ANTHROPOGENIC DRIVERS AND PRESSURES

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OVERVIEW

Fisheries landings of crab and shrimp have increased in recent years, while landings of salmon and groundfish remain at historically low levels. Many non-fisheries pressures (e.g., shipping activity, industrial pollution, recreational use) have decreased over the short term, possibly reflecting slowing economic conditions; however, seafood demand, dredging, and shellfish aquaculture may be increasing to historically high levels if short-term trends persist over the next few years. Methods were developed to examine these pressures as a whole in a way that could be used to investigate linkages and thresholds between multiple pressures and ecosystem components.

EXECUTIVE SUMMARY

As human population size and demand for seafood increase globally and within the California Current Large Marine Ecosystem (CCLME), numerous human activities that take place in the ocean (e.g., fishing and shipping activity) and on land (e.g., agricultural and industrial activities) need to be recognized and incorporated into management of aquatic resources. However, information about the status and trends of these human-related pressures is often buried in state agency reports, described at small spatial scales, or measured inconsistently among local, state and federal entities. Here, we gathered and produced the best available time series data on anthropogenic pressures across the entire CCLME. We used these data sets to quantify relative changes in anthropogenic pressures, which in turn can provide the foundation for subsequent integrative analyses, such as risk analyses and management strategy evaluations, of cumulative effects on multiple components of the California Current ecosystem (e.g., fisheries, protected species, ecological integrity, and human dimensions).

We developed indicators for 23 anthropogenic pressures on the CCLME. These pressures were divided into fisheries and non-fisheries related pressures and ranged in scope from land-based pressures such as inorganic pollution and nutrient input to at-sea pressures such as fisheries removals, commercial shipping, and offshore oil and gas activities. Ultimately, we evaluated 44 different indicators and selected the best indicator(s) to describe the status and trends of each pressure. Indicators were evaluated using the indicator selection framework developed by Levin et al. (2011) and Kershner et al. (2011) and used in the previous version of NOAA's Integrated Ecosystem Assessment for the California Current (Levin & Schwing 2011). We gathered data for each of the chosen indicators from numerous sources to develop time series and describe the status and trends for each pressure across the entire CCLME.

The status of each indicator was evaluated against two criteria: short-term trend (over the last five years) and status relative to the long-term historic mean. The historical status of each indicator should be placed in context with the temporal range of data available for each time series. For example, data available for some indicators was limited to <10 years while other indicators had data spanning >50 years; thus, the short-term mean will not likely be different from the long-term mean for time series of shorter duration simply because of data availability. However, most indicators were chosen specifically because they were the most fundamentally sound datasets and will continue to be measured over time, providing meaningful comparisons in future iterations of the IEA.

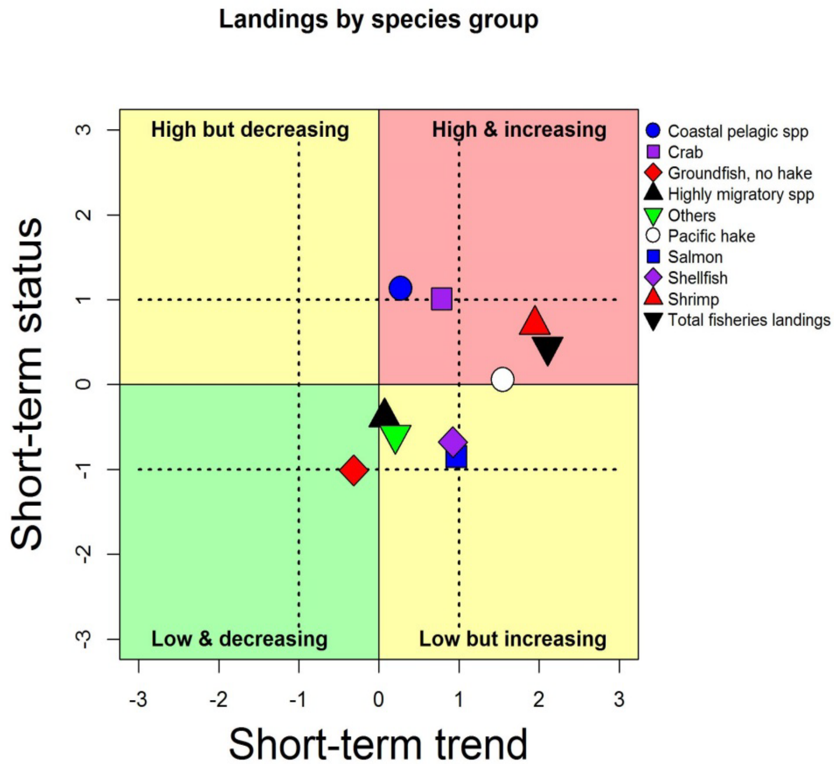


Figure AP.S.1. Short-term status and trends of annual landings (1981 – 2012) by species groups in the CCLME. Prior to plotting, time series data were normalized to place them on the same scale. The short-term trend indicates whether landings increased, decreased, or remained the same over the last five years. The short-term status represents the difference between the mean of the last five years and the mean of the full time series. Data points outside the dotted lines (1.0 standard deviation) are considered to be increasing or decreasing in the short term or show that the current status is lower or higher than the long-term mean of the time series.

Fisheries provide important services to society, including production of food, employment, livelihood, and recreation, but can also affect the ecosystem by directly removing individual fish and by disturbing habitat from the use of bottom trawls and other bottom-tended gear. Total mortality estimates are the best indicator of fisheries removals, but data are limited to very few years and are only calculated for groundfish species. Thus, we evaluated landings of catch as the best indicator of fisheries removals across the entire CCLME (Fig. AP.S.1). Landings of coastal pelagic species and crab were higher than historic levels over the last five years; Pacific hake, shrimp and total fisheries landings from commercial and recreational fishing increased over the short term; and landings of groundfish species (excluding hake) were at historically low levels for the last five years.

All other species groups were within historic landing levels. In addition, trawling effort showed a shift among habitat types, which corresponded, in part, to depth-related spatial closures implemented by the Pacific Fishery Management Council to reduce fisheries' impact on depleted species.

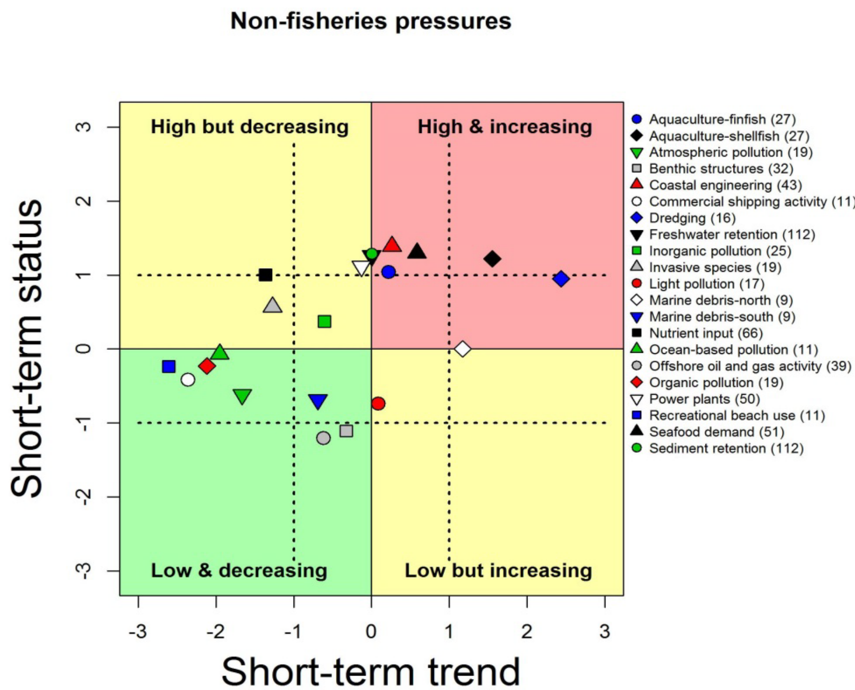


Figure AP.S.2. Short-term status and trends of non-fisheries pressures in the CCLME. See Fig. AP.S.1 for description of axes and interpretation of data points. Numbers in parentheses in the legend are the number of years in the time series for each pressure.

Most indicators of non-fisheries related pressures showed either significant short-term trends or their current status was at historically high or low levels (Fig. AP.S.2). Indicators of atmospheric, organic and ocean-based pollution, nutrient input, commercial shipping activity, recreational beach use and invasive species have all decreased over the short-term, while indicators of dredging, shellfish aquaculture, and marine debris (in the northern CCLME) increased. Indicators of seafood demand, finfish aquaculture, sediment and freshwater retention, power plant activity and coastal engineering remained relatively constant over the short-term, but were above historic levels, while indicators of offshore oil and gas activity and related benthic structures were constant over the short-term, but at historically low levels. Shellfish aquaculture is both at historically high levels and has been increasing over the last five years, whereas nutrient input is at historically high levels but has been decreasing over the last five years of the dataset.

Taken together, these results support two primary conclusions: 1) decreasing trends of several non-fisheries pressures (e.g., shipping related indicators, industrial pollution and recreational activity) potentially reflect slowing economic conditions over the last few years and 2) non-fisheries pressures at historically high levels have leveled off and are not continuing to increase, although seafood demand, shellfish aquaculture and dredging will likely be at historically high and increasing levels if current trends continue for the next couple of years (see specific time series data for each pressure in the *detailed report*).

The interpretation of the status and trends of these pressures may differ depending on the EBM component of interest. For example, a decreasing trend in fisheries removals may be "good" for rebuilding stocks of protected resources or it could be "bad" for the economies of vibrant coastal communities. In addition, none of these pressures act upon the ecosystem individually, and we have little understanding about whether the overall effects of multiple pressures will be additive, synergistic, or antagonistic on populations of interest. Nevertheless, we have developed methodology for reducing the large number of anthropogenic pressures into a smaller set of shared trends that could potentially be used to investigate linkages and thresholds between pressures and ecosystem components (see "Appendix AP1"). In addition, subsequent sections of the IEA begin to integrate the cumulative effects of multiple pressures on multiple EBM components (see "risk" sections for each EBM component and the various management strategy evaluations in the rest of the CCIEA). Moreover, these anthropogenic pressures will interact with the underlying effects of climatic and oceanographic pressures (detailed in *Oceanographic and Climatic Drivers and Pressures*). The integration of anthropogenic, oceanographic, and climatic pressures on multiple EBM components can now be modeled using various "end-to-end" ecosystem models (e.g., Atlantis; Fulton et al. 2011), but marine ecologists and fisheries scientists need to develop creative methods in the field to test the validity of these models' hypotheses and increase managers' confidence in decision making.

DETAILED REPORT

The ultimate aim of the California Current Integrated Ecosystem Assessment (CCIEA) is to fully understand the web of interactions that links drivers and pressures to ecosystem-based management (EBM) components (see *Preface* for description of EBM components addressed in the IEA) and to forecast how changing environmental conditions and management actions affect the status of EBM components. In order to capture the breadth of pressures acting upon the California Current Large Marine Ecosystem (CCLME), a lengthy list of drivers and pressures was compiled. Here we define drivers as factors that result in pressures that in turn cause changes in the ecosystem. For the purposes of an IEA, both natural and anthropogenic forcing factors are considered. Natural forces, such as climate variability, generally cannot be controlled but must be accounted for in management. In contrast, pressures related to anthropogenic factors can be controlled or managed, at least in principle. For example, human population size in the coastal zone can be directly related to anthropogenic pressures such as coastal development, habitat loss and degradation, and fishing effort – all activities that are currently managed by various regulatory agencies and jurisdictions.

The first step was to identify a suite of drivers/pressures that were most closely associated with impacts and changes to the different EBM components in the CCIEA. We used several publications (Halpern et al. 2008, Sydeman and Elliott 2008, Halpern et al. 2009, Sydeman and Thompson 2010, Teck et al. 2010, Peterson et al. 2012) to develop an initial list of potential pressures on the CCLME and then supplemented this list with other identified pressures. During reviews of the literature, we identified 32 primary groups of pressures on the CCLME, and these were categorized as "oceanographic and climatic" or "anthropogenic". Each category of pressures is discussed in separate sections of the CCIEA. Indicators for each of these pressures were then evaluated using the indicator selection framework developed by Levin et al. (2011) and Kershner et al. (2011) and used in the previous version of NOAA's Integrated Ecosystem Assessment for the California Current (Levin and Schwing 2011). Briefly, each indicator was scored against 18 different criteria in three categories: Primary considerations (e.g., is the indicator theoretically sound?), data considerations (e.g., do data exist across time and space?), and other considerations (e.g., is the indicator easily understood by managers and the public?). Scoring was based on whether each indicator had good support (score of 1), mixed support (score of 0.5) or no support (score of 0) in the scientific literature for each criterion. These scores were added up and compared across indicators for the same pressure. Highly-ranked indicators were used in further analyses.

The second step was to compile or develop time series of data for each of the top indicators for each pressure. These time series were analyzed to determine the current status of each pressure in the CCLME based on short-term and long-term trends of the dataset. We end with examples of the linkages between certain drivers and pressures and specific EBM components of the CCLME.

ANTHROPOGENIC DRIVERS AND PRESSURES

As human population size and demand for seafood increases globally and within the CCLME, numerous human activities in the ocean (e.g., fishing and shipping activity) and on land (e.g., agricultural and industrial activities) need to be recognized and incorporated into management of marine resources. However, data on the status and trends of these human-related pressures are often buried in state agency reports, described at small spatial scales and measured inconsistently among local, state and federal entities. Here, we attempted to gather and produce the best available time series data on anthropogenic pressures across the entire CCLME. These data sets are intended to quantify relative changes in anthropogenic pressures and provide the foundation for subsequent integrative analyses of cumulative effects on multiple EBM components (e.g., Appendix AP1, risk analysis and management strategy evaluations).

We identified 23 anthropogenic pressures on the CCLME, primarily relying on previous work by Halpern et al. (2008, 2009) and Teck et al. (2010). Anthropogenic pressures ranged in scope from land-based pressures such as inorganic pollution and nutrient input to at-sea pressures such as fisheries removals, commercial shipping and offshore oil and gas activities. The general impacts of pressures on the marine environment have been broadly categorized by Eastwood et al. (2007) and we summarized anthropogenic pressures for the CCLME into this modified framework (Table AP1). Because these pressures originate from human activities, we should be able to assess current and historic levels, as well as predict future levels of the pressure. Here, we describe how fisheries and non-fisheries related human pressures affect various components of the CCLME, evaluate which indicators are best suited to capture the trends and variability of these pressures, and then gather time series data that describe the status and trends of each pressure based on chosen indicators. Indicator evaluation, data indices and sources are summarized in Tables AP2-5.

The 'status' of each pressure (see *Data Analysis and Presentation* box) was measured on a short-term basis (increasing, decreasing or the same over the last five years) and measured relative to the historic average of the dataset (higher than, lower than or the same as historic levels). The historical status of each indicator should be placed in context with the amount of data available for each time series. For example, the entire time series for some indicators was only six years while the time series for other indicators was > 50 years. For shorter time series, the mean of the last five years (short-term) was not likely different from the mean of the entire time series; thus, the relative status for indicators with short time series was more related to the availability of data and not actual historic trends. However, many of these indicators were chosen because they were the most fundamentally sound datasets and will continue to be measured over time, providing meaningful historic comparisons in future iterations of the IEA.

Table AP1. General ecosystem impacts, types and identified anthropogenic pressures in the CCLME.

General ecosystem impact	Type	Identified pressures
Habitat loss	Smothering	Benthic structures Dredging Sediment input
	Obstruction	Benthic structures Coastal engineering Ocean mining
Habitat modification	Siltation	Freshwater retention Sediment input Dredging Coastal engineering Ocean mining
	Abrasion	Commercial shipping activity
	Conversion	Habitat destruction Dredging Aquaculture
Non-physical disturbance	Noise	Commercial shipping activity Tourism
	Visual	Recreational use Light pollution Coastal engineering Tourism
Toxic contamination	Introduction of synthetic compounds	Inorganic pollution Atmospheric pollution Marine debris Ocean-based pollution
	Introduction of non-synthetic compounds	Offshore oil and gas activity Ocean-based pollution
Non-toxic contamination	Nutrient enrichment	Nutrient input
	Organic enrichment	Organic pollution
	Changes in thermal regime	Power plants
	Changes in turbidity	Freshwater retention Power plants Sediment input Dredging
	Changes in salinity	Freshwater retention Power plants
Biological disturbance	Introduction of microbial pathogens	Aquaculture
	Introduction of non-native species	Invasive species
	Translocations or aggregation of individuals	Coastal engineering Benthic structures Offshore oil & gas activity Marine debris Ocean mining
	Extraction of species	Fisheries removals Seafood demand

***General ecosystem impacts and types based on pressure categories identified in Eastwood (2007)**.

In this section of the CCIEA, we do not provide interpretation of the status and trends of each pressure because this may vary depending on the EBM component of interest. For example, a decreasing trend in fisheries removals may be "good" for rebuilding stocks of Protected Resources or it could be "bad" for Vibrant Coastal Communities. The interpretation of select pressures' effects on various EBM components will be presented in analyses in the "risk" sections for each EBM component (*Section 3: Status, trends and risk of key ecosystem components in the CCLME*) and in the management strategy evaluations (*Section 4: Management Testing and Scenarios for the California Current*). The pressures identified in this section were selected primarily for their relevance to the non-human components of the CCLME (i.e. Protected Resources, Wild Fisheries, Ecosystem Integrity and Habitat), but some also contain relevant information for Vibrant Coastal Communities. Specific socio-economic indicators for Vibrant Coastal Communities have begun to be developed and can be found in *Section 3: Resilient and Economically Viable Coastal Communities*.

Importantly, the pressures identified below do not act upon the ecosystem individually, but collectively. Pressures from terrestrial-based pollution, shipping, offshore energy development, fisheries and coastal development exert cumulative effects on the ecosystem and should be managed in a holistic way (Vinebrooke et al. 2004, Crain et al. 2008, Halpern et al. 2008, Curtin and Prellezo 2010,

DATA ANALYSIS AND PRESENTATION

The status of each indicator was evaluated against two criteria: recent short-term trend and status relative to the long-term mean—reported as "short-term trend" and "short-term status," respectively.

Short-term trend. An indicator was considered to have changed in the short-term if the trend over the last five years of the time series showed an increase or decrease of more than 1.0 standard deviation (SD) of the mean of the entire time series.

Status relative to the long-term mean. An indicator was considered to be above or below historical norms if the mean of the last five years of the time series differs from the mean of the full time series by more than 1.0 SD of the full time series.

Time series figures. Time series are plotted in a standard format. Dark green horizontal lines show the mean (dotted) and ± 1.0 SD (solid line) of the full time series. The shaded green area is the last five years of the time series, which is analyzed to produce the symbols to the right of the plot. The upper symbol indicates whether the modeled trend over the last 5 years increased (↗) or decreased (↘) by more than 1.0 SD, or was within 1.0 SD (↔) of the long-term trend. The lower symbol indicates whether the mean of the last five years was greater than (+), less (-), or within (•) 1.0 SD of the long-term mean.

Stelzenmüller et al. 2010). However, quantifying the cumulative effects of these pressures is a difficult task primarily because our understanding of whether effects are additive, synergistic or antagonistic is relatively poor (Darling and Côté 2008, Hoegh-Guldberg and Bruno 2010). To conclude this section on anthropogenic pressures (see Appendix AP1), we employ three methods to summarize the temporal patterns of anthropogenic pressures as a whole in the CCLME. First, we create two cumulative pressures indices across a time period for which we have data for the greatest number of pressures. We rely on the work by Halpern et al. (2009, 2012) and Teck et al. (2010) to develop these indices. We then use two different types of dimension-reducing analyses—principal components analysis (Link et al. 2002) and dynamic factor analysis (Zuur et al. 2003a, 2003b) — to identify correlations and common trends among pressures and to reduce the number of multivariate dimensions to a smaller set that explains most of the variance across all pressures.

Two goals for future iterations of the CCIEA will be to (1) identify and evaluate the 'status' of a pressure relative to specific target levels for each indicator, and (2) identify thresholds of pressures that may identify 'tipping points' in indicators of other EBM components of the CCIEA. Establishing specific target levels of a pressure (e.g., fisheries landings quotas or concentration of nitrogen in coastal waters) is a critical step in the management and policy planning process (Samhouri et al. 2012). Placing the current status of an indicator into context with historic levels or with management goals allows managers to determine whether the current status and trend of a specific pressure is moving in the right direction or whether alternative management strategies are necessary. Target levels have been established for many of these pressures in general terms (Halpern et al. 2012), and we will refine these values specifically for the CCLME.

Thresholds represent a level of a pressure (oceanographic or anthropogenic) at which small changes produce large changes in some metric of interest. In this case, we would want to identify thresholds of anthropogenic pressures (e.g., nutrient loading) that affect specific indicators of EBM components in the CCIEA. This could be done using individual pressures or the results from our cumulative pressures indices or the results from our dimension-reducing analyses. We propose to identify nonlinearities in the relationships between indicators of EBM components and pressures (Samhouri et al. 2010).

FISHERIES PRESSURES

Fishing provides important services to society, including production of food, employment, livelihood and recreation. At the same time, fisheries have potential to adversely affect the ecosystem that supports them. Impacts of fisheries on ecosystems have been extensively discussed in the literature (Dayton et al. 1995, Kaiser and Spencer 1996, Goni 1998, Agardy 2000, Garcia et al. 2003, Gislason 2003, Pauly and Watson 2009) with major effects associated with fishery removals and destruction of habitats in which fishing occurs. Below, we discuss these two major pressures (fishery removals and habitat destruction) and illustrate their potential impacts to various components of the CCLME.

FISHERY REMOVALS

BACKGROUND

Fishery removals directly impact target resources by reducing their abundance. When poorly managed, fisheries can exert excessive pressure on fishery stocks, leading to overfishing, and causing major ecological, economic and social consequences. Fisheries for the Pacific ocean perch and widow rockfish are among the most notable examples of overexploitation in the CCLME. Fisheries targeting Pacific ocean perch developed in the Northern California Current Ecosystem in the 1950s, and catches quickly grew from just over 1000 metric tons in 1951 to almost 19,000 metric tons in 1966, eventually reducing the stock below the overfished threshold of 25% of unfished biomass, established by the Pacific Fishery Management Council, in 1980 (Hamel and Ono 2011). Fisheries targeting widow rockfish developed in the late 1970s, after it was discovered that the species forms aggregations in the pelagic waters at night. Widow rockfish catches sharply increased from 1,107 tons in 1978 to 28,419 tons in 1981 and started to drop, indicating reduction in the resource, so that severe catch limits were imposed in 1982 (Love et al. 2002).

Fisheries are rarely selective enough to remove only the desired targets (Garcia et al. 2003), and they often take other species incidentally, along with targets. Even though incidentally taken fish (often referred to as bycatch) are routinely discarded, discard mortality can be quite high, especially for deep-water species. Therefore, fisheries can significantly reduce abundance of bycatch species associated with removals of targeted resources as well. Unintended removals can be also be facilitated by lost (or dumped) fishing gear, particularly pots, traps and gillnets, which may cause entanglement of fish, marine mammals, turtles and sea birds. The extent of such “ghost” fishing in the CCLME is unknown, but studies conducted elsewhere suggest that the impact might be non-trivial (Fowler 1987, Goni 1998, Garcia et al. 2003).

Fisheries typically target larger individuals. By removing particular size groups from a population, fisheries can alter size and age structure of targeted and bycatch stocks, their sex ratios (especially when organisms in a population exhibit sexual dimorphism in growth or distribution), spawning potential, and life history parameters related to growth, sexual maturity and other traits.

Extensive fishery removals may also affect large-scale ecosystem processes and cause changes in species composition and biodiversity. These can occur with gradual decrease in the average trophic level of the food web, caused by reduction in larger, high trophic level (and high value) fish and increase in harvest of smaller, lower trophic level species, a process described as "fishing down the food chain" (Pauly et al. 1998, Pauly and Watson 2009). The extensive removal of forage fish species, mid trophic level components, can also modify interactions within a trophic web, alter the flows of biomass and energy through the ecosystem, and make systems less resilient to environmental fluctuations through a reduction of the number of prey species available to top predators (Garcia et al. 2003, Pauly and Watson 2009).

EVALUATION AND SELECTION OF INDICATORS

Fishery removals consist of two components: retained catch that is subsequently landed to ports (landings) and discarded catch that is thrown overboard. When discarded, fish either survive or die depending upon the characteristics of species and fishing and handling practices employed by the fishery. Thus, the total removals are the sum of landings and dead discard.

The best source for information on stock-specific fishery removals is typically stock assessments that report landings, estimate amount of discard, and evaluate discard mortality. Stock assessments also provide the longest time series of removals, commonly dating back to the beginning of exploitation. Stock assessments conducted for CCLME species are available via the Pacific Fishery Management Council website (http://www.pcouncil.org) by species and year of assessment. However, not all species from each fishery have been assessed. For non-assessed stocks, information on fishery removals can be obtained from a variety of state and federal sources. The most detailed and reliable CCLME fishery landing data are summarized in the Pacific Fisheries Information Network (PacFIN) (http://pacfin.psmfc.org), a regional fisheries database that manages fishery-dependent information in cooperation with the National Marine Fisheries Service (NMFS) and West Coast state agencies. The data in PacFIN go back to 1981. NMFS and its predecessor agencies, the U.S. Fish Commission and Bureau of Commercial Fisheries, has also been reporting fishery landing statistics collected via comprehensive surveys of all U.S. coastal states conducted since 1951. These data are available via NMFS Science and Technology website at (http://www.st.nmfs.noaa.gov/st1/commercial/index.html. Recreational catches since the late 1970's can be found in the Recreation Fisheries Information Network (RecFIN) (http://www.recfin.org), a project of the Pacific States Marine Fisheries Commission.

There have been a few historical studies conducted to evaluate discard in CCLME fisheries (Pikitch et al. 1988, Sampson 2002), but those studies focused on specific areas and/or species groups, so that thorough analysis would be needed to extrapolate those estimates to other areas, species and years. Currently there are two observer programs operated by the NMFS NWFSC on the U.S. West Coast. These programs include the At-Sea Hake Observer Program (A-SHOP), which monitors the at-sea hake processing vessels, and the West Coast Groundfish Observer Program (WCGOP), which monitors catcher vessels that deliver their catch to a shore-based processor or a mothership. The A-SHOP dates back to the 1970s, while WCGOP was implemented in 2001. The WCGOP began with gathering data for the limited entry trawl and fixed gear fleets. Observer coverage has expanded to include the California halibut trawl fishery, the nearshore fixed gear and pink shrimp trawl fishery. Since 2011, the U.S. West Coast groundfish trawl fishery has been managed under a new groundfish catch share program. The WCGOP provides 100% at-sea observer monitoring of catch for the new, catch share based Individual Fishing Quota (IFQ) fishery, including both retained and discarded catch.

Since 2002, the WCGOP has been generating estimates of groundfish total fishing mortality from commercial, recreational and research sources including incidental catch from non-groundfish fisheries. For groundfish, WCGOP total fishing mortality estimates were selected as an indicator of fishery removal, recognizing that the data to inform this indicator are only available for the most recent years. For other species groups, the PacFIN landings were selected as the best long-term fishery removal indicator, since they represent the bulk of removals for most species and have been routinely reported. However, if available, a total mortality estimate would be the preferred indicator for all species groups, due to its higher evaluation in the "Primary considerations" criteria (Table AP2).

STATUS AND TRENDS

The status of total removals was measured using: 1) combined commercial and recreational landings of all taxa and fishing gears as reported by the Pacific Fisheries Information Network (PacFIN) at http://pacfin.psmfc.org and by the Recreational Fisheries Information Network (RecFIN) at http://www.recfin.org for Washington, Oregon, and California; 2) commercial landings, by species group (groundfish, coastal pelagic species, highly migratory species, salmon, crab, shrimp, shellfish and others) and gear (trawl, shrimp trawl, hook and line, net gear, pot and trap, troll, and other miscellaneous gear), as reported by PacFIN for Washington, Oregon and California, and 3) for groundfish, total fishing mortality estimates generated and provided by the West Coast Groundfish Observer Program (WCGOP; Table AP3).

Total fisheries landings – This indicator represents all commercial and recreational landings reported to PacFIN and RecFIN. These estimates represent the best estimate of total fisheries removals from waters off the U.S. West Coast. These data do not include estimates of bycatch that are often discarded at sea; however, comparison of the trends in commercial landings data (e.g. Figs. AP1 & AP2) and total mortality estimates (e.g. Figs. AP19 & AP20) for groundfish and Pacific hake show similar trends. This suggests that landings data are able to capture much of the annual variability in total mortality for targeted species.

Figure AP0 shows that total fisheries landings have increased over the last five years in the CCLME, and the short-term mean was within one standard deviation of the long-term mean of the entire time series. This increasing trend is likely the result of a large rebound in landings of Pacific hake *Merluccius productus* from 2009 to 2013 (see Fig. AP2). Commercial fisheries landings drive the status and trends of this indicator; thus recreational fisheries landings may warrant their own indicator in future iterations of the CCIEA.

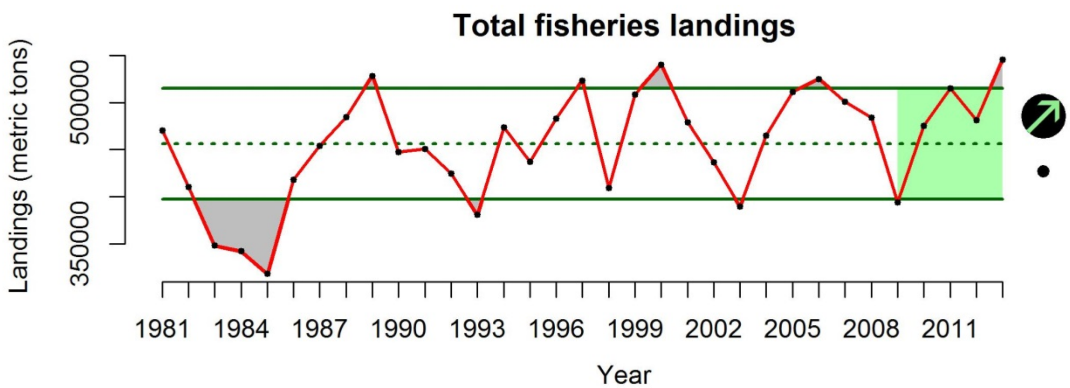


Figure AP0. Annual landings of all commercial and recreational fishing in the CCLME from 1981 – 2013.

Commercial landings – This indicator represents commercial landings from shoreside and at-sea 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 and/or management measures employed by the Pacific Fishery Management Council and NMFS to prevent overfishing.

Figures AP1-AP9 and AP11-AP17 show the time series of commercial landings by different species groups in the CCLME and by gear types, respectively. Figures AP10 and AP18 represent short-term status and trends in landings by species groups and gear, respectively. Landings of Pacific hake are reported separately from other groundfish species, since the Pacific hake fishery is the largest (in weight) on the U.S. West Coast, and when combined with other species, hake overwhelms the landings of the entire group, and obscures interannual changes in catch of other groundfish species.

Since 1981, commercial landings of groundfish species (other than Pacific hake), salmon and shellfish have generally decreased, in part due to management measures (Figs. AP1, AP5, AP8). Pacific hake, coastal pelagic species and crab have exhibited a positive long-term trend in landings (Figs. AP2, AP3, AP6), although over the short-term Pacific hake (Fig. AP2) and shrimp (Fig. AP7) have been increasing. Highly migratory species did not change significantly over the last 40 years, apart from the peak reported in the early 1980s (Figs. AP4). Relative to the mean of the entire time series, landings of coastal pelagic species and crab have been higher over the last five years, and landings for groundfish excluding hake have been at consistently low levels over the last five years. All other species groups have been relatively constant within historic landing levels (Fig. AP10).

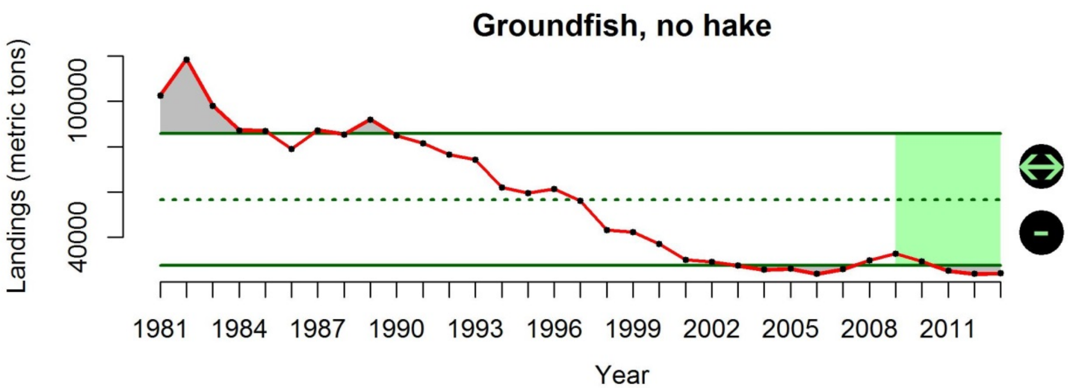


Figure AP1. Annual landings of groundfish in the CCLME from 1981 – 2013 (Pacific hake *Merluccius productus* excluded).

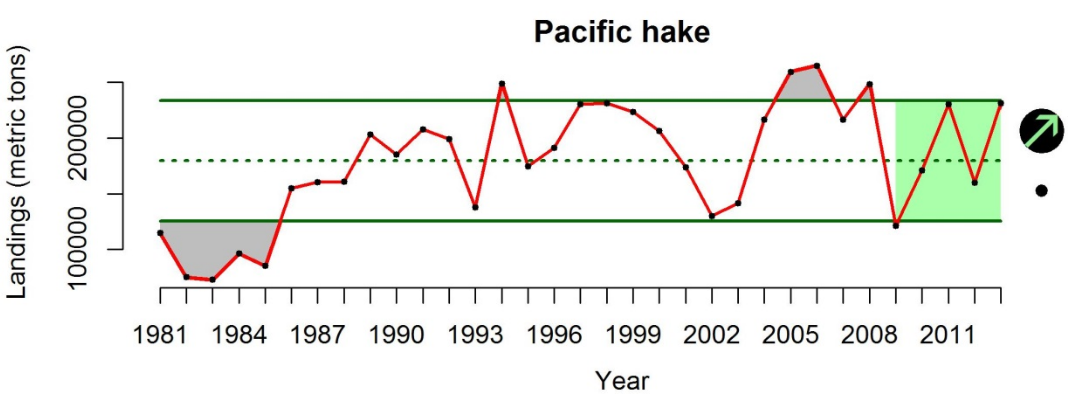


Figure AP2. Annual landings of Pacific hake *Merluccius productus* in the CCLME from 1981 – 2013.

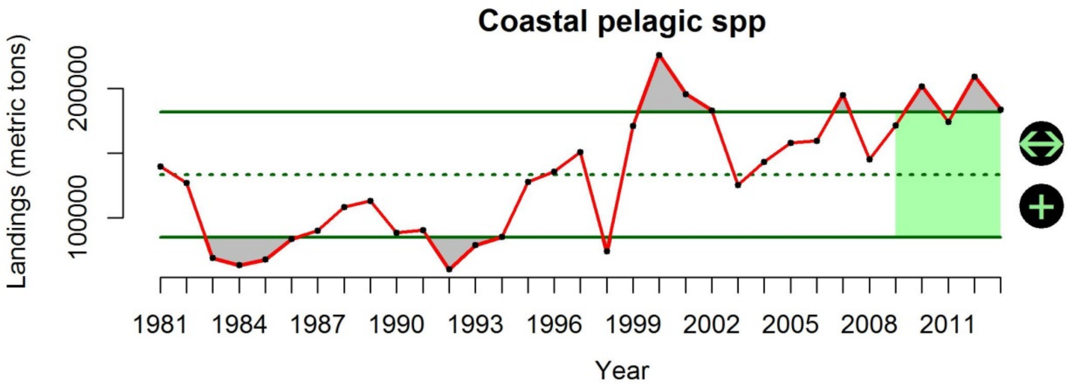


Figure AP3. Annual landings of coastal pelagic species (CPS) in the CCLME from 1981 – 2013. CPS include Pacific sardine *Sardinops sagax*, Pacific mackerel *Scomber japonicus*, northern anchovy *Engraulis mordax*, jack mackerel *Trachurus symmetricus*, and market squid *Loligo opalescens*).

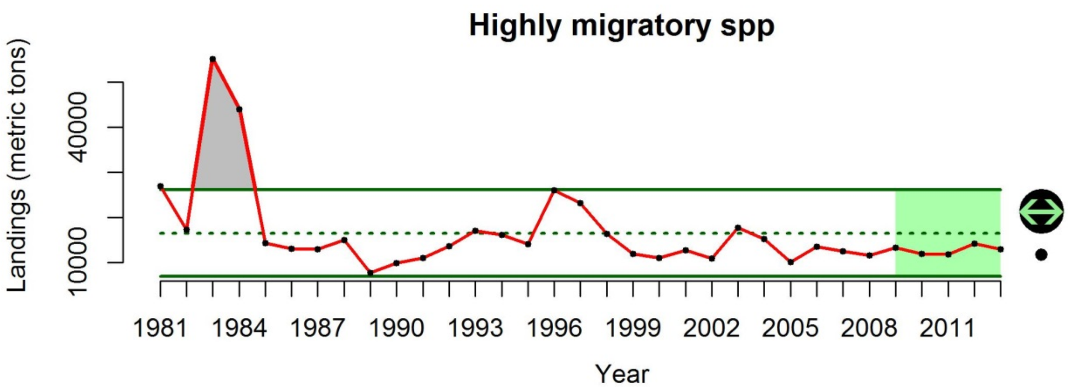


Figure AP4. Annual landings of highly migratory species (HMS) in the CCLME from 1981 – 2013. HMS include tunas, sharks, billfish/swordfish and dorado *Coryphaena hippurus*.

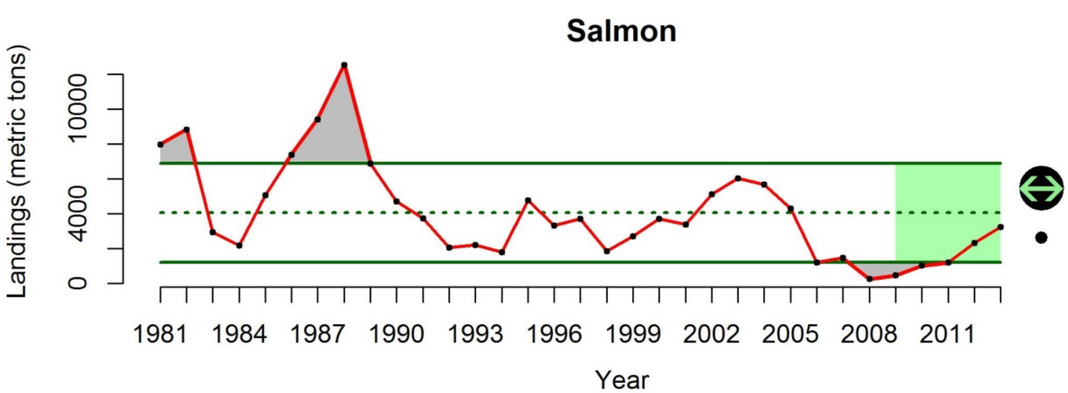


Figure AP5. Annual landings of salmon in the CCLME from 1981 – 2013.

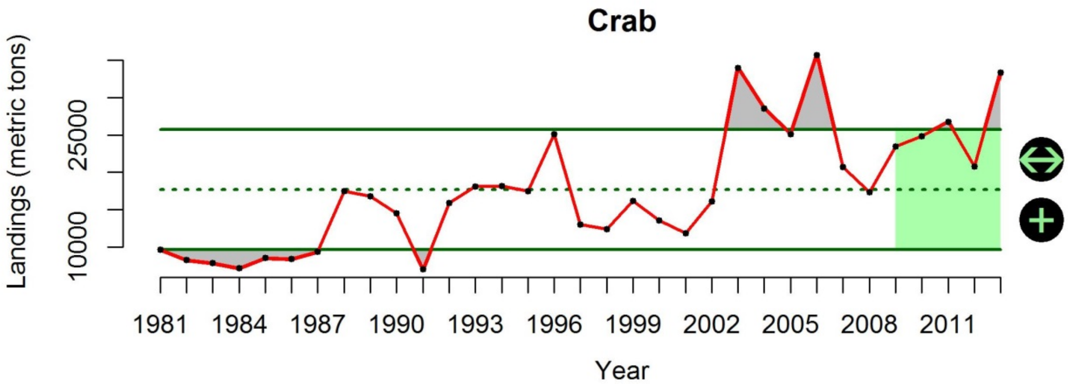


Figure AP6. Annual landings of crab in the CCLME from 1981 – 2013.

