ECOLOGICAL INTEGRITY

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OVERVIEW

Indicators of Ecological Integrity suggest neutral to good feeding conditions (trophic structure) in the California Current through 2013, although low mean trophic level for groundfishes merits watching. Indicators of biodiversity were neutral or mixed in the short-term. All were within long-term norms of the respective time series..

EXECUTIVE SUMMARY

Ecological integrity is "the ability of an ecological system to support and maintain a community of organisms that has a species composition, diversity, and functional organization comparable to those of natural habitats within a region" (Parrish et al. 2003). We identified and evaluated potential indicators of ecological integrity across a variety of species and foraging guilds, using the ecological literature as a basis for their rankings. We selected the mostly highly ranked indicators to track two aspects of the California Current Large Marine Ecosystem (CCLME):

- **Trophic structure**: mean trophic level, scavenger biomass ratio, biomass of gelatinous zooplankton, and the northern copepod biomass anomaly
- **Biodiversity:** Simpson's diversity, species richness or species number for multiple taxa.

The indicators reported in this section are designed to be integrative, community-based measures that draw information from across the taxonomic spectrum. Indicators derive from monitoring time series through recent years (2011-2013, depending on the time series; see Table EI 1). Indicators specific to individual ecological components, such as coastal pelagic species, groundfishes, and protected species (marine mammals, seabirds, and Pacific salmon), also provide information that can influence ecological integrity and are covered in other sections in this report.

The spatial extent of CCLME data coverage varies among taxa. The groundfish data span the U.S. West Coast (~32 to 48 ^{o}N, ~50-1200 m depths) and conclusions related to this dataset (mean trophic level, scavenger biomass, species richness, species density, and Simpson diversity) are applicable to the full CCLME. Note, however, that the trawl survey does not adequately sample complex, rocky habitats and any conclusions are limited to trawlable areas. Data for ichthyoplankton are drawn from southern California and Oregon survey transect lines, while those for gelatinous zooplankton are taken from surveys conducted off central California and the Oregon/Washington coasts. Data for coastal pelagic fishes are also drawn from the Oregon/Washington survey, whereas the copepod data are limited to survey stations in waters off of central Oregon. Thresholds and targets are not currently set for indicators of ecological integrity, and time series are evaluated based on internal statistical properties (detailed below).

TROPHIC STRUCTURE

Indicators of **trophic structure** suggest neutral to good conditions in the CCLME in recent years (Figure EI 1). All indicators were within long-term norms (±1.0 s.d. of the long-term mean), although groundfish MTL was relatively low coastwide and showed a decrease south of Cape Mendocino.

High abundance of gelatinous zooplankton is generally considered a sign of poor conditions because they clog fishing nets, prey on fish larvae and compete with forage fishes for food. Abundances of gelatinous zooplankton (*Aequorea, Aurelia* and *Chrysaora*) were near long-term averages with *Chrysaora* decreasing in abundance in the short-term off of Oregon. However, *Aequorea* increased in June surveys off of Oregon in the short-term. September values showed no trend.

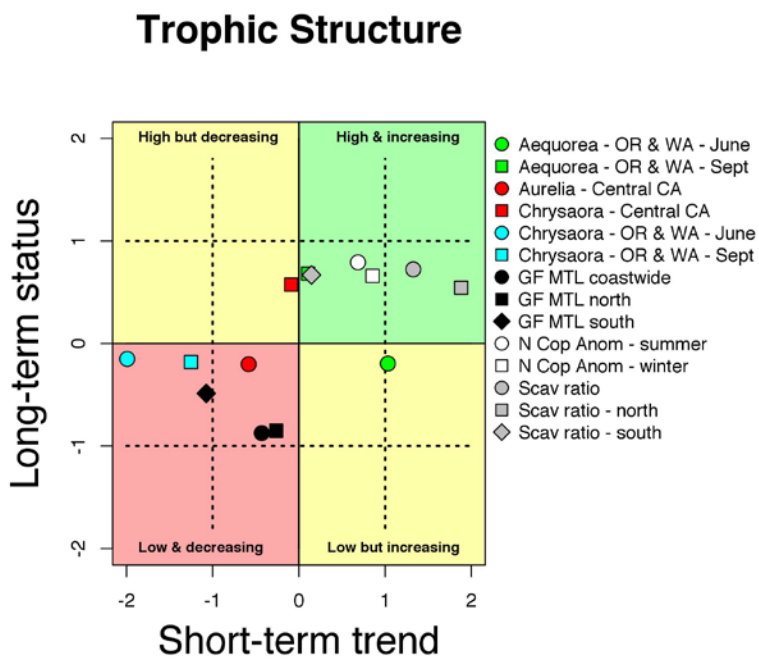


Figure EI 1. Short and long-term status of indicators of Trophic Structure for the Ecological Integrity for the California Current Large Marine Ecosystem. Prior to plotting, time series were normalized to place them on the same scale. The short-term trend indicates whether the indicator increased or decreased over the last 5 years of the time series relative to the long-term mean. The long-term axis compares the mean of the last 5 years to the mean of the full time series. Changes or differences of more than 1.0 standard deviation of the full time series (dotted lines) are considered to show an effect. GF MTL = groundfish mean trophic level, N Cop Anom = northern copeopod anomaly, Scav ratio = ratio of scavengers:total biomass, CA = California, OR = Oregon, WA = Washington. *Aequorea, Aurelia and Chrysoara* are gelatinous zooplankton (jellies). For GF MTL and Scav kg, north and south indicate north and south of Cape Mendocino.

The northern copepod anomaly was relatively high but within long-term historical norms. High abundance of energetically rich northern copepod species generally indicates good feeding conditions for many species.

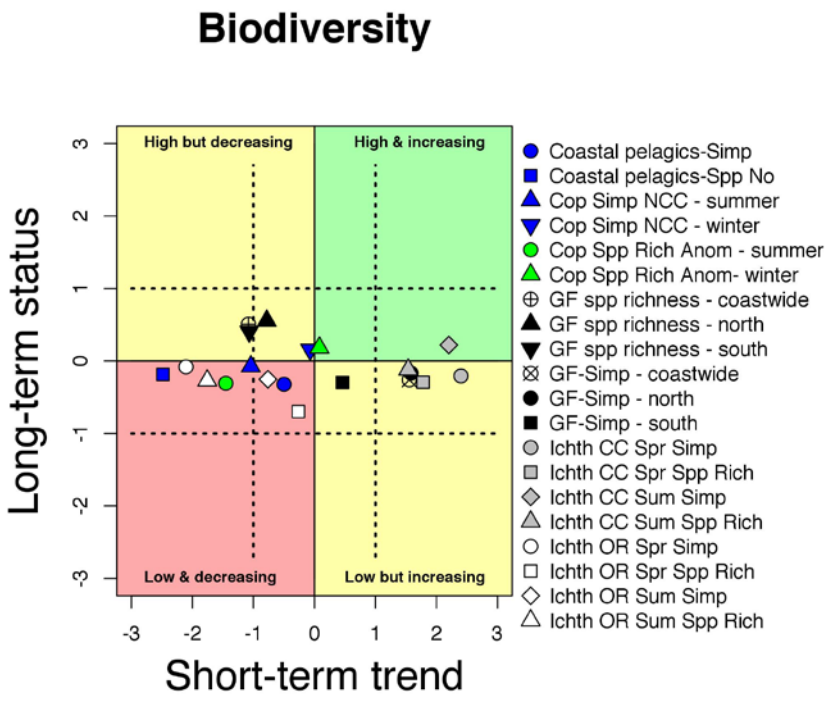
The ratio of scavenger biomass to total biomass for groundfishes and crabs increased in the short-term coast-wide and in water north of Cape Mendocino. The increase appears to have been caused by an increase in crab biomass.

Groundfish mean trophic level (MTL) declined south of Cape Mendocino. While stable overall and north of Cape Mendocino, current MTL was near relatively low but still within 1.0 s.d. of the long-term mean. Low MTL is generally considered an indication of reduced abundance of top predators, and therefore, top-down forcing in the system. However, low groundfish MTL may make food resources (forage fishes and krill) available to groundfish competitors like salmon, seabirds and tuna, indicating good feeding conditions for these species. Previous work has shown that the decline in MTL was caused by a decrease in the abundance of Pacific hake and dogfish.

BIODIVERSITY

Biodiversity indicators showed mixed results (Figure EI 2). No indicators showed changes relative to their long-term trends. Six diversity measures increased in the short-term, while seven decreased. Simpson diversity (~evenness, technically equitability) increased in the short-term for groundfishes coast wide. This rise was driven by changes north of Cape Mendocino. Simpson diversity south of Mendocino did not increase. All measures of ichthyoplankton biodiversity increased in the short-term for the California Current. Conversely, ichthyoplankton spring Simpson diversity and summer species richness both declined in Oregon suggesting different trends in northern and southern regions. Groundfish species richness declined coastwide as did species richness south of Mendocino. North of Mendocino richness also declined but by less than the threshold value. In all three cases, richness was within long-term norms but above the long-term mean. Earlier declines in MTL were caused by loss of Pacific hake and spiny dogfish biomass, and the increase in Simpson diversity may be linked to these trends.

Copepod biodiversity in the summer declined as did species number for coastal pelagic fishes. Seven diversity indicators decreased in the short-term. While decreased diversity is typically considered a negative indication of ecosystem status, low copepod diversity is linked to high abundance of northern, energy-rich species and indicates overall good feeding conditions for species like forage fishes and salmon.



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DETAILED REPORT

BACKGROUND - ECOLOGICAL INTEGRITY

Ecological integrity has been defined as "the ability of an ecological system to support and maintain a community of organisms that has a species composition, diversity, and functional organization comparable to those of natural habitats within a region" (Parrish et al. 2003). Implicit in this definition is the concept that an ecological system has integrity when its dominant ecological characteristics (e.g., elements of composition, structure, function, and ecological processes) occur within their natural ranges of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human disruptions. As it is applied in this report, ecological integrity is defined by indicators of community structure that describe individual components within an ecosystem and the relative extent of their potential interactions. These include community-level metrics such as taxonomic diversity, trophic structure, ratio between different foraging guilds, functional group redundancy and relative biomass. Community composition indicators also include population-level trends and conditions across some lower trophic levels, such as zooplankton, not typically subject to fisheries.

There are numerous publications that cite indicators of ecosystem health or ecological integrity in marine systems. As the basis for the initial indicator selection effort (Levin et al. 2011), we relied on several core references from the literature to develop a list of potential indicators (Jennings and Kaiser 1998, Link et al. 2002, Rochet and Trenkel 2003, Fulton et al. 2005, Jennings 2005, Jennings and Dulvy 2005, Link 2005, Shin et al. 2005, Samhouri et al. 2009, Sydeman and Thompson 2010). In many cases, authors chose indicators identified in the literature based on expert opinion or the context of the researchers' expertise. For example, many reviews of marine ecosystem indicators are put into the context of fisheries (e.g., Fulton et al. 2005, Link 2005) and ask the question: Which indicators reflect changes in the population as a result of fishing pressure?

INDICATOR SELECTION PROCESS

EVALUATION OF POTENTIAL INDICATORS

The process for selecting indicators of ecological integrity began in 2010 during the initial CCIEA and continued into 2012, using a standardized framework grounded in work developed by Kershner et al. (2011). For specific details related to the methods used in the CCIEA indicator selection process, see Levin et al. (2011) and Williams et al. (2013). In this version of the IEA, we expand the final suite of indicators by one to a total of five (5) based on recent work by Samhouri et al. (2014), who conducted a supplemental evaluation focused on those indicators derived specifically from coastal pelagic data sets. The goal of

the Samhouri et al. (2014) study was to complement and balance the previous suite of indicators, which was considered to be heavily reliant on benthic-dwelling taxa of trophic level >3.0. Gelatinous zooplankton (jellyfish) biomass emerged as a promising indicator from this analysis

FINAL SUITE OF INDICATORS

Recent analyses have shown that a single indicator is not sufficient to provide a complete picture of ecosystem state (Fulton et al. 2005); conversely, too many indicators can lead to too many conflicting signals, which may lead to indecision. Therefore, we ranked the evaluation scores of all indicators for the ecological integrity goal and selected five of those ranked in the top quartile. Below, we list the five-indicator portfolio chosen to represent the ecological integrity of the California Current ecosystem during 2013:

- Biodiversity (*Simpson's index of diversity*, with comparison to *Species richness*)
- Zooplankton species biomass anomalies (specifically, *Northern copepod biomass anomaly*)
- *Mean trophic level*
- *Ratio of scavenger biomass to total biomass (Scavenger biomass ratio)*
- *Gelatinous zooplankton biomass*

What follows are brief descriptions of the five (5) top-ranked indicators composing our ecosystem integrity portfolio, generally organized under the larger ecosystem concepts of biodiversity and trophic structure.

BIODIVERSITY

Species diversity is an integrative measure that encompasses species richness - the number of species in the ecosystem, and species evenness - how individuals or biomass are distributed among species within the ecosystem (Pimm 1984). Diversity has remained a central theme in ecology and is frequently seen as an indicator of the wellbeing of ecological systems (Magurran 1988).

Theoretical modeling results have been used to show that some ecosystem structural (e.g., diversity) attributes can be related to thresholds in the level of human-induced pressures. Correlations between diversity and ecosystem function (productivity and stability) have been reviewed recently for terrestrial and marine systems, suggesting that the relationship is complex but communities are more stable at higher richness (Hooper et al. 2005, Stachowicz et al. 2007). In general, populations can be more variable but community-level processes are more stable at higher diversity (i.e., the biomass of species A and species B may fluctuate, but A + B tends to be stable). Linking diversity

indices to targets or reference points is difficult, and the significance of certain types of change is not known for biodiversity indices (Link 2005, Dulvy et al. 2006). However, some authors have provided a rationale to manage for biodiversity as an approach to EBM (Palumbi et al. 2009). The general public tends to have a basic understanding and positive impression toward biodiversity as it relates to ecosystem health (Thompson and Starzomski 2007). Species richness has been shown to decrease with fishing, although these results appear largely related to trawling and dredging on benthic invertebrates (Gaspar et al. 2009, Reiss et al. 2009).

Diversity indices can be used with a variety of existing survey data, including: groundfish trawl surveys (Weinberg et al. 2002, Keller et al. 2010), pelagic or midwater trawl surveys (Brodeur et al. 2003, Sakuma et al. 2006), reef fish surveys conducted by trained divers (REEF 2008), zooplankton surveys (e.g., NWFSC Newport Line, CalCOFI), invertebrates from benthic grabs conducted by the EPA[1], and a variety of seabird and marine mammal surveys (Ainley et al. 1995, Barlow and Forney 2007, Carretta et al. 2007, McClatchie et al. 2009). Other possible data sources include intertidal invertebrate surveys from 2002 to 2010 (PISCO[2]) and datasets available at smaller spatial and temporal scales (e.g., National Park Service kelp forest monitoring program in the Channel Islands). Many of these data would need to be combined to investigate trends over time across the entire scale of the CCLME.

SIMPSON'S INDEX

Simpson's index is a dominance measure that estimates the probability that any two individuals drawn at random from an infinitely large community would belong to different species (Magurran 1988). It is similar to Hurlbert's (1971) concept of the probability of an interspecific encounter when individuals are drawn with replacement, and is relevant to predator-prey and food-web analyses. It is a numerical measure and does not show bias in mean value in relation to the number of individuals in a sample (Clarke and Warwick 2001). Model simulations, used to evaluate the ability of candidate indicators to track ecosystem attributes of interest, have shown that Simpson's diversity was strongly correlated to the biomass of marine mammals in a system. Samhouri et al. (2009) note that the indicator-attribute relationship can switch depending upon the type of fishing pressure used in the model. This result might make the indicator-attribute relationship unpredictable in the real world.

[1] http://www.epa.gov/emap/index.html
[2] http://www.piscoweb.org/

SPECIES RICHNESS

Species richness, which is a count of the number of species present, can provide an extremely useful measure of diversity if the study area can be successfully delimited in space and time and the constituent species enumerated and identified (Magurran 1988). Though ranked low in the evaluation, we included a description here because species richness can be used to help inform other standard measures of diversity. Species richness may not be highly sensitive to change and may not respond unambiguously to variations in ecological integrity or management action; furthermore, the species-sampling intensity relationships will require rarefraction to standardize for sampling effort. Studies have shown that species richness tends to decline with fishing, primarily based on trawling/dredging effects on benthic invertebrate communities (Gaspar et al. 2009, Reiss et al. 2009).

Richness can influence stability and productivity in two ways: 1) sampling/selection effect or 2) compensatory effect (Stachowicz et al. 2007). Under the sampling effect, higher richness leads to a greater chance of highly productive species being present. This type of relationship is not considered a real richness effect by some, but more of a compositional or keystone species effect. Under the compensatory effect, higher production or stability occurs in two ways: via resource complementarity, where more species occupy more niches and better utilize all resources (e.g., different type of nitrogen), and facilitation, where some species combinations do better.

TROPHIC STRUCTURE

Organisms within an ecosystem can be classified according to their trophic level, or position within the food web (e.g., functional groups include herbivores, carnivores or predators, detritivores, and scavengers), and indicators of trophic structure attempt to measure their relative abundance, biomass, and interactions. Indicators related to the biomass of specific trophic levels within the ecosystem ranked highly in the evaluation, especially within the context of theoretical or practical considerations.

