in coastal and shelf waters of the California Current ecosystem is a relatively recent issue (Grantham et al. 2004; Bograd et al. 2008). When dissolved oxygen concentrations fall below 1.4 ml L^{-1} (=2 mg L^{-1}= 64 μM), the waters are considered to be 'hypoxic'. The drawdown of oxygen primarily occurs in bottom waters, which are isolated from atmospheric influences and where a build-up of sinking organic matter fuels microbial degradation and respiration that consumes oxygen. Within the California Current, the primary source of nutrients to the system is from deep waters that are upwelled onto the shelf. There is evidence that the frequency, duration and spatial coverage of hypoxic events has been increasing over the last 20 years (Diaz and Rosenberg, 2008), potentially due to increased stratification (reduced vertical mixing) and a decrease in the oxygen concentration of upwelled waters. In the southern portions of the California Current, the shoaling of the permanent Oxygen Minimum Zone is a contributing factor (Helly & Levin, 2004; Bograd et al. 2008). The impact of hypoxia on organisms in the California Current is poorly understood.

Chlorophyll *a*. Chlorophyll *a* can be used as an indicator of phytoplankton biomass, which itself is a good indicator of the amount of energy fueling the ecosystem (Falkowski & Kiefer 1985, Cole & Cloern 1987, Polovina et al. 2001, Edwards & Richardson 2004, Fulton et al. 2005). The amount of primary productivity, measured as total chlorophyll per unit area (mg m^{-3}), has been recognized as an important aspect of the marine food web, and chlorophyll *a* values are used to estimate phytoplankton biomass for mass-balance models of the CCLME (Falkowski & Kiefer 1985, Brand et al. 2007, Horne et al. 2010). Chlorophyll *a* has been shown to respond predictably to reductions or increases in nutrient inputs (eutrophication). It should be possible to identify time-specific and location-specific limit reference points for upwelling or transition fronts, although the relationship between reflectance and phytoplankton biomass must be derived before this can be accomplished.

Chlorophyll *a* data from from GLOBEC sampling cruises between 1997 and 2004 and CalCOFI cruises from 2000 to 2004 have been used CCLME ecosystem model building and calibration (Brand et al. 2007). Remotely sensed chlorophyll *a* concentration (mg m^{-3}) data can be obtained at minimal cost from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS at http://oceancolor.gsfc.nasa.gov/SeaWiFS/) to derive broad-scale coverage of values over the CCLME (Polovina & Howell 2005) or at smaller regional scales (Sydeman & Thompson 2010). Phytoplankton color, derived from continuous plankton recorder surveys (http://www.sahfos.ac.uk/about-us/cpr-survey/the-cpr-survey.aspx), can also be used to show intensity and seasonal extent of chlorophyll *a* (Edwards & Richardson 2004). Species or subsets of species of phytoplankton that affect chlorophyll *a* concentration can serve as an indicator of change in phytoplankton biomass, but physical measurements of upwelling intensity may provide a better leading indicator.

Coho salmon smolt-to-adult survival rate. The salmon smolt-to-adult survival rate is considered a good indicator of the state of the CCLME because salmon populations are highly influenced by ocean conditions, and coho salmon marine survival in particular is significantly and independently related to the dominant modes acting over the coastal region in the periods when the coho first enter the ocean (Koslow et al. 2002, Logerwell et al. 2003, Scheuerell & Williams 2005, Peterson et al. unpubl. manuscr.). Furthermore, salmon are of high commercial, recreational, and cultural importance along much of the Pacific coast, and therefore have high relevance in the delivery of ocean ecosystem services to the region (NRC 1996). Strong coupling has been demonstrated between smolt-to-adult survival and ocean upwelling in the spring and fall, suggesting management policies directed at conserving salmon need to explicitly address the important role of the ocean in driving future salmon survival (Scheuerell & Williams 2005). Furthermore, the salmon smolt-to-adult survival rate may affect management as it relates to using ocean conditions to determine best release date of hatchery fish.

The Oregon Production Index (OPI), defined as the smolt-to-adult return rate for coho salmon in Oregon, is currently one of several time series considered useful ecosystem indicators within the California Current region (Peterson et al. unpubl. manuscr., Sydeman and Thompson 2010). This dataset is temporally extensive and comprehensive for the central CCLME (PFMC 2010). However, it is considered a lagging or retrospective indicator of ocean conditions due to the protracted life cycle of salmon (Scheuerell & Williams 2005, Peterson et al. unpubl. manuscr.).

Forage fish biomass. Forage fish present some of the best opportunities to understand marine ecosystem responses to climate change. As an important link at the base of the pelagic food web, they are considered a fundamental component in the CCLME (Brand et al. 2007, Horne et al. 2010, Sydeman & Thompson 2010). Because the biomass of planktivorous fish is inversely related to zooplankton biomass, which in turn is inversely related to phytoplankton biomass, zooplankton may prove useful as a leading indicator of what may happen to regional commercial fish stocks several years later (Sherman 1994, Mackas et al. 2007, Mackas & Beaugrand 2010, Peterson et al. unpubl. manuscr.). Zooplankton biomass declines have been correlated with warming of surface waters (Roemmich & McGowan 1995, Sydeman & Thompson 2010) and used to detect regime shifts (Hare & Mantua 2000). However, for time series observations of ecosystem state variables such as biomasses or chemical concentrations, standard deviations may increase, variance may shift to lower frequencies in the variance spectrum, and return rates in response to disturbance may decrease prior to a change (Carpenter et al. 2008).