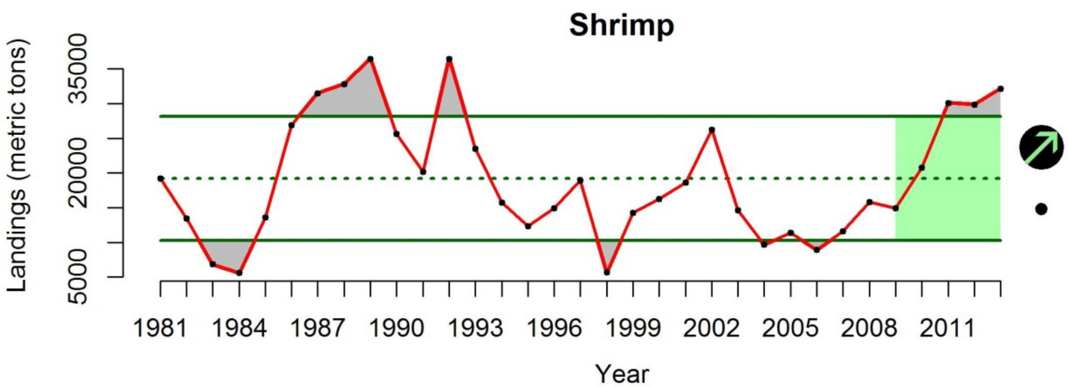


Figure AP7. Annual landings of shrimp in the CCLME from 1981 – 2013.

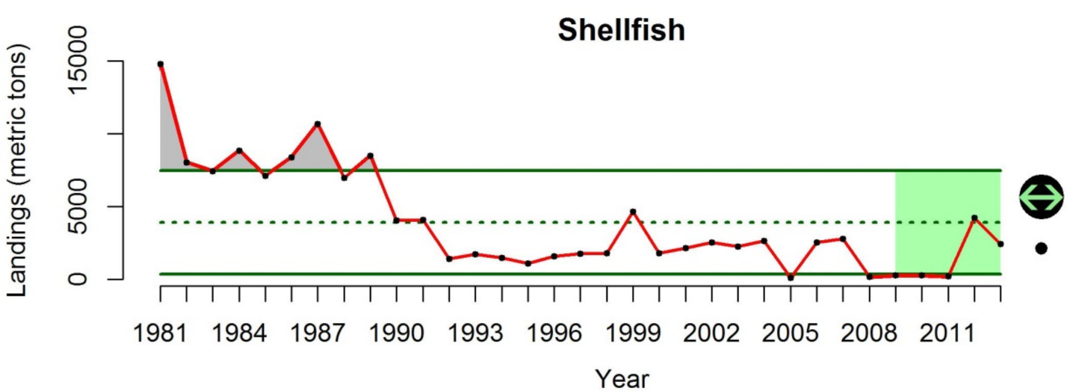


Figure AP8. Annual landings of shellfish in the CCLME from 1981 – 2013.

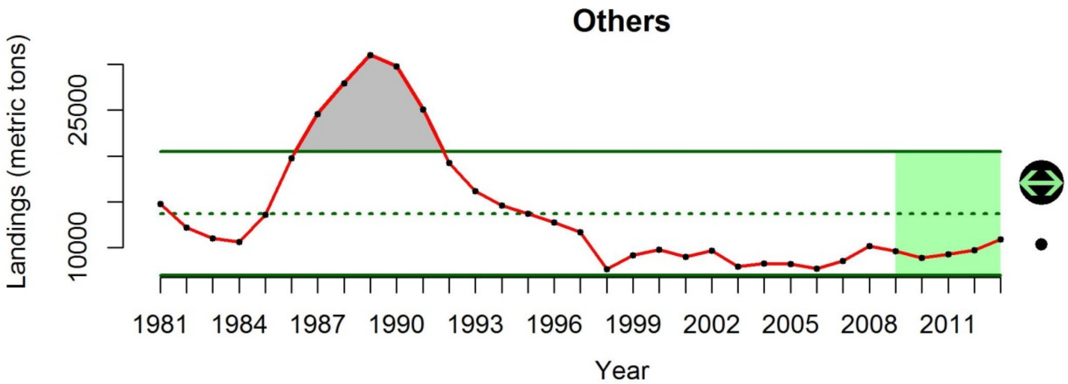


Figure AP9. Annual landings of all other species in the CCLME from 1981 – 2013.

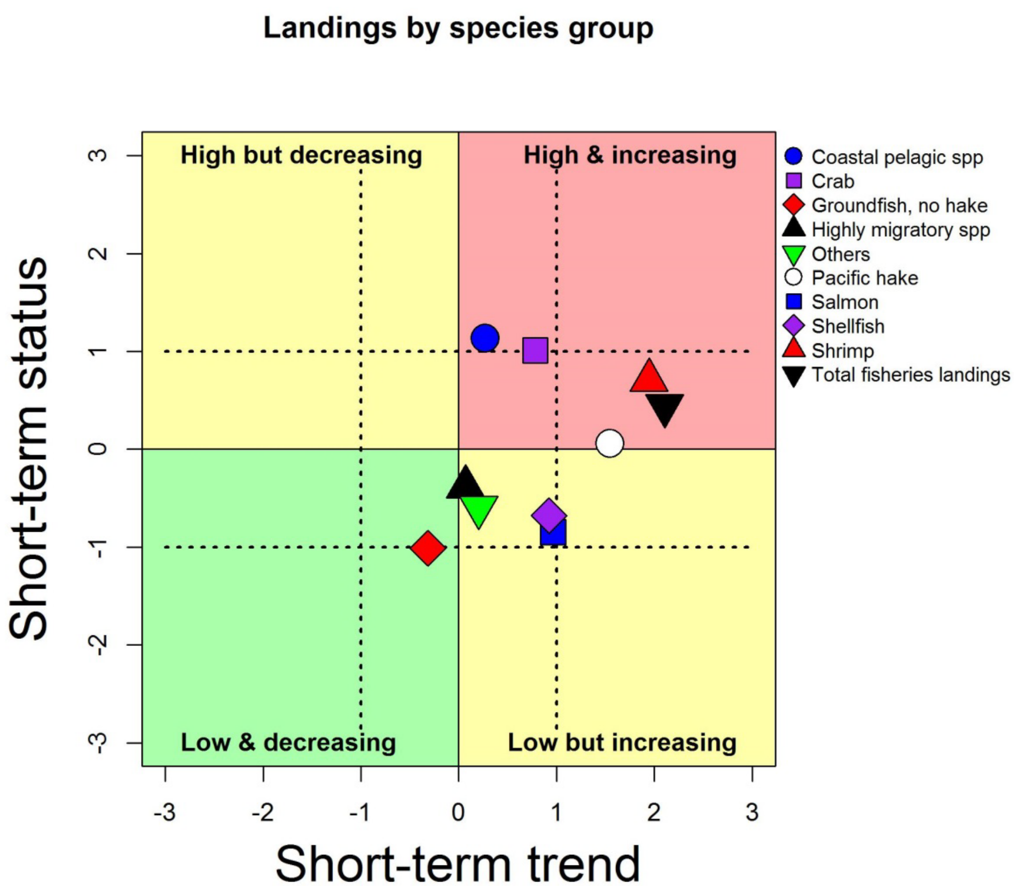


Figure AP10. Short-term status and trends of annual landings (1981 – 2013) by species groups in the CCLME. Prior to plotting, time series data for each indicator were normalized to place them on the same scale. The short-term trend indicates whether landings increased, decreased or remained the same over the last five years. The short-term status represents the difference between the mean of the last 5 years and the mean of the full time series. The dotted lines represent ± 1.0 SD; thus, data points outside the dotted lines are considered to be increasing or decreasing over the short term or the current status is lower or higher than the long-term mean of the time series.

Landings made by most gear types varied considerably over the last 40 years (Figs. AP11 – AP17), but hook-and-line landings (Fig. AP13) exhibited a decreasing trend since the late-1980's while net gear (Fig. AP14) and trolling (Fig. AP16) landings have steadily increased since the early 1990's. Over the last five years, trawl and shrimp trawl landings increased (Figs. AP11 & AP12), while landings made by other gear types did not exhibit clear trends. Hook-and-line landings were below historical landing levels (Fig. AP18) while pot and trap landings were above historical landing levels (Fig. AP15).

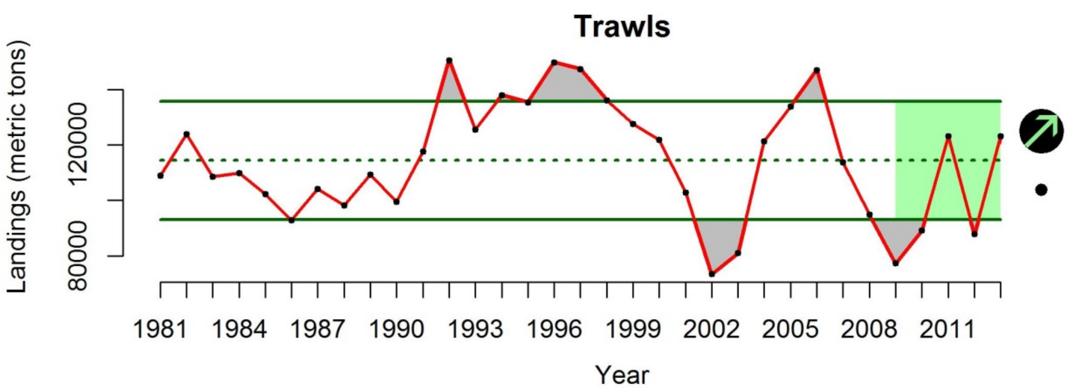


Figure AP11. Annual commercial trawl landings in the CCLME from 1981 – 2013.

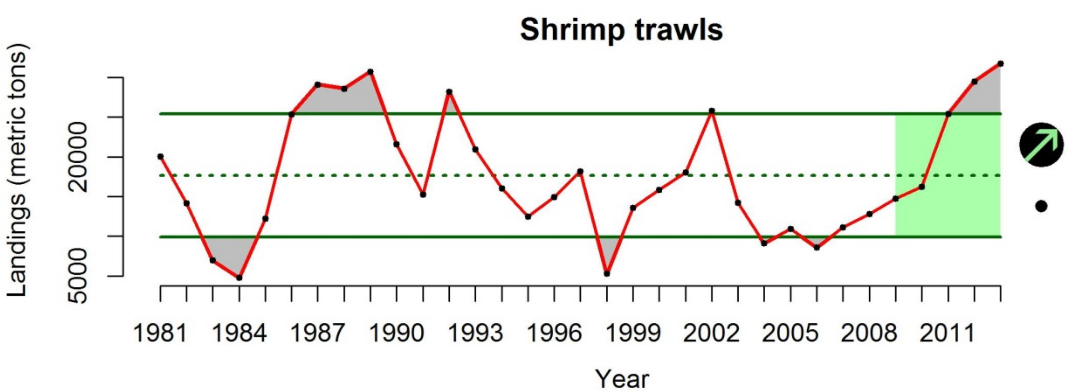


Figure AP12. Annual commercial shrimp trawl landings in the CCLME from 1981 – 2013.

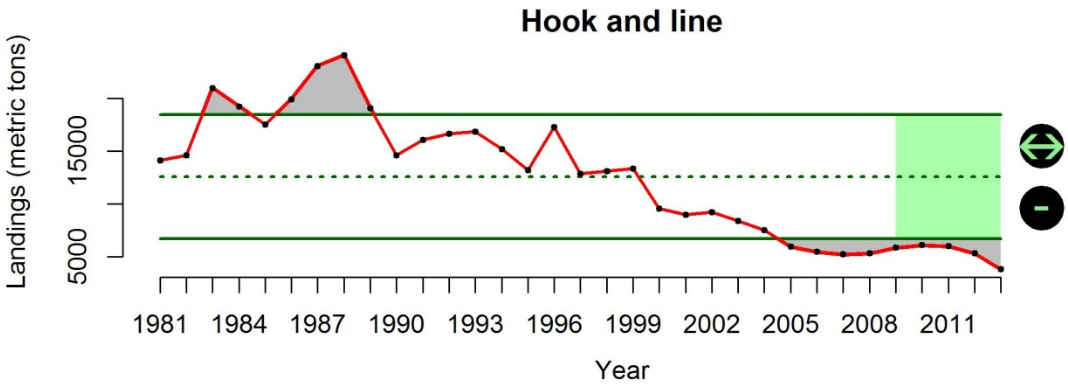


Figure AP13. Annual hook-and-line landings in the CCLME from 1981 – 2013.

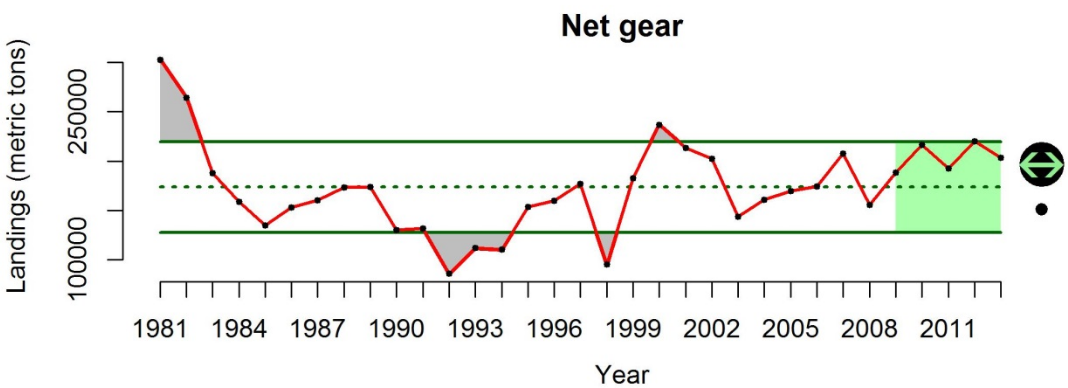


Figure AP14. Annual net-gear landings in the CCLME from 1981 – 2013.

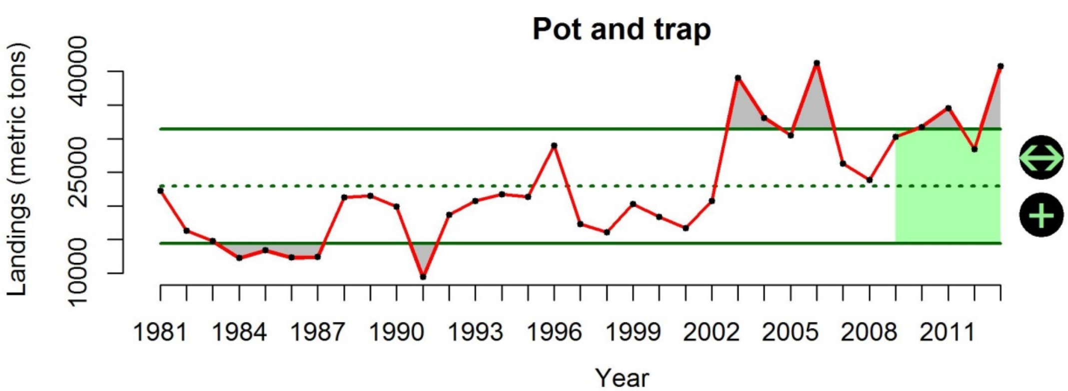


Figure AP15. Annual pot and trap landings in the CCLME from 1981 – 2013.

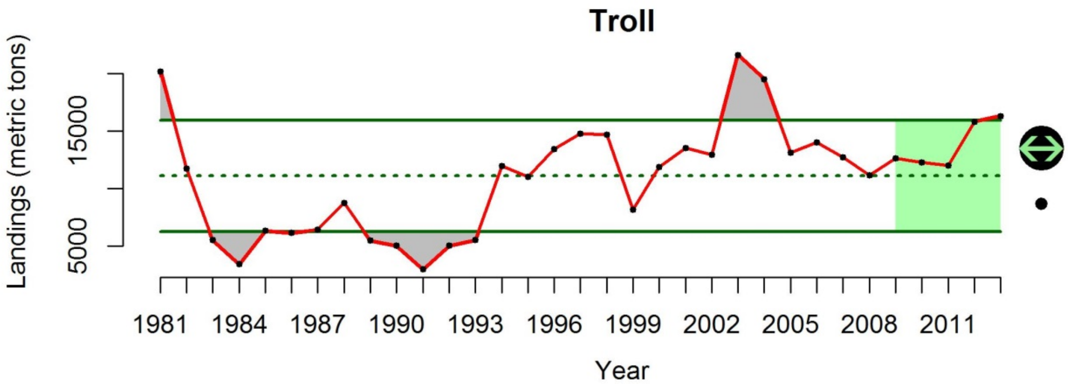


Figure AP16. Annual troll-caught landings in the CCLME from 1981 – 2013.

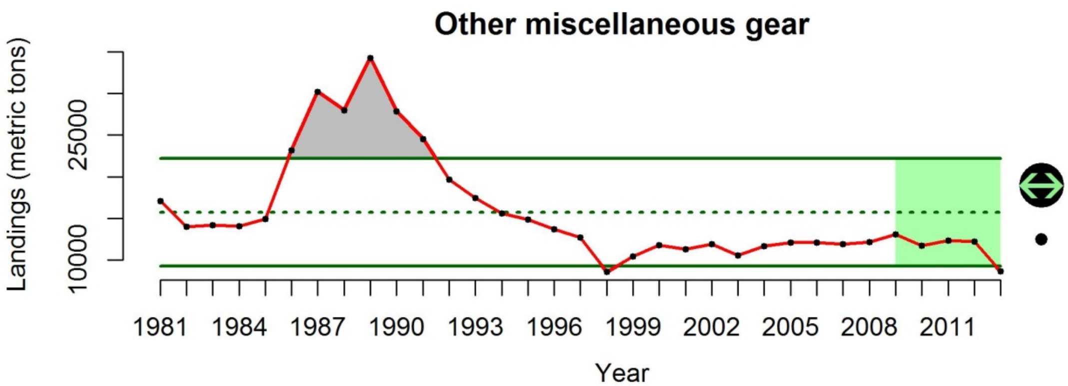
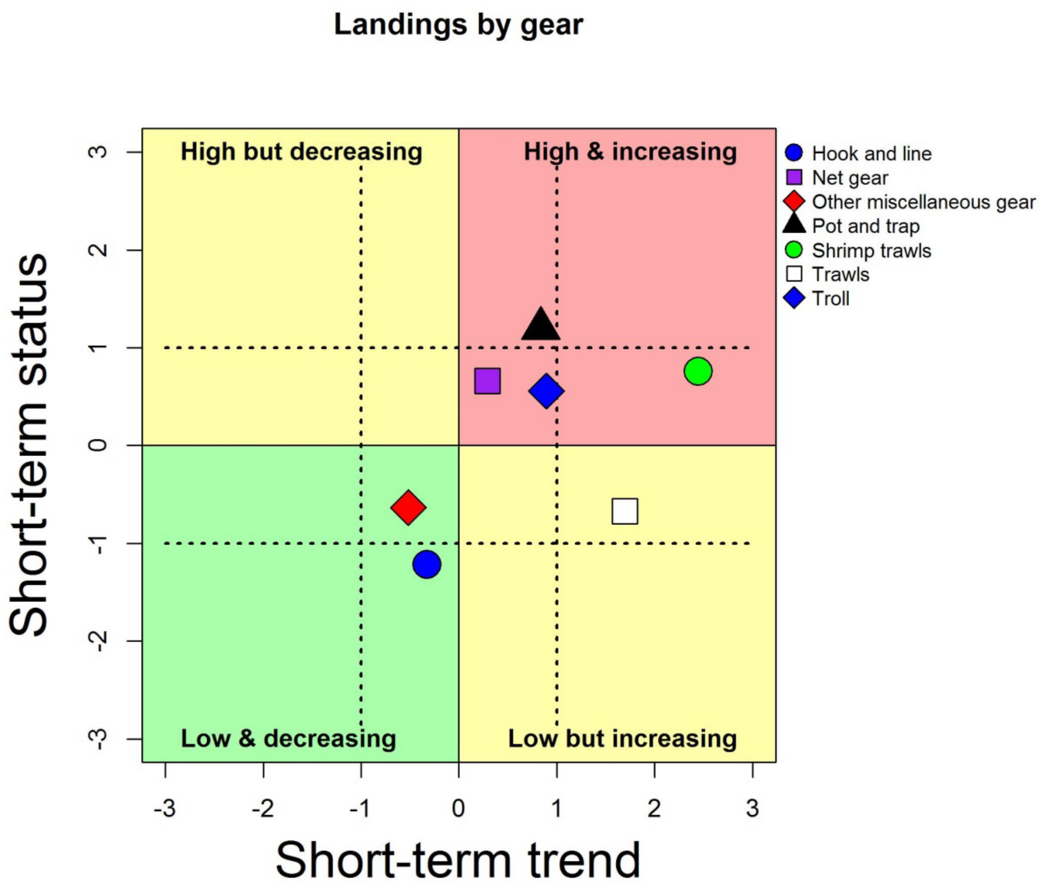


Figure AP17. Annual landings of all other miscellaneous gear in the CCLME from 1981 – 2013.



Figures AP18. Short-term status and trends of annual landings (1981 – 2013) by gear type in the CCLME. Prior to plotting, time series data for each indicator were normalized to place them on the same scale. The short-term trend indicates whether landings increased, decreased or remained the same over the last five years. The short-term status represents the difference between the mean of the last 5 years and the mean of the full time series. The dotted lines represent ± 1.0 SD; thus, data points outside the dotted lines are considered to be increasing or decreasing over the short term or the current status is lower or higher than the long-term mean of the time series.

Total fishing mortality estimates (groundfish only)– This indicator represents the total removals of groundfish species from a suite of fishery-dependent and fishery-independent sources, including shoreside commercial fisheries and at-sea hake removals, tribal and recreational catches, as well as incidental catch of groundfish in non-groundfish fisheries. It also includes removals from the research surveys conducted within the CCLME. As in the case of groundfish landings, total fishing mortality estimates of Pacific hake are reported separately. The Pacific hake fishery is the largest (in weight) on the U.S. West Coast, and, when combined with other species, total mortality of the Pacific hake overwhelms the total mortality for the entire group, and obscures changes in catch of other groundfish species. Over the last 5 years, total fishing mortality estimates for groundfish species decreased (Fig. AP19), while those of Pacific hake showed no change (Fig. AP20). The trends associated with estimates for this indicator are nearly identical to the trends found in commercial landings for these two groups across these years (see Figs. AP1 &

AP2). This is also evident in Fig. AP21, which compares short- versus long-term trends in total fishing mortality estimates for Pacific hake and other groundfish species.

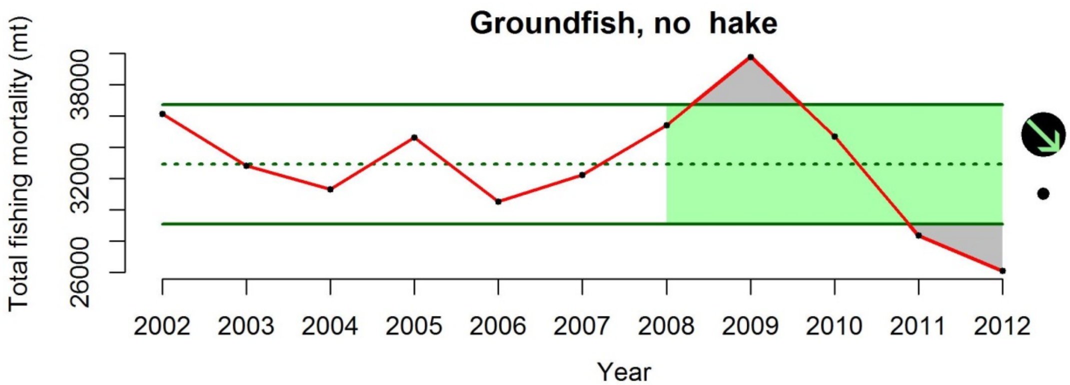


Figure AP19. Total fishing mortality estimates of groundfish (Pacific hake *Merluccius productus* excluded) in the CCLME from 2002 - 2012.

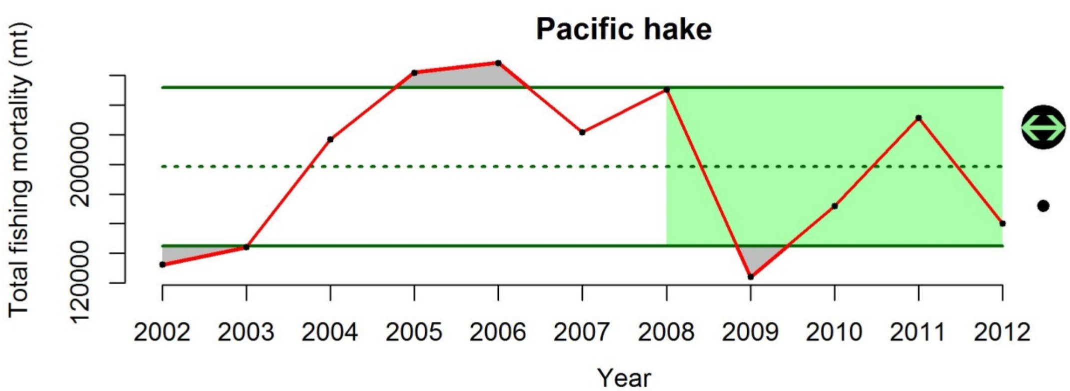


Figure AP20. Total fishing mortality estimates of Pacific hake *Merluccius productus* in the CCLME from 2002 - 2012.

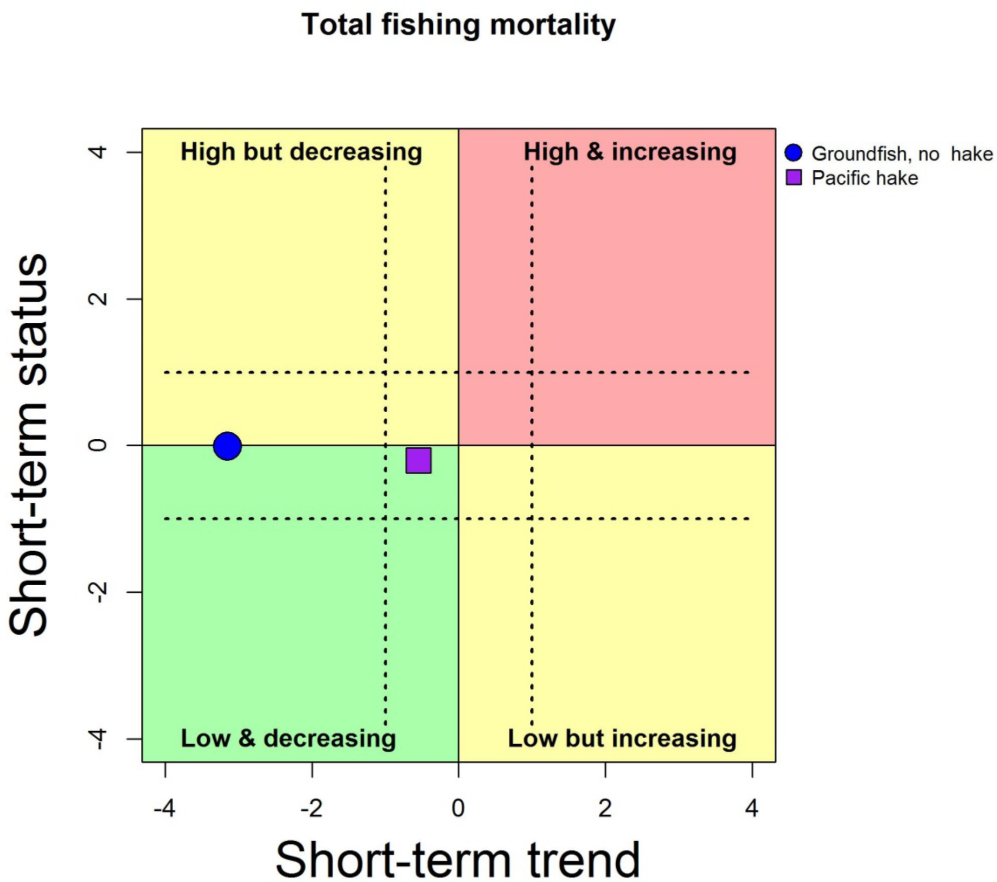


Figure AP21. Short-term status and trends of annual total fishing mortality (2002 – 2012) by species groups in the CCLME. Prior to plotting, time series data for each indicator were normalized to place them on the same scale. The short-term trend indicates whether total fishing mortality increased, decreased or remained the same over the last five years. The short-term status represents the difference between the mean of the last 5 years and the mean of the full time series. The dotted lines represent ± 1.0 SD; thus, data points outside the dotted lines are considered to be increasing or decreasing over the short term or the current status is lower or higher than the long-term mean of the time series.

HABITAT MODIFICATION

BACKGROUND

Fishing can alter benthic habitats by disturbing and destroying bottom topography and associated communities, from the intense use of trawls and other bottom gear (Kaiser and Spencer 1996, Hiddink et al. 2006). Habitat modification, in turn, can lead to extirpation of vulnerable benthic species and disruption of food web processes (Hall 1999, Hiddink et al. 2006). The effect is particularly dramatic when those gears are used in sensitive environments with sea grass, algal beds, and coral reefs, and is less evident on soft bottoms (Garcia et al. 2003). However, fisheries often tend to operate within certain areas more than others (Kaiser et al. 1998), and long-term impacts of trawling may cause negative changes in biomass and the production of benthic communities in any habitat type, to various degrees (Hiddink et al. 2006).

In the CCLME, implementation of Essential Fish Habitats (EFH), areas necessary for fish spawning, breeding, feeding, or growth to maturity, and Marine Protected Areas (MPA), in combination with gear regulation measures, have been used to reduce adverse impact of fisheries on vulnerable habitats. Also, the introduction of the Cowcod Conservation Area (CCA) and Rockfish Conservation Areas (RCAs) as management measures to prevent overfishing makes additional areas along the coast inaccessible to fishing during some or all of the year.

EVALUATION AND SELECTION OF INDICATORS

Habitat modification could be expressed using a metric such as distance trawled by certain gear types, in certain habitat types. Development of such a metric, however, is non-trivial and requires a thorough analysis, since the destructive capacity of different trawl gear varies according to habitat/bottom type in which it is used. Such an analysis would also require very detailed habitat data that are currently unavailable.

Bellman and Heppell (2007) estimated distance trawled within the limited entry groundfish trawl fishery in the U.S. West Coast by habitat type, defined based on type of bottom substrate. The habitat types considered were of four basic categories, including shelf, slope, basin and ridge, and two subcategories, rocky and sedimentary. Logbook data were used to obtain information on vessel, date, time and location of each individual tow as well as gear used (Bellman and Heppell 2007). These data were then overlaid with GIS seafloor habitat maps off Washington, Oregon and California compiled by Goldfinger et al. (2003), Romsos (2004) and Green & Bizzarro (2003). In addition, logbook data on trawling and fixed gear locations from 2002 – 2012 were entered into the same GIS framework (NMFS 2013).

We used estimates of coast-wide distances trawled from 1999 – 2004 (Bellman et al. 2007) and 2002 – 2012 (NMFS 2013) as an indicator for habitat modification (Table AP3). The estimates from 2002 – 2012 also include estimates of habitat modified by fixed fishing gear. Set and retrieval location of pot, trap and longline gear allowed for an estimate of the amount of bottom habitat disturbed (NMFS 2013). Distances for bottom trawling and fixed gear were summed to determine total amount of habitat modification from 2002 to 2012. Estimates from 1999 to 2004 did not include fixed gear distances estimates, but the overall distances of fixed gear are approximately 1% of the distances trawled; thus we simply incorporated the estimates for 1999 – 2001 from the previous data set into the more complete data from 2002 – 2012. Different habitat substrate types were used in the classification of the two data sets, so we limited habitat specific data to the longest data set

(NMFS 2013), while including data from both data sets in the total habitat disturbed estimate.

STATUS AND TRENDS

The status and trends of habitat modification were measured using distance trawled and distance disturbed by fixed gear by habitat type, made by the groundfish bottom-trawl fishery and the fixed-gear fishery, as estimated by Bellman and Heppell (2007) and NFMS (2013). Overall, distance trawled declined coast-wide over the last five years (Fig. AP22). During this period, the majority of habitat modification occurred in soft upper slope habitat (Fig. AP28), followed by the soft shelf habitat (Fig. AP25). A shift in trawling effort between habitat types was observed during the mid-2000's (Figs. AP23 to AP30), which in part corresponded to depth-related spatial closures implemented by the Pacific Fishery Management Council to reduce fisheries' impacts on depleted species (Bellman and Heppell 2007). If compared to the mean for the entire time series, the distance disturbed across all habitats has been within historic levels; however, if the magnitude of disturbance continues at similarly low levels as observed over the last two years (2011 – 2012), habitat modification may be at historically low levels in a few years (Fig. AP22 & AP31). Moreover, the implementation of a new management framework (i.e. Individual Transferable Quota system) in January 2011 has caused some of the fishing community to switch from trawling gear to fixed gears. Fixed gear has less impact on bottom habitats than trawling gear (NMFS 2013), further reducing the overall impact of fishing gear on habitats necessary for the diversity of seafloor communities. Reductions in the pressure may not coincide with recovery times of habitat depending on how fast recovery happens, which is likely to differ among habitat types (e.g., hard and mixed habitats will take longer to recover than soft habitat).

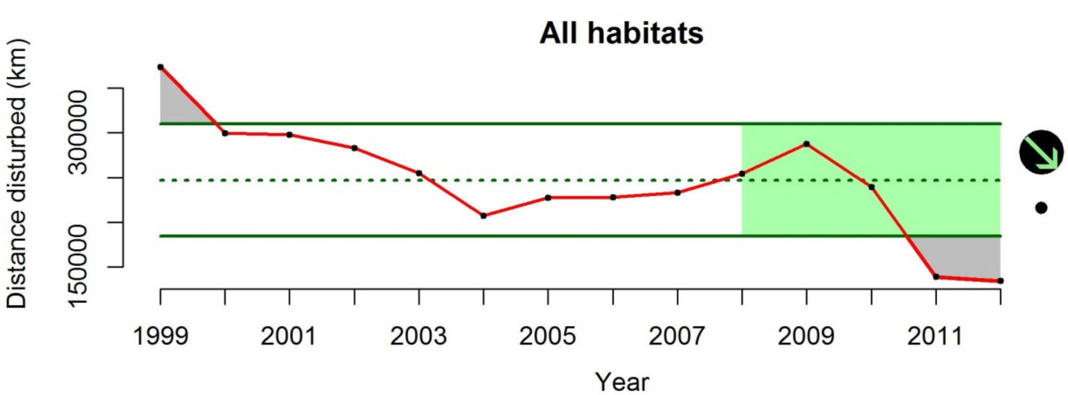


Figure AP22. Total distance disturbed (km) across all habitat types along the coast of Washington, Oregon and California by bottom-trawl and fixed-gear fisheries.

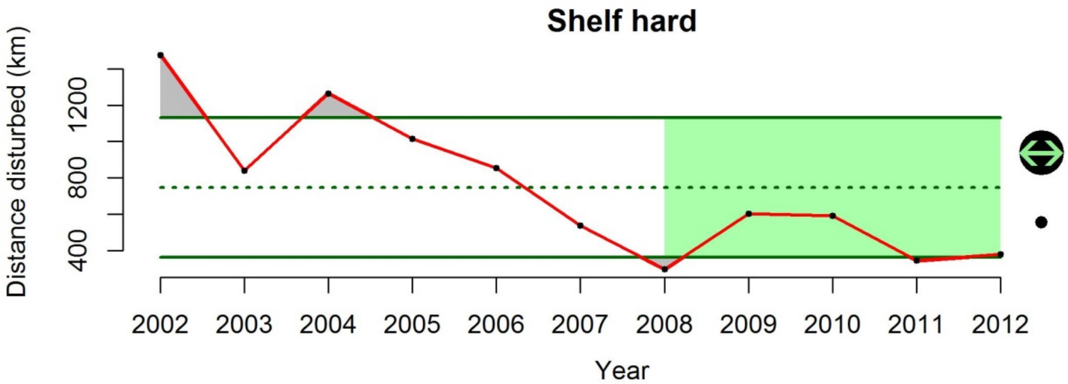


Figure AP23. Distance disturbed (km) within hard, shelf habitats along the coast of Washington, Oregon and California by bottom-trawl and fixed-gear fisheries.

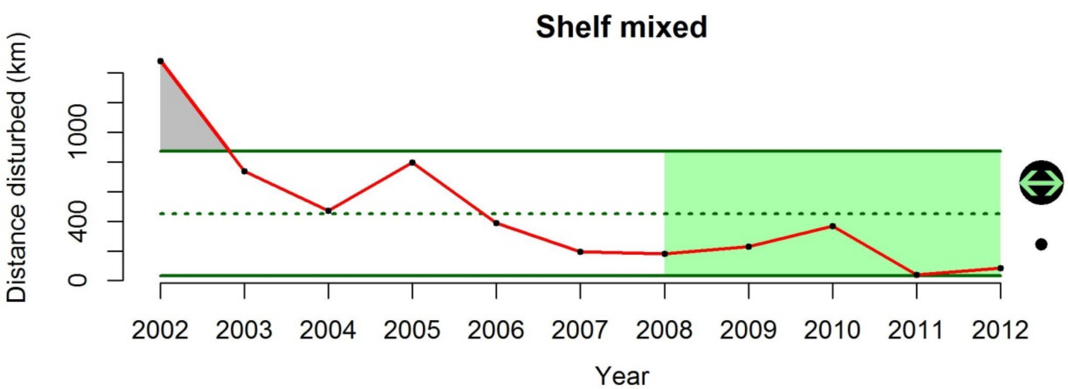


Figure AP24. Distance disturbed (km) within mixed, shelf habitats along the coast of Washington, Oregon and California by bottom-trawl and fixed-gear fisheries.

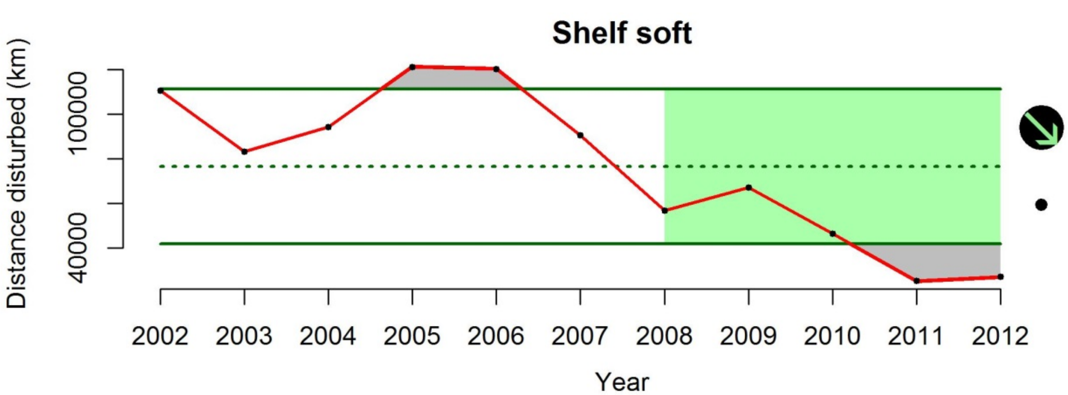


Figure AP25. Distance disturbed (km) within soft, shelf habitats along the coast of Washington, Oregon and California by bottom-trawl and fixed-gear fisheries.

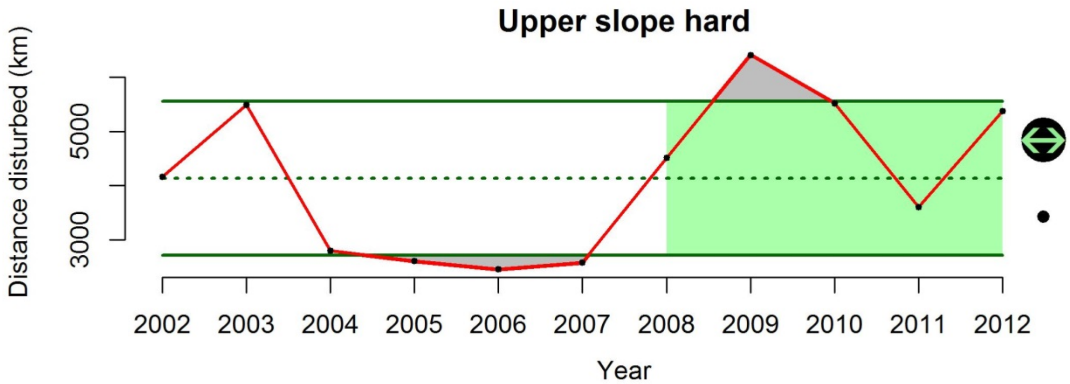


Figure AP26. Distance disturbed (km) within hard, upper slope habitats along the coast of Washington, Oregon and California by bottom-trawl and fixed-gear fisheries.

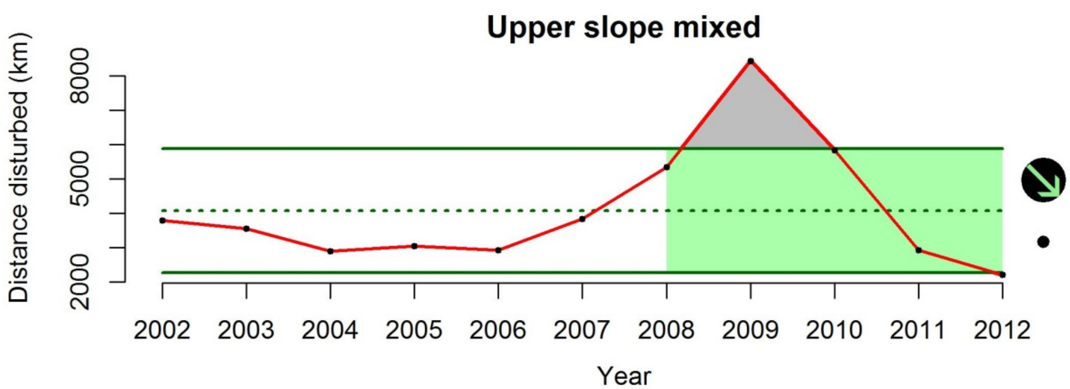


Figure AP27. Distance disturbed (km) within mixed, upper slope habitats along the coast of Washington, Oregon and California by bottom-trawl and fixed-gear fisheries.