ZOOPLANKTON SPECIES BIOMASS ANOMALY (NORTHERN COPEPOD BIOMASS)

Zooplankton time series provide some of the best opportunities to understand marine ecosystem responses to climate change because zooplankton are the foundation of the ocean food web, linking oceanographic conditions and primary production to upper trophic levels and fueling the delivery of ocean ecosystem services. Zooplankton life cycles are short (on the order of weeks to a year) and populations have the potential to respond to and reflect event-scale and seasonal changes in environmental conditions (Hooff and Peterson 2006). Moreover, many zooplankton taxa are known to be indicator species

whose presence or absence may represent the relative influence of different water types on ecosystem structure. Thus zooplankton may serve as sentinel taxa that reflect changes in marine ecosystems by providing early indications of a biological response to climate variability and are often used as an indicator to detect climate change or regime shifts (Hooff and Peterson 2006, Mackas et al. 2006, Peterson 2009). Finally, zooplankton are abundant and can be quantified by relatively simple and comparable sampling methods and, because few zooplankton are fished, most population changes can be attributed to environmental causes (Mackas and Beaugrand 2010). As such, they may prove useful as a leading indicator of what may happen to regional commercial fish stocks several years in the future (Mackas et al. 2007, Peterson et al. unpubl. manuscr.).

All along the California Current, anomalies in zooplankton species composition shifts have been correlated with regional climate patterns (Mackas et al. 2006). For example, off the Oregon coast zooplankton indices have been developed based on the affinities of copepods for different water types: those with cold water and those with warm water affinities (Peterson et al. unpubl. manuscr.). The cold water group usually dominates the coastal zooplankton community during the summer (typically May through September) upwelling season, whereas the warm water group usually dominates during winter, although this pattern is altered during summers with El Niño events or when the Pacific Decadal Oscillation (PDO) is in a positive (warm) phase. Perhaps the most significant aspect of the copepod index is that two of the cold water species, *Calanus marshallae* and *Pseudocalanus mimus*, are lipid-rich species. Therefore, an estimate of northern copepod biomass may also index the total food web uptake of wax esters and fatty acids, compounds which appear to be essential for many pelagic fishes if they are to grow and survive through the winter.

Several long-term zooplankton monitoring programs, representing seven subregions spanning the entire CCLME from Baja California to Vancouver Island, now provide zooplankton time series of various lengths from 1969 to the present. Although differences in sampling and processing zooplankton introduce a variety of biases that often prevent comparisons between datasets, many major questions can still be answered because an individual dataset can be presented and analyzed as a time series of log-scale anomalies relative to the local long-term-average seasonal climatology. Anomalies are primarily used to separate interannual variability from the often large annual seasonal cycle of zooplankton stock size (Mackas and Beaugrand 2010). The specific species associated with these anomalies vary regionally, but can generally be classified as resident versus nonresident species. Regional anomalies can be combined into a single index using multivariate techniques (e.g., principal component analysis) in similar fashion to the calculation of regional climate indices, such as the Multivariate El Niño Southern Oscillation (ENSO) Index (Wolter and Timlin 1993). The zooplankton anomaly index can then be

tested for use as a leading indicator of regional climate signals, such as ENSO or PDO, using existing time series from the last 20 years, during which time the California Current saw at least two major climate regime shifts.

MEAN TROPHIC LEVEL

Mean trophic level (MTL) is the biomass-weighted average trophic level of all species in an ecosystem. Mean trophic level provides a synoptic view of the organization of trophic structure in marine ecosystems, and is a pervasive and heavily discussed indicator used to measure marine ecosystem status, especially in communities dominated by exploited species (Pauly and Watson 2005, Essington et al. 2006, Branch et al. 2010). Conceptually, MTL is linked to top-down control and trophic cascades; a decline in MTL represents a decrease in the ability of predators to 'control' prey populations and may have far-reaching consequences to ecological communities (Daskalov 2002, Estes et al. 2004, Pauly and Watson 2005, Baum and Worm 2009). Theoretical modeling results have been used to show that mean trophic level can be a good univariate indicator of fishing effects on an ecosystem, although it may be sensitive to data quality (e.g., landings v. survey data) (Fulton et al. 2005, Samhouri et al. 2009). Trends in 'catch' MTL, estimated from fisheries landings and other fishery-dependent data sources may not provide a good indicator of actual changes in the ecosystem. Instead, 'ecosystem' MTL, estimated from data sources like fisheries-independent surveys, is indicative of current ecosystem status especially when coupled with an exploration of the processes responsible for such patterns (Branch et al. 2010, Tolimieri et al. 2013).

A decrease in MTL is generally considered to be undesirable, as it may represent a loss of high trophic level predators, which are often the target of intensive fisheries (Pauly and Watson 2005, Essington et al. 2006, Branch et al. 2010). However, the causes and consequences of changes in MTL are complex. A decrease can be the result of a loss of top predators or an increase in the abundance of lower trophic level species. Regardless, a drop in MTL indicates a change in trophic structure and probable decrease in the strength of top-down control. While a decrease in MTL may indicate an undesirable trend for the taxa in question (e.g., groundfishes), the effect on other species can be positive if those are competitors or prey of the high TL species. For example, modeling work has shown that a decrease in groundfish MTL should correlate with positive responses in competitors like crabs, squid, salmon, tuna and seabirds (Tolimieri et al. 2013). Thus, determining the 'desired status' for MTL may include trade-offs between multiple taxonomic groups.

Mean trophic level is an operationally simple, concrete, numerical indicator, calculated each year using the simple mean of biomass-weighted trophic levels within an

ecosystem. Trophic levels can be estimated for species worldwide from Fishbase[3], an online database; species biomass can be obtained from historical, annual estimates derived from standardized surveys throughout the California Current (various groundfish, zooplankton, marine mammal, and seabird surveys, etc.). These surveys are generally continuous, have broad spatial coverage, and are designed with appropriate power to have a high signal-to-noise ratio for most species. The spatiotemporal variation in these time series is becoming increasingly understood as more data are collected each year.

Although included here as a measure of trophic structure, mean trophic level is included in the list of provisional indicators for assessing progress toward the 2010 biodiversity target, proposed by the Convention of Biological Diversity[4]. As such, it is understood by the public and policymakers, considered internationally compatible, and demonstrates a relatively recent history of reporting (Pauly and Watson 2005, Stergiou and Tsikliras 2011). Mean trophic level can be estimated in a cost-effective manner using existing survey data (various groundfish Stock Assessments, REEF.org, etc.).

RATIO OF SCAVENGER BIOMASS TO TOTAL BIOMASS

Scavengers play significant roles in the ecosystem by recycling dead and decomposing organic matter back into the food web. However, human interference in the marine ecosystem has likely increased the abundance and number of species that forage on carrion (Britton and Morton 1994). For example, many fishing operations discard dead bycatch or fishery offal to the ocean floor, or damage organisms on the seabed with bottom-contact fishing gears (Ramsay et al. 1998). Scavenger population increases may be related to these types of fishing activities (Britton and Morton 1994, Ramsay et al. 1998, Demestre et al. 2000).

When evaluating this indicator, we used the definition of scavenger from the Atlantis ecosystem models for the California Current (Brand et al. 2007, Horne et al. 2010). Further detail was taken from Yeh and Drazen (2011) who used baited-cameras to evaluate scavenger ecology on the California slope, and from Buckley et al. (1999) who examine food habits of several groundfishes. Detectable changes in the community composition may be a result of changes in various foraging guilds, but a change (or no change) in a single guild may not be indicative of the ecosystem as a whole. Fisheries-based reference points include B40 (target level where production is predicted to be greatest) and B25 (overfished). These single-species reference points could be adapted and used for foraging guilds such as scavengers. Alternatively, Link (2005) describes a framework of reference points that could be applied to most any indicator.

[3] http://www.fishbase.org/search.php)
[4] http://www.cbd.int/

Fishery-independent data are available since 1977 for all scavenger species susceptible to bottom trawling across the U.S. portion of the CCLME. There are also data available at smaller spatial scales and at various temporal scales in untrawlable habitats from submersible, ROV, and the NWFSC hook-and-line surveys. Fishery-dependent data for crab species are available in the PacFIN database (http://pacfin.psmfc.org/). New surveys will be needed to sample some species of the scavenger guild, such as isopods, amphipods, and polychaetes. Benthic grab samples are commonly used to quantify benthic infauna, but it may be difficult to perform this type of survey at the scale of the CCLME at necessary temporal scales. Moreover, quantifying a value for many foraging guilds will require quantitative analyses to combine datasets which collect data using very different methods. For example, bottom trawl surveys, longline surveys, and benthic grab samples will need to be combined at various spatial and temporal sampling scales to quantify the biomass of grenadiers, crabs, large demersal sharks, and deposit feeders.

The public can easily understand whether a foraging guild, such as scavengers, is trending up or down, but this particular indicator may be less attractive to the public than more charismatic groups (i.e., marine mammals or sharks). Detecting changes in the biomass of scavengers would likely be measured against long-term averages, so unless dramatic changes are observed, scavenger biomass will be a lagging indicator of changes in community composition. Monitoring foraging guilds such as scavengers has been performed in other regions of the United States (Link and Almeida 2002) and in other nations (Demestre et al. 2000, Greenstreet and Rogers 2000).

Using raw biomass (kg per km^{-2}) would not separate an increase in scavenger biomass from an increase in the biomass of all species. Instead we use the ratio of scavenger biomass to total biomass in the trawl survey to test for a change in the trophic structure because it indicates whether scavengers are more or less prevalent in the assemblage than in previous years.

GELATINOUS ZOOPLANKTON BIOMASS (JELLIES)

Gelatinous zooplankton (jellyfish) are a lower trophic level, high-productivity functional group with important effects on ecosystem trophic structure. High abundance of jellies may 'interfere' with the transfer of biomass, nutrients and energy from zooplankton up the food web to taxa important to human activities (fishes, squids, birds and marine mammals). In the Northern California Current (NCC), early stages of euphausiids, gelatinous taxa, and cladocerans are particularly vulnerable to predation by jellyfish (Suchman et al. 2008). Gelatinous zooplankton are increasingly thought to be a keystone group in some systems (Pauly et al. 2009). The abundance of gelatinous zooplankton has been linked to overfishing, eutrophication, habitat modification (shoreline armoring),

climate change and several other human activities (Purcell et al. 2007, Pauly et al. 2009, Richardson et al. 2009, Purcell 2012).

Jellyfish populations can grow quickly in response to abundant prey, producing jellyfish "blooms." Because of fast growth rates and one-year life cycles, gelatinous zooplankton respond quickly to variability in local or regional environmental conditions, but general abundance patterns and the mechanisms responsible for those patterns have been difficult to discern (Suchman et al. 2012). The highest catches of medusae in the NCC appear correlated with cool spring–summer conditions, or negative anomalies of the Pacific Decadal Oscillation, and low winter–summer runoff from the Columbia River (Brodeur et al. 2008, Suchman et al. 2012). Recent publications suggest they have increased in abundance throughout world, and human problems with jellyfish have increased and have captured public attention (Purcell et al. 2007, Richardson et al. 2009). However, Condon (2013) suggests there is no robust evidence for a long-term, global increase in jellyfish (ostensibly due to global warming); rather, jellyfish populations undergo larger, worldwide oscillations with an approximate 20-year periodicity.

Jellyfish biomass can be a sensitive indicator of changing ecosystem status (Richardson et al. 2009). Jellyfish biomass served as the best proxy for ecosystem attributes related to community energetics using seven food web models from the North Pacific and the Baltic Sea (Samhouri et al. 2009). Increases in jellyfish are generally associated with negative impacts on ecosystem attributes (Pauly et al. 2009, Ruzicka et al. 2012). There are also numerous negative effects on humans including interference with tourism (stinging swimmers), fishing (clogging nets), aquaculture (killing fish in net-pens), and power plants (clogging cooling-water intake screens) (Purcell et al. 2007). Median biovolume of gelatinous zooplankton has been included in suites of indicators used for decision criteria (Link 2005).

INDICATOR DATA SOURCES

The data sources we propose for these indicators, including extent of time series and sampling frequency, are documented in Table EN1. The indicators we selected integrate a variety of time series from among several components of the ecosystem (i.e., pelagic and demersal communities). For the *diversity indicator*, the relative coverage of the ecosystem is obviously driven by the time series used. The *copepod biomass anomaly* indicator focuses on a single, critical component known to form the foundation of the ocean food web, linking oceanographic conditions and primary production to upper trophic levels. *Scavenger biomass* is a benthic/demersal indicator of trophic structure, which has been shown to respond to various fishing activities; it also serves to integrate data on crustacean populations, which can be responsive to top-down effects in the food web and predatory finfish populations. At this point in time, the *mean trophic level* indicator is

focused on the demersal community associated with the West Coast groundfish trawl time series; future iterations will integrate other trophic levels and communities (e.g., seabirds and marine mammals). Finally, *standardized gelatinous zooplankton biomass* represents a pelagic, lower trophic level, high-productivity functional group that shows relatively strong correlations with at least half of the ecosystem attributes in a food-web modeling exercise that evaluated the performance of candidate indicators of ecosystem structure and function (Samhouri et al. 2009).

Table EI 1 Top-ranked indicators for Ecosystem Integrity and corresponding data time series.

Attribute / Guild	Indicator	Definition and source of data	Region (State)	Time series	Sampling frequency
Biodiversity	Simpson's index & Species Richness	Index of zooplankton community composition; measures dominance & number of species present in study area (Peterson et al., NOAA)	North (OR)	1996 – 2013	Biweekly
		Index of ichthyoplankton community composition using CalCOFI and BPA time series (Thompson et al.)	North & South (OR/CA)	2004-2011	Quarterly
		Index of pelagic nekton species community composition (Brodeur et al., NOAA)	North (WA/OR)	1998 – 2013	June, Sept; Annual
		Index of groundfish community composition (Keller et al. NWFSC)	Entire	2003 - 2013	Summers, Annual
		Index of seabird community composition (Zamon et al. NWFSC; Sydeman et al.) (*Not updated here. Currently being revised. See previous IEA reports for trends through 2011).*	North & South (WA/OR; CA)	2004 - 2012; 1987 - 2012	Summers, Annual
Trophic structure	Mean trophic level	Trophic structure of groundfish community (Keller et al. NWFSC)	Entire	2003 - 2013	Summers, Annual
		Trophic structure of coastal pelagic fish community (*currently in development*) (Brodeur et al., NOAA)	North	1998 – 2013	June, Sept; Annual
		Trophic structure of seabird community (*currently in development*)			
		Trophic structure of marine mammal community (*currently in development*)			
Trophic structure	Scavenger biomass	Relative biomass of scavengers, as defined by esp. Brand et al. (2007), from fishery independent surveys (Keller et al. NWFSC)	Entire	2003 - 2013	Summers, Annual
Trophic structure	Northern copepod anomaly	Monthly anomalies in the relative biomass of copepods with cold-water affinities off Newport, OR (Peterson et al., NOAA);	North (OR)	1996 – 2013	Biweekly
Trophic structure	Gelatinous zooplankton biomass	Standardized abundance or biomass of jellyfish associated with near-surface waters (Brodeur et al., NOAA; Field et al., NOAA))	North & South (OR/WA; cent. CA)	1998 – 2013; 1986-2013	June, Sept; Annual; Annual

DATA ANALYSIS AND PRESENTATION

The status of each indicator is evaluated against two criteria: recent short-term trend, and status relative to the long-term mean—reported as short-term status and long-term status, respectively. This approach holds for those indicators for which thresholds have not currently been set. For those indicators with established thresholds, those specific thresholds are used to evaluate the indicators.

Short-term trend. An indicator is 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 deviations (s.d.) of the mean of the entire time series.

Status relative to the long-term mean. An indicator is 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 s.d. of the full time series.

Northern and Southern Trends. Some datasets have limited range and describe trends only in certain regions. Other datasets span the entire CCLME. For the latter, we present three trends: coastwide, northern and southern. Northern trends are the area north of Cape Mendocino (40.4^{o} N), an important biogeographic break point. Southern trends are for the area south Cape Mendocino. In many cases, regional trends do not match the coastwide pattern.

MAJOR FINDINGS

Indicators for **Ecological Integrity** are ecosystem and community level indices that were chosen to track two community level aspects of the CCLME: **trophic structure** (mean trophic level, scavenger biomass, gelatinous zooplankton, and the northern copepod anomaly) and **diversity** (Simpson diversity, species richness for multiple taxa). The extent to which the data for these indicators cover the California Current Large Marine Ecosystem (CCLME) varies among taxa. The groundfish data span the U.S. West Coast (~32 to 48 ^{o}N, ~50-1200 m depths). Thus, conclusions for indicators based on the groundfish dataset (MTL, scavenger biomass, species richness, species density and Simpson diversity) are applicable to the full extent of the CCLME. Data for ichthyoplankton are drawn from southern California and Oregon survey transect lines, while those for gelatinous zooplankton are taken from surveys conducted off central California and the Oregon/Washington coasts. Data for coastal pelagic fishes are also drawn from the Oregon/Washington survey, whereas the copepod data are limited to survey stations in

waters off of central Oregon. See the Ecological Indicators: Data Sources and Methodology for a more complete discussion of the datasets.

TROPHIC STRUCTURE

Indicators of trophic structure suggest neutral to good conditions in the CCLME (Figure EI 3). All indicators were within long-term norms although groundfish MTL was relatively low coastwide and north of Cape Mendocino and decreased south of Mendocino.