PRESSURES

We evaluated four potential indicators of pressures on pelagic habitats (Table H3). These were previously examined by Andrews et al. (2013) as potential indicators of anthropogenic pressures. Of the four examined, we recommend three metrics – commercial landings, atmospheric pollution, and vessel traffic – as the primary and measurable pressures to pelagic habitats in the CCLME.

Commercial landings. This indicator represents commercial landings of coastal pelagic species from shoreside commercial fisheries. It also includes tribal removals and catches from exempted fishing permit studies. Commercial landings represent the bulk of fishery removals for highly priced, high retention rate species, but not for bycatch species that are often discarded when caught. Status and trends of this indicator, therefore, may not thoroughly represent changes in fishery removals, and will also reflect changes in markets or/and management. Data are summarized by the Pacific Fisheries Information Network (PacFIN) at http://pacfin.psmfc.org for Washington, Oregon, and California.

Atmospheric pollution. The impact of pollutants deposited from the atmosphere on marine populations is largely unstudied; however, many nutrient, chemical and heavy-metal pollutants are introduced to marine ecosystems from sources that are geographically far away via this process (Ramanathan & Feng 2009). Substances such as sulfur dioxide, nitrogen oxide, carbon monoxide, lead, volatile organic compounds, particulate matter, and other pollutants are returned to the earth through either wet or dry atmospheric deposition (Johnson et al. 2008). Atmospheric nitrogen input is rapidly approaching global oceanic estimates for N2 fixation and is predicted to increase further due to emissions from combustion of fossil fuels and production and use of fertilizers (Paerl et al. 2002, Duce et al. 2008). Atmospheric deposition is one of the most rapidly increasing means of nutrient loading to freshwater systems and the coastal zone, as well as one of the most important anthropogenic sources of mercury pollution in aquatic systems (Johnson et al. 2008). Industrial activities have increased atmospheric mercury levels, with modern deposition flux estimated to be 3-24 times higher than preindustrial flux (Swain et al. 1992, Hermanson 1998, Bindler 2003). In the southwestern U.S., atmospheric deposition rates have been calculated at the upper end of this range, 24 times higher than pre-industrial deposition rates (Heyvaert et al. 2000). We assume these pollutants represent similar pressures on marine populations as pollutants introduced through other mechanisms (e.g., urban runoff and dumping).

We evaluated only one indicator for atmospheric deposition: the mean concentration of sulfates monitored by the National Trend Network (NTN) of the National Atmospheric Deposition Program (Table H3). The NTN provides a long-term record of precipitation chemistry for sites located throughout the U.S. Data have been consistently collected weekly using the same protocols since 1994. Specific ions that are measured include calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), sulfate (SO_4^{2-}), nitrate (NO^{3-}), chloride (Cl^{-}), and ammonium (NH^{4+})ions. These data are easily accessible via the NADP website: http://nadp.isws.illinois.edu/ntn/. This indicator of atmospheric deposition evaluated very high under all criteria categories (Table H3).

Volume of water displaced by vessel traffic. Andrews et al. (2013) evaluated three indicators of commercial shipping activity in the CCLME: port volume of cargo, number of vessel trips, and the volume of disturbed water during transit. Each of these indicators is certainly correlated with some aspect of commercial shipping activity. The port volume of cargo moved through ports along the Pacific Coast of the U.S. describes the total volume moving between ports, but this value does not give us any indication of how far shipping vessels are transporting these goods throughout the CCLME. This indicator is also probably not a relevant measure that management could use to “turn the dial” up or down. Increases or decreases to port volume may not have anything to do with the risk associated with ships striking marine mammals or increases to noise pollution off the coast.

Using the number of vessel trips within the CCLME as an indicator of commercial shipping activity provides a better link between the amount of risk shipping vessels have on various components of the CCLME; however, this indicator does not distinguish between vessels of different sizes or between trips that occur within a single port (exposure is low) and trips that span the entire length of the U.S. Pacific Coast (exposure is high).

The final indicator evaluated was the volume of disturbed water during transit. We have not found this metric used specifically in other literature sources, but it is similar to metrics used as an indicator of habitat modification caused by the disturbance of bottom-trawl fishing gear (Bellman & Heppell 2007). The metric examined the distance traveled within the CCLME by each vessel during transit from their shipping port to their receiving port and multiplied this value by the vessel's draft and the vessel's breadth. These values were then summed across domestic and foreign fleet vessels for the years 2001 – 2010. This indicator provided a more accurate estimate of the absolute exposure of the CCLME to commercial shipping vessels. There are not any likely reference points or target values for this indicator on a coastwide basis, but this indicator could be used in a spatially-explicit way (create GIS data layers) to monitor trends in shipping activity in specific corridors or during specific times of year that are frequently used by marine mammals. The time series of this metric tracked recent reductions in shipping resulting from the recent global recession.

Table H3. Summary of pelagic indicator evaluations across five primary considerations, seven data considerations, and six other criteria. Each criterion was scored 0, 0.5, or 1 depending on the level of literature support for that criterion. The numerical value that appears under each of the criteria groupings represents the number of evaluation criteria supported by peer-reviewed literature. For example, plume size has peer-reviewed literature supporting five out of five primary considerations criteria. . *Indicators in the top quartile; ** Promising indicators with gaps; unmarked indicators scored poorly and will not be considered further.