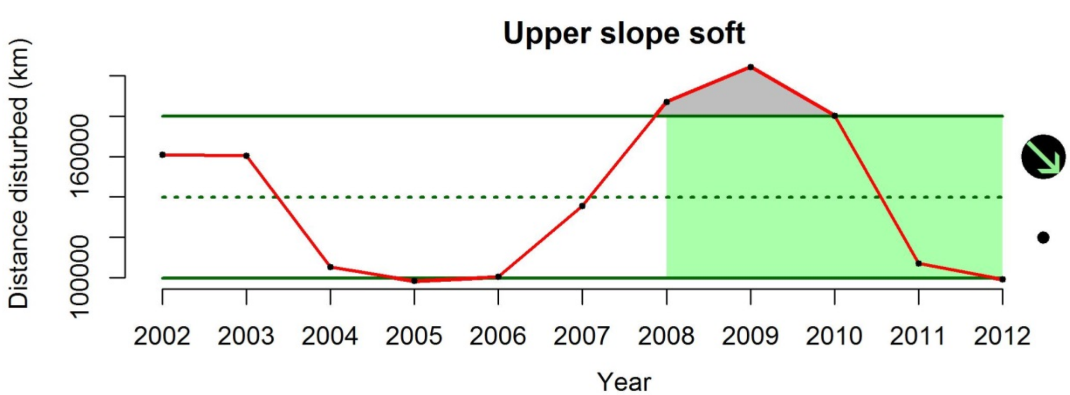


Figure AP28. Distance disturbed (km) within soft, upper slope habitats along the coast of Washington, Oregon and California by bottom-trawl and fixed-gear fisheries.

Figure AP29. Distance disturbed (km) within hard, lower slope habitats along the coast of Washington, Oregon and California by bottom-trawl and fixed-gear fisheries.

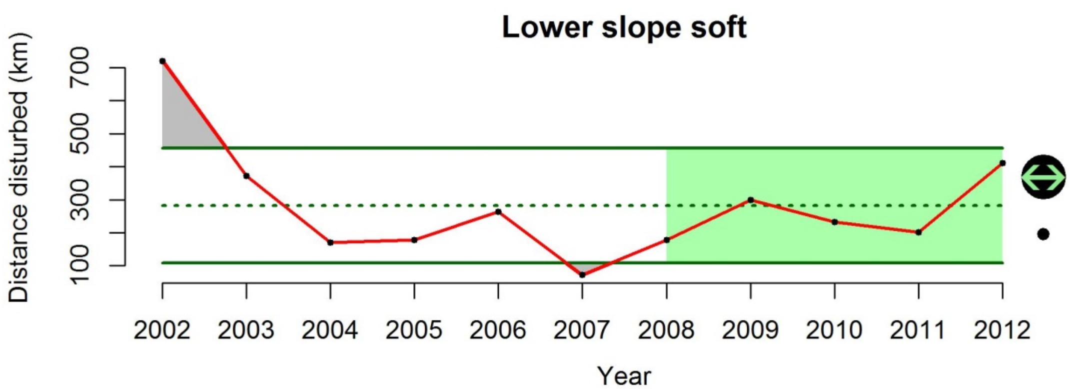


Figure AP30. Distance disturbed (km) within soft, lower slope habitats along the coast of Washington, Oregon and California by bottom-trawl and fixed-gear fisheries.

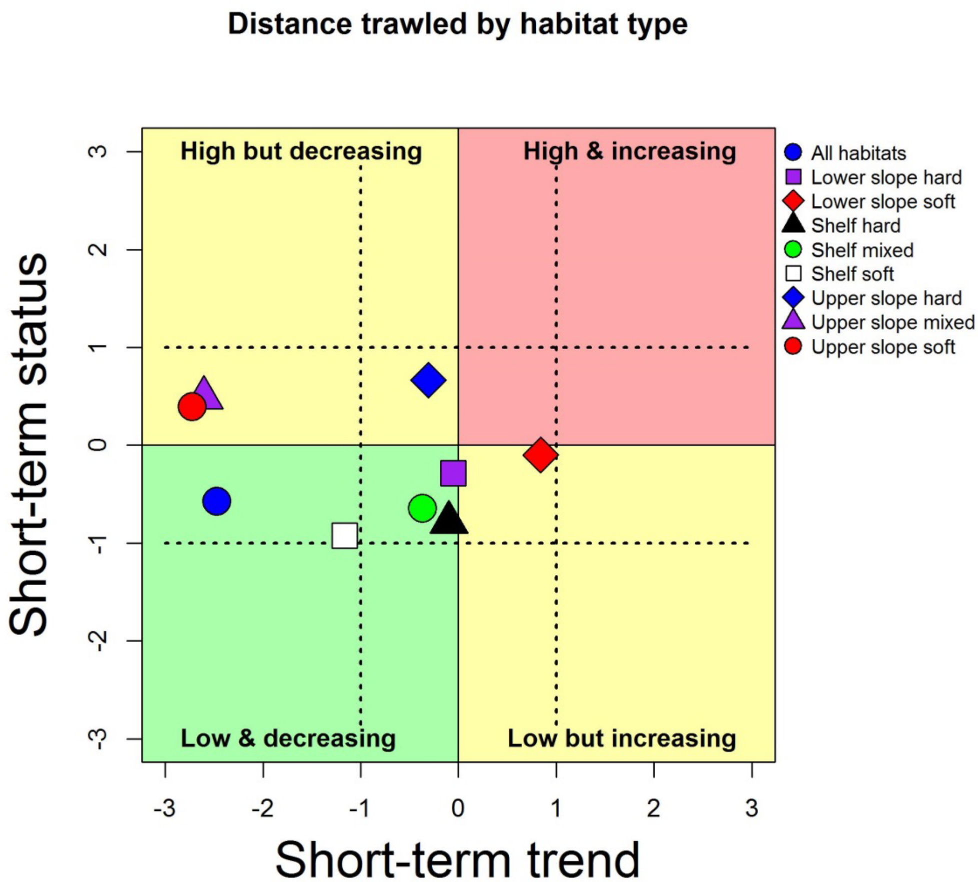


Figure AP31. Short-term status and trends of total distance disturbed across all habitats (1999 – 2012) and by habitat type (2002 – 2012) in the CCLME. Prior to plotting, time series data for each indicator were normalized to place them on the same scale. The short-term trend indicates whether distance trawled increased, decreased or remained the same over the last five years. The short-term status represents the difference between the mean of the last 5 years and the mean of the full time series. The dotted lines represent ± 1.0 SD; thus, data points outside the dotted lines are considered to be increasing or decreasing over the short term or the current status is lower or higher than the long-term mean of the time series.

Table AP2. Summary of fisheries indicator evaluations. The numerical value that appears under each of the considerations represents the number of evaluation criteria supported by peer-reviewed literature. For example, three out of five primary considerations criteria support "landings" as an indicator of fishery removals.

Pressure	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Fisheries removals	Landings	3	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.
Fisheries removals	Groundfish total fishing mortality estimates	5	4	4	Groundfish total fishing mortality estimates are generated by the West Coast Groundfish Observer Program. These estimates are for groundfish only. The data are available from 2002 forward.
Habitat modification	Distance trawled	2	2	1	Coast-wide estimates of distance trawled by habitat type were generated by Bellman and Heppell (2007) and NMFS (2013) distance disturbed by bottom-trawl and fixed-gear fisheries based on logbook data on each individual tow (or set) and GIS seafloor habitat maps. These estimates are available from 1999 to the present.

Table AP3. Top indicators for fisheries pressures.

Pressure	Indicator	Definition and source of data	Time series	Sampling frequency
Fishery removals	Landings	Metric tons and pounds of the species landed by commercial fisheries in CA, OR and WA. Data are available from the Pacific Fisheries Information Network at http://pacfin.psmfc.org.	1981 – Present	yearly
Fishery removals	Total mortality estimates	Metric tons and pounds of the groundfish species removed by commercial, recreational and research sources as well as incidental catch from non-groundfish fisheries in CA, OR and WA. Data are available from the West Coast Groundfish Observer Program in the FRAM division of NOAA's Northwest Fisheries Science Center.	2002 – Present	yearly
Habitat modification	Distance trawled	Kilometers (km) disturbed by bottom-trawl and fixed-gear fisheries in CA, OR and WA by habitat type. Data are available from Bellman and Heppell (2007) and NMFS (2013).	1999-present	yearly

NON-FISHERIES PRESSURES

For non-fisheries related anthropogenic pressures in the CCLME, we primarily focused on pressures identified by Halpern et al. (2008, 2009) and Teck et al. (2010). The range of identified pressures affects all habitats in the CCLME, from beaches to canyon outfalls and from estuarine to offshore pelagic waters. We describe below the definition, potential impacts and the selection and evaluation of indicators for each identified pressure in alphabetical order. For many non-fisheries related pressures, human population growth (particularly along the coast) is the ultimate driver and can be used as an indicator of the status and trends of numerous pressures. In most instances, however, we have found or developed more specific indicators that capture the spatiotemporal variability in the pressure more closely than human population growth and present the individual time series below.

SUMMARY OF NON-FISHERIES PRESSURES

We developed indicators for 21 non-fisheries pressures on the CCLME. These pressures ranged in scope from land-based pressures such as inorganic pollution and nutrient input to at-sea pressures such as commercial shipping and offshore oil and gas activities. Ultimately, we evaluated 41 different indicators and selected the best indicator(s) to describe the status and trends of each pressure. Indicators were evaluated (Table AP4) using the indicator selection framework developed by Levin et al. (2011) and Kershner et al. (2011) and used in the previous version of NOAA's Integrated Ecosystem Assessment for the California Current (Levin and Schwing 2011). Data for each of the chosen indicators were compiled to develop time series and determine the status and trends for each pressure (Table AP5).

Most indicators of non-fisheries related pressures showed either significant short-term trends or their current status was at historically high or low levels (Fig. AP32). Indicators of atmospheric, organic and ocean-based pollution, nutrient input, commercial shipping activity, recreational beach use and invasive species have all decreased over the short-term, while indicators of dredging, shellfish aquaculture, and marine debris (in the northern CCLME) increased. Indicators of seafood demand, finfish aquaculture, sediment and freshwater retention, power plant activity and coastal engineering remained relatively constant over the short-term, but were above historic levels, while indicators of offshore oil and gas activity and related benthic structures were constant over the short-term, but at historically low levels. Shellfish aquaculture is both at historically high levels and continues to increase, whereas nutrient input is at historically high levels but has been decreasing over the last five years of the dataset. Taken together, these results support two primary conclusions: 1) decreasing trends of several non-fisheries pressures (e.g., shipping related indicators, industrial pollution and recreational activity) potentially reflect slowing economic conditions over the last few years and 2) non-fisheries pressures at historically high levels have leveled off and are not continuing to increase, although seafood demand, shellfish aquaculture and dredging will likely be at historically high and increasing levels if current trends continue for the next couple of years.

The interpretation of the status and trends of these pressures may differ depending on the EBM component of interest. For example, a decreasing trend in fisheries removals may be "good" for rebuilding stocks of Protected Resources or it could be "bad" for the economies of Vibrant Coastal Communities. In addition, none of these pressures act upon the ecosystem individually (i.e. many pressures are acting simultaneously on populations), and we have little understanding about whether the cumulative effects of multiple pressures will be additive, synergistic or antagonistic on populations of interest. Subsequent sections of the IEA begin to integrate the cumulative effects of multiple pressures on multiple EBM components (see "risk" sections for each EBM component and the various management strategy evaluations). Moreover, these anthropogenic pressures will interact with the underlying effects of climatic and oceanographic pressures (detailed *in Oceanographic and Climatic Drivers and Pressures*). The integration of anthropogenic, oceanographic and climatic pressures on multiple EBM components can now be modeled using various "end-to-end" ecosystem models (e.g., Atlantis; Fulton et al. 2011), but marine ecologists and fisheries scientists need to develop creative methods in the field to test the validity of these models' hypotheses and increase managers' confidence in decision making.

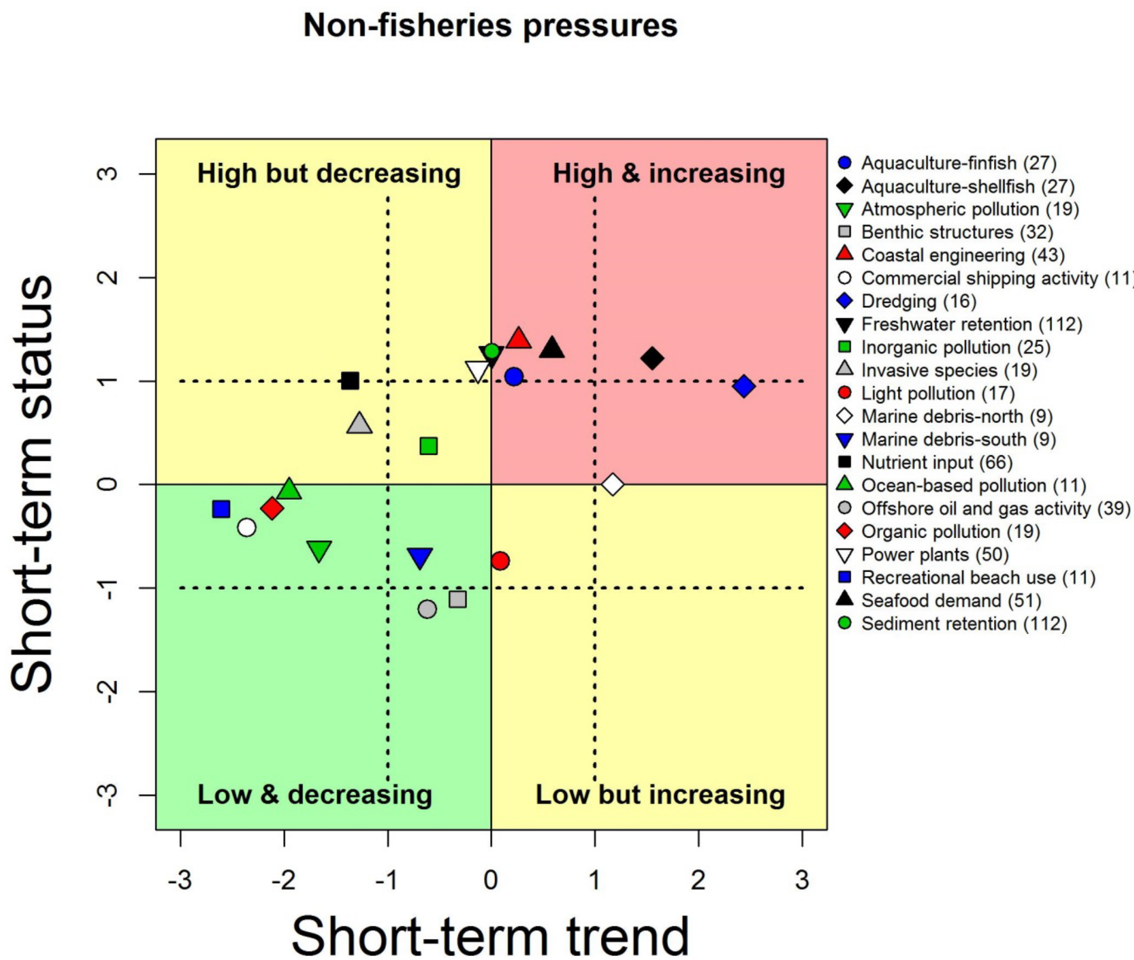


Figure AP32. Short-term status and trend of non-fisheries pressures in the CCLME. Prior to plotting, time series data for each indicator were normalized to place them on the same scale. The short-term trend indicates whether the indicator increased, decreased or remained the same over the last five years. The short-term status represents the difference between the mean of the last 5 years and the mean of the full time series. The dotted lines represent ± 1.0 SD; thus, data points outside the dotted lines are considered to be increasing or decreasing over the short term or the short-term status is lower or higher than the long-term mean of the time series. Numbers in parentheses in the legend are the number of years in the time series for each pressure. Some symbols are smaller or larger than others to help distinguish them from overlapping symbols.

Table AP4. Summary of non-fisheries indicator evaluations. The numerical value that appears under each of the considerations represents the number of evaluation criteria supported by peer-reviewed literature. For example, finfish production as an indicator of finfish aquaculture has peer-reviewed literature supporting two out of five primary considerations criteria.

Pressure	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Aquaculture (finfish)	Finfish production	2	7	4	Finfish 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 (finfish)	Acres of habitat used	1	2	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 netpen dimensions of the current year's permit, so there is little temporal data.
Aquaculture (finfish)	Wild fish used to feed aquaculture	1	0	0	Increases in feed will impact wild-caught fisheries as well as contribute to effluent and waste effects on the local environment. Fishmeal increases with increased production of carnivorous species, but that may change with new sources of protein. Data are not available due to proprietary information.
Aquaculture (shellfish)	U.S. Shellfish production	2	7	4	Shellfish production has positive (e.g., filtering, removal of nutrients) and negative effects (e.g. habitat modification, invasive species) but the cumulative effects are unknown and these effects may change over time with advances in technology or growing capabilities. Washington state produces the greatest quantity of shellfish in the U.S., so total U.S. shellfish production should reflect the current status and trends of shellfish production on the West Coast
Aquaculture (shellfish)	CCLME Shellfish production	2	5	4	Shellfish production has positive (e.g., filtering, removal of nutrients) and negative effects (e.g. habitat modification, invasive species) but the cumulative effects are unknown and these effects may change over time with advances in technology or growing capabilities. Estimates of production are available for CA and OR, but WA (which produces the most) does not have reliable estimates.
Aquaculture (shellfish)	Acres of habitat used	1	5	3	The amount of habitat used for aquaculture is relevant to determining the effects of aquaculture activities on various elements of the ecosystem. However, this metric may not account for advances in technology that allow more production per acre. Data are available from 1971 for CA, 1996 for OR and 2005 for WA.

Pressure	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Atmospheric pollution	Concentration of deposited sulfate	5	7	4	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.
Benthic structures	# oil & gas wells	1	7	3	Potential negative impacts of offshore oil and gas wells may be balanced out by the possible enhanced productivity brought about by colonization of novel habitats by associated fishes and invertebrates. Annual reports of the California State Department of Conservation's Division of oil, gas, and geothermal resources contain information on the total number of offshore oil and gas wells in production an annual basis from 1970 to the present.
Coastal engineering	% modified shoreline	2	2	1	Detailed inventories of coastal engineering have been carried out throughout the Pacific Coast of North America by a variety of federal, state, and local agencies under a number of programs. Most, however, provide a baseline indication of current or recent conditions and are generally unavailable coastwide or over time.
Coastal engineering	Coastal population	2	6	2	The rate of shoreline armoring has been shown to correspond with the rate of population growth in coastal areas, and in the absence of good time series of geospatial data for hardened shorelines, coastal population data (U.S. Census) for the west coast of the United States provide a good proxy for this stressor.
Commercial shipping activity	Tons of cargo moved	0	7	5	The size of vessels plays an important role in determining how well "activity" compares to cargo moved. As this pressure is used to describe the probability of striking marine organisms, ground strikes, etc., this metric is not as good as an indicator including "number of trips" or "volume of water disturbed during transit".
Commercial shipping activity	# of trips	3	6	5	Correlated with shipping activity; perhaps this indicator could be improved if size of vessel and transit mileage was added to quantify the vessel's footprint and pathway. Otherwise, the number of trips doesn't tell us anything about the extent of the CCLME affected by these trips.
Commercial shipping activity	Volume of water disturbed	4	7	4	This indicator has not been used before, but it is 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.

Pressure	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Direct human impact	Beach attendance	4	6	4	Beach attendance has been used as a proxy for direct human impacts to the intertidal and nearshore ecosystems.
Disease/ pathogens	% of scientific articles	0	5	2	The percentage of scientific articles reporting disease in marine taxa is a worldwide measure, so there may be significant differences in this trend and what is occurring in the CCLME. This indicator also does not account for the severity of the disease outbreak, a very large outbreak counts the same as a relatively small outbreak.
Dredging	Dredge volumes	3	7	5	The amount of material (in cubic yards - CY) dredged from all U.S. waterways off the U.S. West Coast is a concrete, spatially explicit indicator that concisely tracks the magnitude of this human activity throughout the California Current region.
Dredging	Dredge dump volumes	2	5	3	Annual offshore dump volumes are not summarized and reported separately, but can be determined with some data manipulation. Most dredging-associated material disposal on the U.S. West Coast occurs in open water or is integrated into beach nourishment programs.
Freshwater retention	Runoff magnitude	3	4	4	Discharge trends for many rivers mostly reflect changes in precipitation, primarily in response to short- and longer-term atmospheric-oceanic signals, and it is difficult to distinguish signal from noise in rivers with widely variable interannual discharge. Stream discharge data are accessible from a variety of gauged streams; incomplete gauging records or unmonitored streamflow can be simulated by a comprehensive land surface model.
Freshwater retention	Impoundment volume	2	6	2	Data series associated with parameters of consumption and storage likely provide some of the best indicators of human impacts to freshwater input. For most normal rivers, reservoirs can affect the timing of discharge, but appear to have little effect on annual discharge. Freshwater storage data are available from state agency databases, which include information on construction date and impoundment area/volume for all dams.
Inorganic pollution	Total inorganic pollutants	3	7	4	Measures of total inorganic pollutants disposed or released on site or in water will provide a relative measure over time of what gets into the CCLME. However, variation in other variables (e.g., precipitation and specific pollutants released) will de-couple these measurements from observations in the CCLME as well as the impact on organisms.

Pressure	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Inorganic pollution	Total inorganic pollutants * toxicity	3	7	4	Adding a measure of toxicity to the amount of pollutants released will provide better context to 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.
Inorganic pollution	Total inorganic pollutants * toxicity* impervious surface areas	5	1	1	Including ISA helps to account for other variables and more closely links how much land-based pollutants reach the CCLME; however, the data are only available for 2000-2001 and 2010 at the time of this evaluation. We assumed a linear relationship between years to provide weightings for each year. New analyses of archived data could produce yearly measures of ISA with appropriate levels of funding.
Invasive species	# of invasive species	5	2	4	A quantitative global assessment scored and ranked invasive species impacts based on the severity of the impact on the viability and integrity of native species and natural biodiversity (http://conserveonline.org/workspaces/global.invasive.assessment/). This database is pooled by go-region, serves as a baseline for invasion, and has not been updated since its creation.
Invasive species	# of shipping ports	2	5	4	Shipping is considered the key invasion pathway for habitats in northern California and the southern California Bight; 'number of shipping ports' was significantly correlated with harmful species introductions in most regions globally. Simple indicator, but perhaps less informative due to lack of time series data.
Invasive species	Shipping cargo volume	2	4	4	Shipping is considered the key invasion pathway for habitats in northern California and the southern California Bight; 'shipping cargo volume' was significantly correlated with harmful species introductions in most regions globally. Port volume data (in metric tons) were available from the U.S. Army Corps of Engineers Navigation Data Center (http://www.ndc.iwr.usace.army.mil/data/datawcus.htm) during 1993-present.
Light pollution	Nighttime stable lights	4	7	5	Light pollution has considerable effects on some organisms' nocturnal behaviors, predator/prey relationships, bioenergetics, nesting and migratory patterns. Data using average nighttime lights from the National Geophysical Data Center from 1994-present were used (http://www.ngdc.noaa.gov/dmsp/downloadV4composites.html#AXP)
Marine debris	National Marine Debris Program coastal trash	2	4	4	Standardized sampling programs of measuring marine debris will be better than community groups, but it is unknown whether coastal measurements correlate with ocean measurements.

Pressure	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Marine debris	Coastal trash cleanup programs	2	1	5	Community group clean-ups are great, but they are not standardized and data will vary with sampling effort, not necessarily with abundance of marine debris. Coastal measurements may not correlate with ocean measurements. Beach trash is cleaned up by volunteers during the annual California Coastal Cleanup Day along California beaches, bays, rivers, and streams. Data are recorded by volunteers and summarized by the California Coastal Commission's Public Education Program: www.coastal.ca.gov/publiced/ccd/data.xls. 1989 to present.
Marine debris	Ocean-based measurement	2	1	2	Ocean-based surveys have not used consistent methods and have been performed sporadically at small spatial scales. Estimates are likely lagging indicators of debris currently going into the ecosystem.
Nutrient input	Nutrient loading	3	5	4	Nutrient loading from surface waters can be estimated using publicly available data on nutrient concentrations and flow rates from various U.S. watersheds sampled by the USGS and various state and local agencies. Flow adjusted trends in concentration can be complex, as there often are multiple and possibly counteracting anthropogenic factors influencing nutrient source and transport in a watershed.
Nutrient input	Fertilizer loading	3	5	5	Models can predict the probability of nitrate contamination in ground waters of the United States based on fertilizer loading and other factors; it is unclear how this relates to coastal systems, however. County-level estimates are available of nutrient inputs (kg/km^2) to the land surface of the U.S. from 1982-2001 (data to 2010 are preliminary) based on fertilizer use, livestock manure, and atmospheric deposition. Nationwide fertilizer application data are available from 1945-1986.
Ocean-based pollution	Shipping activity and port volume	4	7	4	Ocean-based pollution was assumed to be primarily driven by vessel activities and port volume. This indicator evaluated well in most criteria and is a combination of the indicators for commercial shipping activity and invasive species. See these indicators for location of data.
Ocean mining	Unknown	.	.	.	This pressure has not been evaluated to date.
Offshore oil & gas activities	Annual production	4	7	3	The environmental risks posed by offshore oil and gas exploration and production are well known. Annual reports of the California State Department of Conservation's Division of oil, gas, and geothermal resources contain information on the number of barrels of oil/ cubic feet of gas produced on an annual basis from 1970 to the present.

Pressure	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Offshore oil & gas activities	# oil & gas wells	1	7	3	The environmental risks posed by offshore oil and gas exploration and production are well known. Annual reports of the California State Department of Conservation's Division of oil, gas, and geothermal resources contain information on the total number of offshore oil and gas wells in production an annual basis from 1970 to the present.
Organic pollution	Toxicity-weighted pesticide concentration	5	6	4	This indicator is well supported for use as a measure of organic pollution. Data are collected as part of the U.S. Geological Survey's National Water-Quality Assessment Program, so data will continue to be collected using standardized methods that will be useful for temporal and spatial analyses in the future.
Power, desalination plants	Water withdrawal volumes	2	5	2	Coastal power plants draw in huge amounts of marine water for cooling purposes, creating an area around the intake pipes where larvae and small plants are entrained. The USGS has conducted water-use compilations in the U.S. by state every 5 years since 1950, and thermoelectric power has represented the largest total category of water withdrawals in every compilation since 1960.
Power, desalination plants	Entrainment mortality	3	3	3	Models for estimating organism entrainment mortality relies on estimates of power plant entrainment and source water larval populations; however, a variety of other considerations may play a more important role in determining entrainment impacts. In California, calculation of daily entrainment mortality has been limited to a few power plants; historical data are limited and time series information is generally lacking.
Seafood demand	Total consumption	5	7	5	Total consumption of edible and non-edible fisheries products is well supported as an indicator of seafood demand. Data are available at national levels, which is likely the right scale as products are used all over the nation as well as internationally, and over long temporal scales.
Seafood demand	Per capita consumption	3	7	5	Per capita consumption of edible and non-edible fisheries products may not be the best indicator if thinking about total impact to the CCLME, but it is important because if this indicator rises, as recommended by U.S. Dept. of Agriculture (DGAC 2010), then increases in total consumption may increase dramatically.
Sediment input	Impoundment volume	4	6	3	Decreases in sediment input are largely the result of river damming or diversions, which directly influence the rate of coastal retreat. Dam impoundment area volume data are available from state agency databases, which include information on construction date and impoundment area/volume for all dams.

Pressure	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (6)	Summary comments
Sediment input	Suspended sediment loading	4	2	3	Sediment loading from surface waters can be estimated using publicly available data on suspended sediment concentrations and flow rates from various U.S. watersheds sampled by the USGS and various state and local agencies. Flow adjusted trends in concentration can be complex, as there often are multiple and possibly counteracting anthropogenic factors influencing sediment source and transport in a particular watershed.
Tourism	Unknown	.	.	.	This pressure has not been evaluated to date.

Table AP5. Top indicators for non-fisheries related anthropogenic pressures.

Pressure	Indicator	Definition and source of data	Time series	Sampling frequency
Aquaculture: finfish	Finfish production	Washington state estimates (from WDFW) of Atlantic salmon aquaculture production (kg).	1986 – 2012	yearly
Aquaculture: shellfish	U.S. Shellfish production	Total U.S. shellfish production: Fisheries of the United States 2010: http://www.st.nmfs.noaa.gov/st1/publications.html. Using only "clams", "mussels" & "oysters" estimates.	1985 – 2011	yearly
Atmospheric pollution	Atmospheric deposition of sulfate	Annual precipitation-weighted mean concentrations of sulfate measured at sites in CA, OR, and WA from the National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu/data/ntndata.aspx)	1994 – 2012	yearly
Benthic structures	# offshore oil & gas wells	Total number of offshore oil and gas wells in production: Annual reports of the California State Department of Conservation's Division of oil, gas, and geothermal resources (ftp://ftp.consrv.ca.gov/../pub/oil/annual_reports/).	1981 - 2012	yearly
Coastal engineering	Human coastal population	Population size of coastline counties in CA, OR, WA; U.S. Census Bureau (http://www.census.gov/prod/2010pubs/p25-1139/p25-1139st1.csv)	1970 – 2012	yearly
Commercial shipping activity	Volume of water disturbed	Calculated using draft, breadth and distance traveled within CCLME while in transit between shipping and receiving ports for domestic (data from USACE Navigation Data Center, New Orleans, LA) and foreign (http://www.ndc.iwr.usace.army.mil/data/dataclen.htm) vessels.	2001 – 2011	yearly
Disease/ pathogens	No appropriate indicator data available.			
Dredging	Dredge volumes	U.S. Army Corps of Engineers navigation data center dredging information system: http://www.ndc.iwr.usace.army.mil/data/datadrgsel.htm; data includes dredge volumes for individual private contracts and Corps operated dredge projects from 1997 through 2011 in WA, CA, and OR.	1997 – 2012	yearly
Freshwater retention	Impoundment volume	Total reservoir storage area in CA and Pacific Northwest water resource regions; data from state agency databases, which include information on construction date and impoundment area/volume for all dams (California: http://cdec.water.ca.gov/misc/resinfo.html, Idaho: http://www.usbr.gov/projects/FacilitiesByState.jsp?StateID=ID, Oregon: http://www.usbr.gov/projects/FacilitiesByState.jsp?StateID=OR, Washington: https://fortress.wa.gov/ecy/publications/summarypages/94016.html).	1900 – 2011	yearly

Pressure	Indicator	Definition and source of data	Time series	Sampling frequency
Inorganic pollution	ISA-toxicity-weighted chemical releases	Total pounds of inorganic pollutants disposed of or otherwise released on site to the ground or water for '1988 core chemicals'; Environmental Protection Agency, Toxics Release Inventory (http://www.epa.gov/tri/). These release values were weighted by toxicity scores (Indiana Relative Chemical Hazard Score) and impervious surface area in the drainage watersheds of the CCLME (http://www.ngdc.noaa.gov/dmsp/download_global_isa.html).	1988 – 2012	yearly
Invasive species	Tons of cargo	Total tons of cargo moved through ports in CA, OR and WA; Data from U.S. Army Corps of Engineers Navigation Data Center (http://www.ndc.iwr.usace.army.mil/data/datawcus.htm)	1993 – 2011	yearly
Light pollution	Average nighttime visible light	Data are cloud-free composites of average visible nighttime lights made using all the available archived DMSP-OLS smooth resolution data for each calendar year. Data grid cell size is 1 km^2 at the equator ; NOAA's National Geophysical Data Center's Version 4 DMSP-OLS Nighttime Lights Time Series Average Lights X Pct (http://www.ngdc.noaa.gov/dmsp/downloadV4composites.html)	1994 – 2010	yearly
Marine debris	Predicted counts of debris	The National Marine Debris Monitoring Program established standardized sampling of coastal trash along the Pacific coast. Ribic et al. (2012) modeled the predicted counts of debris in the northern and southern CCLME. This provides a standardized method that is not biased by number of volunteers or by type of debris collected.	1999 – 2007	yearly
Nutrient input	Nitrogen and phosphorus input from fertilizers	Total nitrogen and phosphorus input from fertilizer use by county has been summarized from 1987 – 2006 by the USGS (Ruddy et al. 2006, Gronberg and Spahr 2012). We use these data along with nationwide data (1945 – 2001) to develop an index for the CCLME across the longer time series. County-level data are available at: http://water.usgs.gov/lookup/getspatial?sir2012-5207_county_fertilizer. Nationwide data are from Ruddy et al. (2006)	1945 – 2010	yearly
Ocean-based pollution	Commercial shipping activity combined with tons of cargo	This indicator combines two previously used indicators. See "Commercial shipping activity" and "Invasive species" for details of data.	2001 – 2011	yearly
Offshore oil activities	Offshore oil & gas production	Number of barrels of oil/ft^3 of gas produced: Annual reports of the California State Department of Conservation's Division of oil, gas, and geothermal resources (ftp://ftp.consrv.ca.gov/../pub/oil/annual_reports/); verified by National Ocean Economics Program at the Monterey Institute of International Studies (http://www.oceaneconomics.org/Minerals/oil_gas.asp).	1974 – 2012	yearly

Pressure	Indicator	Definition and source of data	Time series	Sampling frequency
Organic pollution	Toxicity-weighted concentrations	Data are toxicity-weighted concentrations of 16 pesticides measured in water samples from stream-water sites in WA, OR and CA; U.S. Geological Survey Scientific Investigations Report 2010-5139 (http://pubs.usgs.gov/sir/2010/5139/).	1992 – 2010	yearly
Power plants	Saline water withdrawal volumes	Average daily withdrawal volumes (millions of metric tons per day) of saline water from all thermoelectric power plants on the west coast of North America (Pacific Northwest and California regions, from Kenny et al. (2009) and other previous USGS water use reports (http://water.usgs.gov/watuse/50years.html).	1955 – 2005	Every 5 years
Recreational beach use	Beach attendance	Summed beach attendance from CA, OR, and WA based on data from California State Park System Annual Statistical Reports, Oregon Parks and Recreation Dept., and Annual Attendance Reports from the Washington State Parks and Recreation Commission.	2002 – 2012	yearly
Seafood demand	Total consumption	Total consumption or utilization of edible and non-edible fisheries products as reported by annual NOAA Fisheries of the United States reports: (http://www.st.nmfs.noaa.gov/st1/publications.html)	1962 – 2012	yearly
Sediment input	Impoundment area	Same as “Freshwater input”	1900 – 2011	yearly

AQUACULTURE

BACKGROUND

The increased demand for seafood products in conjunction with declines in capture fisheries has led to worldwide increases in commercial aquaculture (Naylor et al. 2000, Sequeira et al. 2008). Aquaculture provides several socio-economic benefits including improved nutrition and health and the generation of income and employment (Barg 1992). Environmental benefits of aquaculture include the prevention and control of aquatic pollution because of the inherent need for good water quality, the removal of excess nutrients and organic matter in eutrophic waters from the filtering action of molluscs and seaweeds, and the removal of incorporated nitrogen by shellfish when individuals are harvested (Barg 1992, Shumway et al. 2003). However, environmental impacts resulting from aquaculture production include: (1) impacts to the water quality from the discharge of organic wastes and contaminants; (2) seafloor impacts; (3) introductions of exotic invasive species; (4) food web impacts; (5) gene pool alterations; (6) changes in species diversity; (7) sediment deposition; (8) introduction of diseases; (9) habitat replacement or exclusion; and (10) habitat conversion (Johnson et al. 2008).

The impacts of aquaculture operations on various components of the CCLME vary according to the species cultured (finfish or shellfish), the type and size of the operation, and the environmental characteristics of the site (Johnson et al. 2008). Finfish aquaculture generally occurs in large cage and floating net-pen systems that release excess food and waste directly into the environment, whereas shellfish aquaculture is generally associated with benefits to water quality aspects (Shumway et al. 2003). The relative impact of finfish and shellfish aquaculture also differs depending on the foraging behavior of the cultured species. Finfish require the addition of a large amount of feed into the ecosystem, which can result in environmental impacts from the introduction of the feed, but also from the depletion of species harvested to provide the feed. Bivalves are filter feeders and typically do not require food additives; however, fecal deposition can result in benthic and pelagic habitat impacts, changes in trophic structure and nutrient and phytoplankton depletion (Dumbauld et al. 2009). Aquaculture activities can affect fisheries at both a habitat and species-level. Planting of culture species, harvesting practices and structure placement can alter the habitat as well as the community composition of the seafloor (Goldburg and Triplett 1997, Ruesink et al. 2005, Bendell-Young 2006, Dumbauld et al. 2009)

Growing U.S. and worldwide demand for seafood is likely to continue as a result of increases in population and consumer awareness of seafood's health benefits. The most recent federal *Dietary Guidelines for Americans (DGAC 2010)* recommend Americans more than double their current seafood consumption. Because wild stocks are not projected to meet increased demand even with rebuilding efforts, future increases in supply are likely to come either from foreign aquaculture or increased domestic aquaculture production, or some combination of both (NOAA Aquaculture Draft Policy).

EVALUATION AND SELECTION OF INDICATORS

Based on differences in the suite of impacts caused by different types of aquaculture, we have separated finfish and shellfish aquaculture and selected indicators for each. For finfish aquaculture, we evaluated 3 indicators (Table AP4): finfish production, acres of area used, and the amount of wild fish needed to feed aquaculture fish. For shellfish aquaculture, we evaluated 3 indicators (Table AP4): Total U.S. shellfish production, CCLME shellfish production and acres of land leased by shellfish growers.

For both types of aquaculture, production estimates were rated the best indicator for measuring the status and trends of aquaculture activities in the CCLME primarily because production values are a direct measure of the intensity of aquaculture operations, whereas indicators such as acres of land will not reflect advances in technology and growing capabilities over time. For finfish, the only marine netpen operations in the CCLME occur in Washington State. Data are available from the Washington Department of Fish & Wildlife (WDFW) for the years 1986-present. For shellfish production, "Total U.S. shellfish production" ranked higher than "CCLME shellfish production" for two reasons: (1) Washington State produces the most shellfish aquaculture in the United States and produces ~86% of shellfish on the West Coast; thus, total U.S. estimates should reflect the primary status and trend of shellfish aquaculture production in the CCLME, and (2) Shellfish production data are collected by the California Department of Fish and Game and the Oregon Department of Agriculture, but these data are not collected by any state agency in Washington; thus, values from CA and OR may not reflect the actual status and trends of shellfish aquaculture in the CCLME since WA represents 86% of production on the West Coast. Two years of data (2000 (PSAT 2003) & 2009 (PCSGA 2011)) were found for Washington State, but this lack of historical data and a continuous time series causes "CCLME shellfish production" to score lower than "Total U.S. shellfish production" as the best indicator.

STATUS AND TRENDS

The status and trends of aquaculture were divided into an indicator for finfish aquaculture and an indicator for shellfish aquaculture. The status and trends of finfish aquaculture were measured using estimates of Atlantic salmon aquaculture production in the state of Washington (Table AP5) because there are no other commercial marine netpen aquaculture operations along the U.S. West Coast. Using this dataset, finfish aquaculture over the last five years has been constant and at levels greater than the long-term average (Fig. AP33).

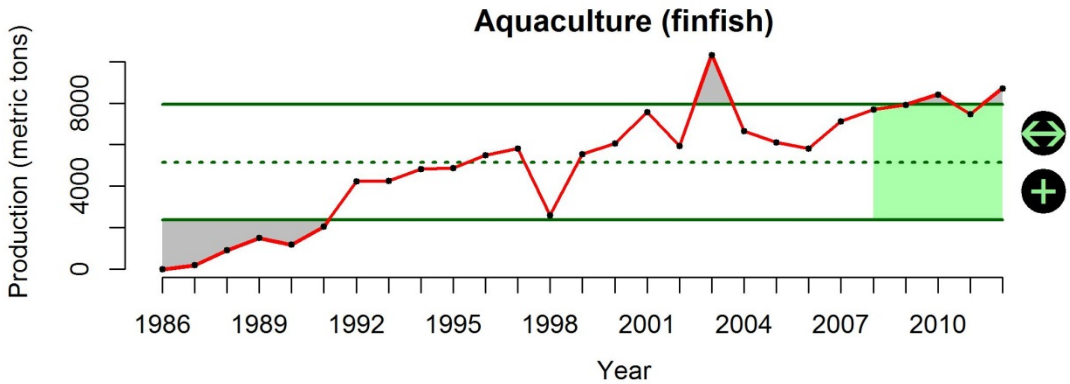


Figure AP33. Production of finfish aquaculture occurring in marine waters of the CCLME.