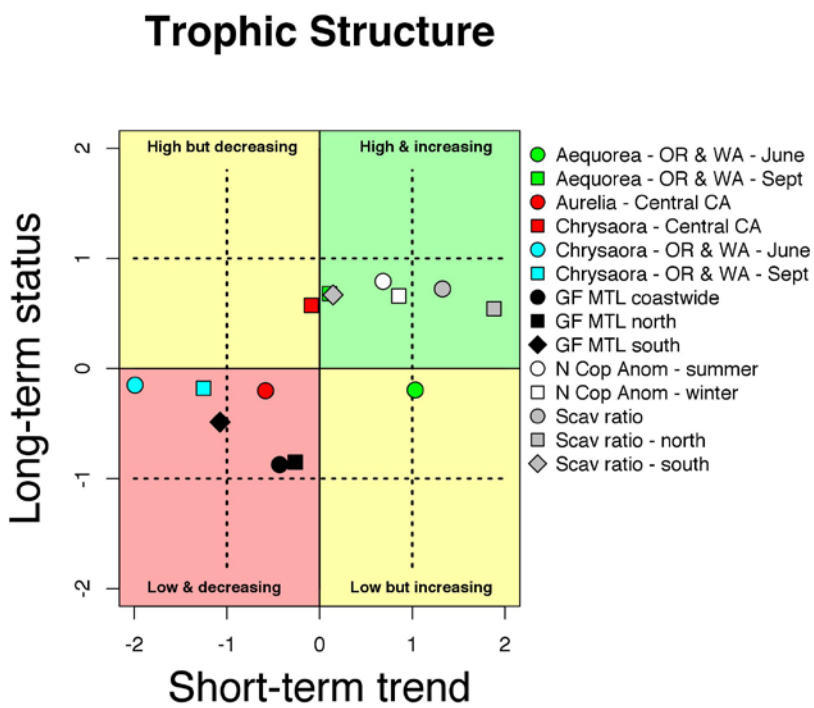

Figure EI 3. Short and long-term status of indicators of Trophic Structure for Ecological Integrity in the California Current Large Marine Ecosystem. Prior to plotting, time series were normalized to place them on the same scale. The short-term trend indicates whether the indicator increased or decreased over the last 5 years of the time series relative to the long-term mean. The long-term axis compares the mean of the last 5 years to the mean of the full time series. Changes or differences of more than 1.0 standard deviation of the full time series (dotted lines) are considered to show an effect. GF MTL = groundfish mean trophic level, N Cop Anom = northern copeopod anomaly, Scav ratio = ratio of scavengers:total biomass, CA = California, OR = Oregon, WA = Washington. *Aequorea, Aurelia and Chrysoara* are gelatinous zooplankton (jellies). For GF MTL and Scav kg, north and south indicate north and south of Cape Mendocino.

Abundances of gelatinous zooplankton (*Aequorea, Aurelia* and *Chrysaora*) were near long-term average with *Chrysaora* decreasing in abundance in the short-term off of Oregon.

However, *Aequorea* increased in June surveys off of Oregon in the short-term. September values showed no trend. High abundance of gelatinous zooplankton is generally considered undesirable because they clog fishing nets, prey on fish larvae, and compete with forage fishes for food.

The northern copepod anomaly was relatively high but within long-term historical norms (within 1.0 s.d. of the long-term mean). High abundance of northern copepod species generally indicates good feeding conditions for many species.

The ratio of scavenger biomass to total biomass for groundfishes and crabs increased in the short-term coast-wide and in waters north of Cape Mendocino. The increase appears to have been driven by an increase in crab biomass.

Groundfish mean trophic level (MTL) declined south of Cape Mendocino. While stable overall and north of Cape Mendocino, current MTL was relatively low but still within 1.0 s.d. of the long-term mean. Low MTL is generally considered to be an indication of reduced abundance of top predators, and therefore, top-down forcing in the system. However, low groundfish MTL may make food resources (forage fishes and krill) available to groundfish competitors like salmon, seabirds and tuna, indicating good feeding conditions for these species.

BIODIVERSITY

Biodiversity indicators showed mixed results (Figure EI 4). No indicators showed changes relative to their long-term means. However, six diversity measures increased in the short-term, while seven decreased.

Copepod biodiversity in the summer declined as did species number for coastal pelagic fishes. Three diversity indicators related to copepods and coastal pelagic fishes decreased in the short-term. While decreased diversity is typically considered a negative indication of ecosystem status, low copepod diversity is linked to high abundance of northern, energy-rich species and indicates overall good feeding conditions for species like forage fishes and salmon.

All measures of ichthyoplankton biodiversity increased for the California Current as a whole. Conversely, ichthyoplankton spring Simpson diversity and summer species richness both declined in Oregon, suggesting different trends in northern and southern regions.

For groundfishes, coastwide Simpson diversity (~evenness, technically equitability) increased in the short-term. This rise was driven by changes north of Cape Mendocino. Simpson diversity south of Cape Mendocino did not increase. Groundfish species richness

declined coastwide, as did species richness south of Cape Mendocino. North of Cape Mendocino richness also declined but by less than the threshold value. In all three cases, richness was within long-term norms but above the long-term mean. Declines in groundfish MTL noted earlier were caused by loss of Pacific hake and spiny dogfish biomass, and the increase in Simpson diversity may be linked to these trends as well. It is not clear at present what caused the decline in groundfish species richness south of Cape Mendocino, but the trend bears watching.

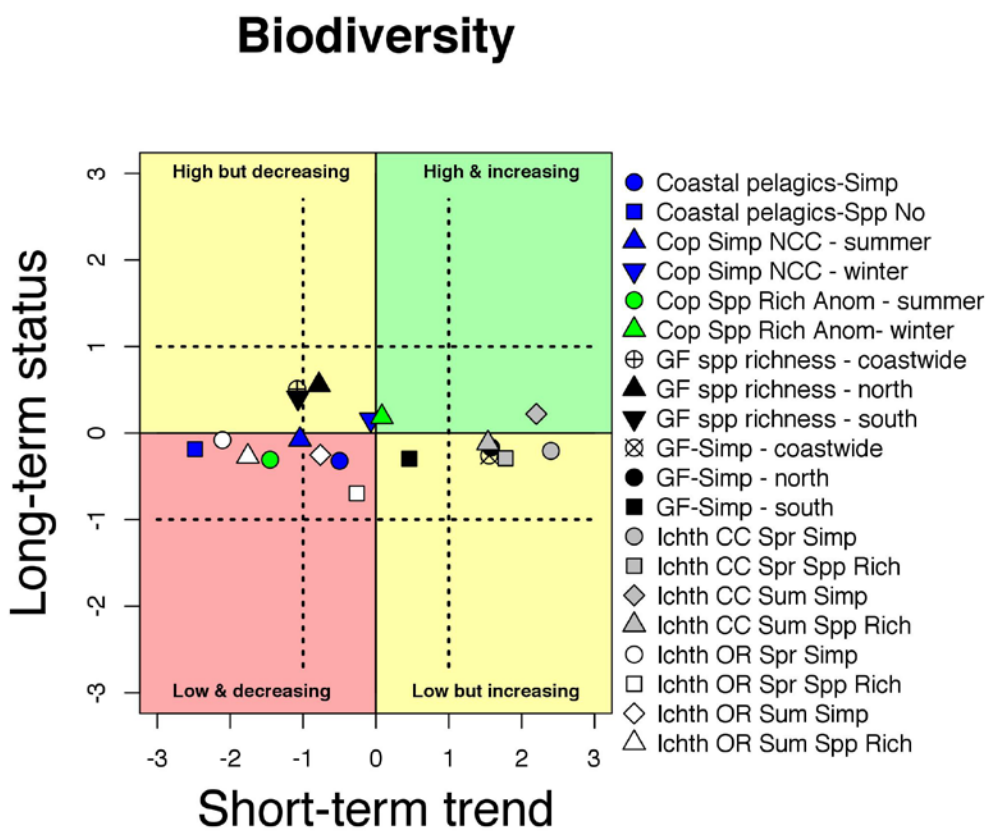

Figure EI 4. Short and long-term status of indicators of Biodiversity for Ecological Integrity in the California Current Large Marine Ecosystem. Prior to plotting, time series were normalized to place them on the same scale. The short-term trend indicates whether the indicator increased or decreased over the last 5 years of the time series relative to the long-term mean. The long-term axis compares the mean of the last 5 years to the mean of the full time series. Changes or differences of more than 1.0 standard deviation of the full time series (dotted lines) are considered to show an effect. Cop = copepod, GF = groundfishes, Ichth = ichthyoplankton, Simp = Simpson diversity, Spp No = species number (not rarefied), Spp Rich = species richness (rarefied), Anom = anomaly, CC = CalCOFI (southern California Current), OR = Oregon, NCC = northern California Current.

LOOKING TO THE FUTURE

Seabird diversity indices were not included in the present report because data were not available to update the previously reported time series. See the 2011 report for these indicators[5]. Work is ongoing to consolidate disparate datasets and produce a more succinct and cogent set of seabird indicators for future IEA reports.

Indicators of trophic structure are currently limited to only a few functional groups, primarily groundfishes (and three crabs) and copepods. MTL time series for coastal pelagic fishes, seabirds and mammals will require some development. Many of the available datasets for these taxa are counts at specific locations, while MTL is a biomass-weighted average. Count data will, therefore, need to be converted to biomass using length-weight relationships or average adult biomass as appropriate for the taxon in question. Ultimately, efforts should focus on using these time series to produce a composite MTL or top predator biomass index that spans the geographic extent of the CCLME.

At present, most of the Ecological Integrity indicators do not have thresholds or targets, and temporal trends are evaluated with regards to the statistical properties of the time series in question. Future work should seek to establish thresholds and targets for each indicator.

STATUS AND TRENDS: TIME SERIES DATA

In this section, we present the status and trends of each of the five ecological integrity indicators for the California Current ecosystem during 2013, as derived from time series data. Most time series are plotted in a standard format: Dark green horizontal lines show the mean (dotted) and ± 1.0 s.d. (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 five years increased (↗), or decreased (↘) by more than 1.0 s.d., or was within 1.0 s.d. (↔) of the long-term trend. The lower symbol indicates whether the mean of the last five years was greater than (+), less than (-), or within (·) 1.0 s.d. of the long-term mean. In some cases, background analyses and interpretation of related information are also included.

NORTHERN COPEPOD BIOMASS ANOMALY

The northern copepod biomass anomaly represents the ratio of northern and southern copepod species off of the Oregon coast. Two of the cold–water species, *Calanus marshallae* and*Pseudocalanus mimus*, are lipid–rich, and the index may represent the amount of lipid (wax esters and fatty acids) available to pelagic fishes for whom these fatty

[5] http://www.noaa.gov/iea/CCIEA-Report/index.html

compounds appear to be essential. Beamish and Mahnken (2001) provide an example of this for coho salmon (see http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/eb-copepod-anomalies.cfm for further detail).

The northern copepod anomaly has fluctuated between 1996 – 2013. The most recent available values for both the winter (Figure EI 5) and summer (Figure EI 6) are relatively high —approximately 1.0 s.d. above the mean of the full time series—indicating generally good conditions. There were no trends in either case. Threshold values for the anomaly have not been set. However, positive values in the summer period are correlated with stronger returns of fall and spring ocean-type Chinook to Bonneville dam, and values greater than 0.2 are associated with better survival of coho salmon. Overall the high anomalies in recent years, especially for the summer data, suggest that ocean conditions are in a generally good state.

See http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/eb-copepod-anomalies.cfm for further detail.

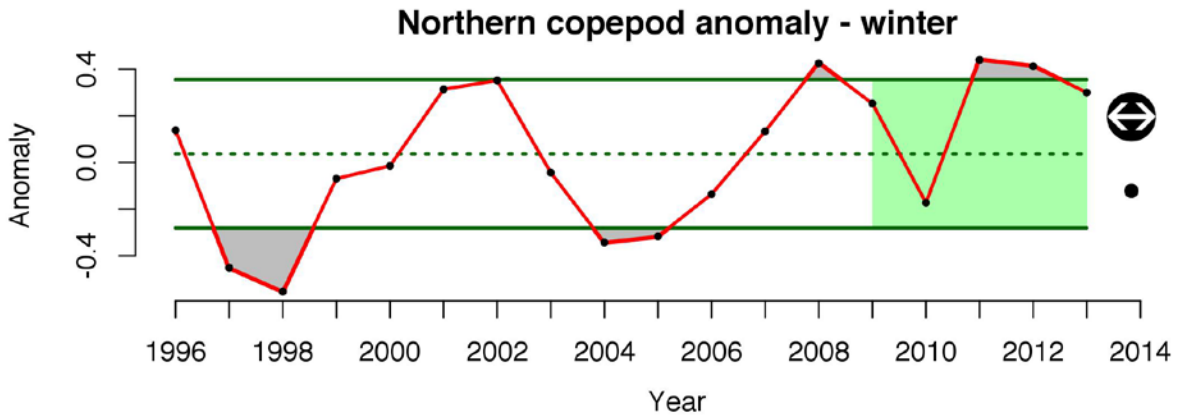

Figure EI 5. Northern copepod biomass anomaly for 1996-2013 in the waters off of Oregon during the winter (Oct-April). Data courtesy of Bill Peterson (bill.peterson@noaa.gov).

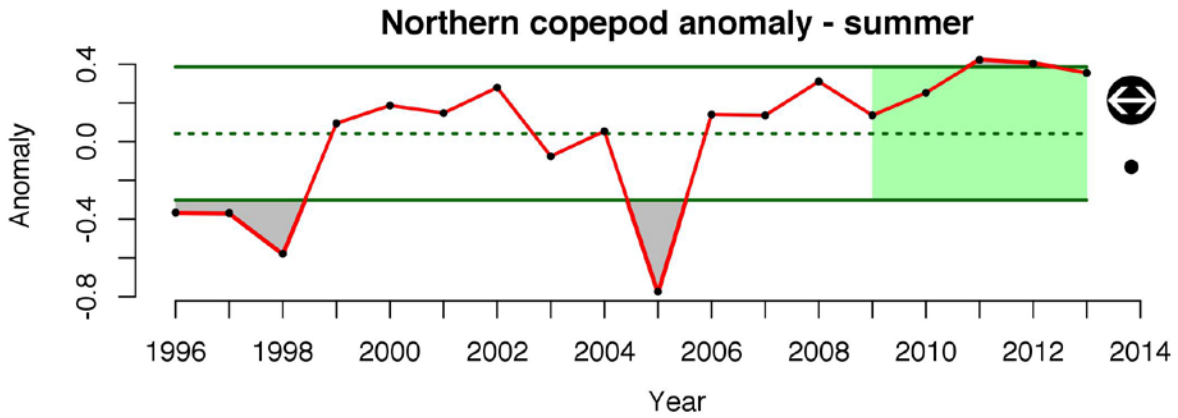

Figure EI 6. Northern copepod biomass anomaly for 1996-2013 in the waters off of Oregon during the summer (May - September). Data courtesy of Bill Peterson (bill.peterson@noaa.gov).

ABUNDANCE OF GELATINOUS ZOOPLANKTON (JELLIES)

Gelatinous zooplankton (jellyfish) are a lower trophic level, high-productivity functional group, potentially with important effects on the transfer of nutrients and energy from lower trophic levels to higher ones. High abundance of gelatinous zooplankton indicates potentially poor conditions for other taxa within the CCLME. The large medusa quantified here, *Chrysoara* sp. and *Aequorea* sp., are highly opportunistic and respond quickly to regional and local forcing factors (Suchman et al. 2012).

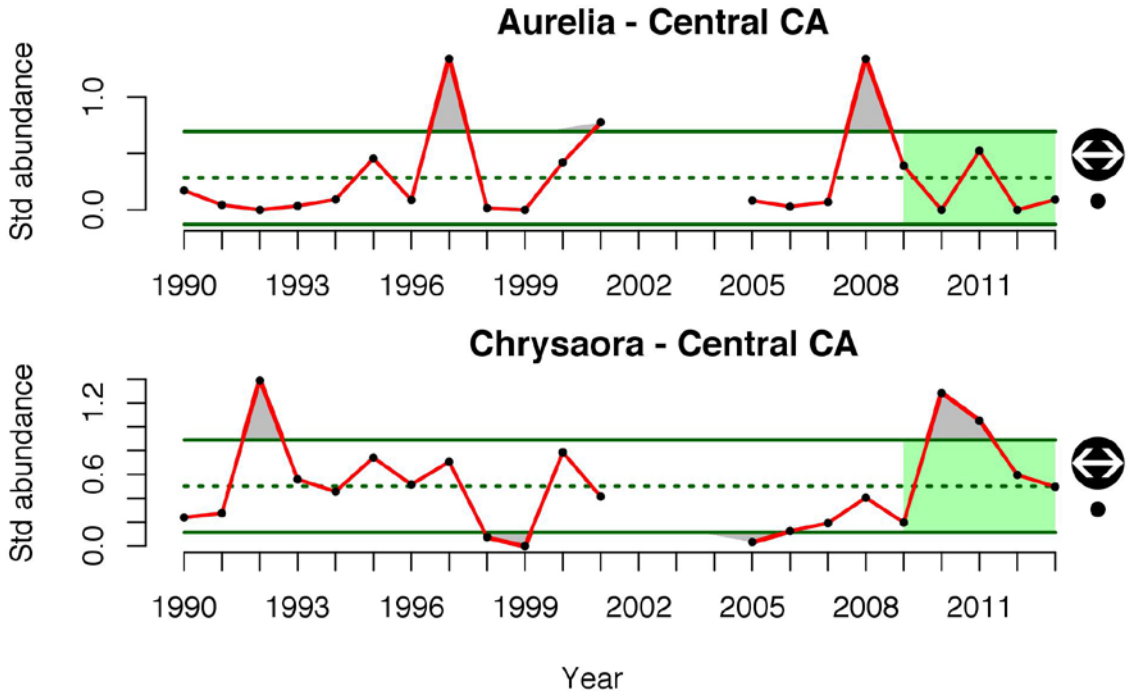

Figure EI 7 Standardized abundance of *Aurelia* and *Chrysaora* jellies in central California waters from 1990-2013. Data are courtesy of John Field (john.field@noaa.gov).

In waters off of central California, jelly abundance has fluctuated since the early 1990's (Figure EI 7). At present both *Aurelia* and *Chrysaora* are near their long-term means and showed no trends over the last five years. Both taxa have, however, decreased in abundance relative to recent peaks in 2008 and 2010 respectively. Both peaks were more than 1.0 s.d. above the long-term mean. Values for 2013 were near the long-term mean, suggesting typical conditions.