Indicator	Primary (5)	Data (7)	Other (6)	Summary Comments
Quantity				
Euphotic depth*	3.5	5	5.5	Euphotic depth is measured using light sensors. These are broadly recorded on multiple surveys across the CCLME and provide a good metric of depth and by extension the volume of water where primary production can occur.
Thermocline depth*	3.5	4	4	Thermocline is routinely derived from temperature measurements by CTD casts on numerous cruises. Thermocline provides the depth and by extension the volume of water defining favorable growth conditions for primary consumers.
Plume size (surface area)	5	5	4	Large river systems in the CCLME can produce plumes of water with lower salinity and higher turbidity, which favor certain fish species. These are largely confined to the Columbia River and Strait of Juan de Fuca and their roles for smaller systems outside this region is not well understood.
Current eddy size (surface area)	4.5	5	3.5	Several large eddies exist in the CCLME. However, the size, structure, and function of these systems as habitat is not fully understood or well-monitored.
Quality				
Dissolved O_2 (mg/l)*	4	6.5	5.5	Important indicator of growth potential in pelagic environments and of hypoxic conditions. Data are commonly measured during surveys across the CCLME. In some places, data may be limited in time or space.
Temperature (deg C)*	4.5	4.5	4	Temperature is an important variable predicting production and species distributions, and is widely measured on surveys and by satellite.
Turbidity*	3.5	6	4.5	Turbidity is strongly related to coastal sediment inputs and high local productivity, and can provide a predator refuge to small pelagic fish. Satellite measurements provide good spatial and temporal coverage across the CCLME.
Chlorophyll (mg/l)*	5	6	4	Good indicator of phytoplankton biomass and amount of energy fueling the ecosystem, satellite remotely sensed chlorophyll concentration data available system wide.

Forage fish biomass (aggregate)*	4.5	5.5	5.5	Changes in a single group may or may not be indicative of entire community. Most forage fish data are fishery dependent but new surveys are coming on-line.
Salmon smolt to adult survival rate*	4	6	5.5	Related to dominant modes acting over the coastal region, extensive historical records, perhaps best as a retrospective (lagging) indicator of historic ocean conditions.
Zooplankton biomass	3	7	4	Base of food web, fundamental component of CCLME, correlated with regime shift and climate change, can be used to estimate thresholds, several ongoing long-term datasets.
Euphausid biomass	3	6	4	Indicator of plankton biomass changes, critical link in marine food web, low counts and high patchiness in samples may increase variability, data availability as above.
Sardine & anchovy biomass	2.5	5	3	These two species are often the most abundant fish in pelagic waters and therefore are important indicators of the system's productivity. However, biomass can depend on factors other than productivity, and time series across the coast are limited.
Cetacean species status	3	6	3	Theoretically sound sentinel species, but high variability in data; low sample size and numerous coverage gaps; slow population response rate.
Salinity (ppt)	4	4	5	Extensive measurements of salinity have been made during cruises, but salinity is not a major source of variation in pelagic habitat characteristics. The exception occurs at large river plumes, where salinity variation can be important for some fish species.
Topographic upwelling (alongshore distance)	2.5	3	3.5	In several coastal areas, shelf and slope topography can facilitate upwelling, creating nutrient hotspots. Several of these sites have been identified, but the extent of these locations across the CCLME is not well documented and the time course of topographic upwelling events is therefore not broadly characterized.
Pressures				
Commercial landings of coastal pelagic fisheries*	4	7	4	Commercial landings represent the majority of removals for most species. This metric does not include discarded catch. Landings records from 1981 forward are available via http://pacfin.psmfc.org.
Atmospheric pollution*	5	7	5	The concentration of sulfate deposition measured by the National Atmospheric Deposition Program is a proxy for all chemicals deposited across the landscape. This dataset has been used in multiple publications as an indicator for atmospheric pollution.

Volume of water displaced by vessel traffic*	4	6.5	5	Similar to indicators that measure habitat modification caused by bottom-trawl fishing gear. Using the actual draft and breadth of each vessel times the distance travelled each trip provides a better estimate of the risk associated with the movement of shipping vessels through the CCLME.
Marine debris	3.5	4.5	4.5	Standardized sampling programs of measuring marine debris will be better than community groups, but it is unknown whether coastal measurements correlate with ocean measurements.

EVALUATION OF SEAFLOOR HABITAT INDICATORS

HABITAT QUANTITY

We evaluated three indicators used to measure the quantity of seafloor habitat (Table H4). These indicators include the areal extent (and distribution and abundance) of seafloor substrate substrata (e.g. rock, sand, mud, gravel), spatial patterns in substratum types, and metrics quantifying coverage of live corals and sponges. Areal extent of various substratum types ranked in the top quartile of our evaluation and is discussed here as the primary indicator of change in the quantity of seafloor habitat. In general, indicator data were collected in targeted high-priority areas (e.g. Sanctuaries, state waters) and were collected once per area. Consequently, data are unevenly distributed across the shelf and slope, and are challenging to use in time series analysis.

One seafloor habitat indicator ranked in the top quartile of our evaluation:

Extent of substratum type. The extent of seafloor substrate influences the distribution and abundance of demersal fishes (Love et al. 2002; Yoklavich et al 2000; Yoklavich et al. 2002; Anderson and Yoklavich 2007; Love et al. 2009; Pearcy et al. 1989; Stein et al. 1992). Consequently, substrate data are commonly used to infer fish distributions, and to regulate and monitor ocean uses (e.g. Rockfish Conservation Areas, Essential fish Habitats and Habitat Areas of Particular Concern, Marine Life Protection Act Marine Protected Areas).