The status and trends of shellfish aquaculture were measured using estimates of U.S. shellfish production (Table AP5) because estimates of shellfish production in Washington State are not readily available and because Washington produces the most shellfish in the entire U.S. Using this dataset, shellfish aquaculture has increased significantly over the last five years, and the short-term average is greater than the long-term average (Fig. AP34).

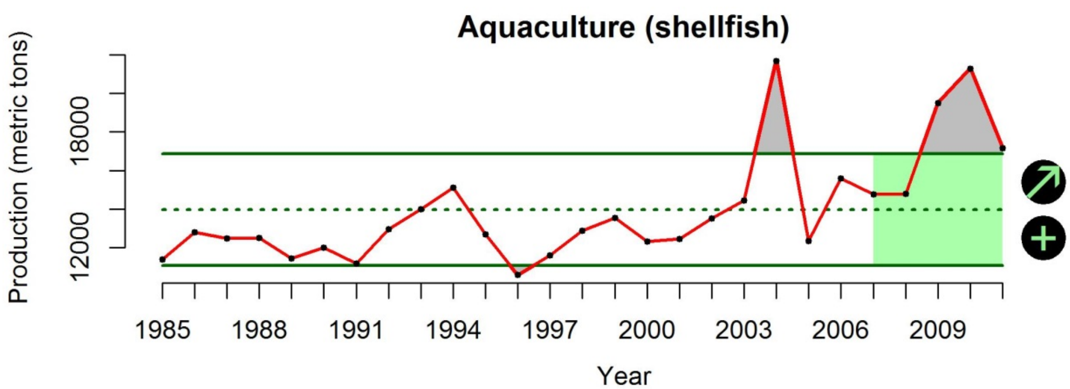


Figure AP34. U.S. production of shellfish (clams, mussels and oysters) aquaculture.

ATMOSPHERIC POLLUTION

BACKGROUND

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 and 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 N_2 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 both 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).

EVALUATION AND SELECTION OF INDICATORS

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 AP4). 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.sws.uiuc.edu/data/ntndata.aspx). This indicator of atmospheric deposition rated very high under all criteria categories (Table AP4).

STATUS AND TRENDS

The status and trends of atmospheric pollution were measured using the National Atmospheric Deposition Program's National Trends Network database (Table AP5). Annual precipitation-weighted means (mg/L) from all sites located within watersheds of the California Current ecosystem (see 'Inorganic Pollution' for description of watersheds) were used to calculate annual means for sulfate deposition in the CCLME. This monitoring network has data that go back to 1985, but there was a major protocol shift in 1994, so we have limited the dataset to years from 1994 to the present. Using this dataset, atmospheric pollution has declined over the last five years in the CCLME and is within 1SD of the long-term average (Fig. AP35).

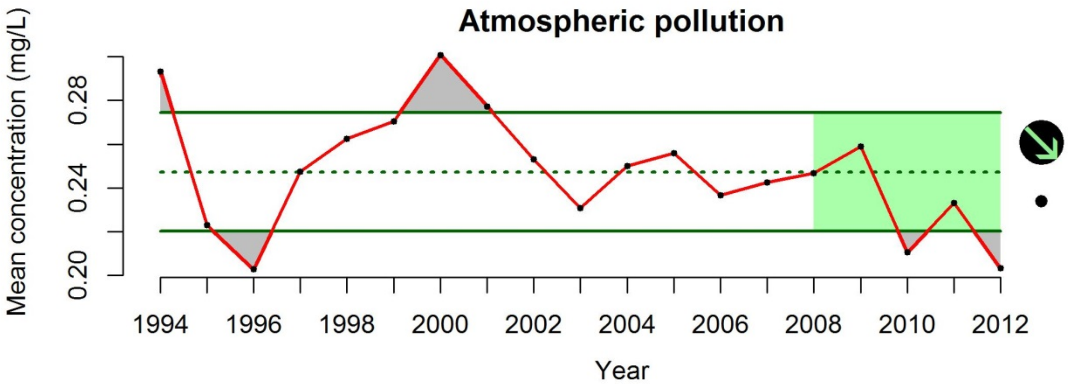


Figure AP35. Precipitation-weighted mean concentration (mg/L) of sulfates deposited out of the atmosphere at sites located within watersheds of the CCLME.

BENTHIC STRUCTURES

BACKGROUND

The effects of benthic structures, such as oil rigs, wells and associated anchorings, on fish and other organisms will be initially destructive with the loss or modification of habitat, but these risks may dissipate in the long term by potential enhanced productivity brought about by colonization of novel habitats by structure-associated fishes and invertebrates (e.g., rockfish, encrusting organisms, etc.) (Love et al. 2006). Decommissioned rigs could also enhance biological productivity, improve ecological connectivity, and facilitate conservation/restoration of deep-sea benthos (e.g. cold-water corals) by restricting access to fishing trawlers.

Petroleum extraction and transportation can lead to a conversion and loss of habitat in a number of other ways. Activities such as vessel anchoring, platform or artificial island construction, pipeline laying, dredging, and pipeline burial can alter bottom habitat by altering substrates used for feeding or shelter. Disturbances to the associated epifaunal communities, which may provide feeding or shelter habitat, can also result. The installation of pipelines associated with petroleum transportation can have direct and indirect impacts on offshore, nearshore, estuarine, wetland, beach, and rocky shore coastal zone habitats. The destruction of benthic organisms and habitat can occur through the installation of pipelines on the seafloor. Benthic organisms, especially prey species, may recolonize disturbed areas, but this may not occur if the composition of the substrate is drastically changed or if facilities are left in place after production ends (Johnson et al. 2008).

Increasing pressure to find energy resources, such as oil and gas on continental shelves, will likely increase exploration and the addition of various structures on the seafloor in the North Pacific: Canada, the U.S.A., Republic of Korea and Japan have all indicated that they intend either to begin or to expand exploration on the continental shelves of the Pacific, and drilling already occurs off Alaska and California and in the East China Sea (Macdonald et al. 2002).

EVALUATION AND SELECTION OF INDICATORS

We evaluated only one indicator of benthic structures in the CCLME: the number of oil and gas wells within the CCLME (Table AP4). In the future, the inclusion of other large-scale benthic structures with emerging uses, such as tidal- and offshore wind energy, large ocean net-pen aquaculture operations and ocean mining projects should be done to account for the increasing activity of these industrial sectors. The number of oil and gas wells only provides estimates of structures off California waters, as this is the only state along the coast of the CCLME that has offshore wells. Data are available from 1981 – 2009 on a yearly basis. The number of wells is easily understood and communicated to the public and policymakers.

STATUS AND TRENDS

The status and trends of benthic structures were measured using the number of oil and gas wells in offshore waters of the CCLME (Table AP5). These data are available in annual reports from the California Department of Conservation's Oil, Gas and Geothermal Resources Division from 1981 – 2012 (ftp://ftp.consrv.ca.gov/pub/oil/annual_reports/). We summed the number of state and federal offshore wells "producing" and "shut-in" (i.e. temporarily sealed up). The number of benthic structures in the CCLME has been constant over the short term, but has been greater than 1SD below the long-term average of the entire time series for the last decade (Fig. AP36).

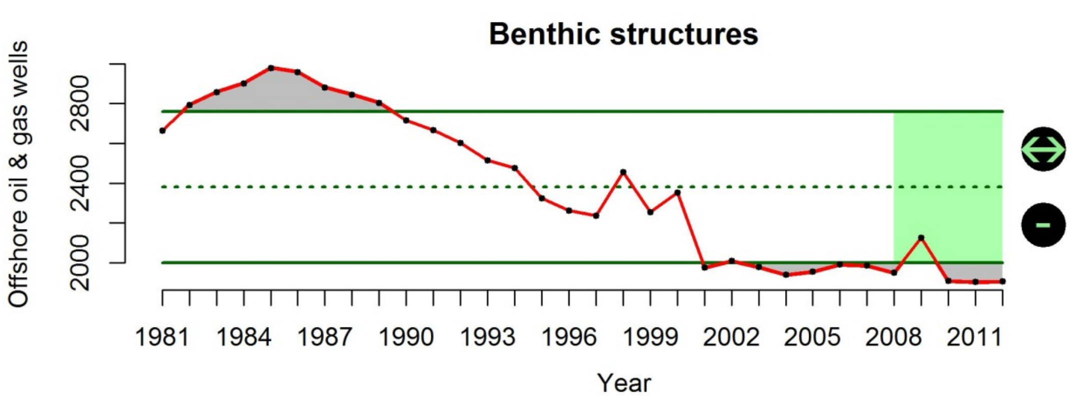


Figure AP36. The number of offshore oil and gas wells in production or shut-in in the CCLME.

COASTAL ENGINEERING

BACKGROUND

Many of the largest cities in the world are located in the coastal zone, and more than 75% of people worldwide are expected to live within 100 km of a coast by 2025 (Bulleri and Chapman 2010). In 2003, 53% of the population of the United States lived in the 673 coastal counties and this is expected to increase (Crossett et al. 2005). Transformation of coastal landscapes in response to urbanization also affects the intertidal zone and nearshore estuarine and marine waters, which are also increasingly altered by the loss and fragmentation of natural habitats and by the proliferation of a variety of built structures, such as breakwaters, seawalls, jetties and pilings.

Coastal engineering structures destroy the habitat directly under them and can significantly modify surrounding ecosystems through changes in circulation patterns and sediment transport (National Research Council 2007, Halpern et al. 2009, Shipman et al. 2010). Any structural modification of the shoreline will alter several important physical processes and can therefore be considered an impact (Williams and Thom 2001, Shipman et al. 2010). For the most part, impact potential can be related to the size and location of the structure and the types of physical processes it alters. Impacts may be considered direct or indirect. Direct impacts are generally associated with construction activities, including excavation, burial, and various types of pollution. Indirect impacts occur following physical disturbance, and are chronic in nature due to permanent alteration of physical processes such as sediment transport and wave energy. “Cumulative impacts” are associated with increasing number or size of indirect or direct impacts, which can have either linear or non-linear cumulative responses. Various engineering approaches have been adopted to minimize these effects, however (Thom et al. 2005, Bulleri and Chapman 2010).

Many shoreline “hardening” structures, such as seawalls and jetties, tend to reduce the complexity of habitats and the amount of intertidal habitats (Williams and Thom 2001, Bulleri and Chapman 2010). Because shorelines are highly diverse in their geologic nature and wave climate, acceptable ranges of armoring likely differ significantly from one location to another (Shipman et al. 2010). The definition of acceptable also will vary depending on the ecosystem response variable of interest. Differences in fish behavior and usage between modified and unmodified shorelines are caused by physical and biological effects of the modifications, such as changes in water depth, slope, substrate, and shoreline vegetation (Toft et al. 2007, Morley et al. 2012). Urban infrastructure supports different epibiota and associated assemblages and does not function as a surrogate of natural rocky habitats (Bulleri and Chapman 2010). Its introduction in the intertidal zone or in nearshore waters can cause fragmentation and loss of natural habitats. Furthermore, the novel hard substrata along sedimentary shores can alter local and regional biodiversity by modifying natural patterns of dispersal of species, or by facilitating the establishment and spread of exotic species.

Almost all coastal engineering activities are subject to environmental reviews associated with the Coastal Zone Management Act, Endangered Species Act, and the U.S. Army Corps of Engineers to assess potential impacts to natural resources and navigation. As coastal populations build, artificial structures are becoming ubiquitous features of coastal waters in urbanized centers, where they can form the dominant intertidal and shallow subtidal habitat. Ecological issues related to the introduction of coastal engineering structures into shallow coastal waters are only now beginning to receive more attention, with several recent reviews being published (e.g., Bulleri and Chapman 2010).

EVALUATION AND SELECTION OF INDICATORS

We evaluated two indicators of coastal engineering: proportion of modified shoreline (e.g., armoring, overwater structures); and coastal population estimates. Although both scored equally well with regard to theoretical considerations, the coastal population indicator scored significantly better for data considerations (Table AP4).

Inventories of coastal engineering have been carried out throughout the Pacific Coast of North America by a variety of federal, state, and local agencies under a number of programs, including Washington State's shoreline management act (http://www.ecy.wa.gov/programs/sea/sma/st_guide/intro.html), the USGS national assessment of shoreline change (http://coastal.er.usgs.gov/shoreline-change/), and NOAA's environmental assessment program (http://response.restoration.noaa.gov/maps-and-spatial-data/environmental-sensitivity-index-esi-maps.html), and the California Coastal Conservancy. However, time series data of coastal engineering do not exist coastwide and therefore cannot be used to conduct change analysis. Most of these inventories only provide a baseline indication of current or recent conditions (e.g., Halpern et al. 2009) and if they represent data over multiple time periods, are generally only available over smaller spatial scales (e.g., county- or region-wide; personal communication, Lesley Ewing, California Coastal Commission). Coastal engineering structures are classified in a variety of ways, but primarily account for the percent of modified shoreline along a particular reach. The NOAA Environmental Sensitivity Index (ESI) maps provide a concise summary of coastal resources that are at risk if an oil spill occurs nearby. Anthropogenic structures are classified as follows: exposed, solid man-made structures (1B), riprap (class 6B), sheltered, solid man-made structures (8B), and sheltered riprap (8C). Inventories exist primarily for central and southern California (http://www.coastal.ca.gov/recap/rcpubs.html) and parts of Puget Sound; GIS ESI atlases have been completed for all of California, Puget Sound, and the lower Columbia River; ESI atlases (no GIS) have been completed for the outer coasts of WA and OR. Inventories of shoreline classification and modifications maps (baselines) exist for the following years: southern CA: 1980, 1995, 2010; San Francisco Bay: 1986, 1998; central CA: 1995, 2006; northern CA: 1995, 2008 (M. Sheer, NOAA *pers. comm*); OR and WA coast: 1985; and Puget Sound: 2000 (http://response.restoration.noaa.gov/maps-and-spatial-data/shoreline-rankings.html). To classify each shoreline unit, ESI map developers use information and observations from a combination of sources, including: overflights, aerial photography, remotely sensed data, ground-truthing (visits to individual shorelines to validate aerial observations), and existing maps and data. Future assessments will attempt a change analysis as more recent classification actions are completed. This analysis will correlate the changes observed in shoreline armoring of specific counties in southern California with corresponding changes in coastal population growth.

The rate of shoreline armoring has been shown to correspond with the rate of population growth in coastal areas (Douglass and Pickel 1999), and in the absence of good time series of geospatial data for hardened shorelines, coastal population data for the coastline counties of the West Coast of the United States provides a good proxy for this stressor. Population density has a long history of reporting and is known to affect coastal regions disproportionately (Crossett et al. 2005). Population density is becoming increasingly understood in some regions as an agent of shoreline change (e.g. Puget Sound Partnership; http://www.psp.wa.gov/vitalsigns/shoreline_armoring.php). Coastline counties of the United States, located along the country's saltwater edges, account for just 254 of the nation's 3,142 counties yet contain 29 percent of its population, 5 of its 10 most populous cities, and 7 of its 10 most populous counties (Wilson and Fischetti 2010). To qualify as coastline, a county has to be adjacent to water classified as either coastal water or territorial sea. Transformation of coastal landscapes in response to urbanization also affects the intertidal zone and nearshore estuarine and marine waters, which are also increasingly altered by the loss and fragmentation of natural habitats and by the proliferation of a variety of built structures, such as breakwaters, seawalls, jetties and pilings. Unclear however, at this time, is the explicit relationship between coastal population levels and the relative amount of shoreline affected by coastal engineering structures; this data gap is likely driven by the lack of good time series data on the latter.

STATUS AND TRENDS

The status and trends of coastal engineering were measured using estimates of human population in counties classified as "coastline" in WA, OR and CA (Table AP5). Data for coastline population estimates were retrieved from county estimates from the U.S. Census Bureau (2010 – 2012; http://www.census.gov/popest/data/datasets.html) and the National Bureau of Economic Research (1970 – 2009; http://www.nber.org/data/census-intercensal-county-population.html). Using this indicator, coastal engineering has been increasing steadily over the entire time series. Over the last five years of this dataset, however, there was no change, but the current status is >1SD above the long-term average (Fig. AP37). Populations along the coast continue to increase and the ultimate driver of many non-fisheries related pressures will continue to increase for the foreseeable future.

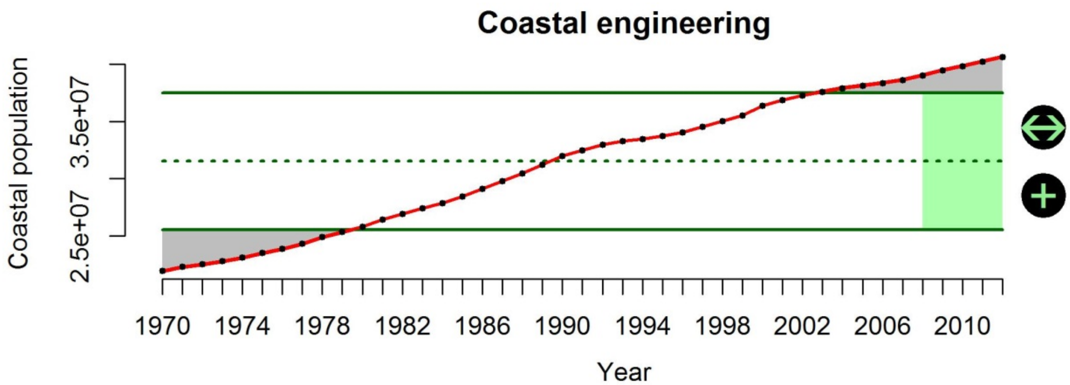


Figure AP37. U.S. population in coastline counties of WA, OR and CA.

COMMERCIAL SHIPPING ACTIVITY

BACKGROUND

Approximately 90% of world trade is carried by the international shipping industry and the volume of cargo moved through U.S. ports is expected to double (as compared to 2001 volume) by 2020 (AAPA 2012) due to the economic efficiencies of transporting goods via ocean waterways. The impacts of commercial shipping activity on the CCLME are numerous, but we used commercial shipping activity as a proxy for the potential risk of ship strikes of large animals, noise pollution and the risk of habitat modification due to propeller scouring, sediment resuspension, shoreline erosion, and ship groundings or sinkings (similar definition as Halpern et. al. (2008)). Vessel activity in coastal waters is generally proportional to the degree of urbanization and port and harbor development within a particular area (Johnson et al. 2008). Benthic, shoreline, and pelagic habitats may be disturbed or altered by vessel use, resulting in a cascade of cumulative impacts in heavy traffic areas. The severity of boating-induced impacts on coastal habitats may depend on the geomorphology of the impacted area (e.g., water depth, width of channel or tidal creek), the current velocity, the sediment composition, the vegetation type and extent of vegetative cover, as well as the type, intensity, and timing of boat traffic (Johnson et al. 2008).

Ship strikes have been identified as a threat to endangered blue, humpback and fin whales (NMFS 1991, 1998, 2006), and this is of particular concern along the California coastline (Abramson et al. 2009, Berman-Kowalewski et al. 2010, Davidson et al. 2012). In addition to direct mortality from ship strikes, shipping vessels increase noise levels in the ocean, which could interfere with normal communication and echolocation practices of marine mammals. When background noise levels increase, many marine mammals amplify or modify their vocalizations, which may increase energetic costs or alter activity budgets when communication is disrupted among individuals (Holt et al. 2009, Dunlop et al. 2010). Underwater noise levels associated with commercial shipping activity increased by approximately 3.3 dB/decade between 1950 and 2007(Frisk 2012).

The effects of commercial shipping activity on fish populations are not very well understood, but some data suggest responses will be behavioral in nature (e.g. Rostad et al. 2006) and related to loss of habitat (Uhrin and Holmquist 2003, Eriksson et al. 2004) or noise pollution (Slabbekoorn et al. 2010). Some fish species may be attracted to vessels, rather than repelled by them, and are not bothered by noisy, passing ships (Rostad et al. 2006). However, frequently traveled routes such as those traveled by ferries and other transportation vessels may impact fish spawning, migration, communicative, and recruitment behaviors through noise and direct disturbance of the water column (Barr 1993, Codarin et al. 2009).

EVALUATION AND SELECTION OF INDICATORS

We 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 scored high in nearly all of the “Data Considerations” criteria (Table AP4) because most data are available from the U.S. Army Corps of Engineers (USACE) Navigation Data Center (http://www.ndc.iwr.usace.army.mil/index.htm). Each of these indicators is certainly correlated with some aspect of commercial shipping activity. The port volume of cargo moved through ports along the West 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 (Table AP4).

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. West 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 and Heppell 2007). We calculated 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 (e.g., to 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 (Table AP4).

In order to develop this indicator, we received port-to-port coastwise trip data with shipping and receiving drafts and names of all domestic shipping vessels for years 2001 – 2010 from the USACE Waterborne Commerce Statistics Center, New Orleans, LA. From the USACE Navigation Data Center database (http://www.ndc.iwr.usace.army.mil/data/dataclen.htm#Foreign Traffic Vessel Entrances and Clearances), we downloaded foreign traffic vessel entrances and clearances data to get all foreign port-to-port trips with draft and vessel names of each vessel for years 2001 – 2010. We then looked up the breadth of individual vessels from the USACE "Vessel Characteristics" database (http://www.ndc.iwr.usace.army.mil//data/datavess.htm). For vessels that were not contained within this database, we used the mean breadth of vessels within the same "Vessel type" for domestic vessels or within the same "Rig type" for foreign vessels.

We categorized trips into two categories. If the shipping and receiving port was the same (i.e., the vessel was moving from one dock to another or moving a barge within the port), this was categorized as "port" traffic, while all other trips were categorized as "coastal" traffic. For this analysis, we removed all "port" traffic because this pressure is defined as a measure of the risk of vessels striking marine mammals, causing noise pollution, and modifying coastal habitat. We include "port" traffic in the indicator for ocean-based pollution below. In order to calculate the distance traveled within the CCLME for each vessel, we used distances between ports as measured by NOAA's Office of Coast Survey and documented in USDOC (2012). For trips that traveled outside of the CCLME, we used the distance from the port within the CCLME to the boundary of the CCLME following the major shipping lane pathways. For example, if a vessel traveled from San Diego, CA to Houston, TX, we calculated the distance from San Diego to the southern boundary of the CCLME on the vessel's way toward the Panama Canal (estimated at 602 nm (1115 km)).

These distances were then multiplied by the vessel's shipping draft (m) and breadth (m) to give a volume (m^3) of water directly disturbed by the vessel during transit through the CCLME. Obviously the wake of a vessel will disturb more than our calculated volume, so this is a conservative estimate of absolute volume, but the trends over time will be relative.

STATUS AND TRENDS

The status and trends of commercial shipping activity were measured using the volume of water disturbed by commercial shipping vessels within the CCLME (Table AP5). Using this dataset, we found that commercial shipping activity in the CCLME has decreased over the last five years, but the short-term mean is within 1SD of the long-term mean of the entire dataset (Fig. AP38). The decreasing trend in this dataset likely reflects economic conditions during the recent recession and it appears this indicator is beginning to increase as economic conditions improve. The predominant contributor to this trend is foreign vessel traffic and these data are available back to 1997, while the domestic data may be available back to 1994 if funding were available to the USACE to perform this data inquiry.

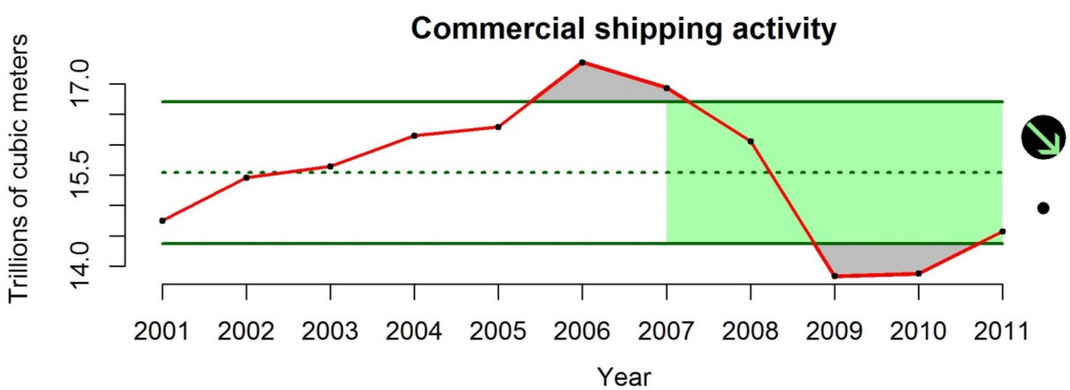


Figure AP38. Volume (trillions m^3) of water disturbed during transit of commercial shipping vessels along the coast of the CCLME.

DISEASE/PATHOGENS

BACKGROUND

The last few decades have seen a worldwide increase in the reports of disease in the marine environment (Harvell et al. 1999), though these increases appear to be taxa related (Ward and Lafferty 2004). Diseases are thought to be fostered by increases in climate variability and human activity as many outbreaks are favored by changing environmental conditions that increase pathogen transmission or undermine host resistance (Anderson 1998). Marine flora and fauna serve as hosts for numerous parasites and pathogens that may affect the host populations as well as have cascading effects throughout the ecosystem.

For example, the near elimination of seagrass (*Zostera marina*) beds from many North Atlantic U.S. coastlines in the 1930's due to wasting disease (thought be caused by a pathogenic strain of *Labyrinthula*, which has since been confirmed and identified in eelgrass beds in the 1980's on both coasts of the United States (Short et al. 1987)) was responsible for numerous alterations to coastal habitats (Rasmussen 1977) and fauna, including a reduction or loss of migratory waterfowl populations (Addy and Aylward 1944) and the loss of the scallop fishery in the mid-Atlantic coast of the U.S. (Thayer et al. 1984).

The population dynamics of many pathogens are sensitive to changes in their physical environment (e.g., temperature), which could modify pathogen development and survival, disease transmission and host susceptibility (Harvell et al. 1999, Harvell et al. 2002, Selig et al. 2006). Thus, understanding how climate variability affects disease transmission in the marine environment is necessary for successful management efforts. These efforts, however, are hindered by the absence of baseline and epidemiological data on the normal disease levels in the ocean (Harvell et al. 1999).

EVALUATION AND SELECTION OF INDICATORS

The only indicator we evaluated for marine disease/pathogens was the percentage of scientific articles published each year that reported disease among marine taxa (Ward and Lafferty 2004). Overall, this indicator did not evaluate well in Primary Considerations criteria (Table AP4). The percentage of scientific articles reporting disease in marine taxa is a very broad proxy for testing whether diseases in the marine environment are increasing or decreasing - though it is the first quantitative baseline created to measure this. This measure may or may not respond predictably to actual measurements of disease in the ocean. There are many other factors - such as funding and the number of investigators interested in studying this topic - which will heavily influence this indicator each year. However, data are available from Ward & Lafferty (2004) for several marine taxa from 1970-2001 and the methods seem to be reproducible such that the time series could be updated in the future with yearly literature searches. Ward & Lafferty's (2004) data are a worldwide estimate, so spatial variation is not understood and is not specific to the CCLME. It is easily understood by the public and policymakers, but there has been no history of reporting the trend of disease in the marine environment with this indicator.

The overall trend of the Ward & Lafferty (2004) data suggests that disease may be increasing in marine ecosystems globally, but there are no time series data available to evaluate disease incidence in the CCLME; thus, we have concluded that there are no appropriate indicators of disease to include at this time. The methods of Ward & Lafferty (2004) could be applied to studies of disease in the CCLME and used as a baseline, but determining whether the trends are due to actual increases in disease or simply increases in the investigation and reporting of disease will be difficult to separate. The California

Cooperative Oceanic Fisheries Investigations (CalCOFI) and NOAA's Southwest Fisheries Science Center's ecosystem surveys have been collecting and archiving plankton samples since 1951. If pathogens are preserved in these samples, perhaps this could be a line of research that could produce a baseline of disease incidence in the CCLME given necessary funding.

DREDGING

BACKGROUND

Dredging is the removal or displacement of any material from the bottom of an aquatic area (USACE 1983). It is required in many ports of the world to deepen and maintain navigation channels and harbor entrances. Elsewhere, commercial sand mining and extraction of sand and gravel from borrowing areas is conducted to meet demand for sand for construction and land reclamation. Excavation, transportation, and disposal of soft-bottom material can have various adverse impacts on marine or estuarine environments (Johnston 1981). These effects may be due to physical or chemical changes in the environment at or near the dredging site, and may include: reduced light penetration by increased turbidity; altered tidal exchange, mixing, and circulation; reduced nutrient outflow; increased saltwater intrusion; alteration, disruption, or destruction of areas in which fish live, feed and reproduce; re-suspension of contaminants affecting water quality; and creation of an environment highly susceptible to recurrent low dissolved oxygen levels.

EVALUATION AND SELECTION OF INDICATORS

We evaluated two indicators of dredging impacts: dredging volumes and dredge dump volumes (Table AP4). Dredge volumes scored better than the latter, primarily due to reporting omissions related to spatial coverage.

Most of the dredging activities conducted on the U.S. West coast involve maintenance dredging of harbor or port areas and associated navigation channels, with associated material disposal in open water or integrated into beach nourishment programs. The amount of material (in cubic yards - CY) dredged from all U.S. waterways off the U.S. West Coast is a concrete, spatially explicit indicator that concisely tracks the magnitude of this human activity throughout the California Current region.

These data are accessible through the U.S. Army Corps of Engineers navigation data center dredging information system: http://www.navigationdatacenter.us/data/datadrgsel.htm. There are two sources of data: 1) Dredging contracts and 2) Corps-owned dredges. Data include dredge volumes, locations, and costs for individual private contracts and Corps operated dredge projects from 1997 through 2012 nationwide. We summarized annual dredge volumes (converted to cubic meters) for all private contracts conducted in California, Oregon, and Washington. We summarized annual dredge volumes (converted to cubic meters) for all dredging activities performed by the "Portland" Division which represents the only dredging performed by the Corps along the U.S. West Coast. Annual offshore dump volumes are not summarized and reported separately, but can be determined with some data manipulation from this database. In some locations, dredge dump volumes are also reported to give an indication of the extent of, and trends in dredging activities (e.g., Annual OSPAR Reports on the Dumping of Wastes at Sea).

STATUS AND TRENDS

The status and trends of dredging in the CCLME were measured using dredged volume (millions of m^3) of sediments from projects originating in WA, OR and CA waters (Table AP5). Using this indicator, dredging has increased over the last five years, but the short-term average is still within 1SD of the long-term average of the entire time series (Fig. AP39). If dredging activities within the CCLME remain at current levels or increase, the short-term status of this indicator will be greater than the long-term average by 2013.

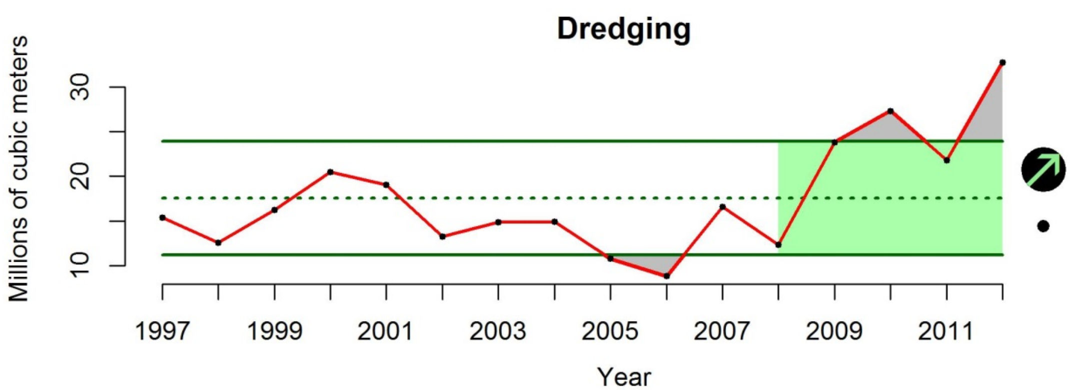


Figure AP39. Volume (millions m^3) of dredged sediments from projects originating in WA, OR and CA.

FRESHWATER RETENTION

BACKGROUND

As the world's population grows and its demands for freshwater increase, interannual variability and long-term changes in continental runoff are of great concern to water managers (Dai et al. 2009). Freshwater flow also affects fisheries and ESA-listed species. River discharge into many estuaries and coastal marine areas has been substantially altered by diversion for human use (Vorosmarty et al. 2000). Water withdrawals for public-supply and domestic uses have increased steadily since estimates began, with freshwater withdrawals of almost 1.32 billion m^3/d in 2005. Thermoelectric-power generation (see Power Plants, below) and irrigation withdrawals have generally been the two largest human use categories since these estimates were made. Hydropower is considered an "in-stream use" of freshwater, but associated dams and dam operations also alter flow patterns, volume, and depth of water within and below impoundments. Dam projects operating as "store and release" facilities drastically affect the magnitude, timing, and duration of downstream water flow and depth, resulting in dramatic deviations to natural fluctuations in habitat accessibility, acute temperature changes, and overall water quality.

Modified freshwater flow regimes change the salinity gradient and pattern in salinity variation within estuaries and coastal systems, and can induce large shifts in community composition and ecosystem function (Gillanders and Kingsford 2002). These ecosystems often respond most strongly on an interannual timescale to variability in freshwater flow. Several mechanisms for positive or negative flow effects on biological populations in estuaries have been proposed (Kimmerer 2002). Positive effects appear to operate mainly through stimulation of primary production, with effects propagating up the food web. Overall impacts on the biota are generally considered negative, however, with documented changes to migration patterns, spawning habitat, species diversity, water quality, and distribution and production of lower trophic levels (Drinkwater and Frank 1994). For freshwater systems, a framework has been developed for assessing environmental flow needs for many streams and rivers to foster implementation of environmental flow standards at the regional scale (Poff et al. 2010). Studies focused on reductions in freshwater flow have generally shown detrimental ecosystem effects and altered community composition (Gillanders and Kingsford 2002). However, freshwater subsidies to estuaries or hypersaline lagoons have also been shown to cause major shifts in vegetation, fish, and macroinvertebrate assemblages (Nordby and Zedler 1991, Strydom et al. 2002, Rutger and Wing 2006).

Discharge trends for many rivers reflect mostly changes in precipitation, primarily in response to short- and longer-term atmospheric-oceanic signals; notably, the cumulative discharge from many rivers globally decreased by 60% during the last half of the 20th century, reflecting in large part impacts due to damming, irrigation and interbasin water transfers (Dai et al. 2009). However, a comprehensive analysis of worldwide river gauging data suggests that direct human influence on annual streamflow is likely small compared with climatic forcing during 1948–2004 for most of the world's major rivers (Dai et al. 2009). The immediate effect of dams on freshwater impact is also seemingly mixed. Reservoirs can affect the timing of discharge as well as the amount of discharged sediment and dissolved constituents, but for most normal rivers, reservoirs appear to have little effect on annual discharge (Milliman et al. 2008). However, most deficit rivers have flow regulation and irrigation indices, underscoring the importance of reservoirs and irrigation in facilitating water loss by increased consumption and (ultimately) increased evapotranspiration (Milliman et al. 2008).

EVALUATION AND SELECTION OF INDICATORS

We evaluated two potential indicators of freshwater input: river runoff or stream discharge and impoundment area behind dams (Table AP4). Other potential indicators of consumption and flow regulation (Milliman et al. 2008) were identified but not comprehensively evaluated at this time. Stream discharge data are accessible from a variety of gauged streams (http://water.usgs.gov/nsip/) from 1948-2004, although one of the major obstacles in estimating continental discharge is incomplete gauging records or unmonitored streamflow. Dai et al. (2009) have updated streamflow records for the world's major rivers with streamflow data simulated by a comprehensive land surface model. However, it has been shown that it is very difficult to distinguish signal from noise in rivers with widely variable interannual discharge (Milliman et al. 2008). The effects of human activities on annual stream flow are likely small compared with those of climate variations during 1948–2004 (Dai et al. 2009) and ENSO-induced precipitation anomalies are a major cause for the variations in continental discharge (Dai et al. 2009). Furthermore, regional analyses of trends in U.S. streamflow (generally characterized by increases in streamflow across all water-resource regions of the conterminous U.S. between 1940 and 1999) have been designed specifically to detect climate signals and minimize anthropogenic effects (Lins and Slack 2005)

River runoff (R) can also be expressed as the difference between precipitation (P) and the sum of evapo-transpiration (ET), storage (S) (e.g., groundwater), and consumption (C) (e.g., irrigation) (Milliman et al. 2008). Therefore, data series associated with the anthropogenically-derived parameters, C and S, likely provide some of the best indicators of human impacts to freshwater input. Freshwater storage (S) data are accessible and can be obtained on an annual basis from state agency databases, which include information on construction date and impoundment area/volume for all dams (California: http://cdec.water.ca.gov/misc/resinfo.html; Idaho: http://www.usbr.gov/projects/FacilitiesByState.jsp?StateID=ID; Oregon: http://www.usbr.gov/projects/FacilitiesByState.jsp?StateID=OR; Washington: https://fortress.wa.gov/ecy/publications/summarypages/94016.html). Furthermore, large-scale hydrological alterations are known to cause a variety of downstream habitat changes, such as deterioration and loss of river deltas and ocean estuaries (Rosenberg et al. 2000).

We selected impoundment volume as our indicator of changing freshwater flow, primarily based on the long-term availability of annual impoundment data and the additional known effects of these large-scale hydrological alterations to downstream habitats (Table AP4).

STATUS AND TRENDS

The status and trends of freshwater retention in the CCLME were measured using the total impoundment volume (millions m^3) of freshwater stored behind dams in CA, OR, ID and WA (Table AP5). Using this dataset, the storage of freshwater has been relatively constant for the last 40 years, but the short-term average was greater than 1SD above the long-term average of the entire time series (Fig. AP40). This time series reflects the large increases in reservoir impoundment during the period of major dam building from the 1940's to the early 1970's with relatively little change since then. This indicator highlights the legacy of historical pressures, but the relative stability of this indicator in the short-term may not provide a useful indicator of change in freshwater retention moving forward. Further development of indicators for this pressure is likely necessary.

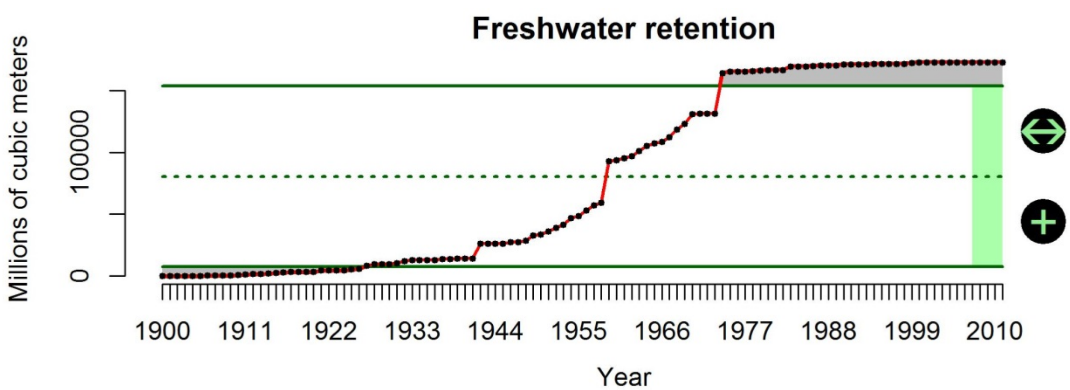


Figure AP40. Volume (millions m^3) of freshwater stored behind dams in WA, OR and CA.

INORGANIC POLLUTION

BACKGROUND

Tens of thousands of chemicals are used by industries and businesses in the United States for the production of goods on which our society depends. Many of the chemicals used in the manufacturing and production of these goods are toxic at some level to humans and other organisms and some are inevitably released into the environment. The production, use and release of various toxic chemicals have changed over time depending on economic indices, management methods (recycling and treatment of chemicals), and environmental regulations (USEPA 2010). The pathway of these chemicals to estuarine and marine environments can be direct (e.g., wastewater discharge into coastal waters or rivers) or diffuse (e.g., atmospheric deposition or urban runoff). Over the past 40 years, direct discharges have been greatly reduced; however, the input of pollutants to the marine environment from more diffuse pathways such as runoff from land-based activities is still a major concern (Boesch et al. 2001).

While all pollutants can become toxic at high enough levels, there are a number of compounds that are toxic even at relatively low levels (Johnson et al. 2008). The U.S. Environmental Protection Agency (USEPA) has identified and designated more than 126 analytes as "priority pollutants." According to the USEPA, "priority pollutants" of particular concern for aquatic systems include: (1) dichlorodiphenyl trichloroethane (DDT) and its metabolites; (2) chlorinated pesticides other than DDT (e.g., chlordane and dieldrin); (3) polychlorinated biphenyl (PCB) congeners; (4) metals (e.g., cadmium, copper, chromium, lead, mercury); (5) polycyclic aromatic hydrocarbons (PAHs); (6) dissolved gases (e.g., chlorine and ammonium); (7) anions (e.g., cyanides, fluorides, and sulfides); and (8) acids and alkalis (Kennish 1998, USEPA 2003). While acute exposure to these substances produces adverse effects on aquatic biota and habitats, chronic exposure to low concentrations probably is a more significant issue for fish population structure and may result in multiple substances acting in "an additive, synergistic or antagonistic manner" that may render impacts relatively difficult to discern (Thurberg and Gould 2005).