Surveys from Oregon and Washington waters showed mixed results (Figure EI 8, Figure EI 9). *Aequorea* abundance increased in the short-term in June surveys but showed no trend over the last five years in September surveys. However, *Chrysoaroa* abundance declined in the short-term in both June and September surveys.

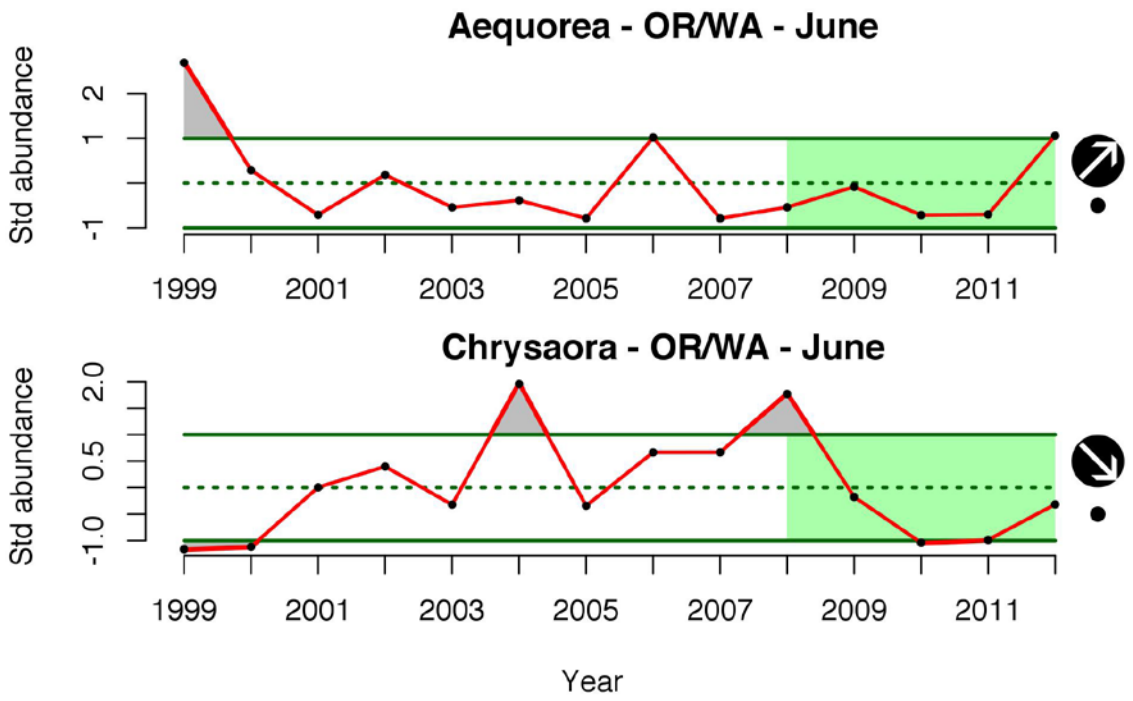

Figure EI 8 Standardized biomass of *Chrysoara* and *Aequorea* jellies in June surveys in the NCC from Newport, OR (44.6°N, 124.0° W) to Tatoosh Island, WA (48.4 N°, 124.7° W). Data are courtesy of Ric Brodeur (rick.brodeur@noaa.gov).

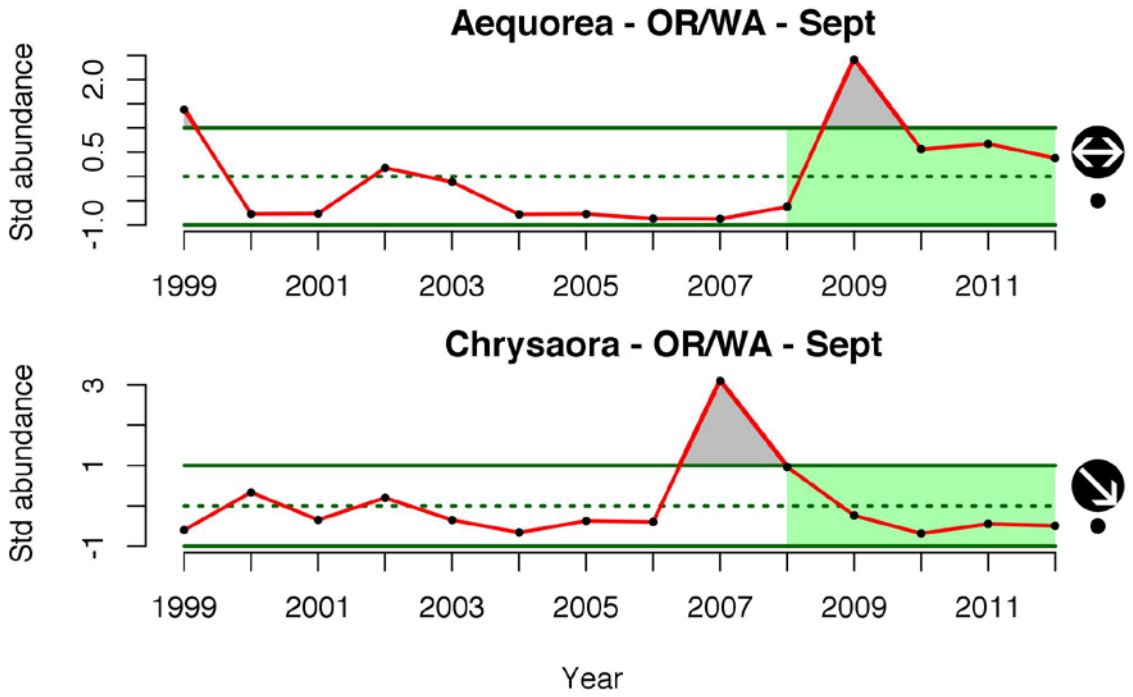

Figure EI 9 Standardized biomass of *Chrysoara* and *Aequorea* jellies in September surveys in the NCC from 1999 to 2012 off Newport, OR (44.6°N, 124.0° W) to Tatoosh Island, WA (48.4 N°, 124.7° W). Data are courtesy of Ric Brodeur (rick.brodeur@noaa.gov).

MEAN TROPHIC LEVEL (GROUNDFISHES)

Mean trophic level (MTL) is the biomass-weighted average of the trophic levels of the species in a sample (Pauly et al. 1998). It is widely used as an indicator of change in trophic structure (Pauly and Watson 2005). MTL is conceptually linked to trophic cascades (Estes et al. 2011). A drop in MTL is generally considered a negative indicator of ecosystem status, as it should result in a decrease in the strength of top-down forcing. However, a fall in MTL of one component (e.g., groundfishes) of the ecosystem may make prey resources available to competing taxa (e.g., salmon, seabirds and tuna), especially in wasp-waist systems where many predators rely on a small suite of prey (Tolimieri et al. 2013).

MTL comes in two forms (Branch et al. 2010). 'Catch' MTL is calculated from fisheries-dependent data and reflects changing fishing practices and availability of target species. 'Ecosystem MTL' is calculated from fisheries-independent data and represents changes in the ecosystem. Here we report 'Ecosystem' MTL for West Coast groundfishes. MTL was calculated from the West Coast Groundfish Bottom Trawl Survey. Trends are presented for the entre CCLME and for northern and southern regions, separated by Cape Mendocino (40.4°N).

MTL for groundfishes declined from 2003 until 2010 and has remained low since (Figure EI 10). The fluctuation over the entire time series was approximately 0.077, from a

high of 3.72 in 2004 to a low of approximately 3.64 in both 2010 and 2012. This decline represents a ~25% decrease in the primary productivity required to support a given amount of catch (Pauly and Christensen 1995, Essington et al. 2006). While threshold values for MTL have not been set, future work could set thresholds based on changes in necessary primary production.

Previous reports document a decline in MTL from 2003 to 2010 and 2011 largely due to a decrease in the abundance of Pacific hake, *Merluccius productus* (Keller et al. 2012, Tolimieri et al. 2013). However, over the last five years of the time series (2008-2012), groundfish MTL has been low but stable with no further decline. The mean of the last five years of the time series is within 1.0 s.d. of the full time series, but MTL for 2012 was below 1.0 s.d. of the full time series and bears watching in the future. Comparisons with other long-term datasets suggest that fluctuations in MTL are not uncommon (Branch et al. 2010).

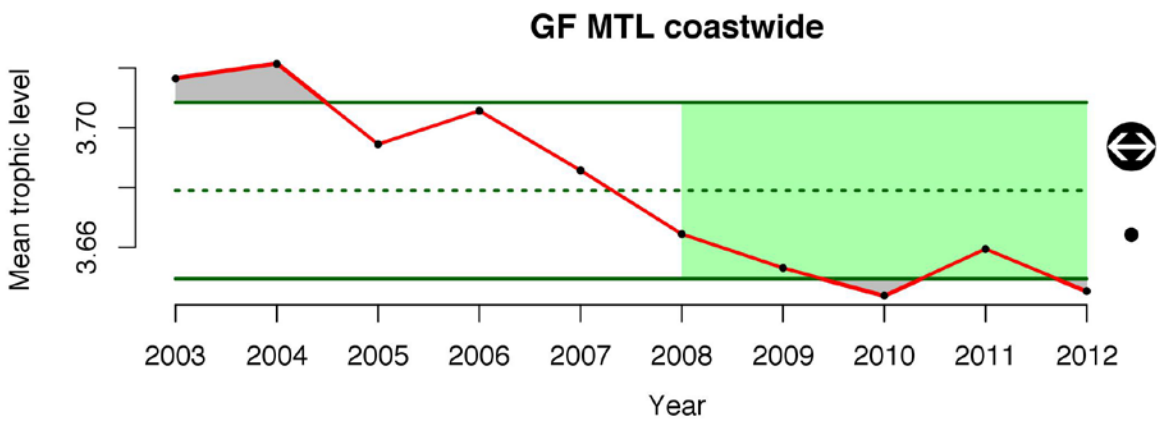

Figure EI 10. Area-weighted mean trophic level (MTL) for West Coast groundfishes from 2003 – 2012. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness.

In the region north of Cape Mendocino, MTL declined steadily from 2003 to 2010 from approximately 3.76 to 3.66 in 2010 (Figure EI 11). However over the last five years, MTL has remained low but fairly stable with no short-term trend (change over the last five years was less than 1.0 s.d. of the full time series). The mean of the last five years was also within 1.0 s.d. of the long-term mean.

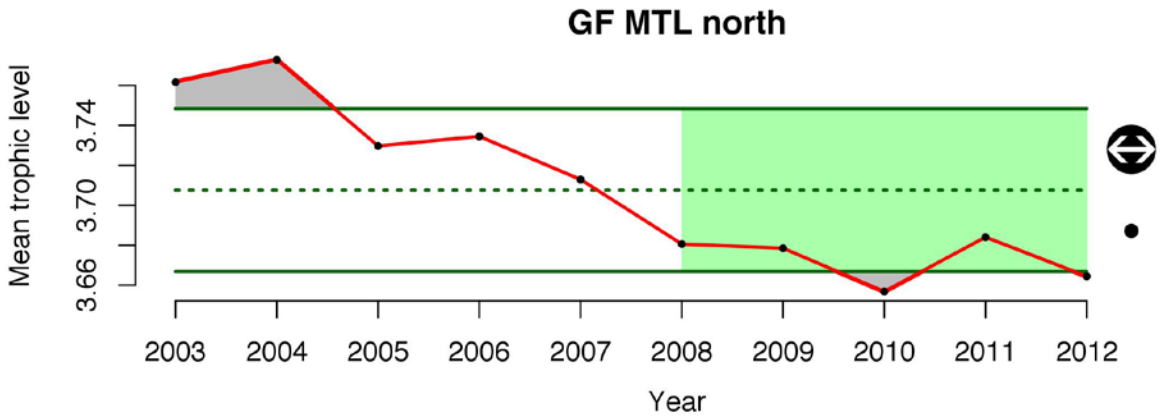

Figure EI 11. Area-weighted mean trophic level (MTL) for West Coast groundfishes north of Cape Mendocino (40.4° N) from 2003 – 2012. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

South of Cape Mendocino, MTL initially increased from 2003 to 2006 but then declined until 2012, with the last five years declining more than 1.0 s.d. of the long term mean (Figure EI 12). However, the mean of the last five years was within 1.0 s.d. of the long-term mean and the value in 2012 was similar to that in 2003. Most of the decline occurred from 2008 to 2009 and MTL has largely been low but stable since.

Low groundfish MTL may indicate good conditions for the competitors of groundfishes. Many predators in the CCLME eat krill and forage fishes. Food web modeling suggests that a drop in groundfish MTL due to a loss of higher TL species makes these prey available to other taxa such as squid, salmon, tuna and seabirds leading to positive population forcing for these taxa (Tolimieri et al. 2013). Therefore, setting targets for groundfish MTL may entail making trade-offs with these other species.

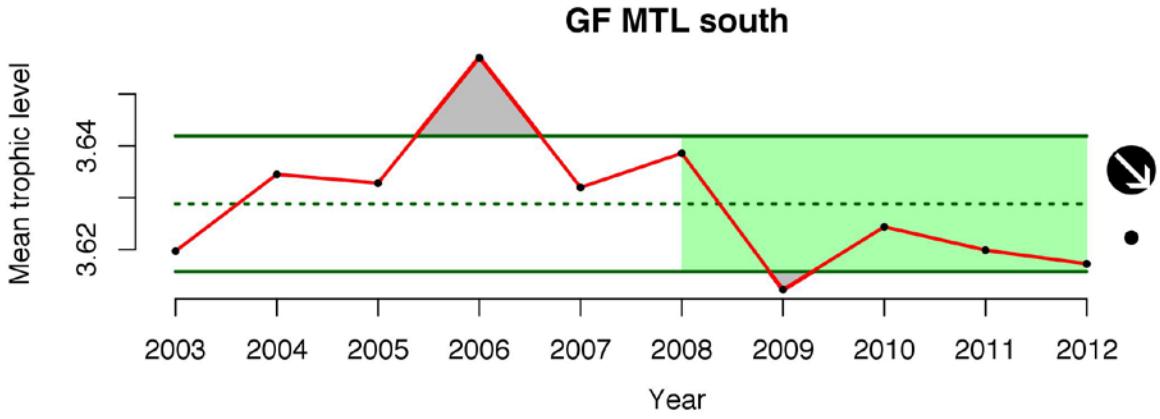

Figure EI 12. Area-weighted mean trophic level (MTL) for West Coast groundfishes south of Cape Mendocino (40.4° N) from 2003 – 2012. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

RATIO OF SCAVENGER BIOMASS: TOTAL BIOMASS (GROUNDFISHES & CRABS)

Scavengers are generally defined as active foragers of carrion (Britton and Morton 1994). Changes in the biomass of scavengers have been related to responses to fisheries discards and disturbance of bottom habitat due to trawling. The indicator presented here includes multiple groundfishes and three species of crab quantified in the West Coast Groundfish Bottom Trawl Survey (see Table EI 4, Data Sources and Methodology for a list of included taxa). Because using raw biomass (kg per km^{-2}) would not separate an increase in scavenger biomass from an increase in the biomass of all species, we use the ratio of scavenger biomass to total biomass in the trawl survey to test for a change in the trophic structure. This modification provides a more sensitive indication of whether 'scavengers' are more or less prevalent in the assemblage than in previous years.

The ratio of scavengers to total biomass increased from 2008 to 2012 (Figure EI 13) with the trend over the last five years showing an increase of more than 1.0 s.d. of the full time series. However, the ratio declined from a high of 0.27 in 2010 to just over 0.25 in 2012. The mean of the last five years was within 1.0 s.d. of the long-term mean.

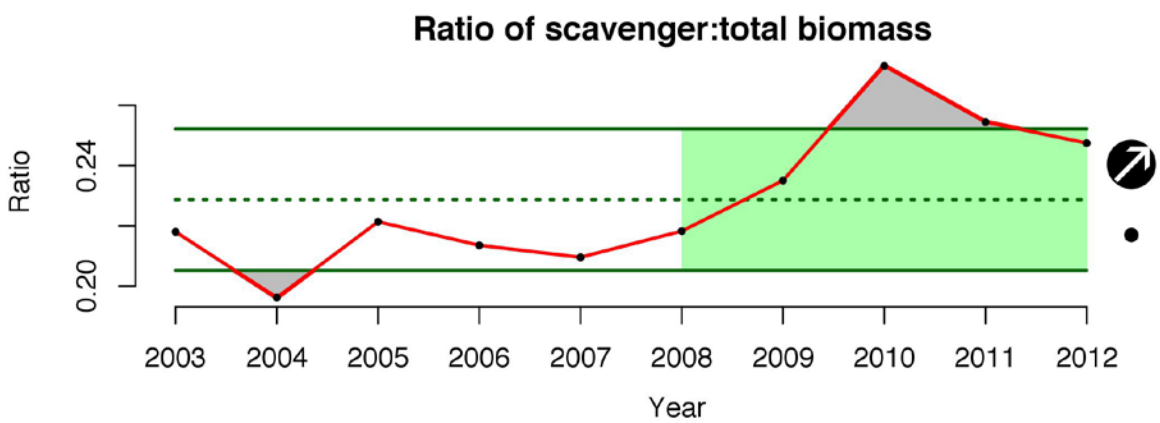

Figure EI 13. Ratio of groundfish and crab scavengers to total biomass for the West Coast shelf and slope from 2003-2012. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

Patterns north and south of Cape Mendocino (40.4° N) differed. Trends north of Cape Mendocino mirrored the coastwide pattern with an increase from just over 0.16 to over 0.22. (Figure EI 14).