There are few areas where analysis of change in substrate types over time would be meaningful at the scale of the California Current. Historic data exist at relatively low resolution (e.g., nautical charts etc.) for most of the CCLME, and more recent mapping surveys provide new substrate data in some areas.

The need to measure the extent of substrate types and the connection between substrate and fishes is easily understood by the public and managers. For instance, most people understand that the probability of catching certain species of fish changes in relation to bottom type. Managers can influence substrate through management of anthropogenic disturbances such as benthic trawling, construction and sediment deposition, and can use qualitative reference points inferred from the relative degree of association between substrate types and demersal fish species (see Love et al. 2002 and Allen et al. 2006 for reviews).

Areal extent of various substratum types is the primary indicator of change in the quantity of seafloor habitat (Table H4). The extent of substratum types influences the distribution and abundance of demersal marine fish and invertebrate species in the CCLME are significantly influenced by extent of substratum types (Love et al. 2002; Yoklavich et al 2000; Yoklavich et al. 2002; Anderson and Yoklavich 2007; Love et al. 2009; Laidig et al.; Pearcy et al. 1989; Stein et al. 1992). The relative degree of association of substratum type and demersal fish species is known (see Love et al. 2002 and Allen et al. 2006). Accurate information on the extent of substratum types (e.g., rock outcrops, boulder fields, mud and sand) can greatly improve predictive models of abundance/biomass of these organisms. The distribution and amount of substratum types are critical components in effectively regulating and monitoring ocean use off the U.S. west coast (e.g., EFH closures; California Marine Life Protection Act Marine Protected Areas), of which one intended result is to protect and improve seafloor habitats.

The extent of substratum types can be directly measured and the metrics are generally compatible throughout the CCLME. The accuracy of the metrics depends on the resolution of the data. Substratum types are interpreted from bathymetric and backscatter acoustic data, other geologic data, and ground-truthing from visual surveys using submersibles and remotely operated vehicles and from sediment grabs. Various derived indices are used to quantify substratum types. Resolution of these types of data varies regionally. In general, the spatial coverage and resolution of substrata data is greater within state waters compared to deeper, offshore areas. For example, the seafloor has been completely mapped with high-resolution multibeam sonar inside California's 3-mile jurisdiction. (i.e., high resolution data available in California state waters; much of federal waters has low resolution of interpreted substratum types; NMFS 2013). Historic data on extent of substratum types exist at relatively low resolution (e.g., nautical charts) for most of the CCLME; recent mapping surveys provide higher resolution data on the extent of substratum types in limited areas. As survey tools and technologies to map the seafloor advance, the resolution of the extent of substratum types improves.

An assessment of change in the extent of the substratum types would be meaningful only in a few relatively small areas, and would be difficult to evaluate on the scale of the CA Current. In addition, alterations in the sensitivity of survey technologies (e.g., improved sensors and geographic positioning) and in survey methods and interpretation of substratum types present challenges in discerning real change in the extent of seafloor substratum types. That said, change in the extent of substratum types could be a lagging indicator of impacts from sedimentation, scour, ocean engineering, and fishing. Change in the extent of substratum types could be a leading indicator of change in distribution and abundance of some species. An assessment of change in the extent of the substratum types would be meaningful only in a few relatively small areas, and would be difficult to evaluate on the scale of the CA Current.

The distribution and amount of substratum types, and their importance to communities on the seafloor, are easily understood by the public and often used by resource managers. For instance, most people understand that the probability of catching certain species of fishes changes in relation to seafloor substratum type. Managers can influence substrate impacts to seafloor substratum types through management of anthropogenic disturbances such as benthic trawling, construction, and sediment deposition, and can use qualitative reference points inferred from the relative degree of association between substrate substratum types and demersal fish species (see Love et al. 2002 and Allen et al. 2006 for reviews).

HABITAT QUALITY

We evaluated six indicators to measure the quality of seafloor habitats: dissolved oxygen, seafloor temperature, ocean acidification, terrain complexity, density of prey, and sediment accumulation (Table H4). Seafloor temperature, dissolved oxygen, and terrain complexity were judged to be the three primary indicators of change in quality of seafloor habitat, and are discussed in detail below.

Seafloor temperature. Temperature is a fundamental parameter monitored in oceanography, and the physiological response of demersal marine organisms to temperature is well studied. Change in temperature of seafloor habitats can reflect atmospheric-ocean processes such as upwelling on regional and local spatial scales and on seasonal, interannual, and decadal temporal scales (with potential for longer-term trends related to climate change). Changes in ocean temperature have been linked to shifts in population abundance and community structure of many demersal organisms. Regional reference points and time series of temperature are found in oceanographic databases for specific regions of the CCLME (e.g., CalCOFI; archives of various oceanographic institutions), and have been predicted at depth from oceanographic models (such as the regional oceanographic modeling system, ROMS).

Temperature can be directly and precisely quantified using well-established methods and standards set by the oceanographic community. Historically, ocean temperature was measured using bottle casts with reversing thermometers at fixed water depths, and is now measured continuously with widely available sensors on CTD (conductivity, temperature, depth) rosettes, moorings, and autonomous vehicles. There are ocean temperature data from the early 1950s, with spatial and temporal limitations. Our current understanding of CCLME oceanography can explain diel and seasonal variability in temperature, while variability on annual, decadal, and longer temporal scales is an active area of research. Change in temperature in seafloor habitats could be a leading indicator of latitudinal and depth-related shifts in distribution and abundance of demersal species (Perry et al. 2005, Dulvy et al. 2008).