Coastal and estuarine pollution can affect all life stages of fish, but fish can be particularly sensitive to toxic contaminants during the first year of life (Rosenthal and Alderdice 1976). Over time, organisms will accumulate contaminants from water, sediments or food in their tissues, which then transfers to offspring through reproduction and throughout the food web via trophic interactions. Negative impacts of pollution on commercial fish stocks have generally not been demonstrated, largely due to the fact that only drastic changes in marine ecosystems are detectable and the difficulty in distinguishing pollution-induced changes from those due to other causes (Sindermann 1994). Normally, chronic and sublethal changes take place very slowly and it is impossible to separate natural fluctuations from anthropogenic causes. Furthermore, fish populations themselves are estimated only imprecisely, so the ability to detect and partition contaminant effects is made even more difficult. However, measurements of marine biodiversity have shown that species richness and evenness are reduced in areas of anthropogenic pollution (Johnston and Roberts 2009).

EVALUATION AND SELECTION OF INDICATORS

We used inorganic pollution releases to describe the status and trends of inorganic pollution at locations that likely drain into the CCLME. We excluded releases of inorganic pollution into the air, as this pressure is covered by "atmospheric pollution" above. We evaluated three different indicators of inorganic pollution in the CCLME: total inorganic pollutants, toxicity-weighted inorganic pollutants, and ISA-(Impervious Surface Area) toxicity-weighted inorganic pollutants (Table AP4). Each of these indicators relies on data contained within the USEPA's Toxic Release Inventory (TRI; http://www.epa.gov/tri/) database. Thousands of facilities from all across the United States have been required to report detailed information on the disposal (onsite and offsite) and releases to air, water, land or underground wells of over 650 chemicals since 1988. This provides a long-term, continuous time series of data across watersheds that drain directly into the CCLME.

Two of the three indicators scored high in our evaluation based on the amount of data available and the historical use of this type of data to communicate trends to the public. However, users of TRI information should be aware that TRI data reflect releases and other waste management activities of chemicals, not whether (or to what degree) the public has been exposed to those chemicals. Release estimates alone are not sufficient to determine exposure or to calculate potential adverse effects on human health and the environment. TRI data, in conjunction with other information, can be used as a starting point in evaluating exposures that may result from releases and other waste management activities which involve toxic chemicals. The determination of potential risk depends upon many factors, including the toxicity of the chemical, the fate of the chemical, and the amount and duration of human or other exposure to the chemical after it is released. Thus, simply using "total inorganic pollutants" data from the database scored lower than the other two indicators because it does not take any other factors into account.

Toxicity-weighted pollutants provide more context to the types and risk of pollutants being released by industrial facilities; however, most studies trying to account for and quantify runoff of pollutants into streams and watersheds or the contamination of groundwater sources use impervious surface area (ISA) as an indicator or a leading contributing factor (Arnold and Gibbons 1996, Gergel et al. 2002, Halpern et al. 2008, Halpern et al. 2009). Impervious surface area generally allows greater concentrations of excess nutrients and pollutants to run into nearby streams and rivers. This can lead to stream communities with fewer fish species and lower indices of biotic integrity (Wang et al. 2001). Other researchers have documented increased erosion, channel destabilization and widening, loss of pool habitat, excessive sedimentation and scour, and reduction in large woody debris and other types of cover as a consequence of urbanization (Lenat and Crawford 1994, Schueler 1994, Arnold and Gibbons 1996, Booth and Jackson 1997).

The difficulty of incorporating ISA into this indicator was that there were only two years of data which quantify the amount of ISA within all of the watersheds that drain into the CCLME. Because these data were lacking, its evaluation is much lower in the data consideration criteria than the other two potential indicators. However, spatially-explicit ISA data for all the watersheds of the CCLME could be quantified from archived satellite data by the U.S. National Geophysical Data Center if it became a higher priority; thus we have chosen this as the best indicator in hopes that future processing of satellite data will increase the precision of ISA estimates at the scale of the CCLME.

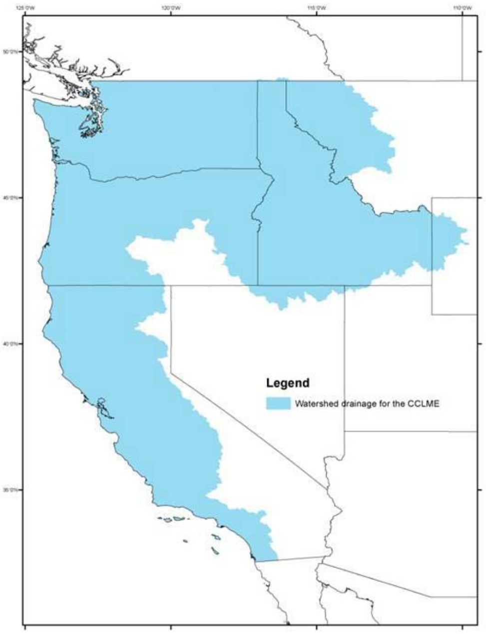


Figure AP41. Polygon of the watershed that drains into the CCLME and used to clip impervious surface area data layers (based on Halpern et al. 2009).

In order to calculate this indicator, we downloaded data from 1988 – 2012 from the TRI EZ search database (http://www.epa.gov/enviro/facts/tri/ez.html) using the "Flat (Denormalized) Form R". We selected the following data columns for download: "TRI Facility Id", "Reporting Year", "Chemical Name", "TRI Chemical Id", "County Name", "State Abbreviation", "Facility Latitude", "Facility Longitude", "Land Total Release" and "Water Total Release" and selected for states that occur in watersheds that drain into the CCLME (Fig. AP41). Only facilities located within CCLME watersheds were used to sum all releases to land and water. Data (lbs of releases) for each chemical were converted to kg and summed across each release category. In order to weight each chemical by its relative toxicity, we multiplied the amount of releases for each chemical by its score in the Indiana Relative Chemical Hazard Ranking Score (IRCHS; http://cobweb.ecn.purdue.edu/CMTI/IRCHS/) divided by 100:

Toxicity-weighted releases = chemical releases * (IRCHR/100)

For chemicals not listed in the IRCHR, we used the most closely-related substance on the list. These relative toxicity scores can range from 0–100, but within our dataset, the highest scoring chemical was methyl hydrazine (IRCHR = 58.3). Toxicity-weighted releases were then summed across all chemicals for each year.

In order to provide weightings of ISA for each year, we used the ISA GIS data layers developed by the U.S. National Geophysical Data Center for the years 2000-2001 (global estimates) and January – June 2010 (estimates for the United States only). These data are available at http://ngdc.noaa.gov/eog/dmsp/download_global_isa.html. We used the watershed drainage boundary for the CCLME developed by Halpern et al. (2009) to delineate the watersheds in which ISA values would be summed across (Fig. AP41). The 2000 – 2001 and 2010 ISA data layers were clipped to the watershed boundary polygon and then ISA values were summed across all cells. Because there were only two years of ISA data, we assumed a linear relationship between 2001 and 2010 and simply extrapolated summed ISA values to the remaining years between 1988 and 2012 based on this linear assumption. Summed ISA values were then standardized as a proportion of the maximum value (i.e., summed ISA value each year/maximum summed ISA value) such that the year with the highest summed ISA value had a weighting of 1 and all others were a proportion. Toxicity-weighted releases were then multiplied by the corresponding ISA weighting for each year. Finally, the ISA-Toxicity-weighted releases were normalized.

In 1998, the EPA began collecting pollution information from the commercial hazardous waste treatment sector. Because of this change during our time series, there was a very large change in the magnitude of reported chemicals in the TRI database. To account for this magnitude shift, the ISA-Toxicity-weighted releases were normalized independently across the two time periods. Data from 1987 – 1997 were normalized and data from 1998 – 2012 were normalized and then appended to each other to create a continuous time series from 1988 – 2012. We investigated the influence of different chemicals being added to or removed from the list reported by TRI by calculating the exact same time series as described above using only chemicals from the 1988 Core Chemical list. This resulted in differences at the beginning of the time series (1988 – 1993), but had virtually no effects on the status and trends of the rest of the time series; thus, we decided to include all chemicals reported by the TRI database into the calculation of this indicator.

STATUS AND TRENDS

The status and trends of inorganic pollution in the CCLME were measured using ISA-toxicity-weighted chemical releases from data collected by the Environmental Protection Agency and reported by the Toxics Release Inventory (TRI) Program (Table AP5). This indicator incorporates the amount and toxicity of chemicals released into water and onto land by industrial facilities as well as the amount of impervious surface area in the CCLME's drainage basin. Using this indicator, inorganic pollution has not changed over the last five years, and is within 1SD of the long-term average of the entire time series (Fig. AP42).

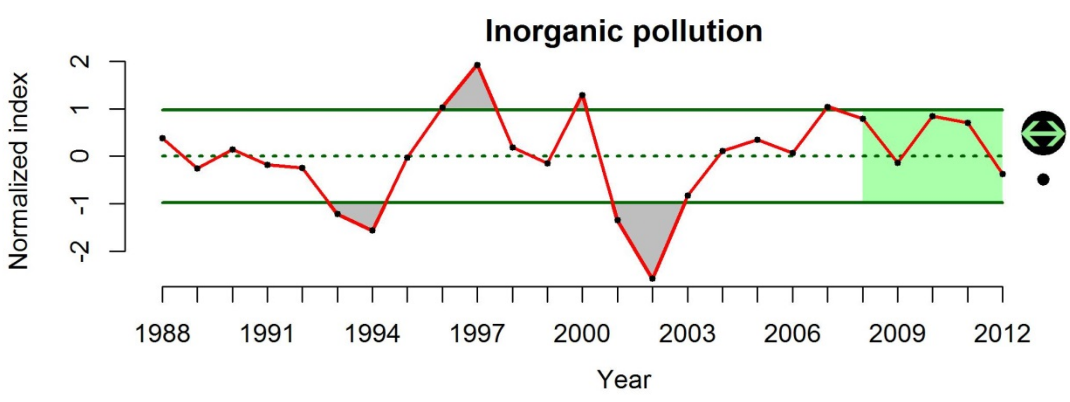


Figure AP42. Normalized index of ISA-toxicity-weighted chemical releases on land or into water by industrial facilities within watersheds of the CCLME.

INVASIVE SPECIES

BACKGROUND

Introductions of nonnative invasive species into marine and estuarine waters are considered a significant threat to the structure and function of natural communities and to living marine resources in the United States (Carlton 2001, Johnson et al. 2008). The estimated damage from invasive species in the United States alone totals almost $120 billion per year (Pimentel et al. 2005). The mechanisms behind biological invasions are numerous, but generally include the rapid transport of invaders across natural barriers (e.g. plankton entrained in ship ballast water, organisms contained in packing material (Japanese eelgrass *Zostera japonica*) or fouling on aquaculture shipments, aquarium trade with subsequent release to natural environments) (Molnar et al. 2008). Nonnative species can be released intentionally (e.g., fish stocking and pest control programs) or unintentionally during industrial shipping activities (e.g., ballast water releases), aquaculture operations, recreational boating, biotechnology, or from aquarium discharge.

EVALUATION AND SELECTION OF INDICATORS

We evaluated three indicators of invasive species from the literature: number of alien species from regional records, number of shipping ports, and shipping cargo volume (Table AP4).

The rate of biological species introductions has increased exponentially over the past 200 years, and it does not appear that this rate will level off in the near future (Carlton 2001). In a recent paper, Molnar et al. (2008) provided a quantitative global assessment of invasive species impacts, scored and ranked based on the severity of the impact on the viability and integrity of native species and natural biodiversity (http://conserveonline.org/workspaces/global.invasive.assessment/). This database serves as a regional baseline for invasion worldwide; unfortunately, it has not been updated since its creation and therefore lacks time series information, limiting its utility as an indicator.

Molnar et al. (2008) also examined potential pathways for invasion, using generalized linear models to quantify the correlation between the number of harmful species reported and various pathways of introduction (e.g., shipping, aquaculture, canals). Shipping was considered the most likely pathway of harmful species introductions in most regions, with statistically significant correlations found between the shipping indicators number of ports and shipping cargo volume. In the California Current, shipping was the key invasion pathway for northern California and the southern California Bight, whereas aquaculture was considered the more important invasion pathway in the Puget

Trough/Georgia Basin and Oregon, Washington, Vancouver region. Empirical evidence increasingly indicates that the number of released individuals and number of released species are key determinants of the species that successfully invade new habitats (Lockwood et al. 2009). However, recent studies suggest this relationship may be taxa-specific, with invertebrates and diatoms appearing to be more sensitive to selective pressures during transportation that cause greater fluctuations in the number of released species than for other taxa, like dinoflagellates (Briski et al. 2012).

When mapping cumulative human impacts to the CCLME, Halpern et al. (2009) modeled invasive species as a function of ballast water release in ports. In this case, port volume data (in metric tons) were available for 618 global ports from several sources: the 2002 World Port Ranking (N=36) and 2003 U.S. Port Ranking (N=102) compiled by the American Association of Port Authorities (http://www.aapa-ports.org), Australia ports database (N=30; http://www.aapma.org.au/tradestats; access date 3/19/05), and Lloyds List database [N=450; Ref (S17)]. Thus, data are available and comparable at many different scales around the globe. It should be noted, however, that changes in ballast water regulations and treatment technologies may have or will likely in the future influence the risk of invasive species introduction (Waite et al. 2003).

The U.S. Department of Transportation projects that, compared to 2001, total freight moved through U.S. ports will increase by more than 50 percent by 2020 and the volume of international container traffic will more than double (American Association of Port Authorities Fact Sheet 2011: http://www.aapa-ports.org/files/PDFs/facts.pdf). In order to estimate the potential for species invasions, we used data on the total amount of shipping cargo (thousands of short tons converted to millions of metric tons) that moved through each port along the Pacific Coast of the United States. These data were available from the U.S. Army Corps of Engineers Navigation Data Center (http://www.navigationdatacenter.us/data/datawcus.htm). CSV files were available for years 1993 – 2011. Ports in the states of California, Oregon and Washington were used to calculate the sum of cargo being shipped and received in ports within the CCLME.

In addition to port volume, aquaculture has been associated with historic increases in invasive species, so an index that combines port activity and aquaculture (perhaps imports) should be added to this list of indicators and evaluated in the future. There are examples of combining these two metrics into a single spatial snapshot (Halpern et al. 2008, Halpern et al. 2009), but we need to modify this method into a temporal time series.

STATUS AND TRENDS

The status and trends of invasive species in the CCLME were measured using the amount of cargo moving through coastal ports of the CCLME (Table AP5). Using this indicator, the number of potentially invasive species entering ports along the CCLME has decreased over the last five years, but the short-term average is still within 1SD of the long-term average of the entire time series (Fig. AP43). This decreasing trend will quickly revert to an increasing trend if port volumes continue to increase as they have over the last two years of the dataset. In addition to using this indicator, it would be good to develop an index that combines port volume and aquaculture as a more thorough indicator of the status and trends of invasive species.

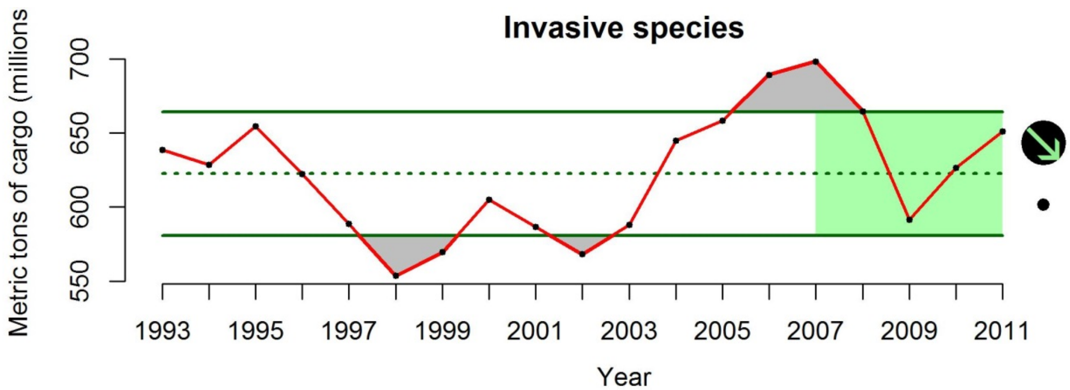


Figure AP43. Metric tons (millions) of cargo moved through ports in WA, OR and CA.

LIGHT POLLUTION

BACKGROUND

Ecological light pollution has demonstrable effects on the behavioral and population ecology of organisms in natural settings (Rich and Longcore 2006). As a whole, these effects derive from changes in orientation, disorientation, or misorientation, and attraction or repulsion from the altered light environment, which in turn may affect foraging, reproduction, migration, and communication (Longcore and Rich 2004). Many nocturnally migrating birds die or lose a large amount of their energy reserves during migration as a result of encountering artificial light sources (Poot et al. 2008). Marine zooplankton and numerous fish species are known to vertically migrate in the water column (Cushing 1951, Enright and Hamner 1967). This diel pattern of behavior allows zooplankton to avoid many visually-based predators while foraging in productive waters at night (Zaret and Suffern 1976). Diel vertical migration to avoid predation is also widespread among pelagic marine fishes (Neilson and Perry 1990, Watanabe et al. 1999). Even intertidal organisms display patterns of movement that are related to abiotic conditions, including patterns of light (Warman et al. 1993). In their early pelagic larval stages, more than 80% of fish and invertebrate species respond positively to light and migrate to the surface layers (Thorson

1964), thus changes in ambient light may have significant influence on the settlement patterns of these species.

For some species that nest on beaches, such as sea turtles, excess amounts of light along the coast cause considerable disruptions to their innate behaviors. Light pollution on nesting beaches alters critical nocturnal behaviors such as, how to choose a nesting site, how to return to the sea after nesting, and how hatchlings find the sea after emerging from their nests (Witherington and Martin 2000). Changes in the amount of polarized light also affect predator-prey relationships. As many marine species are visual predators, they use changes in the surrounding water's polarization signature to identify the presence of prey (Horváth et al. 2009). Planktivores are well-adapted at using changes in the polarization of the water to detect zooplankton that would otherwise be transparent (Flamarique and Browman 2001). Cephalopods also use polarized light as a hunting cue (Shashar et al. 1998) while other aquatic predators use light to detect camouflaged or distant prey resources (Shashar et al. 1998, Marshall et al. 1999). Thus, alterations to the natural light/dark cycles may allow for increased predation rates and subsequent changes to the community structure of areas with high levels of light pollution (Longcore and Rich 2004).

EVALUATION AND SELECTION OF INDICATORS

We evaluated only one indicator of light pollution in the CCLME: a normalized index of nighttime light pixels present in waters of the CCLME (Table AP4). This indicator is based on data collected by the U.S. Air Force Weather Agency and processed by NOAA's National Geophysical Data Center (NGDC). This dataset is available from 1992 – 2010 on the NGDC's website: http://www.ngdc.noaa.gov/dmsp/downloadV4composites.html. Specifically, we used the "Average Lights x Pct" (average nighttime lights, hereafter) data layers for satellites F12-18 and years 1994 – 2010 (we deleted data from satellite F10 based on recommendations from Elvidge et al. (2009)). These data layers were derived from the average visible band digital number (DN) of cloud-free light detections multiplied by the percent frequency of light detection. The inclusion of the percent frequency of detection term normalized the resulting digital values for variations in the persistence of lighting. For instance, the value for a light only detected half the time is discounted by 50%. Note that this product contains detections from fires and a variable amount of background noise.

We clipped each data layer to the area of the CCLME. This polygon was created from the California Current LME data layer provided on NOAA's Large Marine Ecosystems of the World website (http://www.lme.noaa.gov/). However, we extended the northern boundary to the northern tip of Vancouver island, British Columbia as defined by the previous California Current Integrated Ecosystem Assessment (Fig. AP44; Levin and Schwing 2011).

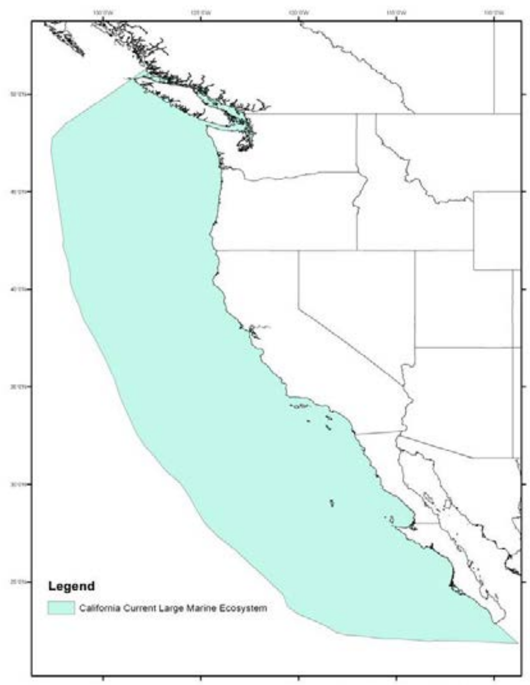


Figure AP44. Polygon of the CCLME used to clip all nighttime lights data layers

Data layers were collected by different satellites with no internal calibration instruments, so data values are not directly comparable among years without a calibration method. Because data were collected by overlapping satellites we were able to calibrate among years using calibration equations provided by Chris Elvidge of the NGDC. We used the coefficients in the calibration equations to standardize the underlying data values in each pixel cell of each data layer. After calibration, we summed the value of all average nighttime lights for each cell in each data layer. For years in which multiple satellites collected data, we averaged the summed values for that year. These sums-of-average nighttime-light values were then normalized across years for the final metric.

STATUS AND TRENDS

The status and trends of light pollution in the CCLME were measured using a normalized index of the sum of average nighttime lights (Table AP5). These data were processed and made available by the U.S. Geophysical Data Center. According to this indicator, light pollution has been constant over the last five years and is within 1SD of the long-term average of the time series (Fig. AP45). This result is a little unexpected due to the contrasting increases observed in coastline populations. The overall time series showed that light pollution steadily decreased from 1995 – 2004 within the CCLME and has been at these relatively low levels ever since.

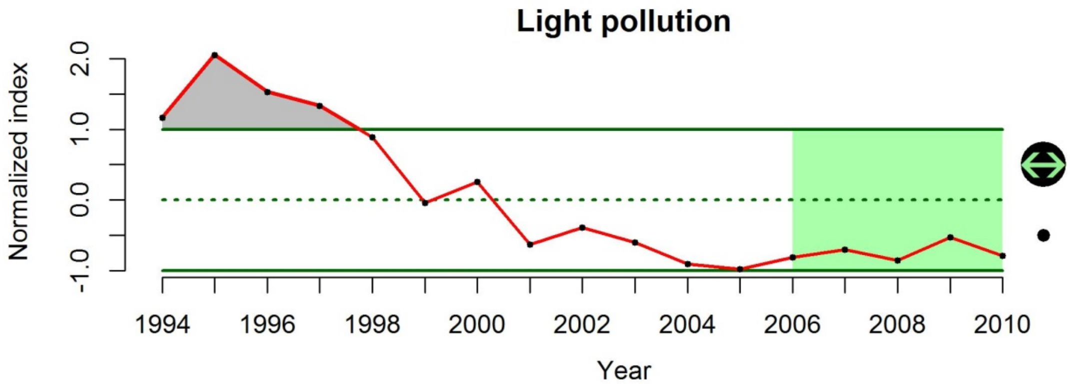


Figure AP45. Normalized index of the sum of average nighttime lights in waters of the CCLME.

MARINE DEBRIS

BACKGROUND

Marine debris is ubiquitous to all habitats of the ocean, for example in the form of metal cans or plastic bags on the beach (Ribic et al. 2012), derelict fishing gear caught on rocky bottom habitats (Good et al. 2010), household garbage in deep-water canyons (Watters et al. 2010) or micro-plastics in offshore surface waters (Doyle et al. 2011). The presence of marine debris along the coast extends from the shoreline to the greatest depths of the California Current, while 80% of this debris has been estimated to be from terrestrial runoff (Faris and Hart 1994). Data collected by Watters et al. (2010) using submersibles showed increases in marine debris on the ocean bottom in deep submarine canyons and continental shelf locations off California from the 1990's – 2007. Bauer et al (2008) found significantly higher densities of recreational fishing and other debris on rock ledges compared to other bottom types due to concentrated fishing effort where recreationally important fishes associate and the likelihood of gear becoming snagged on complex habitat.

While in some areas of the world the quantities of marine debris apparently show a decreasing trend during the past two decades (Ribic et al. 1997), other authors have reported increases (Coe and Rogers 1997). In general, the National Academy of Sciences (Criddle et al. 2008) has concluded that there is little quantitative information on amounts, sources, and trends of marine debris. However, recent programs such as the National Marine Debris Monitoring Program has developed standardized methods to quantify coastal debris and other surveys have begun to systematically quantify debris in meaningful ways (Gilfillan et al. 2009, Keller et al. 2010, Doyle et al. 2011). There are many coastal clean-up programs quantifying "marine debris" from beach clean-up surveys but these are not effective for quantifying temporal trends as the amount of debris collected is most likely related to the number of volunteers instead of the amount of debris. In addition, beach surveys are assumed to be an index of conditions in the surrounding waters, but there are no corresponding estimates of actual debris in the water to validate this assumption. Standardized programs with standardized metrics of measuring marine debris along the coast have been funded by the Environmental Protection Agency in the past (NMDMP) and these methods could be adopted by other community groups, which could make these data more effective.

Numerous researchers have documented the magnitude of marine debris and the threat that its ingestion or entangling poses to marine biota (Fowler 1987, Ryan 1990, Bjorndal et al. 1994, Moore et al. 2001, Moore et al. 2002). Marine debris, especially plastics, produces fragments that can be ingested by many marine organisms, resulting in mortality (Derraik 2002, Thompson et al. 2004, Browne et al. 2008). Marine debris in the form of lost fishing gear continues to “fish” by trapping fish, invertebrates, seabirds and marine mammals (Kaiser et al. 1996, Good et al. 2010). Marine debris may also impact populations behaviorally by concentrating individuals both at the water’s surface (FAD – floating aggregation devices; Aliani and Molcard 2003)) and on the bottom (artificial reefs; Stolk et al. 2007).

EVALUATION AND SELECTION OF INDICATORS

We evaluated three indicators for marine debris in the CCLME. The first is marine debris measured by the National Marine Debris Monitoring Program (NMDMP). This program developed standardized methods using volunteers to record specific types of marine debris among 18 sites in the northern and southern CCLME with Point Conception as the boundary between the two regions. Semi-permanent transects (500 m in length) were sampled at sites every 28 days from 1999 – 2007. This standardized sampling protocol allows for a temporal analysis of the data. Marine debris estimates from beach clean-ups or standardized sampling methods are still suspect as indicators of what debris is actually in the ocean waters or on the seafloor, so this indicator scores poorly in many criteria. However, the data are sound and provide nearly a decade of broad-scale spatiotemporal information that has been lacking.

The second indicator evaluated was beach trash collected during the annual California Coastal Cleanup Day which is organized by the California Coastal Commission’s Public Education Program and occurs on the same day as the International Coastal Cleanup day organized by the Ocean Conservancy. Volunteers show up and remove trash from beaches, lakes and other waterways. This trash is recorded by the volunteers and reported to the Education Program where the data are summarized and available for download: www.coastal.ca.gov/publiced/ccd/data.xls. Sampling is not standardized by material or number of volunteers, so the amount of trash collected is most likely an indicator of the number of people who volunteer each year, rather than the actual amount of trash and debris on the coast; thus this indicator scored low in comparison with the NMDMP program.

The final indicator evaluated was ocean-based measurements. This would be an actual measurement of debris in the oceans rather than measurements of trash on the beach that may or not make its way into the ocean. There are some surveys that record marine debris including the Northwest Fisheries Science Center's annual groundfish bottom trawl survey (Keller et al. 2010) which has collected and recorded marine debris since 2007. There are also examples of plankton surveys (e.g., California Cooperative Oceanic Fisheries Investigations (CalCOFI) and NOAA's Southwest Fisheries Science Center's ecosystem surveys) that also collect and quantify micro-plastics present in samples (Moore et al. 2002, Gilfillan et al. 2009, Doyle et al. 2011). However, these studies are usually short-term studies (1-2 years). The CalCOFI plankton samples (1951 to present) are archived in the Scripps Pelagic Invertebrates Collection, so there is opportunity to retroactively quantify plastics in these samples, but funding for this work is not presently available. Lack of data for ocean-based measurements of marine debris eliminates it from being useful.

Thus, we used estimates of marine debris from the NMDMP as the indicator for marine debris in the CCLME. Christine Ribic (U.S. Geologic Survey) provided predicted counts of marine debris data from the model developed by Ribic et al. (2012). These data were separated into northern and southern CCLME regions and into three different debris categories: land, ocean and general. We summed the predicted counts for all three debris categories to provide a single estimate for each region.

STATUS AND TRENDS

The status and trends of marine debris in the CCLME were measured using data from the Nation Marine Debris Monitoring Program (Ribic et al. 2012). These data were derived from a generalized additive model that used standardized surveys of debris along the coast of the CCLME. Using this indicator, marine debris in the northern CCLME (north of Point Conception, CA) was increasing between 2003 and 2007, but the short-term average was within historic levels (Fig. AP46a). In the southern CCLME, marine debris was relatively constant across the last five years of this time series and within historic levels (Fig. AP46b). This program no longer collects data, so an extension of this dataset will not occur unless funding for the program is revisited.

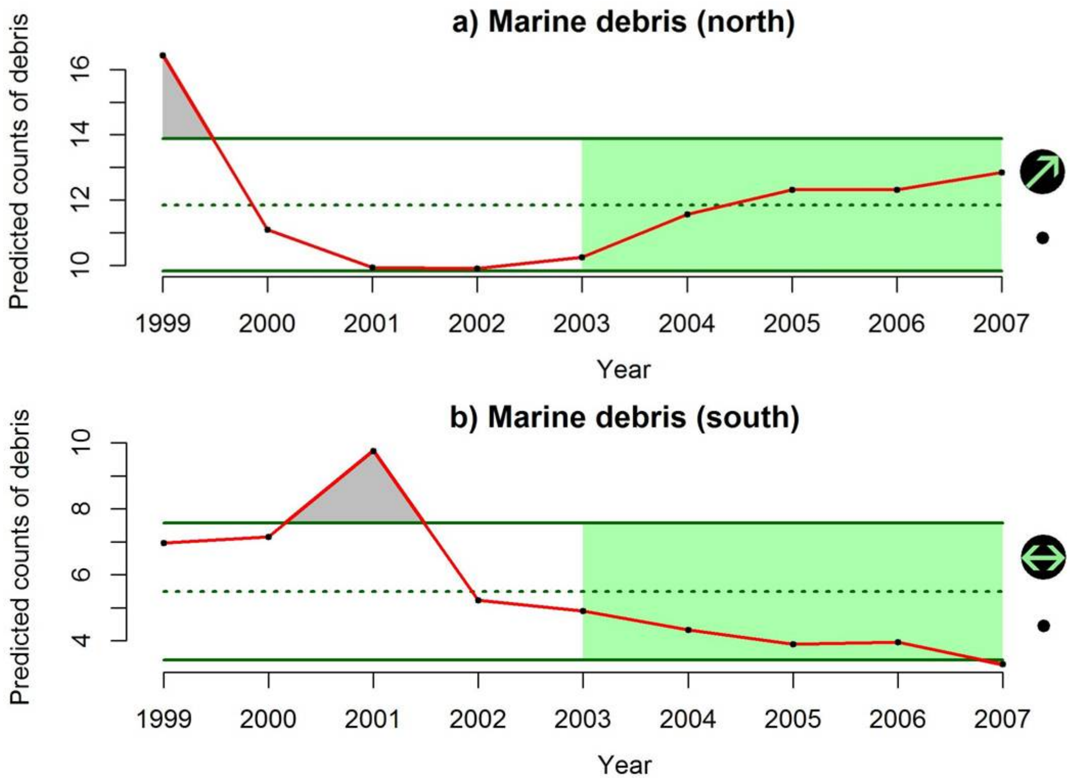


Figure AP46. Predicted counts of debris along the a) northern and b) southern coasts of the CCLME (Point Conception separates the regions). Data provided by Christine Ribic (Ribic et al. 2012).

NUTRIENT INPUT

BACKGROUND

Elevated nutrient concentrations are a leading cause of contamination in streams, lakes, wetlands, estuaries, and ground water of the United States (USEPA 2002). Nutrients (primarily nitrogen and phosphorus) are chemical elements that are essential to plant and animal nutrition; in marine waters, either phosphorus of nitrogen can limit plant growth. However, in high concentrations they can be considered water contaminants (USEPA 1999a).

Excess nutrients in a body of water can have many detrimental effects on drinking water supplies, recreational use, aquatic life use, and fisheries, and there are multiple indirect effects of nutrient enrichment of surface waters on human health. However, excessive nutrients are more often a cause of concern because of their role in accelerating eutrophication, which produces a wide range of other impacts on aquatic ecosystems and fisheries. Severely eutrophic conditions may adversely affect aquatic systems in a number of ways, including: algae blooms; declines in submerged aquatic vegetation (SAV) populations through reduced light transmittance, epiphytic growth, and increased disease susceptibility; mass mortality of fish and invertebrates through poor water quality (e.g., via oxygen depletion and elevated ammonia levels); and alterations in long-term natural community dynamics (Dubrovsky et al. 2010). Algal toxins harmful to animal and human health can be produced from blooms of some cyanobacteria species. High algal biomass also is associated with hypoxia (low dissolved-oxygen concentrations), which can contribute to the release of toxic metals from bed sediments, increased availability of toxic substances like ammonia and hydrogen sulfide, and fish kills. In recent years, nitrate and other nutrients discharged from the Mississippi River Basin have been linked to a large zone of hypoxia in the Gulf of Mexico along the Louisiana-Texas coast (Sprague et al. 2009).

Nonpoint sources of nutrients which affect stream and groundwater concentrations include fertilizer use, livestock manure, and atmospheric deposition (Ruddy et al. 2006). Within some coastal regions of the U.S. (e.g., mid-Atlantic states), much of the excess nutrients originates from point sources, such as sewage treatment plants, whereas failing septic systems often contribute to non-point source pollution and are a negative consequence of urban development (Johnson et al. 2008). However, nutrient loading can be a complex indicator to interpret, as a variety of hydro-geomorphic features (basin slope, basin area, mean annual precipitation, stream flow, and soil type) may also interact with possible nutrient sources to complicate estimates of nutrient concentration and loading. As well, there often are multiple and possibly counteracting anthropogenic factors influencing nutrient source and transport in a watershed, and without detailed knowledge of all important factors in each watershed, it may be difficult to discern the specific cause(s) of a trend in concentration (Sprague et al. 2009). Best land-use practices are known to reduce nutrient loading. Protocols for establishing total maximum daily load (TMDL) values of nutrients have been developed for specific bodies of water throughout the country (USEPA 1999a); however, we uncovered few examples in the literature of TMDLs for marine systems on the Pacific Coast of the U.S..

Despite some of the previous cautions, nutrient loading in freshwater systems is generally a well-understood indicator with a long history of reporting, as evidenced by requirements under the Clean Water Act, intensive nationwide monitoring programs at the federal, state, and local level, and a variety of national and regional trend reports by USGS (Ruddy et al. 2006, Wise et al. 2007, Sprague et al. 2009, Dubrovsky et al. 2010, Kratzer et al. 2011).

EVALUATION AND SELECTION OF INDICATORS

Nutrient input to coastal areas can be estimated in multiple ways. For this analysis, we evaluated only two types of nutrient input indicators: county-level inputs of nitrogen and phosphorus via fertilizers and nutrient loading (TN, TP) from stream monitoring records.

Halpern et al. (2009) used time series data from Nolan and Hitt (2006) on county-level fertilizer application data from 1992-2001 (kgs/hectare) and confined manure (primarily from dairy farms) from 1992-1997. These files (http://water.usgs.gov/GIS/dsdl/gwava-s/index.html) (Nolan and Hitt 2006) have a relatively limited temporal range (between 1992 – 2001). A comparable alternative would be to compile county-level estimates of nutrient inputs (kg/km^2) to the land surface of the conterminous United States, presented from 1982-2006 based on fertilizer use, livestock manure, and atmospheric deposition (Ruddy et al. 2006, Gronberg and Spahr 2012)). An older time series (1945-1986) of nationwide fertilizer application data (Ruddy et al. 2006, Dubrovsky et al. 2010) could expand the time series further by assuming that watersheds bordering the Pacific Coast follow the same historic trends in fertilizer applications. More recent data (2007 – 2010) are expected in a forthcoming analysis and summary (N. Dubrovsky, USGS, *pers comm*). Models have been used to predict the probability of nitrate contamination in ground waters of the United States based on fertilizer loading and other factors (Nolan and Hitt 2006). It is unclear how this relates to coastal systems, however.

A more data-intensive approach would be to estimate nutrient loading from surface waters using publicly available data on nutrient concentrations and flow rates from various U.S. watersheds sampled by the USGS and various state and local agencies. Changes in stream flow are an important influence on nutrient concentrations in streams: depending on the particular nutrient sources in a watershed and how these nutrients are transported to the stream, increases or decreases in stream flow can lead to increases or decreases in concentrations (Sprague et al. 2009). Nutrient data are publicly accessible through the online USGS National Water Information System (NWIS) database at (http://nwis.waterdata.usgs.gov/usa/nwis/qwdata). The majority of data contained in the NWIS database are from water samples collected using standard methods described in U.S. Geological Survey (variously dated). USGS flow data can be accessed from (http://nwis.waterdata.usgs.gov/nwis/dv/?referred_module=sw). Nutrient (TN and TP) loading can be estimated at various time increments (e.g., daily, annual) using LOADEST, a USGS program that finds a best fit data model for flux as a function of discharge. The Yale University interface LOADRUNNER (http://environment.yale.edu/loadrunner/) calculates daily, monthly, and annual element fluxes from these USGS water quality sample and stream flow data sources.

Nutrient trends in West Coast rivers (1993-2003) have been summarized using similar methods in a recent report by Sprague et al (2009), which showed that flow adjusted trends in total phosphorus concentrations were generally upward or non-significant at sites in the Southwestern U.S. and non-significant in the Northwestern U.S.

Trends in total nitrogen concentrations generally were downward or non-significant at sites in the Northwestern U.S., but mixed in all other regions. Regional reports include an analysis of trends (1993 – 2003) in the Columbia River and Puget Sound basins (Wise et al. 2007) and the Sacramento, San Joaquin, and Santa Ana Basins, California (Kratzer et al. 2011). In the Pacific Northwest study, point-source nutrient loads generally were a small percentage of the total catchment nutrient loads compared to nonpoint sources, with most of the monitoring sites showing decreasing trends in TN and TP, indicating that inputs from nonpoint sources of nutrients probably have decreased over time in many of the catchments (Wise et al. 2007). In the California study, most trends in flow-adjusted concentrations of nutrients in the Sacramento Basin and Santa Anna River were downward, whereas nitrogen trends in the San Joaquin Basin were upward, especially over the 1975–2004 time period (Kratzer et al. 2011). As all of these studies note, fertilizer use, livestock manure, atmospheric deposition, population growth, and source loading (e.g., wastewater treatment plants) are all known nutrient sources that can contribute to increasing nutrient stream loads. However, basin slope, basin area, mean annual precipitation, and soil type may also interact with these sources, and flow-adjusted trends in concentration can also be complex, as there often are multiple and possibly counteracting anthropogenic factors influencing nutrient source and transport in a watershed. Without detailed knowledge of all important factors in each watershed, it may be difficult to discern the specific cause(s) of a trend.

Each of these indicators scored relatively well and there were no glaring differences (Table AP4) to discern which to use. One of the goals of the indicator selection process is to develop operationally simple indicators, so we have chosen to use the simple alternative: county-level inputs of nitrogen and phosphorus via fertilizers. We extracted data from Ruddy et al. (2006) and Gronberg & Spahr (2012) for counties in WA, OR, CA, ID, MT and WY that drain into the California Current. We only used counties that had at least 50% of their area within a CC watershed. We then summed 'farm' and 'nonfarm' input of nitrogen and phosphorus from fertilizer use across relevant counties for the years 1987 – 2006 (data available at: http://water.usgs.gov/GIS/metadata/usgswrd/XML/sir2012-5207_county_fertilizer.xml). We then extracted nationwide data for 1945 – 2001 from figure 7 in Ruddy et al. (2006). We calculated the proportion of nitrogen and phosphorus that these counties accounted for in the nationwide data for the years 1987 – 2001. We then used the average proportion and multiplied that by the nationwide data for the years 1945 – 1986 to get estimates of nitrogen and phosphorus input across an extended temporal scale.

There were also statewide preliminary data available from the USGS (*pers comm* J. Gronberg) for 2007 – 2010. Because these data were at the state level, we calculated the proportion of statewide data that was likely contributed by counties within watersheds of the CCLME. In order to do this, we used statewide data from the 1987 – 2006 dataset for each state containing watersheds of the CCLME (CA, OR, WA, ID, MT, WY) and calculated the proportion of farm and non-farm nitrogen and phosphorus that was contributed by counties in watersheds of the CCLME for each year. We then multiplied the average of these proportions and the statewide data from 2007 – 2010 to calculate estimates of nitrogen and phosphorus in the CCLME. These data were appended to the data from 1945 – 2006 to create a full time series from 1945 – 2010. We then normalized the time series data for nitrogen and phosphorus separately, summed the normalized values for each year, and then re-normalized these sums across all years to get a single normalized index of the sum of nitrogen and phosphorus input from fertilizers across counties that drain into the California Current.