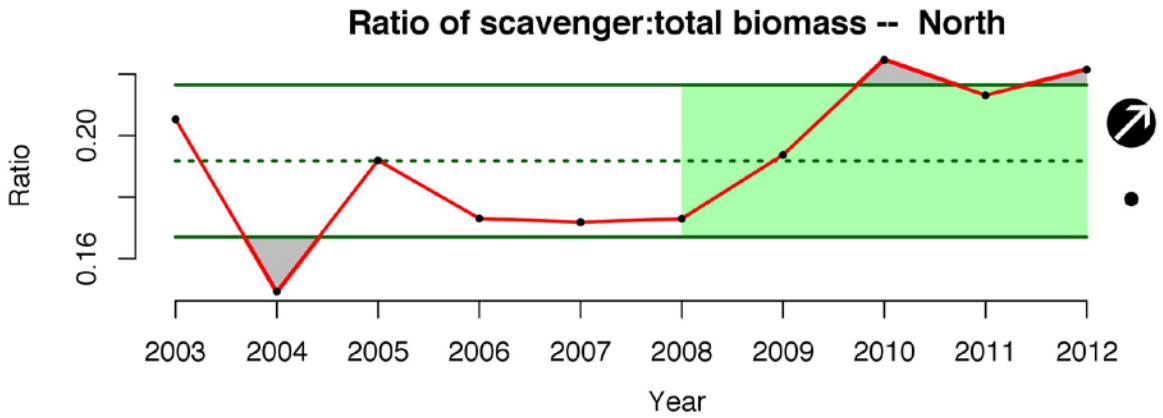

Figure EI 14. Ratio of groundfish and crab scavengers to total biomass for the West Coast shelf and slope north of Cape Mendocino (40.4° N) from 2003-2012. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

South of Cape Mendocino, the ratio of scavenger to total biomass initially increased from 2003 to a high of approximately 0.35 in 2010 (Figure EI 15). However, over the last five years of the time series, the ratio, while fluctuating, showed no trend and the 2012 value is more or less the same as in 2008 at 0.28. The mean over the last five years was within 1.0 s.d. of the long-term mean.

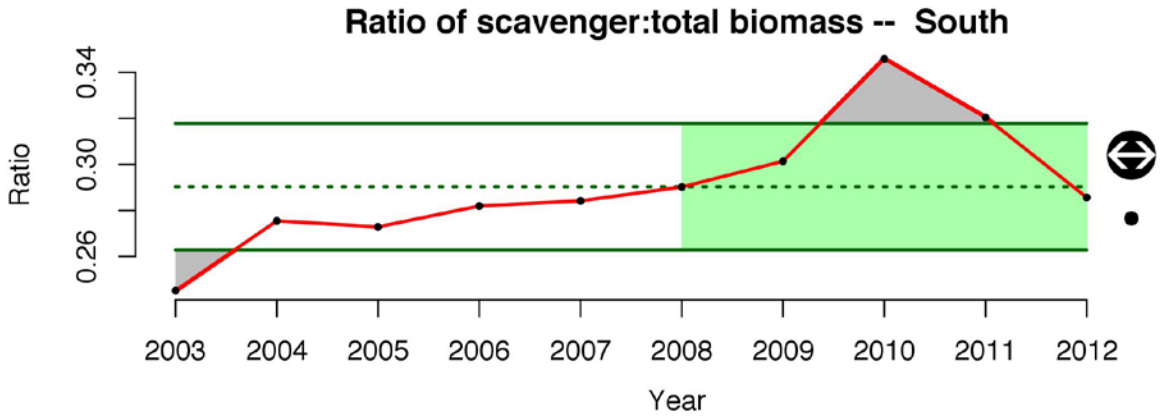

Figure EI 15. Ratio of groundfish and crab scavengers to total biomass for the West Coast shelf and slope north of Cape Mendocino (40.4° N) from 2003-2012. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov)

The increase in the ratio of scavenger to total biomass coastwide and in northern waters appears to be due to an increase in the abundance of crabs (Figure EI 16). In both time series crab to total biomass ratio increased from 2008 – 2012, peaking in 2010 for before declining somewhat. Trends in the south were similar but did not meet the threshold of a change of 1.0 s.d. or more because the southern time series dropped more from 2010 to 2012 than did the northern or coastwide one finising near the long-term mean.

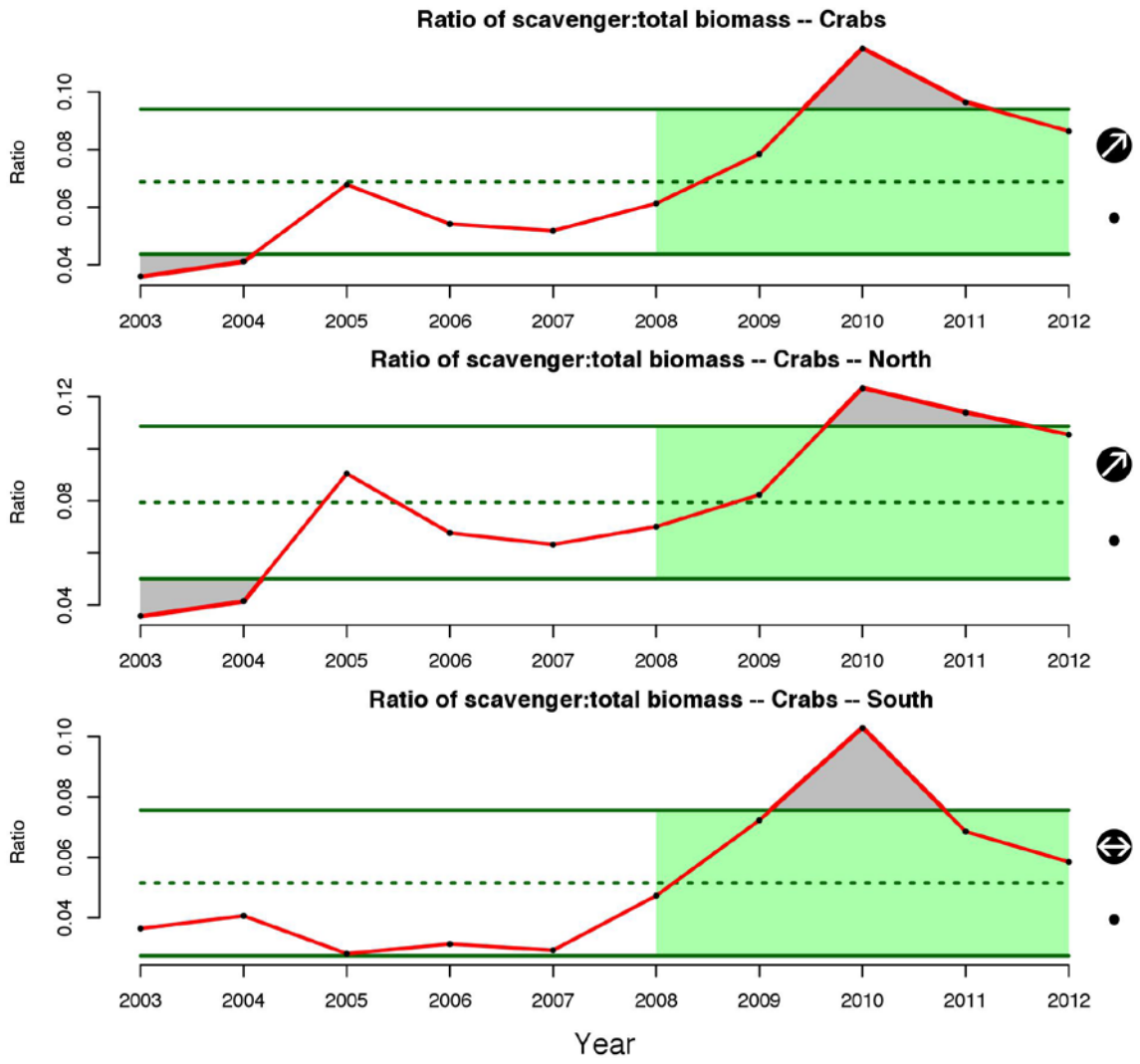

Figure EI 16 Ratio of crab scavengers to total biomass for the West Coast shelf and slope coast-wide, and north or south of Cape Mendocino (40.4° N) from 2003-2012. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov)

The ratio of fish scavengers to total biomass showed no trends over the last five years of the data (Figure EI 17). Coastwide and in northern waters the time series showed little fluctuation. However, in waters south of Cape Mendocino there was substantially more variation in the time series.

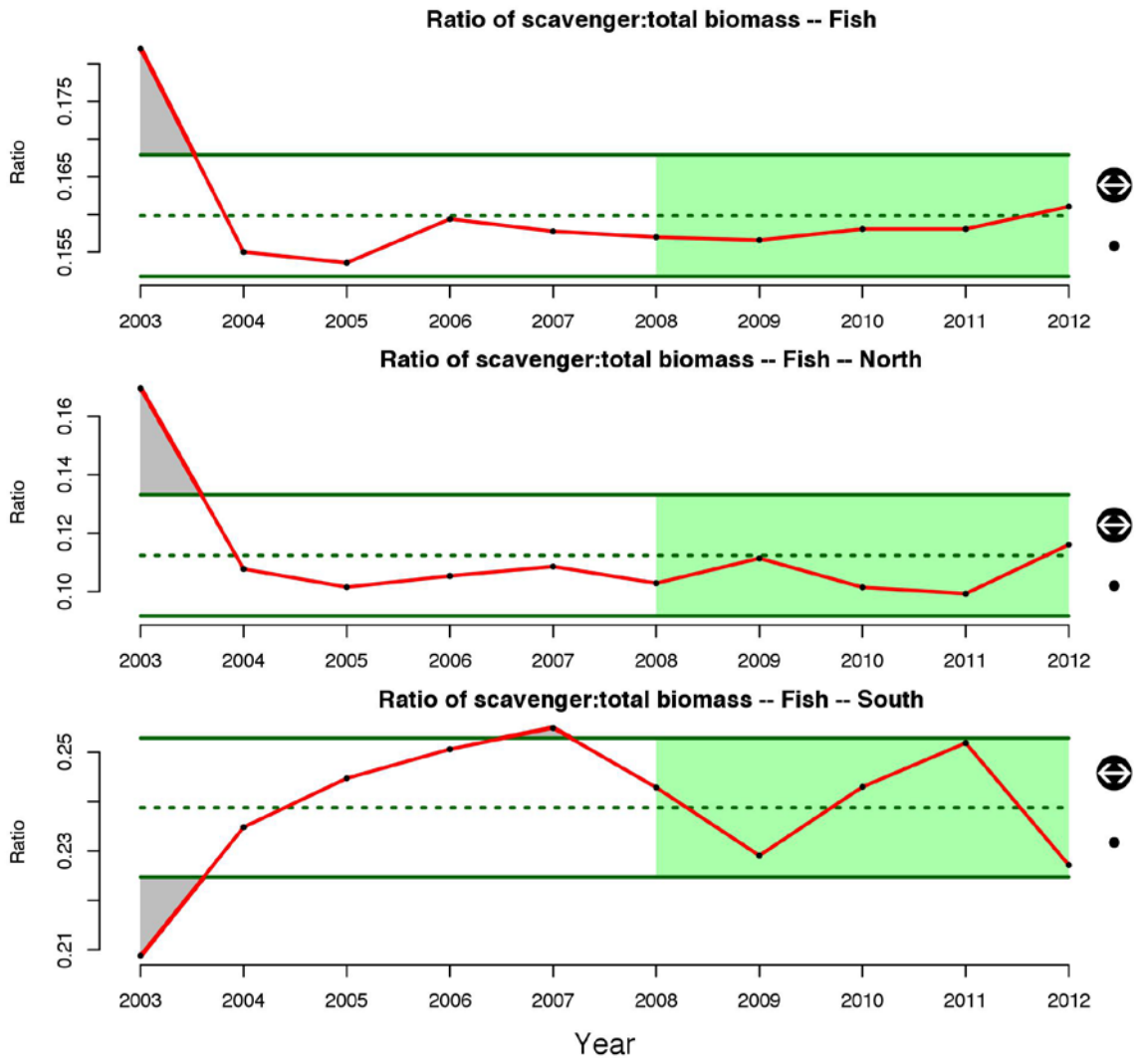

Figure EI 17 Ratio of groundfish scavengers to total biomass for the West Coast shelf and slope coast-wide, and north or south of Cape Mendocino (40.4° N) from 2003-2012. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov)

SIMPSON DIVERSITY (COPEPODS, COASTAL PELAGIC FISHES & GROUNDFISHES)

Along with species richness, evenness is one of the two components of diversity. Simpson diversity (in the 1-λ form, a.k.a. Gini-Simpson index) is a measure of the equitability of species in a sample (Tuomisto 2012). When individuals are well-distributed among species, Simpson diversity is high. For large samples, it approximates the probability of an interspecific encounter and is relevant to predator-prey relationships and food web analyses.

SIMPSON DIVERSITY - COPEPODS

Simpson diversity for copepods in the northern California Current was calculated by season using the same seasons as Peterson (2009) (Figure EI 18). For both seasons, Simpson diversity was variable through time. Simpson diversity for summer (May – Sept) assemblages decreased in the short-term (5-year trend showed a decrease of greater than 1.0 s.d. of the full time series), but the mean of the last five years was within 1.0 s.d. of the full time series. Simpson diversity for winter (Oct – April) assemblages showed no short-term trend, and the mean of the last five years was within historical norms.

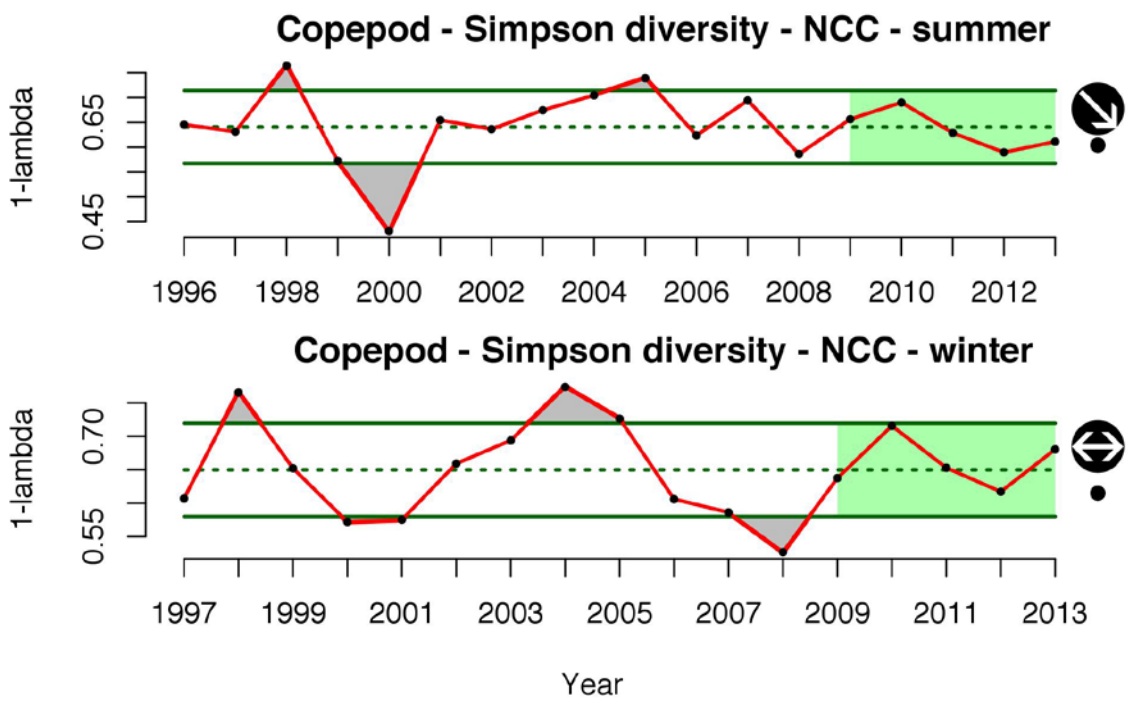

Figure EI 18. Time series of Simpson diversity (1-λ) from 1997 – 2013 for summer (May -- Sept) and winter (Oct–April) for West Coast copepods in the northern California Current (NCC). Data courtesy of Bill Peterson (bill.peterson@noaa.gov).

SIMPSON DIVERSITY - COASTAL PELAGIC FISHES

Simpson diversity for coastal pelagic species has fluctuated through time on approximately a 4-5 year cycle with highs in 2002, 2007-8 and 2011, and lows in 2000, 2005 and 2009-10 (Figure EI 19). Over the last five years, however, there has been no directional trend, and the mean of the last five years is within 1.0 s.d. of the long-term mean. However, peak values have decreased successively since 2002, being well above 1.0 s.d. of the time series in 2002, about 1.0 s.d. above the mean in 2007 and 2008 and around 0.66 s.d. above the mean in 2011.

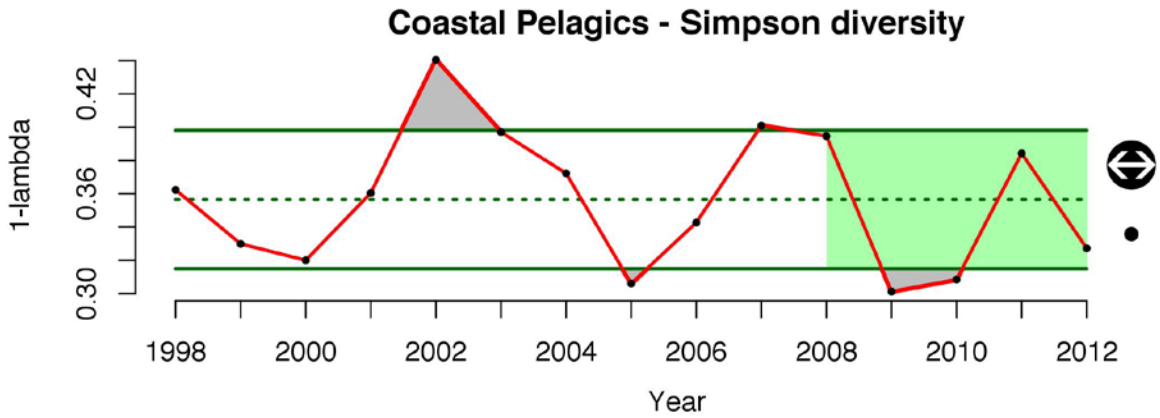

Figure EI 19. Simpson diversity (1-λ, Gini-Simpson index) for coastal pelagic fishes in the Northern California Current from 1998-2012. Data are combined June and September samples. Data courtesy of Richard Brodeur(Rick.Brodeur@noaa.gov).