Collecting data on ocean temperature is relatively cost-effective. Temperature and other key environmental parameters currently are measured during oceanographic cruises. Temperature sensors increasingly are being integrated into autonomous gliders and mooring systems, resulting in much broader collections of temperature data throughout the CCLME. The public can easily understand the impacts of changes in ocean temperature. Explanation of decadal-scale change in temperature patterns in the CCLME, the connection between regional and global patterns, and potential impacts from global warming are areas of active research.

Dissolved Oxygen. Fishes require DO for metabolic processes, and the physiology and biochemistry of respiration in fishes is well studied. The physical chemistry of dissolved oxygen in marine systems also is well studied, and oxygen concentration varies on a seasonal, annual, and decadal time scale. There is a growing literature on the response of marine fishes and invertebrates to varying degrees of hypoxia (oxygen deficiency) in the CCLME (Grantham et al. 2004, Chan et al. 2008, Keller et al. 2010). The onset of hypoxia on the continental shelf can reflect basin-scale fluctuations in atmosphere-ocean processes that alter oxygen content of upwelled water, the intensity of upwelling wind stress, and productivity-driven increases in coastal respiration (Chan et al. 2008). Regional reference points and time series of DO are found in extensive oceanographic databases for specific regions of the CCLME (e.g., CalCOFI; NODC World Ocean Database, archives of various oceanographic institutions), and hypoxia thresholds have been reported by Chan et al. (2008) and PISCO (Partnership for Interdisciplinary Studies of Coastal Oceans).

Dissolved oxygen can be directly and precisely quantified using well established chemical methods and international standards set by the oceanographic community. Dissolved oxygen in the ocean has always been measured broadly during research cruises, first from bottle casts at fixed water depths and now continuously with widely available sensors on CTD rosettes, moorings, and autonomous vehicles. There are data on DO in seawater from the early 1950s, with spatial and temporal limitations. Decreased DO (hypoxia) can be a leading indicator of stress and mortality of seafloor organisms. The public easily understands the need for oxygen by marine organisms. Explanation of recent decadal-scale change in the distribution of DO in the CCLME, its relationship to global patterns in DO, and potential impacts from global warming are not well understood by scientists or the public.

Terrain complexity or rugosity. Rugosity and other topographic metrics such as change in slope and bathymetric position index is an index of terrain complexity. Distribution and abundance of demersal fish species are influenced by the amount and level of terrain complexity, which can indicate size and extent of available shelter (O'Connell and Carlile 1993). Accurate measures of rugosity can improve predictive models of abundance/biomass of demersal organisms, and can be a critical component in effectively regulating and monitoring ocean use in the CCLME (e.g., EFH closures; California Marine Life Protection Act Marine Protected Areas). Change in rugosity could be a lagging indicator of impacts from sedimentation, scour, ocean engineering, and fishing, and could be a leading indicator of change in distribution and abundance of some species. An assessment of change in rugosity would be meaningful on a relatively small spatial scale, and would be difficult to evaluate on the scale of the CA Current.

Rugosity can be derived from bathymetry (continuous measures of depth) or interpreted from visual observations or side scan sonar data. Accuracy is dependent on the level of resolution of the underlying data. Historic data from which to derive rugosity are available at relatively low resolution. There is comprehensive coverage of multibeam bathymetry on the shelf and upper slope within state waters in California. Much less information is available in deeper offshore areas of the CCLME. There are few (if any) relatively small areas in which rugosity can be derived from data collected over time (and none that would be meaningful on the scale of the CCLME). Rugosity and the relationship between level of complexity and distribution of demersal organisms are easily understood by the public and often used by resource managers.

PRESSURES

The first CCIEA report (Andrews et al. 2013) examined a number of anthropogenic threats. The areal extent of bottom contact fishing gear was the only indicator appropriate for spatial and temporal analyses of pressures to seafloor habitat. Other potential metrics, such as artificial structures, were regarded as poor indicators of impacts to habitat because of their small footprint. In addition, some species appear to be attracted to artificial structures (Love et al. 2005). Hence, it remains unclear whether such structures should be viewed as true pressures or as habitat improvements.

The extent of bottom contact gear. Areal extent of bottom trawl fishing is the priority indicator of anthropogenic pressure on seafloor habitats in the CCLME. Due to the size and mass of this gear, and because several parts of the gear are in direct contact with the ocean floor, bottom trawls can physically remove, disturb, or harm rocky outcrops, corals, sponges, eelgrass beds, and other components of seafloor habitats. This type of fishing gear can significantly alter the extent and function of physical and biogenic substratum types by reducing terrain complexity and structure (NRC 2002).

Bottom trawling activity in the CCLME is conducted primarily by the Pacific Coast groundfish fishery, which harvests over 90 species, and by smaller state-managed fisheries targeting shrimp, prawns, and California halibut. Mainly due to restrictions on gear configurations and size, most bottom trawling activities currently occur on soft, unconsolidated sand and mud and adjacent to hard bedrock outcrops on the continental shelf and upper slope. In consultation with treaty tribes, management of the bottom trawl fishery is executed by NMFS, the three west coast states, and the PFMC, and comprises a complicated matrix of stakeholders, seasons, and spatial limitations. The effects of trawling vary by substratum type, and the Pacific Coast Groundfish Fishery Management Plan (PFMC 2011) includes a risk assessment of bottom trawling (and other gears), and a sensitivity index and recovery rates for a variety of components of seafloor habitat. Although bottom trawling occurs throughout the region out to about 1,300 m water depth, many areas within the CCLME have been closed to bottom trawling in order to protect seafloor habitat as well as to recover overfished species. In addition, bottom trawling is prohibited entirely in state waters (to 3 nmi) off Washington and is severely restricted off California.