STATUS AND TRENDS

The status and trends of nutrient input into the CCLME were measured using a normalized index of the sum of nitrogen and phosphorus applied to lands as fertilizers in counties that drain into the California Current (Table AP5). Using this dataset, nutrient input has decreased over the last five years of the dataset (2006 – 2010) but the short-term average was > 1SD of the long-term average of the time series (Fig. AP47). Overall, the application of nitrogen and phosphorus increased steeply since the beginning of this time series until the early 1980's. Input of these nutrients seemed to plateau through the 1980's and 1990's before increasing again in the 2000's. The most recent decline was due to a large decrease in the amount of phosphorus from farms in California in 2009.

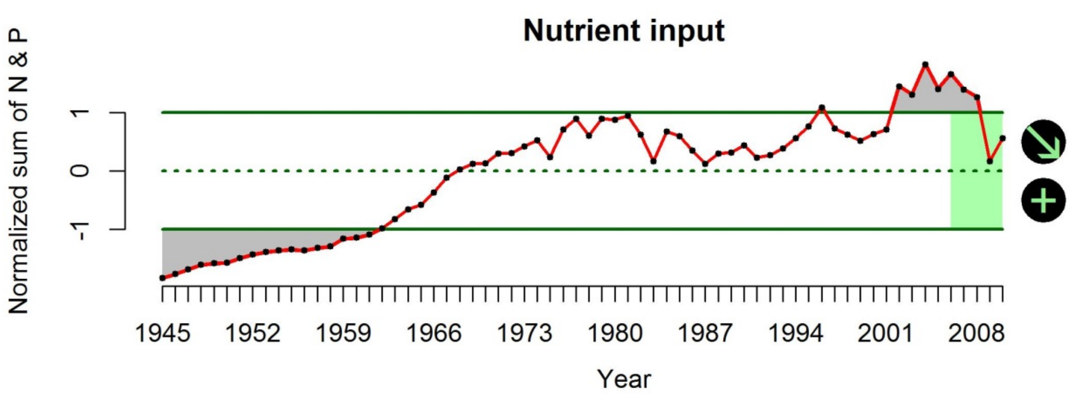


Figure AP47. Normalized index of the sum of nitrogen and phosphorus applied as fertilizers in WA, OR and CA.

OCEAN-BASED POLLUTION

BACKGROUND

The impact of ocean-based pollution is wide-spread, as we include pollution from sea-going vessels and activity within ports throughout the California Current. Marine ports in the United States are major industrial centers providing jobs and steady revenue streams yet contributing significantly to pollution. Ships with huge engines running on bunker fuel without emission controls, thousands of diesel trucks per day, diesel locomotives, and other polluting equipment and activities at modern seaports cause an array of environmental impacts that can seriously affect local communities and marine and land-based ecosystems throughout a region (Bailey and Solomon 2004). As vessels transit within ports, along the coast, and along international shipping lanes, there are inevitable discharges of waste, leaks of oil and gas, loss of cargo during rough seas, and increased risk of oil spills from oil shipping vessels. Beaches close in proximity to oil shipping lanes have been observed to have high tar content related to the degree of oil pollution in the sea (Golik 1982).

The effects of oil pollution on components of the CCLME are both direct and indirect. Because seabirds and marine mammals require direct contact with the sea surface, these taxa experience high risk from floating oil (Loughlin 1994). Oiled seabirds and marine mammals lose the insulating capacity of their feathers and fur, which can lead to death from hypothermia (Peterson et al. 2003). Chronic exposure to partially weathered oil is toxic to eggs of pink salmon *Oncorhynchus gorbuscha* and herring *Clupea pallasii* (Marty et al. 1997, Heintz et al. 2000). Many effects of exposure to oil and the associated polycyclic aromatic hydrocarbons (PAHs) are sublethal and have lasting effects on individual survival that may scale up to population-level responses. For example, embryos of zebrafish *Danio rerio* exposed to PAHs showed delayed changes in heart shape and reduced cardiac output (Hicken et al. 2011). Strandings of oiled seabirds have been used as an indicator of chronic oil pollution along heavily used shipping lanes in the North Sea and recent studies show declining oiling rates, reflecting reduced oil spills (Camphuysen 1998, Camphuysen 2010).

In addition to the potential for pollution, other common impacts of vessel activities include vessel wake generation, anchor chain and propeller scour, vessel groundings, the introduction of invasive or nonnative species, and the discharge of contaminants and debris.

EVALUATION AND SELECTION OF INDICATORS

Ocean-based pollution was used as a measure of the risk associated with pollution that occurs and originates from ocean-use sectors. This pollution was assumed to derive from two primary sources (Halpern et al. 2009): the movement of commercial vessels (oil and gas leaks, loss of cargo, waste dumping, discharges, etc.) and activity within ports (oil and gas leaks, loss of cargo, discharges, etc.). We evaluated only one indicator for ocean-based pollution, which combined data from commercial shipping activity and port volume in the CCLME (Table AP4). This indicator is well-supported in the literature as a proxy for ocean-based pollution and there are long-term continuous time series of data collected by the U.S. Army Corps of Engineers.

This indicator combined the use of two previously described indicators for commercial shipping activity (volume of water disturbed during transit of vessels) and invasive species (port volume). The only difference is that for volume of water disturbed, we summed all vessel movements within ports and along the coast. Commercial shipping activity was a measure of the risk associated with ship strikes on large animals, groundings, and habitat modification, so movement within ports was not relative to that pressure. The addition of the volume of water disturbed within ports was relatively undetectable and did not alter the trends of the original data. In order to combine these two datasets into one indicator, we normalized each time series separately, summed the normalized values, and then re-normalized these sums to produce the final normalized index for ocean-based pollution.

STATUS AND TRENDS

The status and trends of ocean-based pollution were measured in the CCLME using a normalized index which combined 1) the volume of water disturbed by vessels in the CCLME during transit between or within ports and 2) the annual port volume of ports in the CCLME (Table AP5). Using this indicator, ocean-based pollution has decreased over the last five years, but the short-term average is within 1SD of the long-term average (Fig. AP48). The decreasing trend in this dataset likely reflects economic conditions of the shipping and port industries over the last five years; however, this indicator appears likely to reverse its trend in the near future if port volumes and commercial shipping activity continue to increase as they have over the last two years of the dataset. The predominant contributor to the trend for “Commercial shipping activity” is foreign vessel traffic and these data are available back to 1997, while the domestic data may be available back to 1994 if funding were available to the USACE to perform this data inquiry. These data could be integrated with the port volume data, which are available back to 1993, to increase the duration of this indicator’s time series.

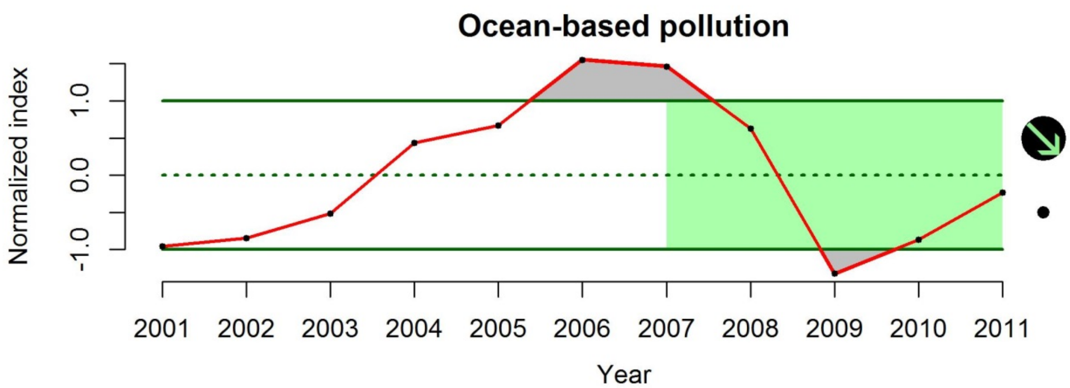


Figure AP48. Normalized index that combines the volume (millions m³) of water disturbed by vessels during transit in port and along the coast and the volume of cargo (millions of metric tons) moving through ports in the states of CA, OR and WA.

OCEAN MINING

BACKGROUND

This pressure has not been evaluated to date.

EVALUATION AND SELECTION OF INDICATORS

This pressure has not been evaluated to date.

STATUS AND TRENDS

Indicators have not been evaluated in order to determine the status and trends of this pressure.

OFFSHORE OIL AND GAS ACTIVITY

BACKGROUND

The environmental risks posed by offshore exploration and production of oil and gas are well known. They include the release of hydrocarbons to the environment, smothering of benthos, sediment anoxia, destruction of benthic habitat, and the use of explosives (Macdonald et al. 2002). Petroleum exploration involves seismic testing, drilling sediment cores, and test wells in order to locate potential oil and gas deposits (Johnson et al. 2008). Petroleum production includes the drilling and extraction of oil and gas from known reserves. Oil and gas rigs are placed on the seabed and as oil is extracted from the reservoirs, it is transported directly into pipelines. While rare, in cases where the distance to shore is too great for transport via pipelines, oil is transferred to underwater storage tanks. From these storage tanks, oil is transported to shore via tanker. According to the Minerals & Management Service, there are 21,000 miles (~38,000 km) of pipeline on the United States outer coastal shelf (OCS). According to the National Research Council (NRC), pipeline spills account for approximately 1,900 tons per year of petroleum into U.S. OCS waters, primarily in the central and western Gulf of Mexico. Other potential negative impacts include physical damage to existing benthic habitats within the “drop zone”, undesired changes in marine food webs, facilitation of the spread of invasive species, and release of contaminants as rigs corrode (Macreadie et al. 2011).

However, the effects of oil rigs on fish stocks are less conclusive, with these risks possibly balanced out by enhanced productivity brought about by colonization of novel habitats by structure-associated fishes and invertebrates (e.g., rockfish, encrusting organisms, etc.) (Love et al. 2006). Decommissioned rigs could enhance biological productivity, improve ecological connectivity, and facilitate conservation/restoration of deep-sea benthos (e.g. cold-water corals) by restricting access to fishing trawlers.

Petroleum extraction and transportation can lead to a conversion and loss of habitat in a number of other ways. Activities such as vessel anchoring, platform or artificial island construction, pipeline laying, dredging, and pipeline burial can alter bottom habitat by altering substrates used for feeding or shelter. Disturbances to the associated epifaunal communities, which may provide feeding or shelter habitat, can also result. The installation of pipelines associated with petroleum transportation can have direct and indirect impacts on offshore, nearshore, estuarine, wetland, beach, and rocky shore coastal zone habitats. The destruction of benthic organisms and habitat can occur through the installation of pipelines on the seafloor. Benthic organisms, especially prey species, may recolonize disturbed areas, but this may not occur if the composition of the substrate is drastically changed or if facilities are left in place after production ends (Johnson et al. 2008).

Offshore oil rigs in the California Current are exclusively found in southern California. Increasing pressure to find oil on continental shelves will probably increase the risk of hydrocarbon pollution to the North Pacific: Canada (British Columbia), the U.S.A. (California), Republic of Korea and Japan have all indicated that they intend either to begin or to expand exploration on the continental shelves of the Pacific, and drilling already occurs off Alaska and California and in the East China Sea (Macdonald et al. 2002).

EVALUATION AND SELECTION OF INDICATORS

To estimate the temporal trend in activities related to offshore oil and gas activities off California, we evaluated two indicators: oil and gas production and the number of oil and gas wells in the CCLME (Table AP4). Both indicators have long time series of data available and are easily understood by the public and policymakers. However, the number of oil and gas wells may not reflect how much continuous activity surrounds each oil platform or well, and thus may not capture the variability associated with impact to the seafloor. Production of oil and gas from producing wells will capture the potential effects of continued activities (e.g., new anchorings, drilling, or maintenance of wells) on the seafloor. In addition, available data for production values have a broader temporal extent (1970 – 2012) than number of wells (1981 – 2012), thus production values rated higher and will be used to measure status and trends of this pressure.

We retrieved state and federal offshore oil and gas production data from reports of the California State Department of Conservation's Division of Oil, Gas, and Geothermal Resources (ftp://ftp.consrv.ca.gov/../pub/oil/annual_reports/) for the years 1981 – 2009. A second on-line data resource, the National Ocean Economics Program at the Monterey Institute of International Studies (http://www.oceaneconomics.org/Minerals/oil_gas.asp), was used to verify these numbers and expand the temporal extent of the production rate data series from 1970 to 2012. Estimates of natural gas production for state and federal offshore wells were accessible through the U.S. Energy Information Administration (http://www.eia.gov/dnav/ng/ng_prod_sum_dcu_rcatf_a.htm). Total oil production and total gas production were normalized independently, summed together and renormalized to create an index of oil and gas production in the CCLME.

STATUS AND TRENDS

The status and trends of offshore oil and gas activity in the CCLME were measured using a normalized index of oil and gas production from offshore wells in state and federal waters in California (Table AP5). Offshore oil and gas activity in the CCLME has been stable over the last five years, but the short-term mean was more than 1 SD below the long-term mean (Fig. AP49). Oil and gas production has declined steadily since the mid-1990's.

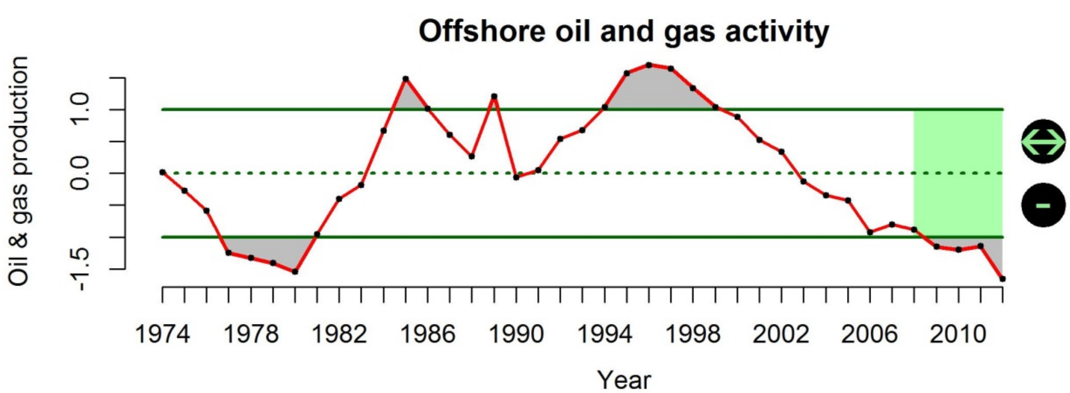


Figure AP49. Normalized index of the sum of oil and gas production from offshore wells in CA.

ORGANIC POLLUTION

BACKGROUND

Organic pollution encompasses numerous classes of chemicals including pesticides, polycyclic aromatic hydrocarbons (PAHs) and other persistent organic pollutants (POPs), and is introduced to the marine environment via runoff to rivers, streams and groundwater, poor-disposal practices and the discharge of industrial wastewater. While all pollutants can become toxic at high enough levels, there are a number of compounds that are toxic even at relatively low levels (Johnson et al. 2008). The U.S. Environmental Protection Agency (USEPA) has identified and designated more than 126 analytes as "priority pollutants." According to the USEPA, "priority pollutants" of particular concern for aquatic systems include: (1) dichlorodiphenyl trichloroethane (DDT) and its metabolites; (2) chlorinated pesticides other than DDT (e.g., chlordane and dieldrin); (3) polychlorinated biphenyl (PCB) congeners; (4) metals (e.g., cadmium, copper, chromium, lead, mercury); (5) polycyclic aromatic hydrocarbons (PAHs); (6) dissolved gases (e.g., chlorine and ammonium); (7) anions (e.g., cyanides, fluorides, and sulfides); and (8) acids and alkalis (Kennish 1998, USEPA 2003). While acute exposure to these substances produces adverse effects on aquatic biota and habitats, chronic exposure to low concentrations probably is a more significant issue for fish population structure and may result in multiple substances acting in "an additive, synergistic or antagonistic manner" that may render impacts relatively difficult to discern (Thurberg and Gould 2005).

Pesticides can affect the health and productivity of biological populations in three basic ways: (1) direct toxicological impact on the health or performance of exposed individuals; (2) indirect impairment of the productivity of the ecosystem; and (3) loss or degradation of vegetation that provides physical structure for fish and invertebrates (Hanson et al. 2003, Johnson et al. 2008). For many marine organisms, the majority of effects from pesticide exposures are sublethal, meaning that the exposure does not directly lead to the mortality of individuals. Sublethal effects can be of concern, as they impair the physiological or behavioral performance of individual animals in ways that decrease their growth or survival, alter migratory behavior, or reduce reproductive success (Hanson et al. 2003, Johnson et al. 2008), but in general the sublethal impacts of pesticides on fish health are poorly understood. Early development and growth of organisms involve important physiological processes and include the endocrine, immune, nervous, and reproductive systems. Many pesticides have been shown to impair one or more of these physiological processes in fish (Gould et al. 1994, Moore and Waring 2001). The direct and indirect effects that pesticides have on fish and other aquatic organisms can be a key factor in determining the impacts on the structure and function of ecosystems (Preston 2002). One of the most widely recognized effects of organic pollution was the decline of bald eagles and brown pelicans during the 1960's and 1970's. These birds accumulated DDT in their tissues, which changed their ability to metabolize calcium, which resulted in birds producing abnormally thin eggshells that led to reproductive failure (Hickey and Anderson 1968, Blus et al. 1971).

Petroleum products, including PAHs, consist of thousands of chemical compounds which can be particularly damaging to marine biota because of their extreme toxicity, rapid uptake, and persistence in the environment (Johnson et al. 2008). PAHs have been found to be significantly higher in urbanized watersheds when compared to non-urbanized watersheds. Low-level chronic exposure to petroleum components and byproducts (i.e., polycyclic aromatic hydrocarbons [PAH]) have been shown in Atlantic salmon *Salmo salar* to increase embryo mortality, reduce growth (Heintz et al. 2000), and lower the return rates of adults returning to natal streams (Wertheimer et al. 2000). Effects of exposure to PAH in benthic species of fish include liver lesions, inhibited gonadal growth, inhibited spawning, reduced egg viability and reduced growth (Johnson et al. 2002). In general, the early life history stages of most species are most sensitive, juveniles are less sensitive, and adults least so.

Municipal wastewater treatment facilities have made great advances in treatment practices to eliminate pollutants prior to discharge, but any discharges will undoubtedly affect the quality of habitat in estuarine environments (Diaz and Rosenberg 1995, Kam et al. 2004). Several studies have shown that many benthic species increase in abundance and biomass in response to increased organic loading (Weston 1990, Savage et al. 2002, Alves et al. 2012). However, excessive nutrient enrichment can lead to hypoxia and potentially anoxic conditions, consequently leading to declines or shifts in biomass and diversity in the benthic community (Ysebaert et al. 1998, Essington and Paulsen 2010). Species richness among benthic communities has been shown to increase in relation to both temporal and spatial distance from organic loading sources (Savage et al. 2002, Wear and Tanner 2007). In addition to municipal wastewater treatment facilities, widely-distributed poorly-maintained septic systems contaminate shorelines in many places (Macdonald et al. 2002).

EVALUATION AND SELECTION OF INDICATORS

We evaluated a single indicator for organic pollution in the CCLME: toxicity-weighted concentrations of pesticides (Table AP4). The toxicity of a chemical is an important factor when trying to understand the potential effects of pollution on biological components and is widely used to weight the relative importance of specific chemicals (Toffel and Marshall 2004); thus, we did not evaluate concentrations alone as an indicator.

Recovery-adjusted concentrations (micrograms/liter) of 16 pesticides detected most frequently in urban streams were assessed by the U.S. Geological Survey using data from sites all across the United States (Ryberg et al. 2010, Martin et al. 2011). These data are easily accessible from the U.S. Geological Survey (http://pubs.usgs.gov/ds/655/). We used data identified for trend analysis (trend = "KEEP" from USGS data) and from sites located in watersheds that drain into the CCLME (states of WA, OR, ID and CA). We calculated the mean recovery-adjusted concentration across all samples within a site for each pesticide for each year (1992 – 2010). We then averaged the mean site values for each pesticide across all sites to provide a final average for each pesticide for each year. Because three of the pesticides (fipronil, desulfinylfipronil, and fipronil sulfide) did not have data prior to 2002, we eliminated them. We then multiplied the averaged concentrations by their toxicity score and summed these values across all pesticides for each year. The toxicity score was calculated by dividing the pesticide's Indiana Relative Chemical Hazard Score (https://engineering.purdue.edu/CMTI/IRCHS/) by 100 (maximum value of the scoring system). For pesticides that were not in the IRCHS list, we used the average value of the other pesticides in our dataset.

STATUS AND TRENDS

The status and trends of organic pollution in the CCLME were measured using a toxicity-weighted index of recovery-adjusted concentrations of 13 pesticides measured in streams in watersheds that drain into the CCLME (Table AP5). Using this indicator, organic pollution has decreased over the last five years of the dataset, and the short-term average is within 1SD of the long-term average of the time series (Fig. AP50). Prior to this most recent trend, organic pollution showed large increases in the mid-2000's.

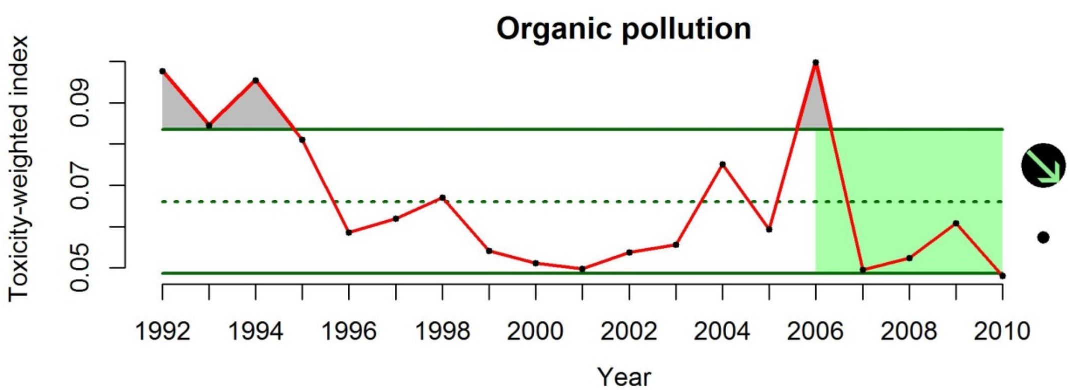


Figure AP50. Toxicity-weighted index of recovery-adjusted concentrations of 13 pesticides measured in streams in watersheds that drain into the CCLME.

POWER PLANTS

BACKGROUND

Water for thermoelectric power is used in generating electricity with steam-driven turbine generators. Coastal power plants draw in huge amounts of marine water for cooling purposes, creating an area around the intake pipes where larvae and small plants are entrained. These entrainment ‘plumes’ will vary in size and shape depending on ocean currents and the size of the power plant. The construction and operation of water intake and discharge facilities can have a wide range of physical effects on the aquatic environment including changes in the substrate and sediments, water quality and quantity, habitat quality, and hydrology. Most facilities in the U.S. that use water depend upon freshwater or water with very low salinity for their needs (Johnson et al. 2008), but facilities in the CCLME primarily depend on marine surface waters.

The entrainment and impingement of fish and invertebrates in power plant and other water intake structures have immediate as well as future impacts to estuarine and marine ecosystems (Johnson et al. 2008). Most of the immediate impact is removal of eggs, larvae and juveniles; not only is that fish and invertebrate biomass removed, but the biomass that would have been produced in the future will not become available to the ecosystem. Water intake structures, such as power plants and industrial facilities, are a source of mortality for managed-fishery species and play a role as one of the factors driving changes in species abundance over time. Organisms that are too large to pass through in-plant screening devices become stuck or impinged against the screening device or remain in the forebay sections of the system until they are removed by other means.

Determining the relative importance of these impacts, however, is more controversial, and may be equally dependent on year-class strength, recruitment, fishery mortality, predation, and a variety of other human facilities (dams, etc.) (Barnthouse 2000). The primary approach for assessing adult-equivalent population losses at coastal power plants in California has used the “Empirical Transport Model” (ETM), which relies on estimates of power plant entrainment and source water larval populations (Steinbeck et al. 2006). Although Steinbeck et al. (2006) conclude that the ETM may be the best current approach for these impact assessments, a variety of other considerations may play a more important role in determining entrainment impacts, including effectively sampling organisms potentially affected by entrainment (often determined by life history, including spawning location and timing), sampling frequency, determining source water areas potentially affected, and design, location, and hydrodynamics of intake structures. Helvey and Dorn (1987) examined the selective removal of reef fish associated with an offshore cooling-water intake structure, and found that removal was a selective process governed by species’ behavioral characteristics associated with the intake currents and visibility (fish may not be capable of rheotropic responses when illumination falls below a critical threshold. Diurnally active species seeking benthic cover at night were least susceptible to intake removal. Diurnally active species that hover in the water column at night and predators that periodically feed at twilight and evening hours (e.g., *Sebastes paucispinis*) were more susceptible to removal. Nocturnally active transient species, such as *Seriphus politus* and *Engraulis mordax*, were most susceptible to removal (Helvey and Dorn 1987).

EVALUATION AND SELECTION OF INDICATORS

We evaluated two indicators of power plant activity in the CCLME: 1) average daily saline water withdrawal volumes and 2) daily entrainment mortality (Table AP4). The largest total thermoelectric withdrawals on the West Coast are in California, where nearly all of the water was withdrawn from marine surface waters for use in once-through cooling systems (Kenny et al. 2009). Washington and Oregon thermoelectric power withdrawals rely almost exclusively on fresh surface waters. In 2005, the total daily water withdrawals for thermoelectric power generation from all West Coast states combined (WA, OR, CA) equaled over 49 million m^3/d, with the vast majority (96%; 47.7 million m^3/d) attributed to CA marine surface water withdrawals. Over the course of record-keeping, marine surface water withdrawals from California have consistently represented more than 80% of West Coast thermoelectric water withdrawals.

The USGS has conducted water-use compilations in the United States every 5 years since 1950 (http://water.usgs.gov/watuse/50years.html), and thermoelectric power has represented the largest total category of water withdrawals in every compilation since 1960 (Hutson et al. 2005, Kenny et al. 2009). Withdrawals by thermoelectric-power plants across the entire U.S. have ranged from a low of 151 million m^3/d during 1950 to a high of 794 million m^3/d in 1980. In 2005, thermoelectric water withdrawals totaled 760 million m^3/d and comprised 49 percent of total water use across the entire U.S. Declines in thermoelectric-power water withdrawals from 1980 to present are primarily a result of Federal legislation requiring stricter water-quality standards for return flow and by limited water supplies in some areas of the United States. Consequently, power plants have increasingly been built with or converted to closed-loop cooling systems or air-cooled systems instead of using once-through cooling systems. By 2000, an alternative to once-through cooling was used in about 60 percent of the installed steam-generation capacity in the power plants (Hutson et al. 2005).

There is a long history of studying and reporting impacts of cooling systems on fish populations, especially the Hudson River and other coastal estuaries along the mid-Atlantic (Barnthouse 2000). In California, calculations of daily entrainment mortality have been limited to a few power plants; historical data are limited and time series information is generally lacking. Furthermore, the uncertainties associated with estimating larval durations and hydrodynamics used in estimating the size of the source water populations make estimating variance for ETM problematic (Steinbeck et al. 2006).

Primarily due to data considerations (Table AP4), we selected average daily water withdrawals to estimate the potential entrainment impact of coastal power plants. We extracted the average daily withdrawal volumes (millions of gallons per day converted to millions of m^3 per day) of saline water over time from all thermoelectric power plants on the west coast of North America (Pacific Northwest and California regions, from Kenny et al. (2009) and other previous USGS water use reports (http://water.usgs.gov/watuse/50years.html). The temporal extent of these data ranges from 1955 to 2005 and the reporting interval is every five years.

STATUS AND TRENDS

The status and trends of power plants in the CCLME were measured using the volume (millions of m^3) of saline water withdrawn daily by thermoelectric power plants in WA, OR and CA (Table AP5). Because these data were sampled every 5 years, we interpolated the annual value over the last five years (asterisks in Fig. AP51) assuming a linear relationship between the last two data points in order to keep the short-term status (most recent five years) consistent with the other pressure indicators. The mean and SD of the dataset were calculated using the original dataset. Power plant activity was stable over the last five years of the dataset (2000 – 2005), but the short-term average was >1SD above the long-term average (Fig. AP51). Trends of water withdrawals by thermoelectric power plants have been stable or decreasing across the U.S. since the 1980's (Kenny et al. 2009), so the CCLME may have slightly elevated its power plant activity compared to the rest of the U.S. in the early 2000's. The 2010 report on estimated use of water in the United States was delayed and data availability is not expected until late in 2014.

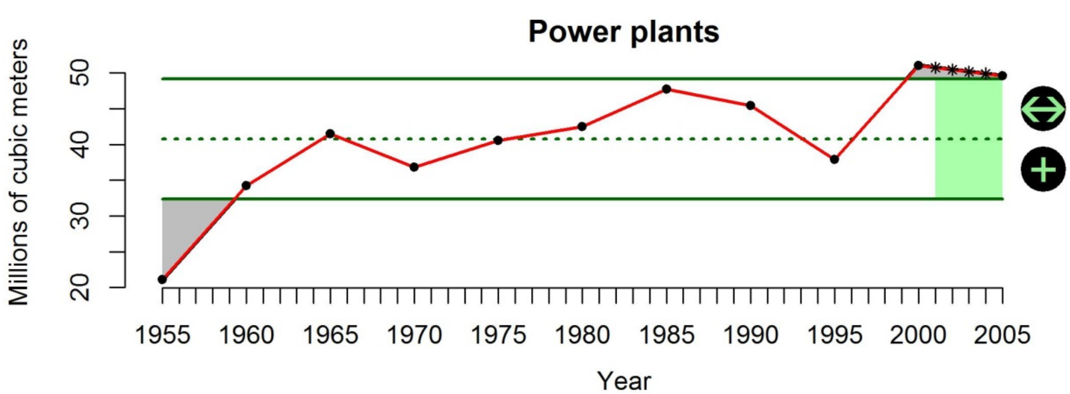


Figure AP51. Daily saline water withdrawals (millions m^3) from thermoelectric power plants in CA, OR and WA. Asterisks are interpolated values, but used to calculate short-term status and trends since this indicator is only measured every 5 years.

RECREATIONAL USE

BACKGROUND

People visiting beaches and coastal areas can impact intertidal and nearshore ecosystems through direct trampling or by disturbing or displacing species that would normally use those locations (Halpern et al. 2009). This may be particularly important to species which inhabit intertidal zones their entire lives or for species that reproduce or rest on populated beaches (Moffett et al. 1998, McClenachan et al. 2006, Defeo et al. 2009). Species which represent some value as a source of food (e.g., shellfish) or collections (e.g. seashells) will also be impacted with increases in beach visitations.

EVALUATION AND SELECTION OF INDICATORS

We evaluated only one indicator of recreational use: beach attendance. This indicator scored highly in most criteria (Table AP4) because it was used in previous studies as an indicator of direct human impact to intertidal and nearshore ecosystems (Halpern et al. 2008, Halpern et al. 2009). However, the use of state beaches and parks may not necessarily reflect how many people are actually spending time walking around on the beach or in the intertidal zones, but rather may reflect time spent at upland areas or simply sitting in their vehicles. There is also recent evidence that the methodologies used to calculate beach attendance by state agencies overestimate actual attendance in a non-random fashion (King and McGregor 2012).

For California, we extracted total visitor attendance at 48 California state parks identified as "State Beach" from the California State Park System Annual Statistical Reports: 2002 -2012 (http://www.parks.ca.gov/?page_id=23308). For Oregon, the only measure of annual beach attendance is collected by the Oregon Parks and Recreation Department's Stewardship Division for the years 2002 – 2013. This estimate is measured using automated car counters in the parking lots of coastal state parks. These estimates are based on the assumption that there are on average four occupants per vehicle (based on results of a statewide visitor survey). These measures are likely an overestimate of actual pressure on the associated beaches as some people use the parking lots and do not go to the beach. For Washington, the Washington State Parks and Recreation Commission collects attendance data at parks with ocean beach access and these data are available in annual "Attendance Reports". We limited these datasets to years in which data were available for all three states (2002 – 2012) and to parks/beaches that were open and censused in all years (i.e. if a state park was closed at some point during the time series, this park was excluded from the analysis). We normalized each state's attendance independently across the time series, summed these normalized values across all states for each year, and then renormalized these data for the final time series. Using the normalized sums of attendance (instead of only the sums of attendance) provided an estimate that weighted changes in annual attendance equally among all states. Otherwise, changes in beach attendance in California would completely drive the final time series due to the much larger magnitude of beach attendance in California.

STATUS AND TRENDS

The status and trends of recreational use were measured using the normalized sums of annual estimates of beach attendance at state parks and beaches in WA, OR and CA (Table AP5). Using this dataset, we found that direct human impact has decreased significantly over the last five years, but the short-term mean is still within 1 SD of the long-term mean of the dataset (Fig. AP52).

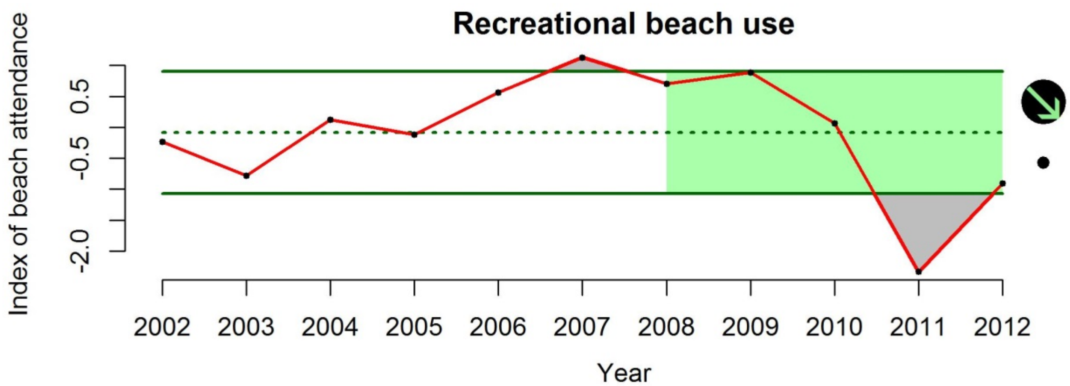


Figure AP52. Index of annual beach attendance at state parks and beaches with access points to a beach in WA, OR and CA.

SEAFOOD DEMAND

BACKGROUND

The global population continues to increase and seafood is one of the most important sources of protein for humans all over the world, so demand for edible fisheries products will continue to be a strong pressure on the world's oceans (Garcia and Rosenberg 2010). In addition to the underlying driver of population growth, the most recent report of the Dietary Guidelines for Americans has recommended Americans more than double their intake of seafood due to a variety of health benefits (DGAC 2010). Depending on the response and potential change in dietary behaviors by humans, pressure could increase greatly for the production of high-quality seafood. However, the production of world capture fisheries has been relatively constant since the 1980's (NRC 2006), and there is little room for increase. The world's demand for seafood has thus become more dependent on aquaculture production, which has been growing at about 8% annually, making it the fastest growing form of food production in the world. However, much of the feed for the aquaculture (and pig and poultry) industry is derived from forage fish species such as anchovy and capelin (Hannesson 2003). This pressure to catch fish in order to grow fish may not necessarily result in a net increase in the production of edible fish. Another common use of fisheries products is for use as fertilizers.

This pressure has obvious effects on the biological components of the CCLME through direct removals of individuals from the benthic and pelagic communities. Direct fishery removals, however, also have a host of indirect effects that have been discussed under the Fisheries Pressures.

EVALUATION AND SELECTION OF INDICATORS

We identified two primary indicators of seafood demand: total consumption and per capita consumption (Table AP4). Both indicators are published in NOAA's "Fisheries of the United States" annual reports to describe the utilization of fisheries products (http://www.st.nmfs.noaa.gov/st1/publications.html). Total edible and non-edible seafood demand evaluates higher (Table AP4) because fundamentally total consumption provides a concrete estimate of what is being used, whereas per capita consumption is simply based on the total consumption estimates divided by the population of the U.S.

We retrieved total consumption estimates (billion pounds) of total (imports and commercial landings) edible and non-edible seafood from each of the Fisheries of the United States annual reports which provided data from 1962 – 2012. Data were converted to millions of metric tons.

STATUS AND TRENDS

The status and trends of seafood demand in the CCLME were measured using total consumption of edible and non-edible fisheries products (Table AP5). Using this dataset, seafood demand has been unchanged over the last five years (Fig. AP53), but the short-term average was greater than 1SD of the long-term average. With total demand already at historic levels, increasing populations, and recommendations by the U.S. Dietary Guidelines to increase our intake of seafood, this indicator will likely increase over the next few years. If per capita consumption increases, as recommended, total consumption could increase dramatically as human populations continue to increase globally as well as in the CCLME. In many ways, seafood demand in states or countries outside of the CCLME will have a large impact on the trends of this indicator and may limit the ability of regional or national managers to alter the effects of this pressure.

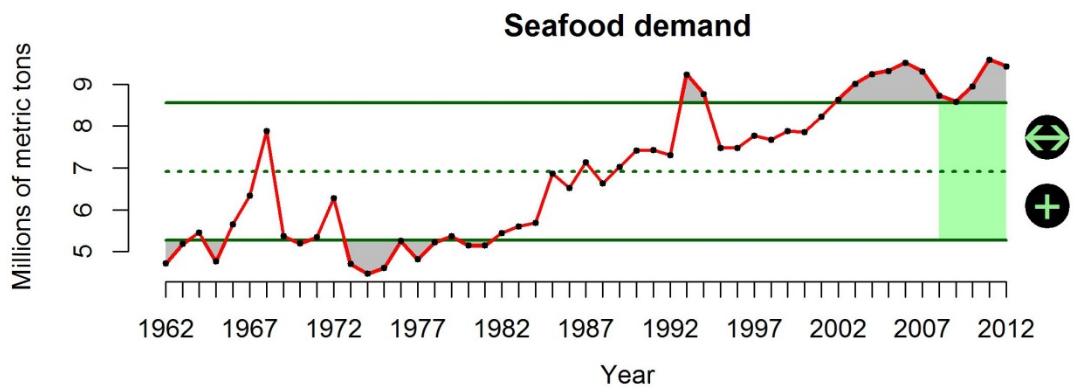


Figure AP53. Total consumption of edible and non-edible fisheries products across the United States.

SEDIMENT INPUT

BACKGROUND

Sediment is a natural component in water bodies and the uses they support, but can also impair them in many ways (USEPA 1999b). Excessive sediments in waterways can cause direct physical harm to organisms (e.g. clogged gills), as well as impairment of aquatic feeding, rearing, spawning, and refuge habitats. As well, sediment deficits can result in stream channel scour and destruction of other habitat features. As a result, the federal Clean Water Act requires states, territories, and authorized tribes to identify and list impaired waters every two years and to develop total maximum daily loads (TMDLs) for sediment in these waters, with oversight from the U.S. Environmental Protection Agency. TMDLs establish the allowable pollutant loadings, thereby providing the basis for establishing water quality-based controls (USEPA 1999b).

Rivers are important conduits of large amounts of particulate and dissolved minerals and nutrients to the oceans, and play a key role in the global biogeochemical cycle (Dai et al. 2009). Humans are simultaneously increasing the river transport of sediment and dissolved constituents through soil erosion activities, and decreasing this flux to the coastal zone through sediment retention in reservoirs (Syvitski et al. 2005, Milliman et al. 2008). The net result is a global reduction in sediment flux by about 1.4 BT/year over pre-human loads. Rivers are globally getting dirtier and would otherwise move more sediment to the coast if not for the impact of reservoirs. The seasonal delivery of sediment to the coast affects the dynamics of nutrient fluxes to the coast and has serious implications to coastal fisheries, coral reefs, and seagrass communities (Syvitski et al. 2005). One example includes a reduction in natural dissolved silicate loads, which translates into silicon limitation in the coastal zone that discourages diatom blooms and favors nuisance and toxic phytoplankton, thereby compromising the integrity of coastal food webs (Vorosmarty and Sahagian 2000). Coastal retreat, which is directly influenced by the reduction of riversupplied sediment, has major implications for human habitat because >37% of the world's population (2.1 billion people in 1994) lives within 100 km of a coastline (Syvitski et al. 2005). Dam removal restores the natural sediment transport regime and has become an increasingly adopted strategy to manage the environmental costs of these structures (Graf 1999, The Heinz Center 2002).