SIMPSON DIVERSITY - GROUNDFISHES

Simpson's index (1-λ) for West Coast groundfishes decreased between 2003 and 2009 (Figure EI 20). Over the last five years (2008-2012), Simpson's index increased by more than one standard deviation (s.d.) of the complete time series. However, much of this evenness was lost in 2012 when Simpson diversity declined markedly. The mean of the last five years is within 1.0 s.d. of the long-term mean. North of Cape Mendocino (40.4° N) the trend was more or less similar to the full, coastwide pattern (Figure EI 21). South of Cape Mendocino, the pattern differed somewhat with a peak in 2007 and lower values since (Figure EI 22). Southern Simpson diversity has remained more or less stable over the last five years.

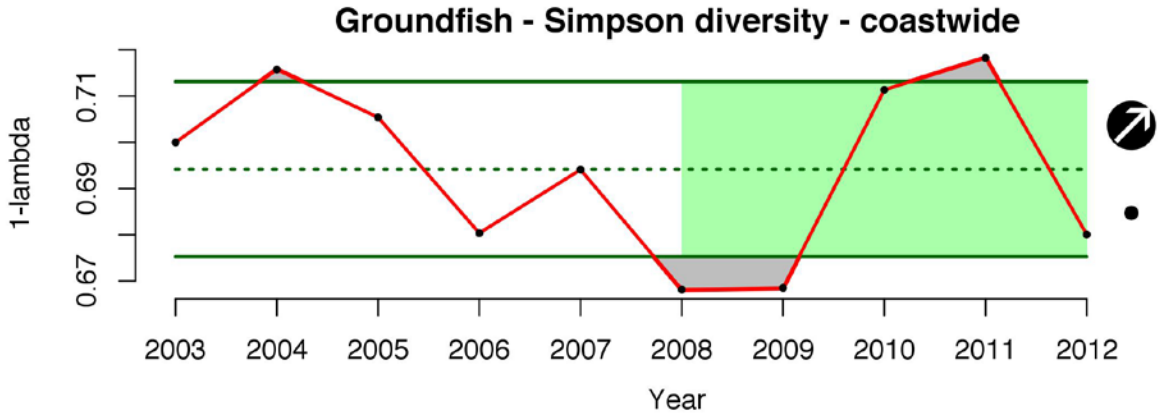

Figure EI 20. Simpson diversity (1-λ) for West Coast groundfishes from 2003 – 2012. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy Beth Horness (Beth.Horness@noaa.gov).

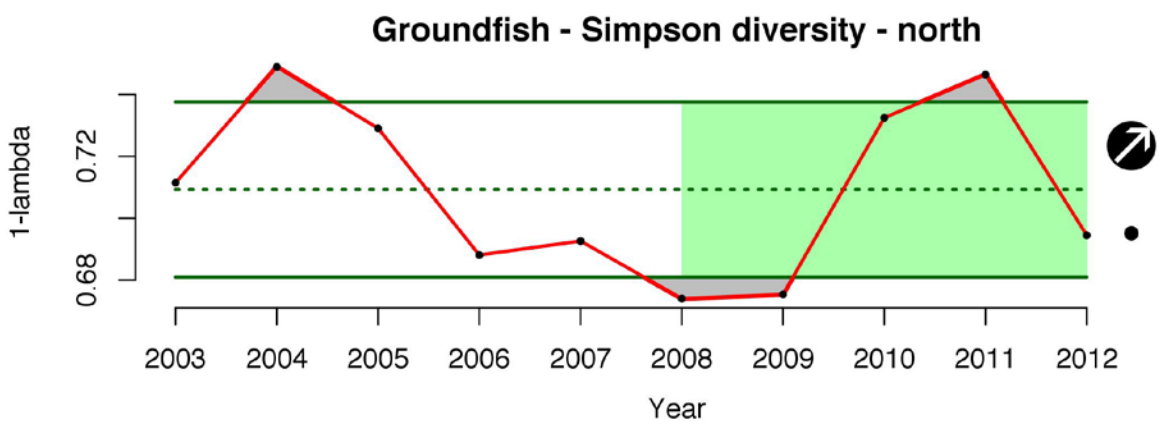

Figure EI 21. Simpson diversity (1-λ) for West Coast groundfishes from 2003 – 2012 north of Cape Mendocino (40.4° N). Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy Beth Horness (Beth.Horness@noaa.gov).

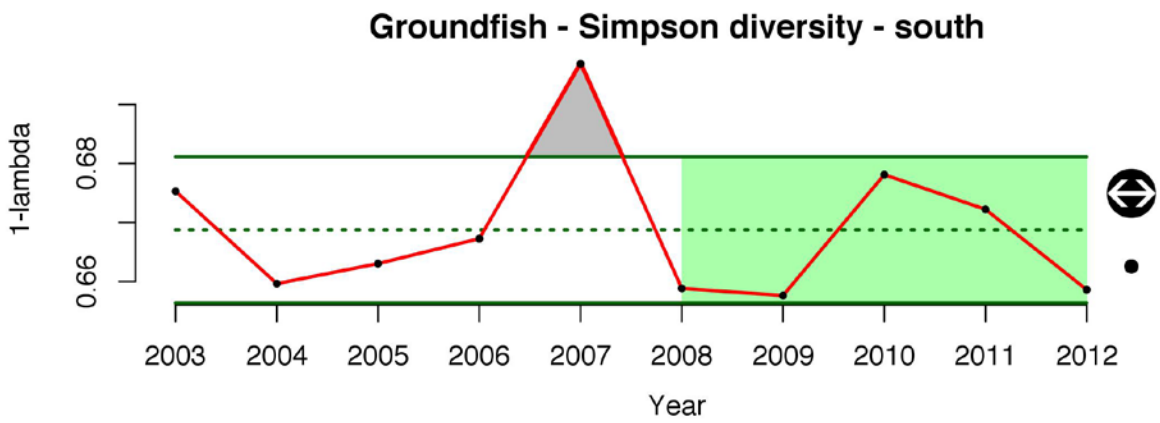

Figure EI 22. Simpson diversity (1-λ) for West Coast groundfishes from 2003 – 2012 south of Cape Mendocino (40.4° N). Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy Beth Horness (Beth.Horness@noaa.gov).

SIMPSON DIVERSITY – ICHTHYOPLANKTON

Oregon and CalCOFI data show opposite trends in diversity of ichthyoplankton, suggesting that different processes occur in the two locations. Simpson diversity (1- λ) in the spring ichthyoplankton from the CalCOFI surveys in summer California during the spring declined from over 0.7 in 2004 to a low of less than 0.5 in 2007 (Figure EI 23). It then increased over the next five years by more than 1.0 s.d. of the full time series to approximately 0.7.

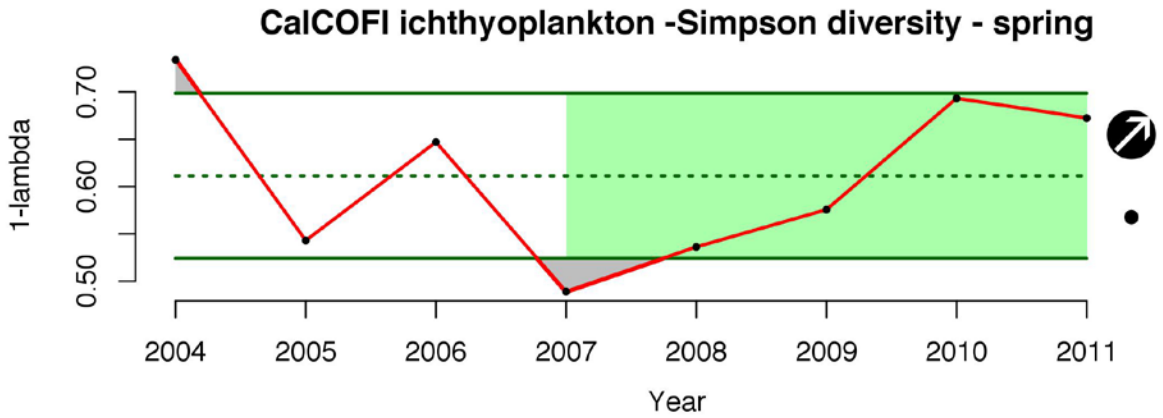

Figure EI 23. Simpson diversity (1-λ) of ichthyoplankton from the CalCOFI surveys in southern California during the spring from 2004 – 2011. Data courtesy of Andrew Thompson (andrew.thompson@noaa.gov).

Simpson diversity (1- λ) in the summer for ichthyoplankton off of southern California in the CalCOFI surveys declined from ~0.64 in 2004 to less than 0.54 in 2007 (Figure EI 24). It then increased to 2011 by more than 1.0 s.d. of the dataset before returning to values similar to 2004. It was highest in 2010 at approximately 0.66.

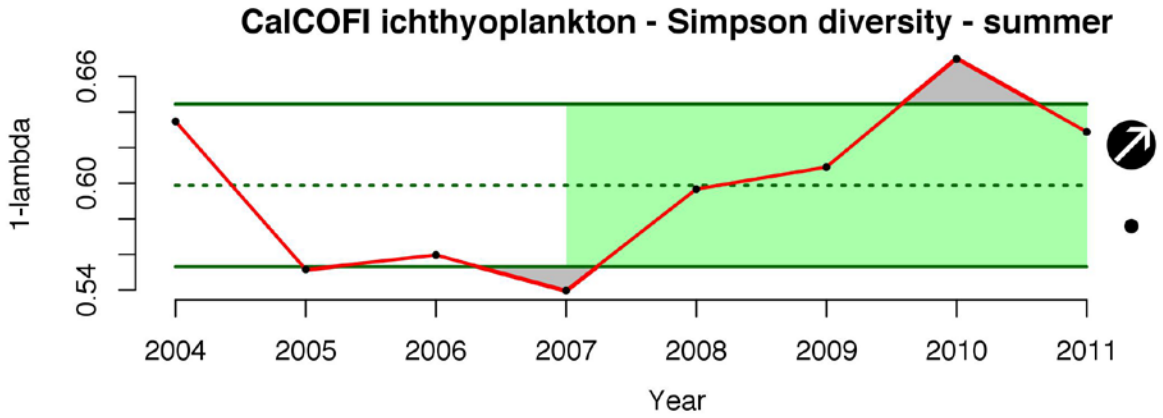

Figure EI 24. Simpson diversity of ichthyoplankton from the CalCOFI surveys in southern California during the summer from 2004 – 2011. Data courtesy of Andrew Thompson (andrew.thompson@noaa.gov).

Interestingly, Simpson diversity in the Oregon ichthyoplankton survey showed the reverse trend to that off of California. Spring Simpson diversity increased to a high of just more than 0.6 in 2007 before declining to as low as 0.4 in 2010 (Figure EI 25), resulting in a decrease over the last five years. However, the value for 2011 was approximately the same as the mean of the full time series.

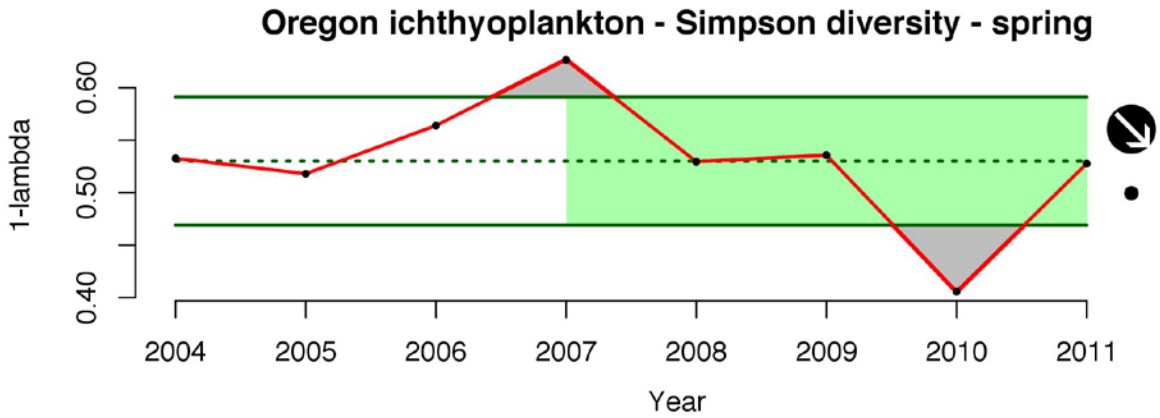

Figure EI 25. Simpson diversity of ichthyoplankton off Oregon in the spring from 2004 – 2011. Data courtesy of Andrew Thompson (andrew.thompson@noaa.gov).

Summer values off Oregon followed a similar trend with an extreme low in 2010 followed by a rebound to the vicinity of the long-term mean in 2011 (Figure EI 26). However, given the increase over the last year of the time series, there was no overall trend over the last five years and the mean was within 1.0 s.d. of the full time series.

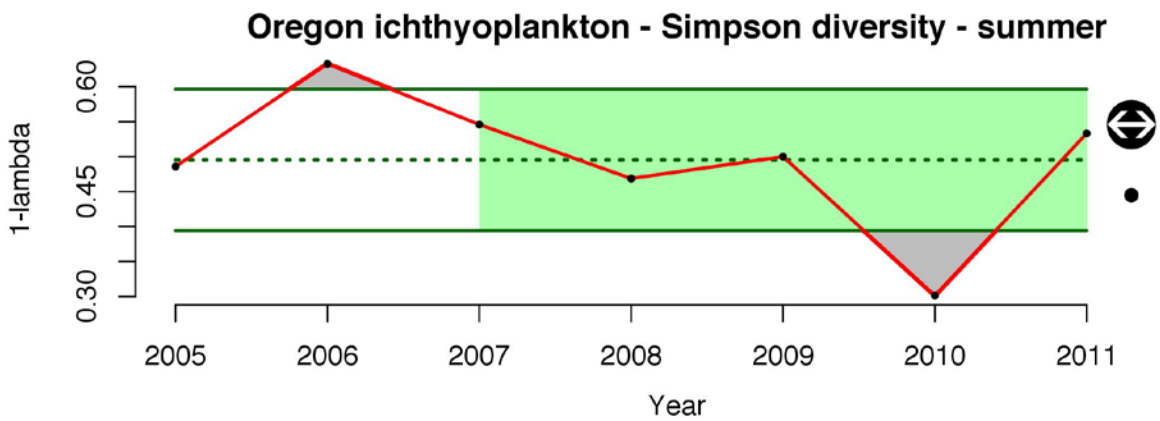

Figure EI 26. Simpson diversity of ichthyoplankton off Oregon in the summer from 2005 – 2011. Data courtesy of Andrew Thompson (andrew.thompson@noaa.gov).

SPECIES RICHNESS & DENSITY (COPEPODS, COASTAL PELAGIC FISHES & GROUNDFISHES)

Along with evenness, richness is one of the two components of diversity and is easily understood as the number of species in a community. Richness is important for many ecological models, and there is a substantial literature on the complex relationship between biodiversity and ecosystem function (Hooper et al. 2005, Stachowicz et al. 2007), with some consensus that community-level processes are more stable at higher richness.

Because sample effort, whether the number of individuals collected or area surveyed or both, has strong, non-linear effects on the number of species encountered, estimates of richness need to be scaled to a common effort level through rarefaction

(Gotelli and Colwell 2001). The number of species in a community can then be presented in two forms: species richness and species density. Species richness in the rarefaction sense is the number of species observed for some number of individuals collected. Species density is the number of species per some unit area. Both are relevant to different questions and purposes. Since most theoretical models in ecology are based on *per capita* interactions, species richness is relevant to these models. At the same time, species density is important to conservation and applied purposes since it measures the number of species in a given area. Here, both species richness and species density are reported where possible based on the attributes of the particular dataset. See Gotelli and Colwell (2001) for further discussion of rarefaction, species richness and species density.

SPECIES NUMBER - COASTAL PELAGIC FISHES

Data for coastal pelagic fishes were not rarefied due to the data format. Mean number of species per sample for coastal pelagic fishes was variable through time with lows in 1999, 2000, 2005 and 2012 and highs in 2003, 2004 and 2008 (Figure EI 27). While the mean of the last five years is within 1.0 s.d. of the long-term mean, species number declined rapidly from 2008 to 2012 by more than 2.0 s.d. of the full time series. Species number as of 2012 was the lowest over the 15-year time series, dropping below the previous lowest year of 1999.

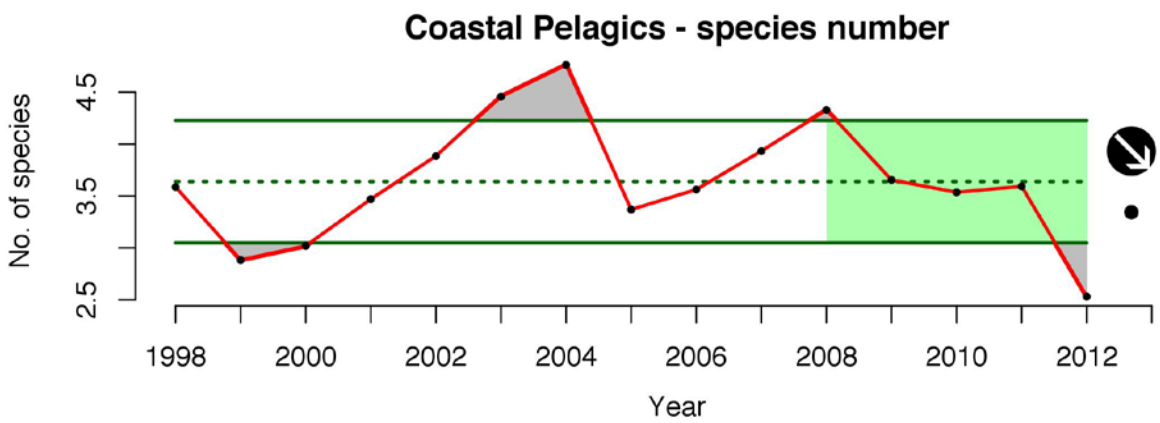

Figure EI 27. Number of species per sample for coastal pelagic fishes in the Northern California Current from 1998-2012. Data are combined June and September samples. Data courtesy of Richard Brodeur (Rick.Brodeur@noaa.gov).