Change in the areal extent of bottom trawl fishing is variable in space and time, and has been evaluated as part of the 5-year review of Pacific coast groundfish essential fish habitat (NMFS 2014). Change in the areal extent of bottom trawl fishing could be a lagging indicator of management strategies, declining fish stocks, redistribution of fish stocks due to ocean conditions, or economic dynamics. Change in the extent of bottom trawl fishing, particularly due to spatial fishing closures, could be a leading indicator of change in 1) distribution and abundance of species that are targeted or removed as bycatch in the trawls, 2) condition of seafloor habitat components, and 3) changes in biodiversity, productivity, and fish yield of the area. In general, the public understands the extent of bottom trawling and potential resultant impacts to seafloor habitats.

Table H4. Summary of seafloor indicator evaluations across five primary considerations, seven data considerations, and six other criteria. Each criterion was scored 0, 0.5, or 1 depending on the level of literature support for that criterion. The numerical value that appears under each of the criteria groupings represents the number of evaluation criteria supported by peer-reviewed literature. For example, areal extent of substrate habitat type has peer-reviewed literature supporting four and a half out of five primary considerations criteria. *Indicators in the top quartile; ** Promising indicators with gaps; unmarked indicators scored poorly and will not be considered further.

Indicator	Primary (5)	Data (7)	Other (6)	Summary Comments
Quantity				
Extent of substratum type (km2)*	4.5	5	4.5	Maps of substratum type exist coast-wide for the CCLME; resolution for substratum data varies regionally; data for state waters is mostly high-resolution, while data for most federal waters is low resolution (NMFS 2013)
Live Coral/Sponge (metrics: density, % cover, diversity)	3.5	3	4.5	The occurrence of live coral/sponge is recorded from bycatch from regional bottom trawl surveys of "trawlable" habitats or during direct visual surveys of habitats "suitable" to corals and sponges (those requiring/preferring high relief, hard substrate). Direct count visual surveys occur throughout the CCLME for a variety of purposes. Metrics of relative abundance are often quantitative, but some records compiled for the region are presence only.
Spatial pattern of substratum types (e.g., number of patches)	1.5	1	1.5	Spatial pattern of substratum type are rarely quantified and reported. Reference points have not been established, and depend on high-resolution multibeam data in order to derive meaningful metrics as a habitat indicator. Multibeam data are localized except for broad coverage in CA and OR territorial seas
Quality				
Dissolved O2 (ml/l, mg/l, µmol/l, µmol/kg, % saturation)*	4.5	5.5	5.5	Regional reference points and time series of dissolved oxygen (DO) are found in extensive oceanographic databases for specific regions of the CCLME. DO measured in seawater from discrete samples, but increasingly measured continuously with sensors on CTD rosettes, moorings, midwater and bottom trawls and underwater vehicles.
Bottom temperature (deg C)*	4.5	5	4	One of the most commonly measured environmental parameters. Regional reference points and time series of temperature are found in extensive oceanographic databases for specific regions of the CCLME. Historically measured from bottle casts with reversing thermometers at fixed water depths, but now uniformly measured continuously with sensors on CTD rosettes, moorings,

				midwater and bottom trawls and underwater vehicles.
Ocean Acidification (pCO2, TCO2, alkalinity, calcite & aragonite saturation state)**	4	3.5	2.5	Regional reference points exist for pH, pCO2, and aragonite saturation state as well as other OA-relevant parameters. There are historical databases for the CCLME and various overlapping and unique academic and institutional archives; NOAA PMEL is one regional and global repository. Note – high-precision pH measurements in deep water can be difficult to achieve due to pressure changes.
Terrain complexity (e.g., rugosity)**	3.5	4.5	1.5	Rugosity can be derived from or interpreted from bathymetry, side scan sonar or visual surveys; Historic data for deriving rugosity are available at relatively low resolution, and currently the necessary comprehensive coverage of multibeam bathymetry exists only on the shelf and upper slope within state waters in California and a portion of OR
Density of Prey spp (# or biomass/km2)	3	4	5.5	Densities for megafaunal species (fishes and invertebrates) are measured during coast-wide bottom trawl surveys or local direct count visual surveys. Regional trawl surveys and direct count visual surveys occur throughout the CCLME for a variety of purposes and pelagic prey are sampled locally via several surveys.
Sediment accumulation rates (g cm-2/yr-1 or mm/yr)	3	4.5	2.5	Historical data exists, but has spatial and temporal limitations. There are reference sites along the US Pacific Coast that have been sampled repeatedly over decades.
Pressures				
Extent of bottom trawling (km2)*	4	6.5	4	Coast-wide estimates of distance trawled by habitat type were generated by Bellman and Heppell (2007) based on logbook data on each individual tow and GIS seafloor habitat maps. These estimates are available between 1999 and 2004 and have been updated through 2010 as part of the NMFS Groundfish synthesis (NMFS 2013).

SUITE OF INDICATORS FOR HABITAT IN THE CALIFORNIA CURRENT

The goal of this report was to determine a suite of indicators sufficient for monitoring habitat conditions across the California Current. We identified 33 high priority indicators to evaluate habitat status and trends across freshwater, estuary and nearshore, pelagic, and seafloor habitats (Table H5). This suite is a balancing act between the need for a relatively small indicator set (Levin et al. 2009, Levin & Schwing 2011), and the importance of adequately representing the complexity of habitat conditions that support

Table H5. Priority indicators of freshwater, estuarine/nearshore, pelagic, and seafloor habitats.