Changes in sediment supply can greatly influence the benthic environment of coastal estuaries, coral reefs, and seagrass communities, and are intimately tied to nutrient fluxes in these systems (Syvitski et al. 2005). Sediment delivery rates also affect harbor maintenance and pollutant burial or resuspension. Decreases in sediment input are largely the result of river damming or diversions, which directly influence the rate of coastal retreat. Dams affect the physical integrity of watersheds by fragmenting the lengths of rivers, changing their hydrologic characteristics, and altering their sediment regimes by trapping most of the sediment entering the reservoirs and disrupting the sediment budget of the downstream landscape (The Heinz Center 2002, Johnson et al. 2008). Because water released from dams is relatively free of sediment, downstream reaches of rivers may be altered by increased particle size, erosion, channel shrinkage, and deactivation of floodplains (The Heinz Center 2002). The consequence of reduced sediment also extends to long stretches of coastline where the erosive effect of waves is no longer sustained by sediment inputs from rivers (World Commission on Dams 2000). The effects to fishes of a reduced sediment regime would be indirect and primarily experienced through the long-term loss of soft-bottom habitat features and coastal landforms and/or changes to benthic habitat composition.

Increases in sediment input are largely due to land use practices that increase erosion rates (e.g., deforestation, wetland drainage, mining) or human activities in or near aquatic habitats (e.g., dredging) that re-suspend bottom sediments and create turbid conditions (Syvitski et al. 2005). Suspended sediments can elicit a variety of responses from aquatic biota; these responses may range from an active preference for turbid conditions, presumably to facilitate feeding and avoidance behaviors, to detrimental physical impacts that may result in egg abrasion, reduced bivalve pumping rates, and direct mortality (Wilber and Clarke 2001). Much of the available data on biological effects on organisms comes from bioassays that measure acute responses and require high concentrations of suspended sediments to induce the measured response, usually mortality (Wilber and Clarke 2001). Although anadromous salmonids have received much attention, little is known of behavioral responses of many estuarine fishes to suspended sediment plumes. There is a high degree of species variability in response to sedimentation; reports of "no effect" were made at concentrations as great as 14,000 mg/L for durations of 3 d and more (oyster toadfish and spot) and mortality was observed at a concentration/duration combination of 580 mg/L for 1 d (Atlantic silversides). For both salmonid and estuarine fishes, the egg and larval stages are more sensitive to suspended sediment impacts than are the older life history stages.

EVALUATION AND SELECTION OF INDICATORS

Two indicators of sediment input were evaluated: dam/reservoir storage area and suspended sediment loading (Table AP4). To estimate the temporal change in sediment decrease, we focused on dams as the key feature affecting this change, per Halpern et al. (2008). Construction of large dams peaked in the 1970's in Europe and North America (World Commission on Dams 2000). Today most activity in these regions is focused on the management of existing dams, including rehabilitation, renovation, and optimizing the operation of dams for multiple functions. The history of total reservoir storage area by U.S. water resource region was summarized from the early 1900's to the early 1990's by Graf (1999), based on data from the U.S. Army Corps of Engineers (1996). Since these data are no longer available electronically from the USACE, we compiled total reservoir storage in 10^9 cubic m over time (year of construction) for the California and PNW water resource regions. Freshwater storage was obtained from state agency databases, which include information on construction date and impoundment area/volume for all dams (California: http://cdec.water.ca.gov/misc/resinfo.html; Idaho: http://www.usbr.gov/projects/FacilitiesByState.jsp?StateID=ID; Oregon: http://www.usbr.gov/projects/FacilitiesByState.jsp?StateID=OR; Washington: https://fortress.wa.gov/ecy/publications/summarypages/94016.html.). Note that the data compiled using this summary do not precisely replicate the Graf (1999) data, but the temporal trends are comparable.

Another more data-intensive approach would involve estimating sediment loading from surface waters using publicly available data on sediment concentrations and flow rates from various U.S. watersheds sampled by the USGS and various state and local agencies. Sediment data are publicly accessible through the online USGS National Water Information System (NWIS) database at (http://nwis.waterdata.usgs.gov/usa/nwis/qwdata). The majority of data contained in the NWIS database is from water samples collected using standard methods described in U.S. Geological Survey (variously dated). USGS flow data can be accessed from http://nwis.waterdata.usgs.gov/nwis/dv/?referred_module=sw. Suspended sediment loading can be estimated at various time increments (e.g., daily, annual) using LOADEST, a USGS program that finds a best fit data model for flux as a function of discharge. The Yale University interface LOADRUNNER (http://environment.yale.edu/loadrunner/) calculates daily, monthly, and annual fluxes from these USGS water quality sample and streamflow data sources. We queried data from the USGS surface water database (http://infotrek.er.usgs.gov/apex/f?p=NAWQA:HOME:5572182579967972) for suspended sediment (SS) levels [mg/L] from sampled Pacific coastal basins from 1991-2011. Flow adjusted trends in concentration can be complex, as there often are multiple and possibly counteracting anthropogenic factors influencing sediment source and transport in a particular watershed.

A recent report from USGS summarizes the annual mean loads for SS in the Puget Sound and Columbia River basins using the USGS computer program Load Estimator (LOADEST), which uses a linear regression model that incorporates flow, time, and seasonal terms to estimate loads of mass over specified time periods (for this study, annual loads) (Wise et al. 2007). During water year 2000, considered an average streamflow year in the Pacific Northwest, the Columbia River discharged about 12,700 metric tons per day of SS to the Pacific Ocean. For most catchments between water years 1993-2003, the net change in non-hydrologic characteristics (land use and other human activities) was not great enough to cause any significant ($p \leq 0.05$) flow-adjusted trend in concentration (FATC) for suspended sediment (SS). Nineteen of the 48 sites available for SS trend analysis had significant FATC for SS (4 increasing, 15 decreasing), seven sites showed significant trend in load for SS (1 increasing, 6 decreasing), and more than 65 percent of the sites had decreasing (but not necessarily significant) FATC and trend in load for SS. There is currently no comparable analysis available for California basins.

We selected dam/reservoir storage area as our proxy for sediment input, primarily based on data considerations (Table AP4); furthermore, the net global reduction in sediment flux to coastal areas is primarily due to reservoir construction (Syvitski et al. 2005).

STATUS AND TRENDS

The status and trends of sediment input in the CCLME were measured using the total reservoir impoundment volume (millions m^3) of dams along rivers in WA, OR, ID and CA (Table AP5). Using this dataset, sediment input has been stable over the last five years and the short-term average was greater than 1SD of the long-term average of the time series (Fig. AP54). Increases in reservoir impoundment volume lead to less sediment making its way to the deltas of the dammed rivers; thus, increases in this indicator represent decreases in sediment input to estuarine and marine habitats. This is one of the longest datasets for non-fisheries pressures, so changes in the long-term trend will only occur in the future if large changes occur over the next few decades. In contrast, many of the other indicators have short time series, so relatively smaller changes over just a few years will impact the short-term status and trends and thus our interpretation of the current status of these indicators.

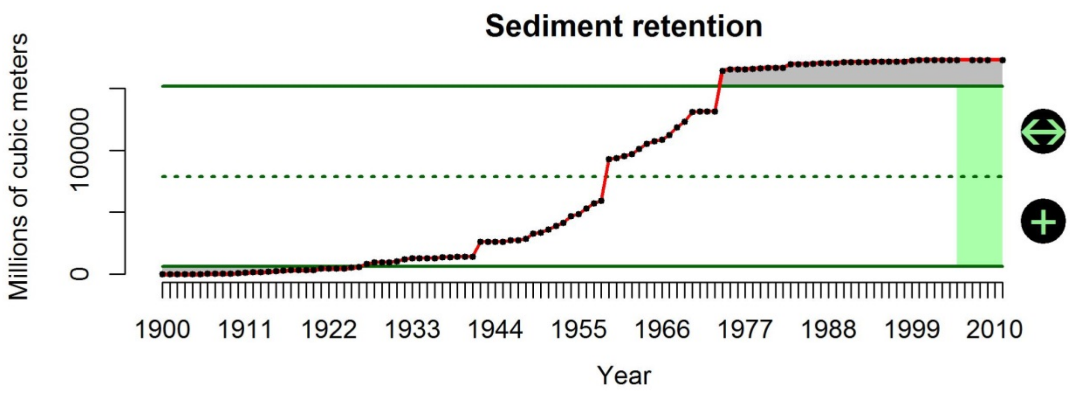


Figure AP54. Volume (millions m^3) of freshwater impoundments in WA, OR and CA (increasing freshwater storage is a proxy for decreasing sediment input).

TOURISM

BACKGROUND

This pressure has not been evaluated to date.

EVALUATION AND SELECTION OF INDICATORS

This pressure has not been evaluated to date.

STATUS AND TRENDS

Indicators have not been evaluated in order to determine the status and trends of this pressure.

LINKAGES BETWEEN DRIVERS AND EBM COMPONENTS

By definition, anthropogenic pressures on the ecosystem are based on human activities and thus the ultimate driver behind most of these pressures is human population growth. The status and trends of individual pressures are then modified by technological advances, management practices and regulatory actions. For the CCLME, the demand for edible and non-edible fisheries products and interest in harnessing natural resources (e.g., oil and gas, tidal energy, aquaculture, ocean mining) has been and is predicted to continue increasing into the foreseeable future. These drivers will ultimately affect the biological components of the CCLME in ways we do not fully understand. Some linkages are direct, such as fisheries removals, habitat destruction and mortality caused by oil spills, while others may be indirect, such as light pollution, which increases the efficiency of visual predators along the coast, subsequently changes predator/prey dynamics, and ultimately affects community structure (Longcore and Rich 2004).

The linkage between fisheries and several IEA EBM components is direct: fishery removals decrease abundance of targeted fisheries as well as some protected species via directed removals and bycatch. The Pacific Fishery Management Council uses biological reference points to determine whether a stock is in an overfished state, and whether overfishing is occurring. For groundfish, for instance, the former is determined using an estimated depletion level, which is the ratio of spawning stock output (number of eggs or embryos) in the fished condition, to the spawning output in the unfished condition. The latter is determined by a fishing mortality rate (F), expressed based on spawning potential ratio (SPR). This ratio is the number of eggs produced by an average recruit over its lifetime when the stock is fished, divided by the same metric when the stock is unfished. The SPR is based on the principle that certain proportions of fish have to survive in order to spawn and replenish the stock at a sustainable level. When removals or fishing mortality exceed established reference points, management measures are implemented to correct the issue. There had been significant declines in a number of groundfish species managed by the Pacific Fishery Management Council. Since implementing the Magnuson-Stevens Act (MSA) of 1976, the Sustainable Fisheries Act (SFA) of 1996, and the reauthorization of MSA in 2006, many species have increased their abundance toward levels where they are not considered overfished, and overfishing of these species is not occurring (Miller et al. 2009). For example, lingcod, which dropped below 10% of its unfished biomass in 1986, was fully rebuilt in 2005, four years earlier than the target year established in the species rebuilding plan (Hamel et al. 2009). Based on the most recent rebuilding analyses, all groundfish species that are still considered overfished exhibit upward trends, with three species (yelloweye rockfish, bocaccio and darkblotched rockfish) being ahead of their rebuilding plan schedules (Field 2011, Stephens 2011, Taylor 2011).

For most of the non-fisheries related pressures, there are few direct mechanistic linkages between pressures and effects on population growth of specific populations (with the notable exception of studies showing population-level effects from oil exposure). This is undoubtedly a function of natural fluctuations in most populations, imprecise estimates of populations across time and space, and a mismatch in the scale at which specific pressures act upon specific populations. Thus, our ability to detect and partition effects of specific contaminants is made even more difficult. In addition, none of these pressures act upon the ecosystem in a vacuum (i.e. many pressures are acting simultaneously on populations), and we have little understanding about whether the cumulative effects of multiple pressures will be additive, synergistic or antagonistic on populations of interest. This makes detecting direct links even more difficult. Moreover, these anthropogenic pressures will interact with the underlying effects of climatic and oceanographic pressures. These types of interactions can be modeled with "end-to-end" ecosystem models (e.g., Atlantis; Fulton et al. 2011) that have been developed over the last decade, and we need to develop creative methods in the field to test the validity of these models' hypotheses and increase managers' confidence in decision making.

ACKNOWLEDGEMENTS

We would like to give thanks to the numerous individuals from various state and federal agencies that helped with the gathering of data for individual pressures including L.L. LaMarca, M.L. Morningstar, J.E. Kerwin, K. Ryberg, C. Elvidge, M. Cummings, C.A. Ribic, J.M. Gronberg, R. Bell, T. Nolan, N. Dubrovsky, L. Hillmann, L. Burnett, and J. Guido.

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APPENDIX AP1. CUMULATIVE INDICES, CORRELATIONS, AND COMMON TRENDS AMONG ANTHROPOGENIC PRESSURES WITHIN THE CCLME

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*Note: This appendix provides a methodological framework for calculating cumulative indices using the time series of all indicators. It also examines methods that reduce the dimensionality of the dataset, so that multiple pressures could be incorporated into other science-based management tools. The analyses performed in this section used time series that had not been updated with 2012 data.

SUMMARY

As human population size and demand for seafood and other marine resources increase, the influence of human activities in the ocean (e.g., fishing and shipping activity) and on land (e.g., industrial and agricultural activities) is increasingly critical to the management and conservation of marine resources. In order to make management decisions related to anthropogenic pressures on marine ecosystems, we need to understand the links between pressures and ecosystem components, and we cannot draw those linkages unless we know how pressures have been changing over time. We developed indicators and time series of indicators for 22 anthropogenic pressures at the scale of the U.S. portion of the California Current ecosystem. Time series suggest that seven pressures have decreased and two have increased over the short term, while five pressures were above and two pressures were below long-term means. Cumulative indices of anthropogenic pressures suggest a slight decrease in pressures in the 2000's compared to the preceding few decades. Dynamic factor analysis revealed four common trends that sufficiently explained the temporal variation found among all anthropogenic pressures. Using this reduced set of time series will be useful when trying to determine whether links exist between individual or multiple pressures and various ecosystem components.

INTRODUCTION

Human activities in, on, and around the ocean—from shipping and fishing to urbanization, oil extraction, aquaculture, and coastal agriculture—are varied and growing. These activities generate many benefits, including production of food, employment, energy, and livelihoods (Guerry et al. 2012). However, they are also associated with anthropogenic pressures on the natural ecosystem that have a variety of consequences, such as loss or modification of habitat, extractions and introductions of species, visual and auditory disturbances, and the introduction of toxic and non-toxic contamination (Eastwood et al. 2007). Despite widespread recognition of the increasing importance of these diverse influences (Wilson et al. 2005, Halpern et al. 2007), it is rare to find a full accounting of how anthropogenic pressures in the marine environment have changed over time.

In contrast, recent spatial analyses of anthropogenic activities have revealed hotspots of individual and overlapping pressures in ecosystems across the globe (Ban and Alder 2008, Halpern et al. 2008, Halpern et al. 2009, Stelzenmüller et al. 2010, Hayes et al. 2012). These maps show patterns of spatial variation among individual and cumulative pressures that provide a framework scientists and managers can use to focus limited resources on areas of concern. They also beg the question of how anthropogenic pressures in specific locations have changed over time. Without an understanding of the legacy of anthropogenic pressures in an area, it is difficult to interpret current and potential future conditions. For instance, the ecological consequences of oil extraction in a previously untouched area like the North Slope of Alaska are likely to be very different than in a historically high-use environment such as the North Sea. Unfortunately, time series data for many human-related pressures are often buried in state and federal agency reports, described at small spatial scales, and measured inconsistently among local, state and federal entities. Thus, it would be helpful to develop a standardized set of time series that reflect the status and trends of these pressures at scales appropriate for management.

Importantly, pressures do not act upon the ecosystem independently, but rather collectively. Pressures are disparate and broadly based, ranging from terrestrial-based pollution, commercial shipping activities, and offshore energy development to fisheries and coastal development, all of which exert cumulative effects on the ecosystem and could benefit from a holistic management approach (Vinebrooke et al. 2004, Crain et al. 2008, Halpern et al. 2008, Curtin and Prellezo 2010). Quantifying the cumulative effects from multiple pressures is a challenging task, however, because we have a limited understanding of how pressures interact and whether the cumulative effects are additive, synergistic or antagonistic (Darling and Côté 2008, Hoegh-Guldberg and Bruno 2010)? Moreover, the results of these interactions may have different consequences for different taxa or ecosystem components (Crain et al. 2008). Additionally, the status and trends of many anthropogenic pressures are likely correlated with each other due to ultimate drivers such as human population growth, seafood demand or economic conditions, and so are best understood in the context of one another (e.g., Link et al. 2002).

Recent studies that aim to evaluate the effect of cumulative pressures on marine ecosystems have assumed that pressures are additive (Halpern et al. 2009, Stelzenmüller et al. 2010); however, the relative importance of each pressure on a given habitat, region, or ecosystem was incorporated into the calculation by assigning relative weightings to each individual pressure (based on expert opinions (e.g., Teck et al. 2010) or based on spatial extent of a pressure (e.g., Stelzenmüller et al. 2010)). These methodologies may also be used to calculate cumulative pressures to determine the relative status and trends over time.

Here, we developed standardized time series of indicators for 22 anthropogenic pressures acting across the entire U.S. portion of the California Current Large Marine Ecosystem (hereafter, the California Current ecosystem (CCE)). These time series were used to quantify the status and temporal trends of each pressure. We then used several approaches to describe the relative status and trends of anthropogenic pressures as a whole. First, we used simple additive models to quantify the relative status and trends of anthropogenic pressures in the California Current ecosystem. Second, we used multivariate models to determine (1) whether pressures were correlated, (2) how the composition of pressures changed over time, (3) whether there were shared trends in the time series of anthropogenic pressures, and (4) whether these trends were related to specific drivers such as coastal population abundance or economic activity. Our synthesis, and corresponding methodological approaches to quantify the status and trends of these pressures, provides a foundation for future integrative analyses on ecological components (e.g., risk analysis and management strategy evaluations) across the CCE.

METHODS

INDICATORS OF ANTHROPOGENIC PRESSURES

We developed indicators for 22 anthropogenic pressures in the California Current ecosystem (CCE). The pressures selected were derived primarily from those identified in spatial analyses by Halpern et al. (2009) and by vulnerability analyses by Teck et al. (2010); they ranged in scope from land-based pressures such as inorganic pollution and nutrient input to at-sea pressures such as commercial shipping and offshore oil and gas activities. Ultimately, we evaluated 41 different indicators and selected the best indicator to describe the status and trends of each pressure. Indicators were evaluated (see “Detailed Report” above) using the indicator selection framework developed and used by Levin et al. (2011), Kershner et al. (2011) and James et al. (2012). Briefly, we evaluated each indicator according to 18 criteria using the scientific literature to determine whether there was support for each criterion for each indicator. This resulted in a matrix of references and notes with a corresponding value of literature support (1 for "support", 0.5 for "ambiguous support", 0 for "no support"). These values of literature support were summed across criteria for each indicator and the highest scoring indicator was chosen for each pressure.

Data for all indicators were compiled from various state and federal reports and databases to create the longest possible time series for each pressure (Table AP1-1). Compatible data from the states of California, Oregon and Washington were pooled to characterize pressures at the scale of the entire CCE. In some instances (see descriptions of individual pressures in "Detailed Report" above), data from other states were included if watersheds in other states drained into the Pacific Ocean. To alleviate some of the complexities associated with different institutional data standards, governing jurisdictions, and geographic discrepancies, we limited our analysis to U.S. data and did not include data from portions of the CCE in Canada or Mexico.

The status of each indicator was evaluated against two criteria: recent short-term trend (increasing, decreasing or remaining the same over the last five years) and status relative to the mean and variance of long-term conditions (short-term status was higher than, lower than or within historic levels) (Levin and Wells 2012). An indicator's current trend was considered to have changed in the short-term if the modeled trend over the last five years of the time series showed an increase or decrease of more than 1.0 standard deviation (SD) of the mean of the entire time series. An indicator's current status was considered to be above or below historical levels if the mean of the last five years was greater than or less than 1.0 SD from the mean of the full time series, respectively. Defining the "short-term" as the last five years of the dataset is consistent with other management review processes that occur at the scale of large marine ecosystems (e.g., National Marine Fisheries Service's Essential Fish Habitat reviews (NMFS 2013) and the National Oceanic and Atmospheric Administration's Integrated Ecosystem Assessments (Levin and Schwing 2011, Levin and Wells 2012)).

Table AP1-1. Top indicators for anthropogenic pressures in the California Current ecosystem (CCE). See "Detailed Report" for "Anthropogenic Drivers and Pressures" above for evaluation and selection, source of data and calculations of indicators for each pressure.

Pressure	Indicator	Definition	Time series	Sampling frequency
***Aquaculture: finfish**	Finfish production	Estimates of Atlantic salmon production in CCE waters.	1986 – 2011	yearly
***Aquaculture: shellfish**	Shellfish production	U.S. shellfish (clams, mussels & oysters) production.	1985 – 2010	yearly
***Atmospheric pollution**	Deposition of sulfate	Annual precipitation-weighted mean concentrations of sulfate measured at sites in CA, OR, and WA.	1994 – 2010	yearly
***Benthic structures**	# offshore oil & gas wells	Total number of offshore oil and gas wells in production.	1981 - 2009	yearly

Pressure	Indicator	Definition	Time series	Sampling frequency
***Coastal engineering**	Human coastal population	Population size of coastline counties in CA, OR, WA.	1970 – 2012	yearly
Commercial shipping activity	Volume of water disturbed	Calculated using draft, breadth and distance traveled within CCE of domestic and foreign vessels.	2001 – 2010	yearly
Dredging	Dredge volumes	Dredge volumes for individual private contracts and Army Corps operated dredge projects in WA, CA, and OR.	1997 – 2011	yearly
***Fishery removals**	Total Landings	Metric tons of all species landed by commercial and recreational fisheries in CA, OR and WA.	1981 – 2011	yearly
***Freshwater retention**	Impoundment storage volume	Total reservoir storage volume in CA and Pacific Northwest water resource regions.	1900 – 2011	yearly
Habitat modification	Distance trawled	Kilometers trawled by the limited-trawl groundfish fishery in CA, OR and WA.	1999-2004	yearly
***Inorganic pollution**	ISA-toxicity-weighted chemical releases	Total pounds of inorganic pollutants disposed of or released on site to the ground or water for '1988 core chemicals' weighted by toxicity scores and impervious surface area (ISA) in the drainage watersheds of the CCE.	1988 – 2010	yearly
***Invasive species**	Tons of cargo	Tons of cargo moved through ports in CA, OR and WA.	1993 – 2010	yearly
***Light pollution**	Average nighttime visible light	Data are cloud-free composites of average visible nighttime lights made using all the available archived DMSP-OLS smooth resolution data for each calendar year.	1994 – 2010	yearly
Marine debris	Predicted counts of debris	Estimates from the National Marine Debris Monitoring Program separated into north and south CCE estimates.	1999 – 2007	yearly
***Nutrient input**	Nitrogen and phosphorus input	Total farm and non-farm nitrogen and phosphorus input from fertilizer used in counties within CCE watersheds.	1945 – 2010	yearly
Ocean-based pollution	Commercial shipping activity combined with tons of cargo	Combines "Commercial shipping activity" and "Invasive species" datasets.	2001 – 2010	yearly
***Offshore oil activities**	Offshore oil & gas production	Normalized sum of the number of barrels of oil and cubic feet of gas produced by offshore wells in CA.	1970 – 2010	yearly
***Organic pollution**	Toxicity-weighted concentrations	Toxicity-weighted concentrations of 16 pesticides measured in water samples from stream-water sites in WA, OR and CA	1993 – 2008	yearly
Power plants	Saline water withdrawal volumes	Average daily withdrawal volumes of saline water from thermoelectric power plants in the Pacific Northwest and California regions.	1955 – 2005	Every 5 years
Recreational beach use	Beach attendance	Summed beach attendance from CA, OR, and WA	2002 – 2011	yearly
***Seafood demand**	Total consumption	Total consumption of edible and non-edible fisheries products in the U.S.	1962 – 2011	yearly
***Sediment retention**	Impoundment storage volume	Same as "Freshwater retention"	1900 – 2011	yearly

*Pressures used in cumulative pressures index and principal components analysis

The historical status of each indicator should be placed in context with the amount of data available for each time series. For example, the entire time series for one indicator (habitat modification) was only six years while the time series for other indicators (e.g., freshwater and sediment retention) was > 100 years. For shorter time series, the mean of the last five years (short-term) was not likely different from the mean of the entire time series; thus, the relative status for indicators with short time series was more related to the availability of data and not historic trends. However, indicators were chosen because they were the most fundamentally-sound datasets based on 18 evaluation criteria, only 7 of which were related to data availability (see "Detailed Report" above). Moreover, most of the indicators chosen will continue to be measured, thus providing meaningful comparisons into the future.

SUMMARIZING ANTHROPOGENIC PRESSURES AS A WHOLE

We employed three different methods to examine the status and trends of pressures as a whole. First, we calculated a cumulative pressures index using a subset of pressures. Second, we used principal components analysis to examine correlations and temporal shifts among pressures. Last, we used dynamic factor analysis to determine whether the 22 pressures could be reduced to a smaller number of common trends.

CUMULATIVE PRESSURES INDEX

In order to calculate a cumulative pressures index, we determined the longest period for which there were the most pressures with continuous indicator data available. For the years 1994 – 2008, we had annual data available for 15 of the 22 pressures (Table AP1-1). Data from these 15 time series were normalized (mean = 0, standard deviation = 1) across the years 1994 – 2008 so that all pressures were on the same scale. We then used two methods to calculate a cumulative pressures index. The first method was simply an additive model in which all 15 normalized pressure values were summed for each year (an equal weighting of "1.0" for each pressure).

The second method weighted the relative importance of each pressure according to mean vulnerability scores determined by Teck et al. (2010). Briefly, we normalized mean vulnerability scores of all pressures to a scale of 0 to 1 and used the scores relevant to our 15 pressures as weightings. Mean vulnerability scores were averaged across pressure categories when more than one related to one of our 15 pressures (e.g., four nutrient input pressures were identified in Teck et al. (2010)). Finally, we multiplied each pressure value in the time series by its respective weighting value and summed across all pressures for each year.

CORRELATIONS AND TEMPORAL SHIFTS AMONG PRESSURES

We used principal components analysis (PCA; PRIMER 6.0; Clarke and Gorley 2006) to identify correlations among pressures and to reduce the number of multivariate dimensions to a smaller set that explained most of the variance of the data sets. Because PCA cannot accommodate missing values, we used the same set of 15 pressures from 1994

– 2008 that we used to calculate the cumulative pressures index to get the greatest number of pressures across the longest period of time. Loadings (correlations between the original time series and a principal component axis) greater than 0.30 were considered to have relevance for interpretation of the results (Tabachnick and Fidell 1996). We used the principal component scores across years to examine how the importance of each axis changed over time.

COMMON TRENDS AMONG PRESSURES

We used dynamic factor analysis (DFA; Zuur et al. 2003a, 2003b) to characterize underlying common trends among the time series of anthropogenic pressures. The objective of DFA is similar to PCA; to reduce the number of multivariate dimensions needed to describe patterns in data. However, DFA is based on time series models that explicitly account for temporal autocorrelation common in time series data; PCA does not. The DFA framework consists of two models: it combines (1) a random-walk model that captures the underlying shared trends among a set of time series and any covariates and (2) a model that describes how well each time series is described by each underlying trend.

In the DFA framework, a set of one or more hidden common trends (linear combinations of a set of random walks) shared by the time series data explains their temporal variations (Zuur et al. 2003a). DFA is particularly useful for our time series because it can account for missing values; thus, we can incorporate a larger number of pressures across a longer period than was possible for the calculation of the cumulative pressures index or the principal components analysis. Because DFA allows for the inclusion of covariates, we could also explore explanatory drivers of the pressures such as population size or economic growth.

Using the MARSS package in R (Holmes et al. 2012, R Development Core Team 2012), we tested models with 1 – 5 common trends and models including zero, one or two covariates (coastal human population abundance and gross domestic product of the U.S. West Coast). Preliminary analyses tested five commonly used variance-covariance matrix structures available in the MARSS package (Holmes et al. 2012) and suggested 'diagonal and equal' was the most appropriate for this data set (*see* "Supplementary Material" below). This model structure had observation variances (along the diagonal) that were equal and covariances that were equal to zero (Holmes et al. 2012).

Prior to the analysis, time series of all 22 pressures (Table AP1-1) were normalized across the period of interest (1985 – 2011). We limited the time series to this period because longer time series have proportionately greater influence than shorter time series in determining common trends and only a third of the indicators had longer time series (*see* individual pressures in "Detailed Report" above). We used Akaike's model selection criterion (AICc; Burnham and Anderson 1998) values to determine the fewest common trends and covariates required to explain the full set of time series of anthropogenic pressures in the CCE. We used an oblique rotation method (promax) to calculate factor loadings as it helped separate factor loadings among trends a little better than the default orthogonal method (varimax). DFA factor loadings > 0.2 were considered relevant for interpreting whether pressures were represented by a specific trend (Zuur et al. 2003b). Loading values represent coefficient values that when multiplied by the respective trend value and summed across all trends produce fitted values for each year for each pressure (i.e. model fits shown in Fig. AP1-6).

For the covariate 'coastal population abundance', we used data from the U.S. Census Bureau (2010 – 2012: http://www.census.gov/popest/data/datasets.html) and the National Bureau of Economic Research (1970 – 2009: http://www.nber.org/data/census-intercensal-county-population.html). We limited data to 'coastal' counties in California, Oregon and Washington as defined by the National Oceanic and Atmospheric Administration (http://www.census.gov/geo/landview/lv6help/coastal_cty.pdf). For the covariate 'gross domestic product', data were summed annually across the states of California, Oregon and Washington from 1963 – 2011 (Bureau of Economic Analysis; http://www.bea.gov/iTable/index_nipa.cfm) using "Regional Data" by state across all industries.

RESULTS

INDICATORS OF ANTHROPOGENIC PRESSURES

Indicators of anthropogenic pressures in the California Current ecosystem (CCE; Table AP1-1) were chosen based on rankings in the indicator evaluation matrix (see "Detailed Report" above). Descriptions, status and trends of individual indicators are described in the "Detailed Report" above, but examples of indicator time series show that the short- and long-term status and trends of anthropogenic pressures in the CCE varied widely (Fig. AP1-1). Most indicators showed either significant short-term trends or their current status was at historically high or low levels (Fig. AP1-2). Indicators of inorganic, organic and ocean-based pollution, commercial shipping activity, recreational use, invasive species and habitat modification have all decreased over the short-term, while indicators of dredging and marine debris (in the northern CCE) increased; all of these pressures, though, remained within historic levels. In contrast, indicators of seafood demand, sediment and freshwater retention, power plant activity and coastal engineering remained relatively constant over the short-term, but were above historic levels, while indicators of offshore oil and gas activity and related benthic structures were at historically low levels. Nutrient input and shellfish aquaculture were at historically high levels, but nutrient input has decreased over the last five years of its time series (Figs. AP1-1 & AP1-2), while shellfish aquaculture has continued to increase (Fig. AP1-2).

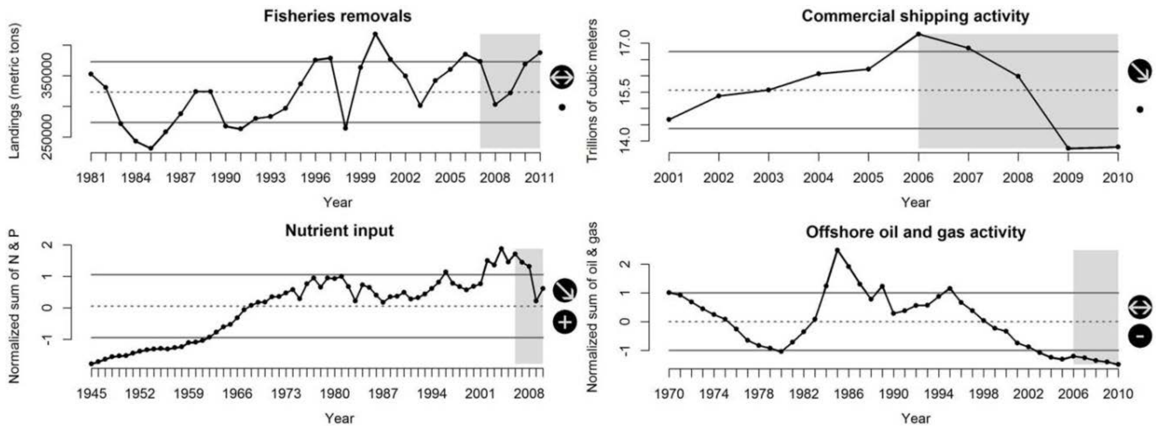


Figure AP1-1. Examples of the status and trends of anthropogenic pressures in the California Current ecosystem. Each pressure is represented by specific indicator data sets described in Table AP1-1 and the "Detailed Report". Arrows to the right of each panel represent whether the modeled trend over the last five years (shaded) increased (↗) or decreased (↘) by more than 1 SD or was within 1 SD (↔) of the long-term trend. Symbols below the arrows represent whether the mean of the last five years was greater than (+), less than (-) or within (•) 1 SD of the mean of the full time series (dotted line). Solid lines are ±1 SD of the mean of the full time series.

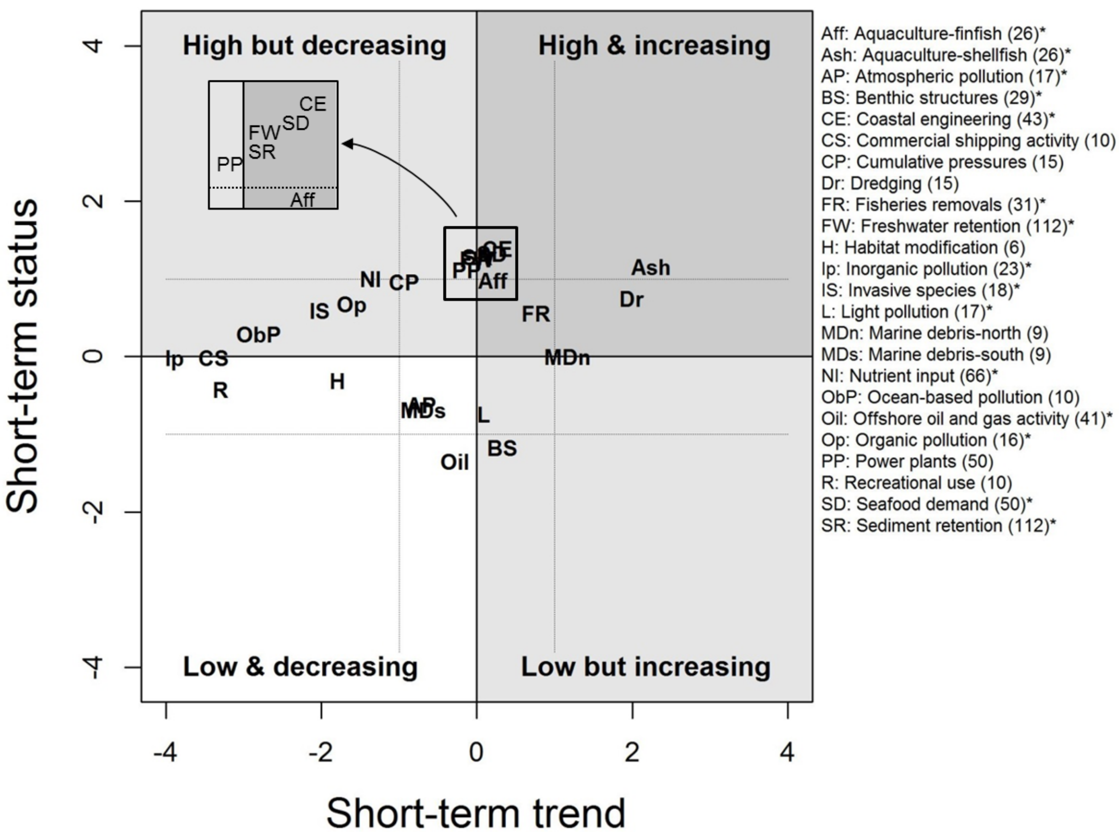


Figure AP1-2. Short-term status and trends of anthropogenic pressures in the California Current ecosystem. Prior to plotting, time series data for each indicator were normalized to place them on the same scale. The short-term trend indicates whether the indicator increased, decreased or remained the same over the last five years. The short-term status indicates whether the mean of the last 5 years was higher, lower, or within historical levels of the full time series. Data points outside the dotted lines (± 1.0 SD) are considered to be increasing or decreasing over the short term or the current status is higher or lower than the long-term mean of the time series. Numbers in parentheses in the legend are the number of years of data for each pressure. The "Cumulative pressures" indicator (see Figure AP1-3) is the additive sum of 15 of these pressures which had annual data from 1994 – 2008 (asterisks).

CUMULATIVE PRESSURES INDEX

The period of 1994 – 2008 provided the longest continuous period of data for the most indicators (15 of 22) to be included in the cumulative pressures index. The 'additive' and 'weighted' methods provided qualitatively similar estimates over this period (Fig. AP1-3). However, the additive index showed a positive trend (adjusted r^2: 0.51, $F_{1,13} = 15.7$, $p = 0.002$), whereas the weighted index showed no trend (adjusted r^2: 0.12, $F_{1,13} = 2.9$, $p = 0.110$) across the entire period. Using the same criteria to define the recent short-term status and trends of individual pressures, there was a short-term decrease in cumulative pressures using the weighted index, whereas there was no significant change in the short-term trend using the additive index (Fig. AP1-3). The short-term status for both indices was within historic levels of this time series.

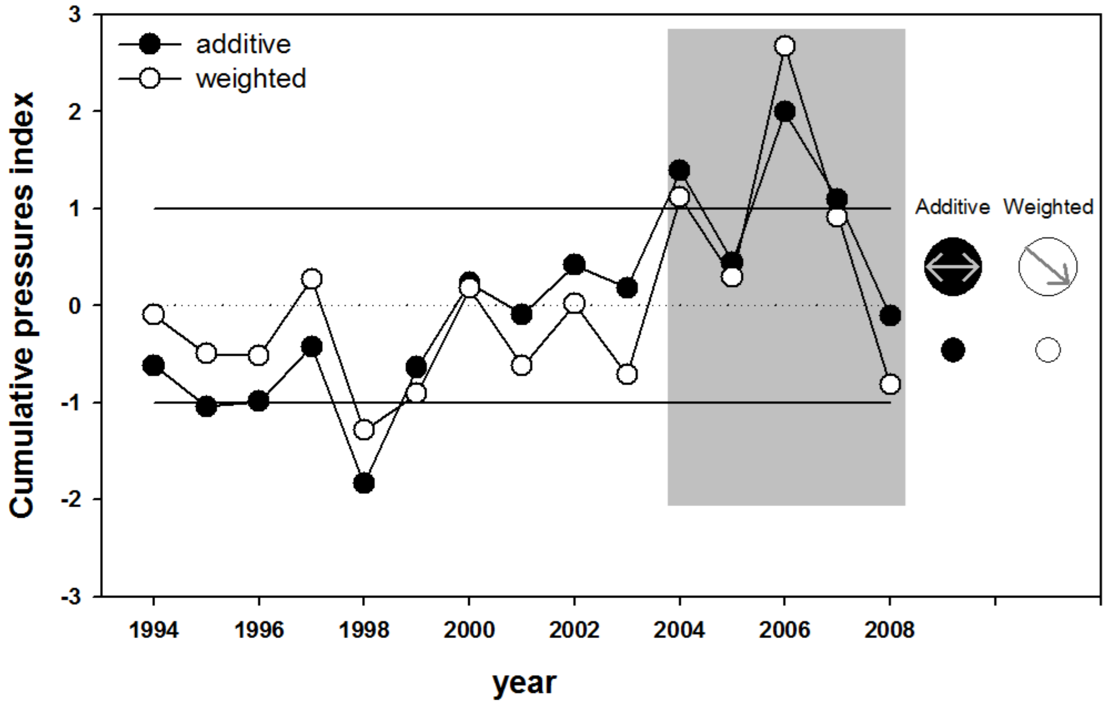


Figure AP1-3. Indices of cumulative pressures from 1994 – 2008 using 15 pressures which had data during this period: atmospheric, light, inorganic and organic pollution, nutrient input, shellfish and finfish aquaculture, invasive species, oil & gas activities, benthic structures, freshwater and sediment retention, coastal engineering, seafood demand and fisheries removals. Each index was normalized prior to plotting to place them on the same scale. 'Additive' is the sum of all pressure values each year; 'Weighted' is the sum of pressure values multiplied by their respective weighting values derived from Teck et al. (2010). See Figure AP1-1 for description of symbols, lines, and shading.

CORRELATIONS AND TEMPORAL SHIFTS AMONG PRESSURES

The first two axes of the principal components analysis explained ~68% of the total variation in the same 15 time series used to calculate the cumulative pressures index from 1994 to 2008, and the first four axes explained 86% (Fig. AP1-4). Plotting the scores of the first two principal components across time showed clear changes in the composition of pressures over this period (Fig. AP1-5). In the 1990's, there was strong influence by oil and gas activities, light pollution and benthic structures, while coastal engineering, seafood demand, nutrient input, aquaculture and organic and inorganic pollution became more important to this multivariate measurement in the 2000's. The spike observed in 2002 can be attributed to a particularly large increase in atmospheric pollution that year and the large change that occurred in 2006 was related to large increases of inorganic and organic pollution.