SPECIES RICHNESS - COPEPODS

Copepod species richness has been tied to food chain structure and survival of coho salmon in the California Current (Peterson 2009). Low species richness is correlated with the southern transport of northern waters, high abundance of lipid-rich northern copepods and increased growth and survival of some species (Peterson 2009).

The species richness anomaly for copepods was highly variable over time. Species richness for the winter assemblage (Figure EI 28) showed no trend in the short-term, and the mean of the last five years was within 1.0 s.d. of the long-term mean. Copepod species richness in the summer declined over the last five years of the data series by more than 1.0 s.d. of the long-term mean (Figure EI 29), suggesting generally good conditions for northern copepods and their predators. However, the mean of the last five years was within 1.0 s.d. of the full time series. The value for summer 2013 was below 1.0 s.d. of the full time series.

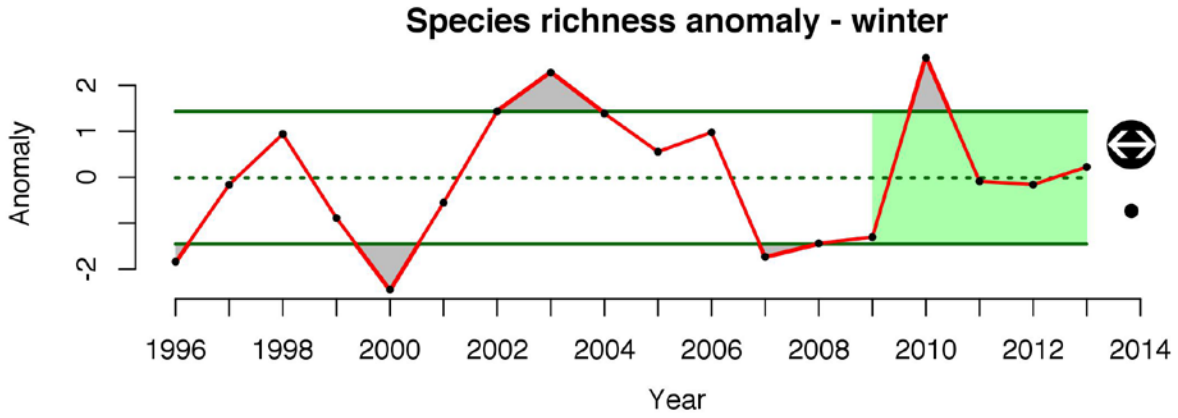

Figure EI 28. Species richness anomaly for copepods in the Northern California Current off Oregon during winter months (October – April) from 1996 to 2013. Data courtesy of Bill Peterson (bill.peterson@noaa.gov).

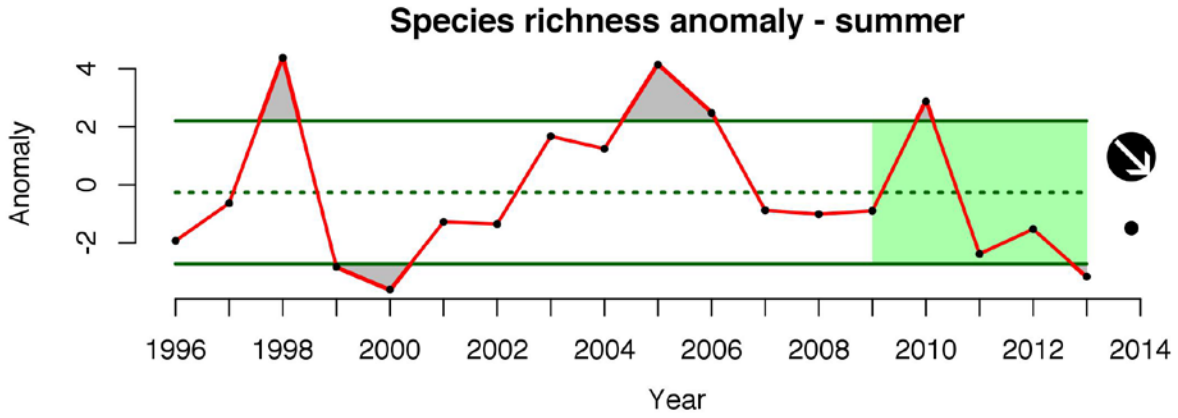

Figure EI 29. Species richness anomaly for copepods in the Northern California Current off Oregon during Summer months (May - September) from 1996 to 2013. Data courtesy of Bill Peterson (bill.peterson@noaa.gov).

SPECIES RICHNESS & DENSITY - GROUNDFISHES

Species richness for West Coast groundfishes increased steadily from just below 28 species per 3900 individuals in 2003 to over 32 species in 2009 (Figure EI 30). However, over the last five years, richness declined more than 1.0 s.d of the long-term mean to approximately 29 species per 3900 individuals. Nevertheless, the mean of the last five years was within 1.0 s.d. of the mean of the full time series. Given the fairly recent implementation of the West Coast Groundfish Bottom Trawl Survey (< 10 years), the increase in richness in the early years may be related in part to better species identification over the development of the survey. It is not clear why richness declined sharply from 2011 to 2012, and the trend should be examined in more detail.

As in other cases, trends north (Figure EI 31) and south (Figure EI 32) of Cape Mendocino differed somewhat. In both areas, richness increased initially before stabilizing. North of Cape Mendocino there was no trend over the last five years. However, south of Cape Mendocino richness declined over the last five years of the time series—markedly between 2011 and 2012.

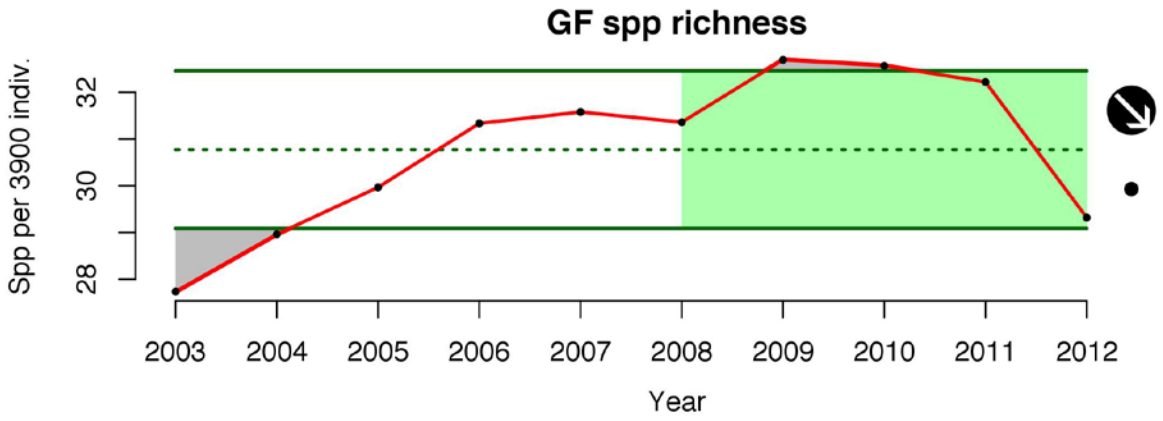

Figure EI 30. Species richness for groundfishes on the West Coast from the West Coast Groundfish Bottom Trawl Survey. Data underwent sample-based rarefaction and were then scaled to 3900 individuals to produce richeness estimates. Data courtesy of Beth Horness (Beth.Horness@noaa.gov).

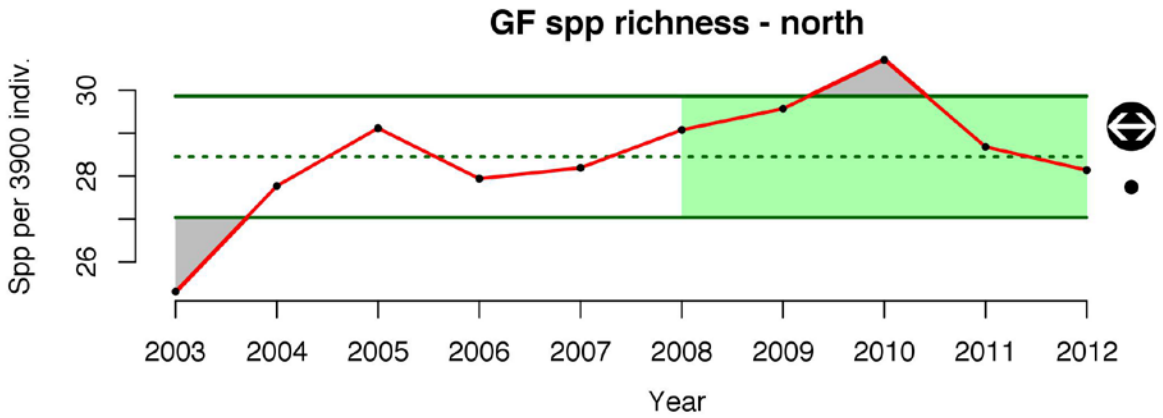

Figure EI 31. Species richness for groundfishes on the West Coast north of Cape Mendocino from the West Coast Groundfish Bottom Trawl Survey. Data underwent sample-based rarefaction and were then scaled to 3900 individuals to produce richness estimates. Data courtesy of Beth Horness (Beth.Horness@noaa.gov).

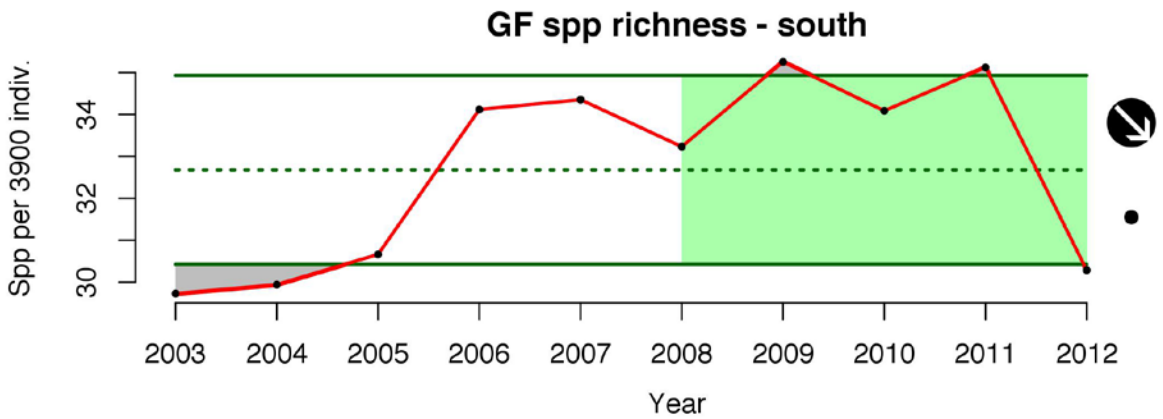

Figure EI 32. Species richness for groundfishes on the West Coast south of Cape Mendocino from the West Coast Groundfish Bottom Trawl Survey. Data underwent sample-based rarefaction and were then scaled to 3900 individuals to produce richness estimates. Data courtesy of Beth Horness (Beth.Horness@noaa.gov).

Species density initially increased from 2003 – 2006 then decreased sharply in 2007-2008 (Figure EI 33). Over the last five years, species density fluctuated but showed no overall trend, and the mean of the last five years was within 1.0 s.d. of the long-term mean. North of Cape Mendocino, there was a slight increase in species density over the last five years, but the increase was within 1.0 s.d. of the long-term mean (Figure EI 34). Trends south of Cape Mendocino were similar to the overall, coastwide tread (Figure EI 35).

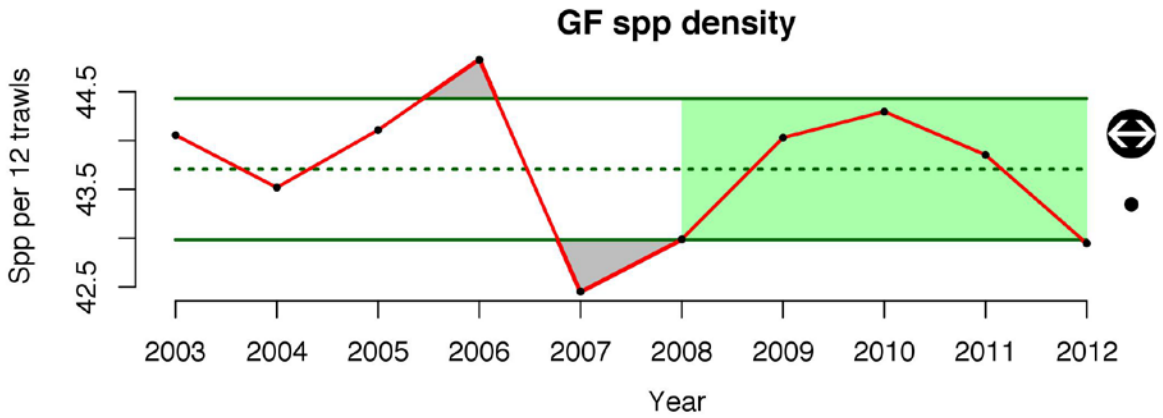

Figure EI 33. Area-weighted mean number of groundfish species per 12 trawls for 2003-2012 from the from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

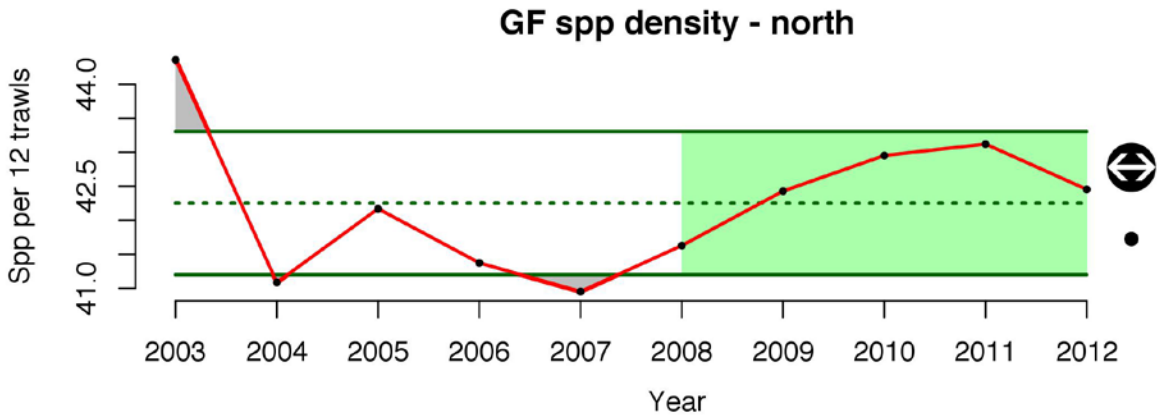

Figure EI 34. Area-weighted mean number of groundfish species per 12 trawls for 2003-2012 north of Cape Mendocino, from the West Coast Groundfish Bottom Trawl Survey; data courtesy of Beth Horness (Beth.Horness@noaa.gov).

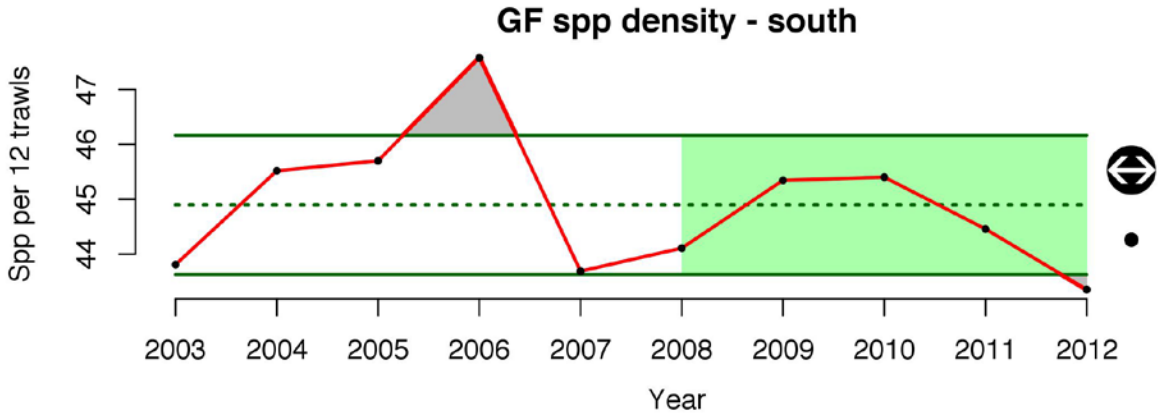

Figure EI 35. Area-weighted mean number of groundfish species per 12 trawls for 2003-2012 south of Cape Mendocino from the from the West Coast Groundfish Bottom Trawl Survey; data courtesy of Beth Horness (Beth.Horness@noaa.gov).

The differences between groundfish species richness and species density trends seen above are likely driven by the changing number of fishes captured in the trawl survey (Figure EI 36, Figure EI 37). Both the mean number fishes per trawl and the median number of fishes per trawl declined from 2003 to 2007, after which they remained stable. From 2007 – 2011 species density increased. During this period the number of individuals per haul remained stable, suggesting the increase was due to other processes.