Habitat	Attribute	Spatial analysis	Trend analysis
Freshwater	Quantity	River discharge	River discharge
		% of network accessible	
	Quality	Temperature	Temperature
		Riparian condition	
	Pressures	% agriculture	% agriculture
		% developed/impervious	% developed/impervious
			Number of dams
Estuary/nearshore	Quantity	SAV extent	SAV extent
		Estuary wetland area	River discharge
		Benthic substrate extent	Sea level rise
	Quality	Temperature	Temperature
		Dissolved O_2	Dissolved O_2
		Nitrogen: Phosphorus	Nitrogen: Phosphorus
			Turbidity
			Chlorophyll a
	Pressures	% agriculture	% agriculture
		% developed/impervious	% developed/impervious
			Beach closures
Pelagic	Quantity	Euphotic depth	Euphotic depth
		Thermocline depth	Thermocline depth
	Quality	Surface temperature	Surface temperature
		Turbidity	Turbidity
		Chlorophyll a	Chlorophyll a
			Dissolved O_2
			Total forage fish biomass
			Marine survival of salmon
	Pressures	Atmospheric pollution	Atmospheric pollution
		Ship displacement volume	Ship displacement volume
			Commercial fishery landings
Seafloor	Quantity	Substratum types	--
	Quality	Temperature	Temperature
		Dissolved O_2	Dissolved O_2
		Rugosity	
	Pressures	Areal extent of bottom trawling	Areal extent of bottom trawling

the huge diversity of aquatic life on the Pacific Coast. When examined for particular species or particular habitat features at smaller spatial scales, indicators not represented on this list may be of greater relevance. Nevertheless, following the goal of representing the state of habitat for the entire California Current ecosystem, this suite represents the most appropriate, scientifically based, and well-monitored set of habitat indicators.

These indicators also relate to key linkages identified in our conceptual model (Fig. H2). In addition to the status of habitats within each habitat type, the conceptual model points to several important linkages worth tracking: ocean drivers, anthropogenic pressures, cross-habitat linkages, species responses, and human wellbeing. When categorized by these relationships, the list of priority indicators does a relatively good job in linking with other ecosystem components (Table H6). All indicators were specifically designed to capture habitat status, and the metrics listed are key examples of habitat elements of key importance within habitat types. Cross-habitat connections are most relevant for estuary/nearshore and pelagic habitats, and our list of priority indicators provides several good examples for cross-habitat linkages for estuary systems. However, indicators describing other habitat linkages were not as highly prioritized.

Table H6. How priority indicators track linkages to other elements in the conceptual model for Habitat (Fig. H2). Italicized gray terms indicate potential indicators not in the priority list.

	Freshwater	Estuary/nearshore	Pelagic	Seafloor
Habitat status	River discharge Riparian condition	SAV extent Benthic habitat extent Wetland area	Euphotic depth Thermocline depth Temperature Chlorophyll a	Substratum types Rugosity
Habitat linkages	*Marine-derived nutrients*	River discharge Water storage Sea level rise	Turbidity	*Sedimentation rate*
Climate and ocean drivers	River discharge Temperature	River discharge Temperature Dissolved O_2 Sea level rise	Thermocline depth Temperature Dissolved O_2	Temperature Dissolved O_2
Anthropogenic pressures	% agriculture % developed Number of dams	% agriculture % developed Nitrogen:phosphorus Water storage	Atmospheric pollution Ship displacement volume	Areal extent of bottom trawling
Species responses	% of network accessible	Wetland area SAV extent	Forage fish biomass Salmon marine survival	*Biogenic habitat*
Human wellbeing	River discharge	Beach closures	Commercial landings	*Groundfish landings*

Indicators sensitive to key climate and ocean drivers received high priority for all habitat types, particularly because these metrics generally represent the best time series. Likewise, we specifically developed indicators to capture anthropogenic pressures on habitat. We also chose indicators to be relevant habitat quantity and quality metrics for living marine resources. However, some indicators are more biologically relevant than others because they specifically examined biogenic components (e.g., submerged aquatic vegetation, salmon marine survival) or targeted a species response (e.g., % of watershed accessible for salmon migrations). We also chose several habitat metrics that people directly benefit from: i.e., water supply, beach use, and the commercial harvest.

Aquatic habitats are of course defined in part by the species that use them. Individual species have particular preferences that would be represented as ranges in habitat indicators; likewise, particular species would be expected to have variable responses to anthropogenic pressures. Hence, habitat indicators need to be tailored to species or suites of species with similar habitat preferences. Pressure indicators will likewise need to be examined in light of how pressures affect habitat for these species. Nevertheless, there may exist thresholds beyond which variation in habitat quantity or quality and concomitant anthropogenic pressures on habitat affect a broad suite of species. For example, hypoxic conditions (<5 mg/l) appears to have negative effects on a broad range of demersal fish species (Keller et al. 2010). Hypoxia represents an extremely well-studied example, and thresholds such as these are difficult to assign for many habitat metrics. Therefore, we expect additional efforts required to improve linkages between habitat indicators and species or suites of species. Explicit links between habitat and the living marine resources that depend upon habitat should improve the ability of assessments to inform habitat conservation actions as one major set of management strategies.