Sediment retention and freshwater input also loaded heavily on PC1, but in the complete time series for these pressures, they are relatively stable from 1994 to 2008 and thus would have little influence on any changes in cumulative pressure if the entire time series could have been used. Interestingly, 'fisheries removals', which was quite variable during this time period, was the only pressure that did not load significantly on PC1 or PC2, but instead loaded heavily on PC3 (Table AP1-2).

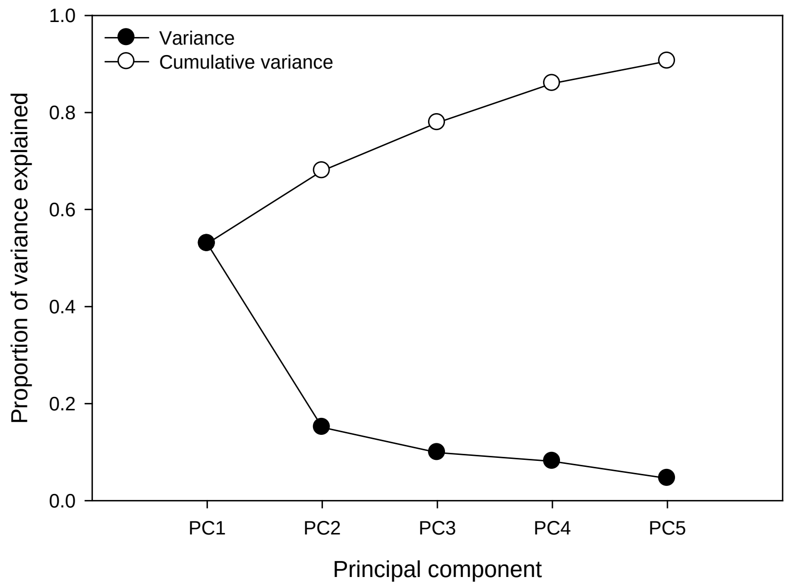


Figure AP1-4. Scree plot of principal components. PC5 had an eigenvalue < 1.0 suggesting that only PC1-4 were statistically relevant.

Table AP1-2. Principal component loadings for 15 pressures that had data from 1994 to 2008. Bold values indicate the principal component that each pressure is most closely correlated with.

Pressure	PC1	PC2	PC3	PC4
Aquaculture: finfish	**-0.64**	0.22	0.14	0.48
Aquaculture: shellfish	**-0.54**	-0.22	0.51	-0.35
Atmospheric pollution	-0.10	**0.76**	-0.22	-0.49
Benthic structures	**0.91**	-0.01	0.00	-0.13
Coastal engineering	**-0.95**	0.07	0.05	0.10
Fisheries removals	-0.21	-0.14	**-0.85**	0.29
Freshwater retention	**-0.90**	0.32	-0.10	0.16
Inorganic pollution	**-0.54**	-0.53	-0.47	-0.32
Invasive species	-0.08	**-0.80**	0.16	0.39
Light pollution	**0.95**	-0.21	-0.04	0.02
Nutrient input	**-0.81**	-0.32	0.14	-0.14
Oil & gas activities	**0.96**	-0.14	-0.04	-0.01
Organic pollution	**-0.56**	-0.48	-0.31	-0.40
Seafood demand	**-0.85**	-0.20	0.23	-0.17
Sediment retention	**-0.90**	0.32	-0.10	0.16

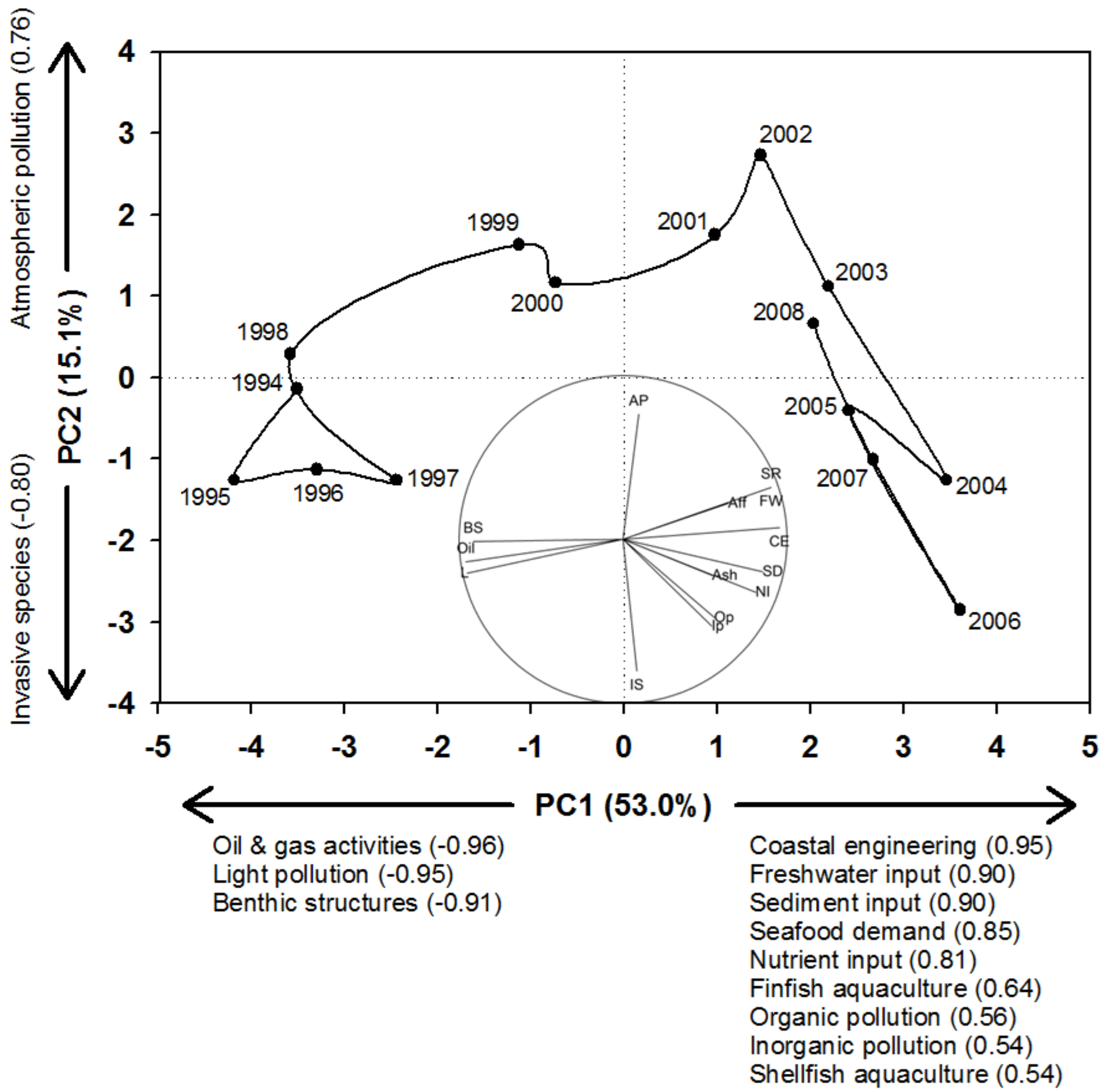


Figure AP1-5. Principal components analysis using indicators of 15 anthropogenic pressures which had data from 1994 – 2008: atmospheric, light, inorganic and organic pollution, nutrient input, shellfish and finfish aquaculture, invasive species, oil & gas activities, benthic structures, freshwater and sediment retention, coastal engineering, seafood demand and fisheries removals. Pressures identified along each axis had eigenvectors > 0.3 for one of the first two principal components, while the values in parentheses are the loading values for the predominant principal component for each pressure. See Figure AP1-2 for abbreviations.

COMMON TRENDS

Using dynamic factor analysis, we were able to include all anthropogenic pressures and data from 1985 to 2011. There were eight pressures having data prior to 1985, but including this data resulted in model convergence problems. Nonetheless, using DFA allowed us to include 7 additional pressures and 12 additional years of data compared to the cumulative pressures index or the principal components analysis. Model selection revealed a model with either 4 or 5 common trends with no covariates sufficiently explained the time series of pressure indicators (Table AP1-3). Because the model with 4 trends was more than twice as likely to be the best model as the two models with 5 trends, we used the 4-trend model to describe the common trends below. The 4-trend model had tight fits with most of the indicator time series, though a notable exception was "Fisheries removals" (Fig. AP1-6).

Table AP1-3. Model selection criteria from the top ten dynamic factor analysis models using all 23 indicator time series from 1985 to 2011 and comparing among different variance-covariance structures (R matrix), 1-5 trends and with 0-2 covariates.

R matrix	Trends	Covariate(s)	K	AICc	ΔAICc	Akaike weight	Cumulative Akaike weight
diagonal and equal	4	none	87	875.5	0.00	0.49	0.49
equal variance-covariance	5	none	107	877.2	1.68	0.21	0.70
diagonal and equal	5	none	106	877.4	1.89	0.19	0.89
diagonal and equal	3	population	90	879.6	4.12	0.06	0.95
equal variance-covariance	4	none	88	881.9	6.42	0.02	0.97
equal variance-covariance	3	population	91	882.7	7.19	0.01	0.98
diagonal and equal	2	both	92	884.5	8.97	0.01	0.99
diagonal and equal	4	population	110	885.4	9.90	0.00	0.99
diagonal and equal	3	gdp	90	885.8	10.30	0.00	1.00
equal variance-covariance	2	both	93	887.3	11.75	0.00	1.00

K = number of parameters; AICc = Akaike information criterion corrected for small sample sizes; ΔAICc = difference between each model and the lowest AICc from all possible models; population = coastal population abundance estimate; gdp = gross domestic product of U.S. West Coast states. See "Supplementary Material" below for description of each R matrix structure.

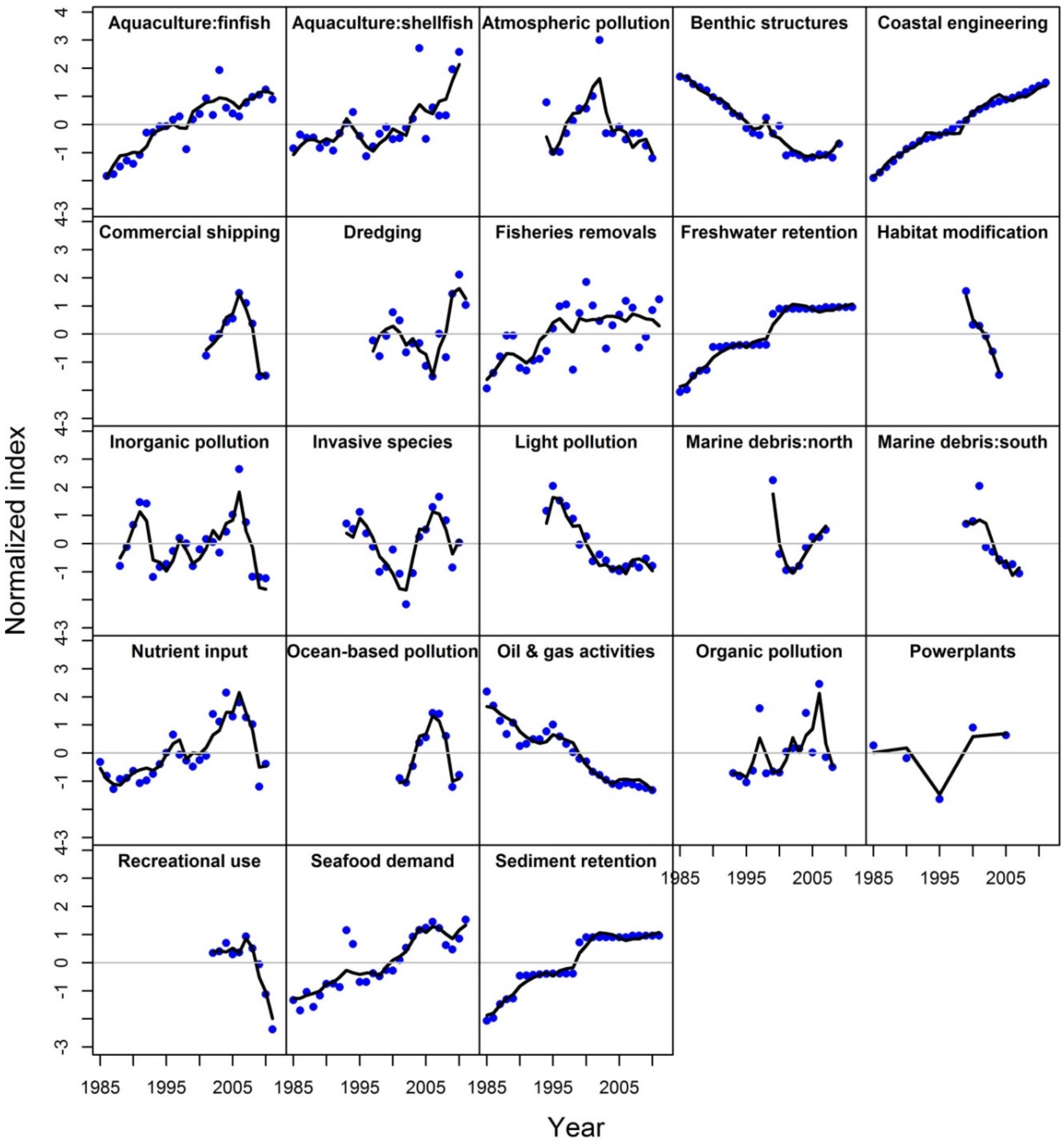
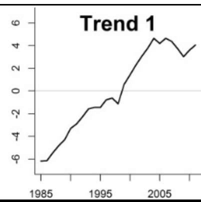
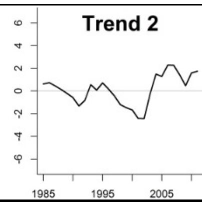
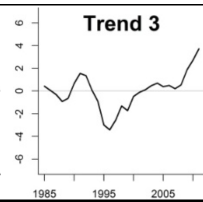
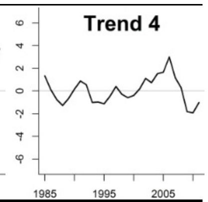


Figure AP1-6. Model fits (black lines) to each pressure time series (blue points) for the dynamic factor analysis model with four common trends, 'diagonal and equal' R matrix and no covariates. Gray line shows the zero-line.

Trend 1 showed a relatively monotonic increase from 1985 to the early 2000's followed by a more variable period during the rest of the 2000's (Table AP1-4). Eight pressures had their highest loadings on this trend and were not related to any other trend. These pressures were related to activities associated with food supply, construction and energy production. Most of these pressures were positively correlated with trend 1, but oil and gas activities and related benthic structures were negatively correlated (Table AP1-4, Fig. AP1-7). Trends 2 – 4 showed a variety of peaks and valleys at various times throughout the period. Six of eight pressures that loaded heavily on trend 2 also loaded heavily on trend 3 or 4 (Table AP1-4), suggesting a fair amount of correlation among these three trends at various time lags. Pressures associated with transportation and coastal disturbance tended to have higher loadings on trend 3, while pressures associated with the input of terrestrial pollutants into the marine environment were generally related to trend 4 (Table AP1-4).

Table AP1-4. Common trends and factor loadings identified from the 4-trend dynamic factor analysis model using 23 pressures and time series data from 1985 to 2011. Bold values indicate which pressures were related to each trend (absolute value of factor loadings >0.2). Boxes indicate which trend was most related to each pressure. Negative loadings mean that a pressure is related to the inverse of the trend shown above each column. Factor loadings are the coefficients that when multiplied by the trend value and summed across all trends produce predicted values for each pressure.

Broad category of pressures	**Pressures**				
Terrestrial pollutants	Atmospheric pollution	0.01	$\boxed{\mathbf{-0.53}}$	0.12	**0.28**
	Inorganic pollution	-0.12	0.01	0.09	$\boxed{\mathbf{0.77}}$
	Organic pollution	-0.19	-0.01	0.00	$\boxed{\mathbf{1.02}}$
	Nutrient input	0.17	0.12	-0.19	$\boxed{\mathbf{0.39}}$
Transportation	Dredging	0.05	-0.03	0.14	$\boxed{\mathbf{-0.58}}$
	Commercial shipping	-0.01	**0.27**	$\boxed{\mathbf{-0.43}}$	**0.36**
	Ocean-based pollution	-0.01	**0.47**	$\boxed{\mathbf{-0.48}}$	0.17
	Invasive species	-0.08	$\boxed{\mathbf{0.60}}$	-0.15	0.07
Coastal disturbance	Marine debris (south)	0.02	$\boxed{\mathbf{-0.34}}$	-0.11	-0.13
	Marine debris (north)	0.00	**0.38**	$\boxed{\mathbf{-1.36}}$	0.04
	Recreational use	**0.26**	0.05	$\boxed{\mathbf{-0.89}}$	-0.18
	Light pollution	-0.10	0.08	$\boxed{\mathbf{-0.41}}$	-0.20
	Habitat modification	-0.09	-0.18	$\boxed{\mathbf{-0.62}}$	-0.14
Food	Fisheries removals	$\boxed{\mathbf{0.22}}$	-0.01	-0.19	-0.14
	Shellfish aquaculture	0.15	**0.22**	**0.25**	$\boxed{\mathbf{-0.31}}$
	Finfish aquaculture	$\boxed{\mathbf{0.29}}$	-0.06	-0.05	-0.20
	Seafood demand	$\boxed{\mathbf{0.22}}$	0.11	0.06	-0.01
Construction	Coastal engineering	$\boxed{\mathbf{0.27}}$	-0.01	0.04	-0.13
	Freshwater retention	$\boxed{\mathbf{0.28}}$	-0.12	0.03	-0.08
	Sediment retention	$\boxed{\mathbf{0.28}}$	-0.12	0.03	-0.08
	Benthic structures	$\boxed{\mathbf{-0.27}}$	0.03	0.11	-0.01
Energy	Oil & gas activities	$\boxed{\mathbf{-0.26}}$	0.04	-0.12	0.07
	Power plant activity	0.08	**-0.45**	0.14	$\boxed{\mathbf{0.54}}$

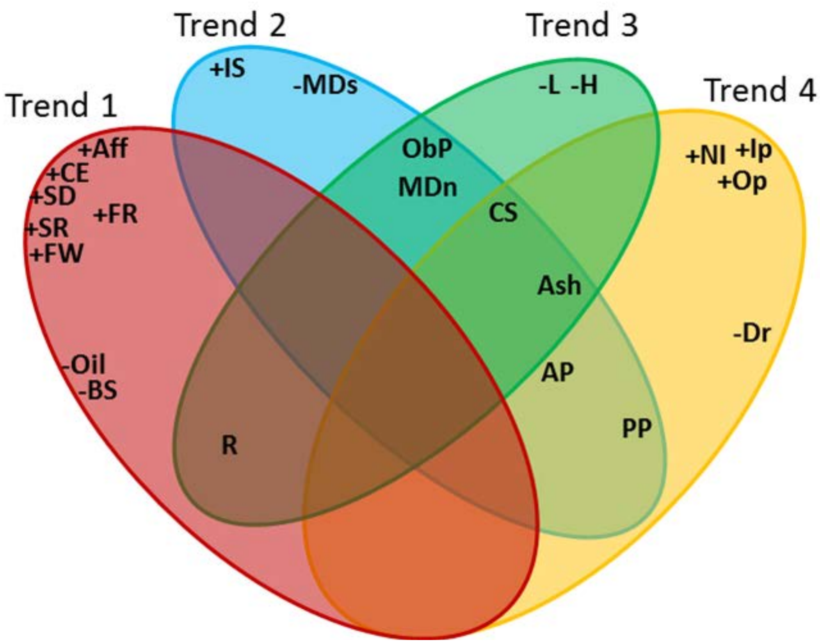


Figure AP1-7. Venn diagram showing factor loadings for each pressure relative to all four trends. Positive (+) or negative (-) loadings are distinguished for pressures that loaded significantly (>2) on only one trend. See Figure AP1-2 for abbreviations.

Because all four trends were estimated simultaneously, we cannot statistically determine which trend was most important; however, some insight can be gained by comparing the results from models with one, two and three common trend(s) with the trends found in the 4-trend model (Zuur et al. 2003a). These comparisons suggested that trend 1 was the most important as it was nearly identical to the trend found in the 1-trend model and other monotonic trends found in the 2- and 3-trend models (Fig. AP1-8).

It is important to note that the strength of the relationship between each pressure and each common trend is a function of the length of each time series. For example, the time series for marine debris in the northern CCE was strongly related to the inverse of trend 3 and less positively related to trend 2 for only a short period of that trend (data for marine debris only available from 1999 to 2007; Tables AP1-1 & AP1-4). In contrast, the time series for seafood demand (data available from 1962 to 2011; Table AP1-1) was related to trend 1 across the entire period of the trend (1985 – 2011; Table AP1-4).

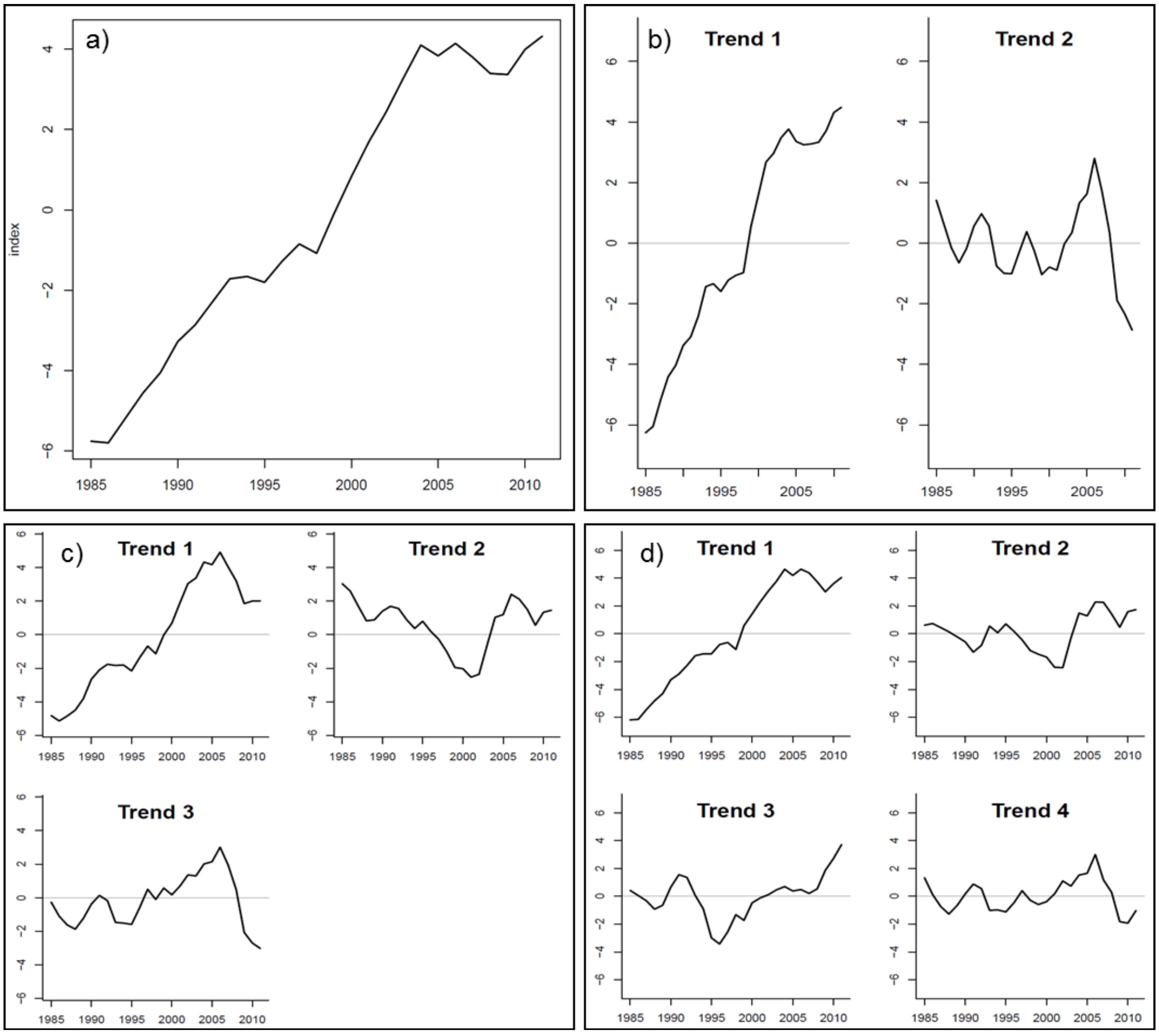


Figure AP1-8. Common trends in dynamic factor analysis models using all 23 anthropogenic pressure indicator time series, 'diagonal and equal' R matrix, no covariates, and a) one, b) two, c) three or d) four common trends. The four common trends model was the best model based on model selection criteria (AICc). Because all trends are estimated simultaneously, we cannot statistically determine which trend is most important; however, it appears that trend 1 explains the greatest amount of variation in this set of time series since it is the trend identified in the 1-trend model and remained relatively unchanged in the 2-, 3- and 4-trend models (Zuur et al. 2003a).

DISCUSSION

One of the central tenets of ecosystem-based management is to address the multiple activities, occurring both on land (e.g., agricultural and industrial practices) and in the ocean (e.g., fishing and energy exploration), that affect various components of marine ecosystems (Leslie and McLeod 2007). Spatial analyses have quantified individual and cumulative pressures across the California Current ecosystem (CCE; Halpern et al. 2009), but prior to this work we are unaware of companion analyses to determine the temporal status and trends of these anthropogenic pressures.

In this study, we evaluated 43 candidate indicators across 22 anthropogenic pressures in the CCE, and developed time series for those that ranked highest for each pressure. Most indicators showed either significant short-term trends or their current status was at historically high or low levels. Taken together, these results support two primary conclusions: 1) decreasing trends of several pressures (e.g., shipping related indicators, industrial pollution and recreational activity) potentially reflect slowing economic conditions during the 'Great Recession' that began around December 2007 (e.g., Grusky et al. 2011), and 2) most pressures at historically high levels have leveled off and are not continuing to increase. Exceptions to these general conclusions are that shellfish aquaculture continues to increase despite being at historically high levels and the time series for seafood demand and dredging suggest these pressures will be increasing at historically high levels if current trends continue over the next few years. In addition to these pressures, relatively new pressures related to wind/wave/tidal energy will need to be incorporated into this framework as activities associated with these technologies will undoubtedly increase over the next decades.

Because each of the pressures we catalogued is associated with one or more human activities, the connotation of their status and trends depends on one's perspective. For example, a decreasing trend in fisheries removals may be "good" for some conservation outcomes, while at the same time, it could be "bad" for human well-being in coastal communities (Levin et al. 2009). Understanding the trade-offs resulting from dynamic changes in these pressures for the social, economic, and biological components of the ecosystem is essential for making informed management decisions (Link 2010, Kaplan and Leonard 2012). The time series we developed here can be used to inform such decisions in the U.S. portion of the CCE, and to populate science-based decision support tools that link biological components of marine ecosystems with human communities and economies.

In addition to quantifying the status and trends of individual pressures, the ultimate goal of this work was to reduce the large number of pressures to a manageable number of trends that could subsequently be used in integrative analyses that investigate linkages between pressures and state variables across the CCE. Our first method, calculated two indices of cumulative pressures across the CCE. Although we did find statistical differences in the status and trends between the additive and weighted models, they provided qualitatively similar results. These results suggest that, at the scale of the U.S. portion of the CCE, either model could be useful for capturing the overall variation in cumulative pressures. The weighted model may be most useful when examining the relationship between cumulative pressures and specific species where the sensitivity of a species to each pressure could be used as weightings. For resource managers interested in the potential impacts of these pressures in specific habitats, habitat-specific vulnerability scores for each pressure identified by Teck et al. (2010) could be used instead of the average vulnerability score across all habitats. The habitat-specific vulnerability scores would be weighted by the proportion of area of each habitat within the region of interest in order to calculate the weighting for each pressure. However, our analysis suggests that if interactions between pressures are not assumed to be synergistic or antagonistic, the qualitative trends will not differ substantially between additive and weighted models.

A clear limitation of any analysis attempting to combine multiple pressures into a cumulative index is the lack of data on the strength and form of interactions between them. Without a clear understanding of the potential synergistic and antagonistic interactions among multiple pressures (Crain et al. 2008, Darling and Côté 2008, Brown et al. 2013), an additive index can be used to describe the cumulative effect of multiple pressures acting on the system (Halpern et al. 2009). However, there is an increasing body of work being performed to more realistically describe the effects of multiple pressures on fish populations as well as on fisheries (Kaplan et al. 2010, Ainsworth et al. 2011, Brown et al. 2013), and there has been an increasing effort to empirically evaluate the strength and direction of interactions among multiple pressures (Lefebvre et al. 2012, Lischka and Riebesell 2012, Sunda and Cai 2012). This research will help better understand cumulative effects of multiple pressures on various species, habitats and ecosystems and reduce uncertainty in quantifying these effects.

We then used two multivariate approaches to reduce the number of pressures into a manageable number of trends. Principal components (PC) analysis is a commonly employed dimension-reducing method that allowed us to reduce a set of 15 pressures down to two principal components that explained 68% of the variation. The analysis showed large changes in the composition of pressures during the period 1994 to 2008. Oil and gas activities, benthic structures and light pollution had significant influence at the beginning of this period, but pressures such as coastal engineering, seafood demand, and nutrient input were more influential in the latter part of the time series. The relative changes among pressures may reflect changes in regulatory actions, business practices, economic activity, technological advances or social norms over this period. The principal component score framework has been suggested as a way to measure the relative status of an ecosystem and to derive specific control rules, analogous to single species management (Link et al. 2002). As the PC score moves around in multidimensional space, managers could determine whether this point falls outside of acceptable conditions (Rockström et al. 2009a, Rockström et al. 2009b, Samhouri et al. 2011, Samhouri et al. 2012). Once this occurs or is approached, pressures that are correlated with the movement outside the acceptable range could be subject to regulatory actions or incentives to reduce these pressures on the marine ecosystem.

However, we caution the use of multivariate analyses as a way to reduce or combine multiple variables when those variables are time series (e.g., Link et al. 2002, Sydeman et al. 2013) for two primary reasons: (1) PC analysis assumes that each year is independent from the year before and after, thus it does not account for autocorrelation that is present in time series data, and (2) PC analysis does not allow for missing data, which can be quite common in time series data, thus reducing the set of time series that can potentially be used. In contrast, dynamic factor analysis (DFA) is an analogous dimension-reducing methodology that explicitly accounts for the nature of time series data and can explicitly account for missing data as well as incorporate the effects of explanatory variables (Zuur et al. 2003b, Holmes et al. 2012).

Using DFA, we were able to include all 23 pressure time series and increase the number of years in the analysis from 15 to 27 compared to the cumulative pressures index and the PC analysis. The DFA reduced the 23 pressure time series to four underlying common trends. Ideally, this analysis would remove the effects of assumed drivers (covariates) and then reveal correlations between each pressure and one common trend. In our analysis, the covariates did not help remove underlying variation, but only 7 of the 23 pressures were related to multiple common trends, making interpretation of the results reasonable. One of the central goals of ecosystem-based management is to identify thresholds and/or reference points of pressures that affect ecosystem state variables (Samhouri et al. 2012, Large et al. 2013). Recent studies have begun to identify thresholds for individual pressures on ecosystem components (Samhouri et al. 2010, Large et al. 2013), but there has been no attempt at identifying thresholds across multiple pressures. Reducing 23 pressure time series to 4 common trends provides a way forward to identify relationships, including thresholds, between pressures and ecosystem components.

It was surprising that coastal population abundance and economic activity did not significantly improve the fit of DFA models to the pressures. However, the trend (trend 1) that appeared to explain the greatest amount of variation across the set of pressures was highly correlated with both covariates (population abundance vs. trend 1: $r = 0.98$; gdp vs. trend 1: $r = 0.95$). This result supports the hypothesis that coastal population abundance and gross domestic product were underlying drivers of anthropogenic pressures as a whole in the CCE and that institutional controls (laws and governance), market forces, technological advances and/or cultural norms likely interacted with these drivers at various times during this period to modify the relationship between pressures and drivers. For example, implementation of the Clean Water Act over the years has provided incentives and regulations which reduced the magnitude of certain industrial pollutants (Adler et al. 1993, Houck 2002, Smail et al. 2012), even though it likely reduced profits in the short-term. Similarly, social norms have changed the way some people feel about littering our roadways and waterways (Lee and Kotler 2011, Naquin et al. 2011), thus reducing per-capita littering in some regions even though the amount of waste we produce has continued to increase over time (USEPA 2011, Brogle 2012). At some point, we expect our governing institutions or social awareness to modify the effects of pressures ultimately caused by increases in the number of humans on the planet.

CONCLUSIONS

Despite the uncertainties about the strength and direction of interactions among pressures, it is useful to understand how the magnitudes of multiple pressures are changing over time. The presence of common trends among pressures can help reduce the number of variables included in ecosystem assessments and may help identify common drivers for multiple pressures. Incorporating numerous anthropogenic pressures into the framework of ecosystem-based management is necessary to understand linkages between these pressures and various biological components, and more importantly, will allow us to identify thresholds (Samhouri et al. 2010, Large et al. 2013) and consider trade-offs among socioeconomic, cultural and biological components of the ecosystem (Rosenberg and McLeod 2005, Link 2010). Combining spatial and temporal patterns of anthropogenic pressures will provide a better understanding of how pressures are changing over time and space and allow managers to make better use of limited funding and resources. Moreover, these anthropogenic pressures interact with the underlying oceanographic conditions and climate change. Recently developed "end-to-end" ecosystem models (e.g., Atlantis; Fulton et al. 2011) and coupled ecological/economic models (Kaplan and Leonard 2012) allow examination of the effects and interactions of anthropogenic, oceanographic and climatic pressures on multiple ecological components and human communities. Now, marine ecologists, fisheries scientists, and social scientists need to develop creative methods to test the validity of these models' results in the field in order to increase resource managers' and stakeholders' confidence in their use as part of the decision-making process.

ACKNOWLEDGEMENTS

We would like to give thanks to the numerous individuals from various state and federal agencies that helped with the gathering of data for individual pressures including L.L. LaMarca, M.L. Morningstar, J.E. Kerwin, K. Ryberg, C. Elvidge, M. Cummings, C.A. Ribic, J.M. Gronberg, R. Bell, T. Nolan, N. Dubrovsky, L. Hillmann, L. Burnett, and J. Guido. N. Tolimieri provided R code for individual time series plots and the quad plot along with statistical advice in the principal components analysis. E.J. Ward, M.D. Scheuerell, A.O. Shelton, and E.E. Holmes provided sage advice with the dynamic factor analysis. The initial selection and evaluation of pressure indicators (see "Detailed Report" above) were greatly helped by reviews from six anonymous reviewers during review of the National Oceanic & Atmospheric Administration's 2012 Integrated Ecosystem Assessment for the California Current. This research received no specific grant from any funding agency, commercial or not-for-profit sectors and we know of no conflicts of interest related to this research.

The variance-covariance matrix (R matrix) in the DFA describes the observation error structure of the set of time series. In the MARSS package (Holmes et al. 2012), there are five common R matrix structures built-in: identity, diagonal and equal, equal variance-covariance, diagonal and unequal, and unconstrained. The simplest is 'identity' which is an identity matrix in which the response variables (each time series) all have variance of 1 and are uncorrelated:

$$R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

'Diagonal and equal' is a diagonal R matrix in which the response variables all have the same variance and are uncorrelated:

$$R = \begin{bmatrix} \sigma^2 & 0 & 0 \\ 0 & \sigma^2 & 0 \\ 0 & 0 & \sigma^2 \end{bmatrix}$$

'Equal variance-covariance' is a diagonal R matrix in which the response variables all have the same variance and are correlated with the same covariance:

$$R = \begin{bmatrix} \sigma^2 & \beta & \beta \\ \beta & \sigma^2 & \beta \\ \beta & \beta & \sigma^2 \end{bmatrix}$$

'Diagonal and unequal' is a diagonal R matrix in which the response variables have unique variances and are uncorrelated:

$$R = \begin{bmatrix} \sigma_1^2 & 0 & 0 \\ 0 & \sigma_2^2 & 0 \\ 0 & 0 & \sigma_3^2 \end{bmatrix}$$

'Unconstrained' is a non-diagonal R matrix in which there are unique variance and covariance values for each response variable:

$$R = \begin{bmatrix} \sigma_1^2 & \sigma_{1,2} & \sigma_{1,3} \\ \sigma_{1,2} & \sigma_2^2 & \sigma_{1,2} \\ \sigma_{1,3} & \sigma_{2,3} & \sigma_3^2 \end{bmatrix}$$

We tested the appropriateness of each R matrix structure to determine which best explained our set of time series. The indicator time series for anthropogenic pressures consist of data measured and sampled using numerous methods across various scales of time and space. Some of these indicators take advantage of similar data sets and may be correlated. Thus, our expectation was that the 'unconstrained' R matrix would be most appropriate. However, the 'unconstrained' structure caused the solution to become unstable and parameters were not identifiable in all models. We attempted to limit the dataset by removing time series that did not resemble a random-walk (e.g., freshwater retention, coastal engineering), but even the model with no covariates and 1 trend became unstable and provided no solution. It is likely that we did not have enough data in several of the time series to estimate the large number of parameters in this type of unconstrained model. Due to these limitations, we removed 'unconstrained' from the analysis.

Models using the 'diagonal and unequal' R matrix suffered from similar issues. Models with 2 or fewer trends with and without covariates could be solved when we limited the dataset by removing time series that did not resemble a random walk, but models with > 2 trends became unstable as estimates of variance for various pressures became negative. We attempted to solve this problem by fixing the variance of pressures that went negative to very small values (0.00001), but subsequently the variance of other pressures went negative, the models became unstable and crashed. Due to these complications, we removed 'diagonal and unequal' from the analysis also.

The final set of models tested and presented in the main text of the manuscript compared the remaining three R matrix structures ('identity', 'diagonal and equal', and 'equalvarcov'). It is plausible that the more complex 'unconstrained' or 'diagonal and unequal' R matrix structures would be most appropriate for an analysis of common trends among time series that no doubt vary dramatically in observation and measurement error. However, for various reasons (perhaps lack of data to estimate the large number of parameters) these time series could not be fit to a full set of models (using 1-5 trends) using these error structures, so we used simpler error structures to determine the best model in our final results.

Of the 'diagonal and unequal' models that ran (1-2 trends) using a subset of pressures (removed freshwater and sediment retention and coastal engineering), the best model was 2 trends with population as a significant covariate. This model produced a solution with common trends (Fig. AP1-S1) that were similar to the common trends we found in the best 'diagonal and equal' model (4 trends with no covariates; Table AP1-4). Thus, we feel that limited data in some of the indicator time series may have precluded the use of the more complex R matrix structures, but it did not change the ultimate results we found using the less complex R matrix structure ('diagonal and equal').

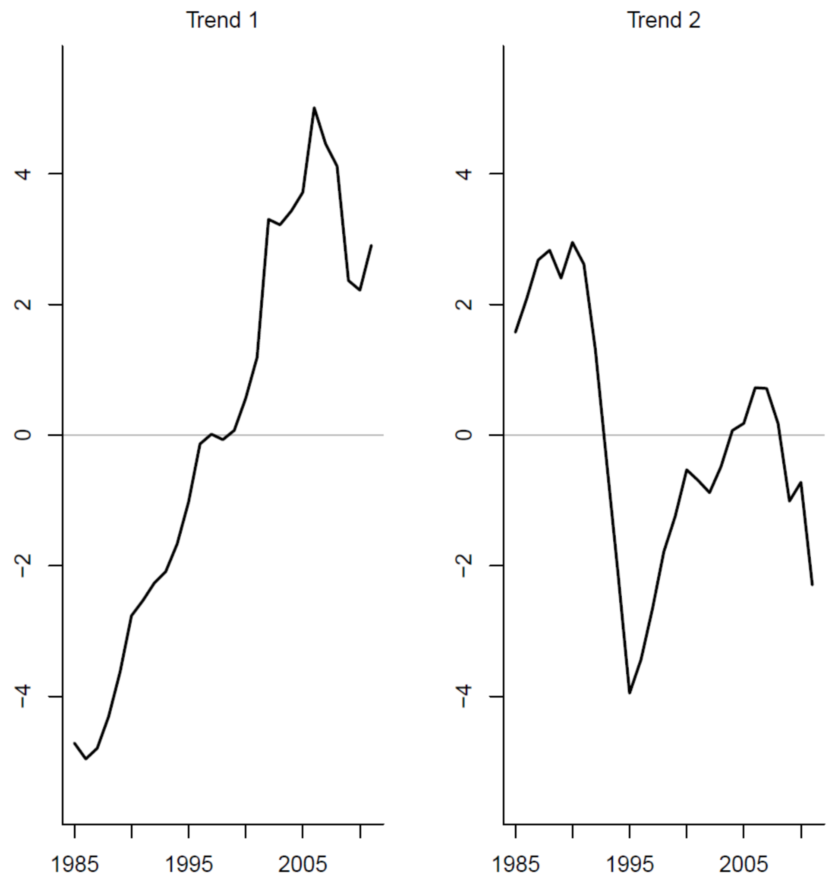


Figure AP1-S1. Common trends identified from dynamic factor analysis using 20 pressures (removed freshwater and sediment retention and coastal engineering) and time series data from 1985 to 2011.

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