INDICATORS AND ADAPTIVE MANAGEMENT

Like all adaptive management programs, we recognize that as additional knowledge, know-how, and management questions arise, some indicators may change in priority for the CCIEA. For example, numerous seafloor researchers have been interested in the habitat roles of biogenic habitat (e.g., sponges, deep-sea corals, and sea pens) but data is currently insufficient for mapping or tracking availability of these habitats (NMFS 2013), and work is just developing for determining their importance for demersal stocks (Tissot et al. 2006). As findings accumulate and better sampling methods and data become available, and if questions concerning the impacts of ocean acidification on biogenic habitat were to rise in importance, we can reevaluate the indicators with the new information which may result in a higher priority for monitoring seafloor biogenic habitats.

In this respect, our indicator selection process can help shed light on priority information and data gaps. Priority indicators are those which have very good scientific support as represented by primary considerations, as well as good data quantity and quality as represented by data considerations. Lower priority indicators exist because of both poorer primary and data considerations (Fig. H3). However, those indicators with high primary considerations but low data considerations could be considered good indicators with poor data, and therefore targets for improvements in monitoring. Examples of these types of indicators were:

- Freshwater: amount of large woody debris, index of biotic integrity scores
- estuary/nearshore: areal extent of salinity zones in estuaries, nonnative plants and animals
- Pelagic habitats: plume size, eddy size
- Seafloor: Areal coverage of biogenic habitat, carbonate chemistry

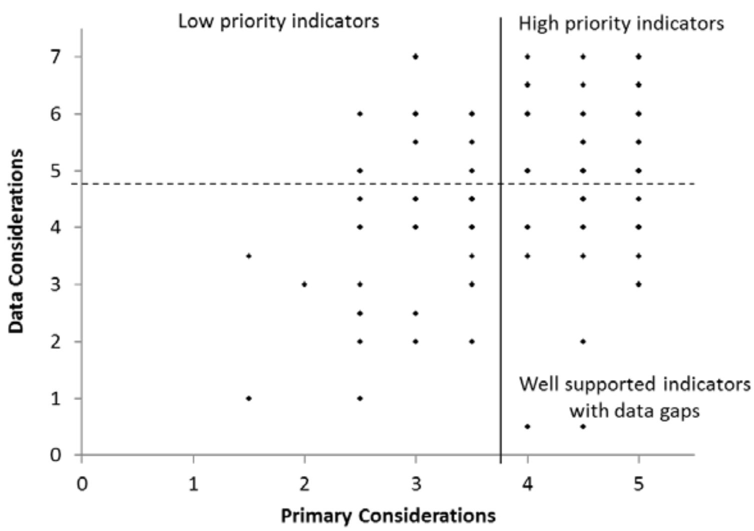

Figure H3. Primary and data considerations of habitat indicators, with lines indicating upper 25th percentile cutoffs. High priority indicators are in the upper right quadrant, while indicators with strong scientific support but lower data considerations are in the lower right hand corner.

Adaptive management requires decision points for re-evaluation of science and management programs over time. As noted in Levin et al. (2009), IEAs include multiple opportunities for adaptive management. This report constitutes an initial screening of potential habitat indicators, and recognizes that some indicators may deserve more attention due to data limitations. Better technology, additional research, and expanded monitoring should help make these better indicators. Where possible, new habitat assessment efforts should incorporate measurements for these promising additional indicators. The best opportunities for re-evaluation of indicators should occur during status and trends updates, when determinations over improvements to data considerations can be made following the same methodology used in this report.

NEXT STEPS

The main purpose of using ecosystem indicators is to evaluate ecosystem health or function (Levin & Schwing 2011). At the scale of the California Current, this question can have both spatial and temporal relevance. We anticipate that dividing status and trend analysis into mapping products and trend analyses will facilitate improvements for our understanding of habitat conditions for the CCLME's living marine resources. This will improve our ability to address where habitat is in good condition or impaired, as well as track how habitat elements are changing over time. Habitat data are well known for their information gaps, and the indicators we have selected are no exception. In this respect, selection of these indicators and tracking their status and trends can also shed light upon where additional information needs to be collected. As we synthesized indicators, we noted particular metrics for which we anticipate additional development time for analysis or data synthesis.

In addition to the indicator development outlined in this report, IEAs examine status and trends of indicators, risk analysis, and management strategy evaluation. Our assessment of indicators for the Habitat Component has highlighted important aspects that make analysis of status and trends different from other Ecosystem Components: habitat is by nature a spatially variable feature, habitats are interconnected, and changes in habitat can occur at very different time scales than living marine resources. These principles will need to be accounted for in future IEA products. Tasks for addressing these issues as part of future research include:

1) Developing a spatial framework connecting habitat types in order to facilitate spatially explicit evaluation of status and trends. Previous status and trends efforts for the CCIEA lack spatial variation, which are important to address region-specific priorities for ecosystem management.
2) Using this framework to build risk analyses relevant at multiple spatial scales (e.g., watersheds, estuaries, ecoregions), which track both local anthropogenic habitat modifications and impacts from climate change.

3) Using spatially referenced habitat indicator sets to update management strategy evaluations. Thus far, much of the ecosystem modeling has incorporated habitat changes in qualitative ways, and these models will likely be improved by quantitative measures of habitat and their effects on species groups and their interactions.
4) Improving linkages between habitat and human wellbeing beyond indicator analyses. Following from research in other marine systems (Kittinger et al. 2012), explicitly incorporating the benefits of habitat conservation to socio-economic systems will improve our ability to determine the relevance of habitat to people in the context of the CCLME. These linkages are best incorporated into management strategy evaluations of habitat conservation.

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