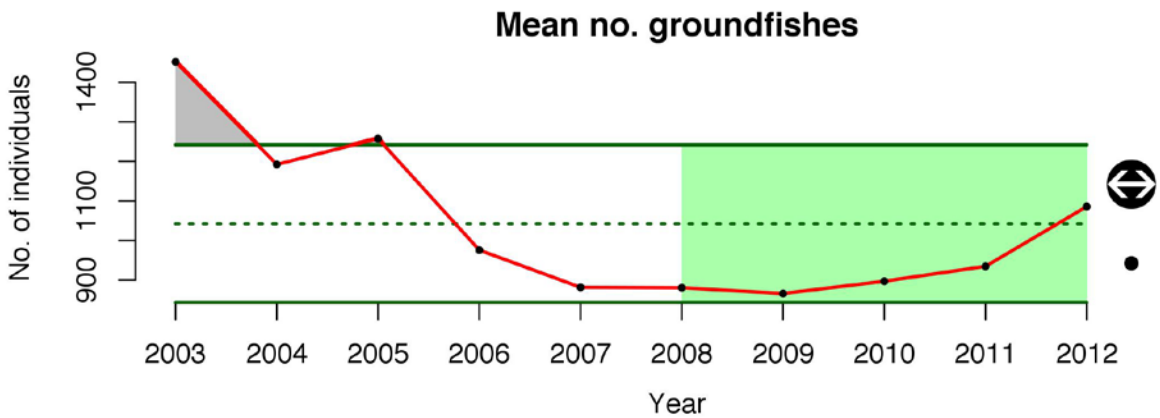

Figure EI 36. Mean number of groundfish individuals per trawl 2003-2012 from the from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

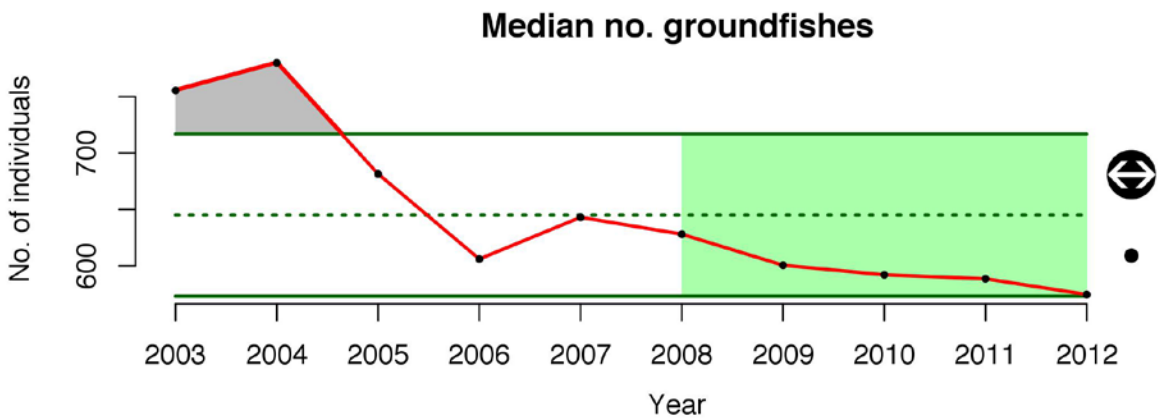

Figure EI 37. Median number of groundfish individuals per trawl 2003-2012 from the from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

Note that the trend in species richness seen here differs from that reported by Keller et al. (2012) who reported an initial decrease in the number of species per haul followed by an increase. The two trends differ because Keller et al. (2012) report raw species number per haul, while the data presented here were subjected to rarefaction (Gotelli and Colwell 2001, Colwell et al. 2004). Additionally, the data in Keller et al. (2012) are better thought of as species densities, because they are species per trawl for trawls with a relatively consistent area swept. The difference between data in Keller et al. (2012) and the richness values seen here is likely due to a decrease in the number of individuals per haul through

time. Sampling effort (whether number of samples, area sampled or number of individuals collected) affects estimates of richness, with the number of species increasing non-linearly with sampling effort. Here data were subjected to sample-based rarefaction (since fish school individuals are not sampled at random) and rescaled to 3900 individuals (Colwell et al. 2004).

SPECIES NUMBER—ICHTHYOPLANKTON

Species number in the CalCOFI spring ichthyoplankton surveys declined from a high in 2005 to low values between 2007 and 2010 (Figure EI 38). However, it increased rapidly in 2011 leading to an overall increase of more than 1.0 s.d. of time series. The mean of the last five years was within 1.0 s.d. of the full time series. However, given the short duration of the dataset, more emphasis should be based on the trend, not mean, over the last five years.

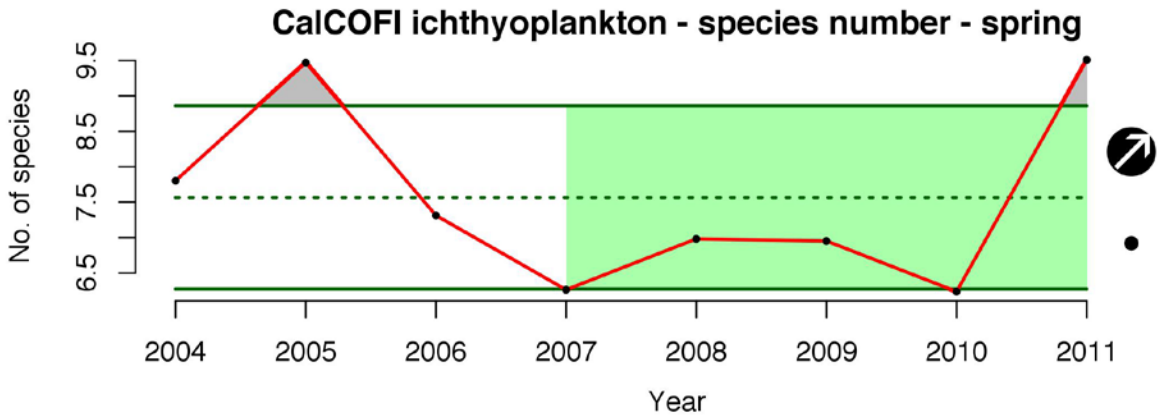

Figure EI 38. Number of species in CalCoFI ichthyoplankton surveys in the spring from 2004 – 2011. Data courtesy of Andrew Thompson (andrew.thompson@noaa.gov).

Species number in the summer CalCOFI surveys also declined to a low in 2007 prior to rebounding over the last five years (Figure EI 39). However, the final data point (2011) showed a decline to slightly lower than the long-term mean and the metric bears watching.

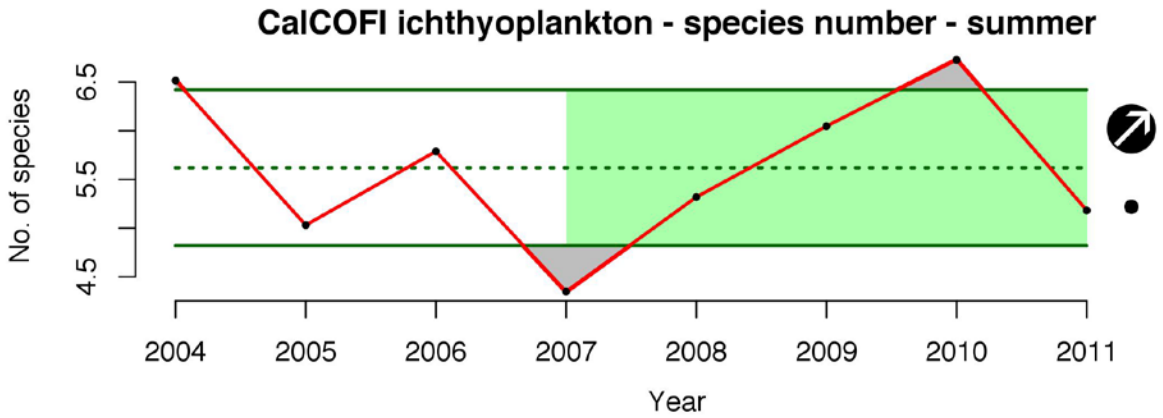

Figure EI 39. Number of species in CalCoFI ichthyoplankton surveys in the summer from 2004 – 2011. Data courtesy of Andrew Thompson (andrew.thompson@noaa.gov).

Ichthyoplankton species number off of Oregon in the spring also declined from high values in 2004 at the beginning of the time series to lows in 2009 and 2010 (Figure EI 40). While low over the last five years of the time series, species number is within 1.0 s.d. of long-term mean and showed no trend over the final five years.

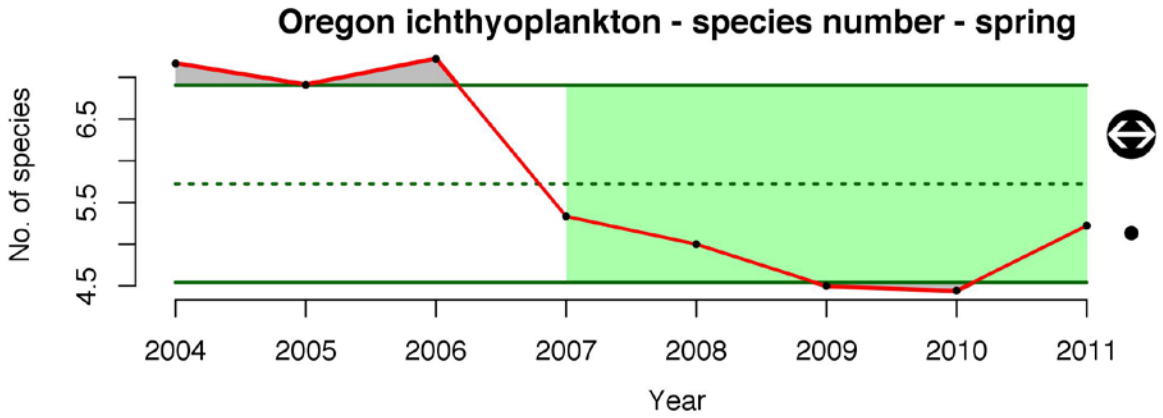

Figure EI 40. Number of species in ichthyoplankton surveys off Oregon in the spring from 2004 – 2011. Data courtesy of Andrew Thompson (andrew.thompson@noaa.gov).

Species number off Oregon in the summer declined over the last five years (2007-2011) by more than 1.0 s.d. of the full dataset (Figure EI 41). The 2011 value was well below 1.0 s.d. of the long-term mean.

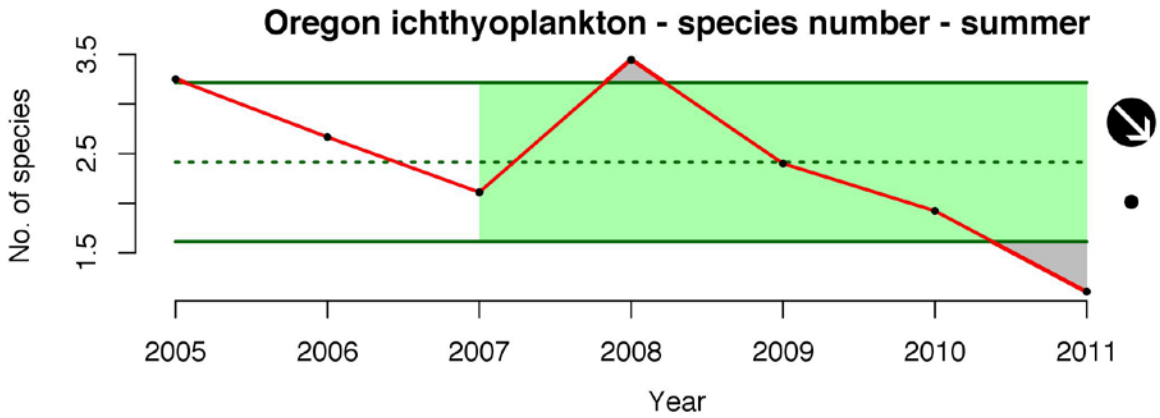

Figure EI 41. Number of species in surveys off Oregon in the spring from 2005 – 2011. Data courtesy of Andrew Thompson (andrew.thompson@noaa.gov).

DATA SOURCES AND METHODOLOGY

COASTAL PELAGIC FISHES

Data are courtesy of Ric Brodeur (Rick.brodeur@noaa.gov). See the 'Data Sources and Methodology' for the Coastal Pelagic Fishes section for details on the data collection and processing.

Simpson Diversity (1-λ, Gini-Simpson index) was calculated for each sample and then averaged for each year. Samples from June and September were pooled to create a single annual value.

Species richness data for coastal pelagic fishes were not subject to rarefaction as they were not count data, and are raw estimates of species per sample. The number of species was calculated for each sample and then averaged for each year. Samples from June and September were pooled to create a single annual value.

COPEPODS

Data are courtesy of Bill Peterson (bill.peterson@noaa.gov). See Peterson (2009) for details on the data collection and processing.

Note that the data are for the 'Newport Line' near Newport OR and do not span the full coast. Future IEA efforts should work to incorporate available datasets to produce better coastwide estimates of zooplankton dynamics. Work has shown that copepod diversity calculated from this data source is a good predictor of system characteristics and correlates with population dynamics of some salmon species (Peterson 2009).

Simpson Diversity (1-λ, Gini-Simpson index) was calculated for each month then averaged for each year by season: winter (Oct - April) and summer (May – Sept). Data were number of individuals by taxa per m^3. Winter means included data from the previous calendar year. That is, winter 2000 was the average of data from Oct – Dec 1999 and Jan – April 2000.

Species richness estimates of species per sample were not subject to rarefaction as in the case of groundfish. Enumeration of zooplankton data uses subsamples of a generally consistent number of individuals (200-400 individuals per sample for copepods, Peterson 2009), and therefore, does not require rarefaction to account for differences in sampling effort.

Northern copepod biomass anomaly—Data are courtesy of Bill Peterson (bill.peterson@noaa.gov). Seasonal estimates of the anomaly were calculated in winter (Oct - April) and summer (May – Sept). Winter means included data from the previous calendar year; for example, winter 2000 was the average of data from Oct – Dec 1999 and Jan – April 2000. See http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/eb-copepod-anomalies.cfm for a discussion of the mechanisms behind the northern copepod biomass anomaly and for methodology in calculating the index.

GELATINOUS ZOOPLANKTON (JELLIES)

Data for gelatinous zooplankton come from two sources:

Oregon & Washington: Gelatinous zooplankton were surveyed in surface, shelf waters of the NCC from Newport, OR (44.6°N, 124.0° W) to Tatoosh Island, WA (48.4 N°, 124.7° W) along ten transect lines (Suchman et al. 2012). Five to ten stations were sampled on each transect line. At each station a Nordic 264 rope trawl (30 m wide x 19 m deep) was towed in surface waters for 30 min at 1.5-2.0 m s^{-1}. Mesh size was 162.6 cm at the throat to 9.8 cm at the cod end with a 6.1 m long, 0.87-cm mesh liner sewn into the cod end. Medusae were identified, counted and measured at sea. Total number of medusae per haul was estimated based on the total weight of species for the haul and mean weight of a subsample of at least 50 individuals. Number per haul was converted to number per km^2 based on the haul length and width of the net. The data presented here are for two dominant taxa (*Chrysaora fuscescens* and *Aequorea* sp.) for surveys conducted in June and September. Time series were standardized by subtracting the mean and dividing by the standard deviation. See Suchman et al. 2012 for further detail. Data are courtesy of Ric Brodeur (rick.brodeur@noaa.gov).

Central California: Data come from the central California rockfish recruitment survey (Wells et al. 2013). Data processing is detailed in Wells et al. (2013). In brief, time series data were standardized by subtracting the mean and dividing by the standard deviation.

Data are courtesy of John Field (john.field@noaa.gov).

GROUNDFISHES

Data for the groundfish time series come from the Northwest Fisheries Science Center's annual West Coast Bottom Trawl Survey (WCBTS, data courtesy of Beth Horness, (beth.horness@noaa.gov) (Keller et al. 2008). The survey is a depth-stratified, random sample that spans approximately 32 - 48.5° N and 55-1200 m depth for 2003-2012. Data were limited to those hauls deemed acceptable for stock assessment. Hauls from areas subsequently closed to sampling were not included in analyses. The data include 6338 trawls/hauls from 2003 - 2012 and 324 fish taxa identified to species. Of these, 3435 trawls were from north of Cape Mendocino and 2953 trawls were from south of Cape Mendocino. Two pairs of rockfishes were combined because of difficulty in discriminating between each species pair in the field: sunset rockfish *Sebastes crocotulus* and vermilion rockfish *S. miniatus* were combined into one taxon, and blackspotted rockfish S. *melanostictus* and rougheye rockfish *S. aleutianus* were combined into another taxon. Both combined taxa were included in species level analyses.

AREA-WEIGHTED MEANS (GROUNDFISHES)

Area-weighted means were calculated for mean trophic level, scavenger biomass ratio[6], Simpson diversity, and species richness because some areas of the shelf and slope are more heavily sampled than others and because the total bottom area of the shelf and slope for any given depth range varies with latitude (Table EI1).

Data (for both groundfishes and bottom area) were binned into five depth zones (<200, 201-600, 600-1200 m depths) and four latitude regions (south of Point Conception [32 - 34.5° N], Point Conception to Cape Mendocino [40.4° N], Cape Mendocino to Cape Blanco [42.5° N], and Cape Blanco to Cape Flattery [to 48.4511° N—the extent of the groundfish data]) based on previous analyses of groundfish assemblage structure (Tolimieri and Levin 2006, Tolimieri 2007). The areal extent of each depth x region bin was calculated from the U.S. Coastal Relief Model:

http://www.ngdc.noaa.gov/mgg/coastal/crm.html

The native coordinate system of these bathymetry data does not conserve area throughout the study region (e.g., a 1 X 1 degree area in the south is larger than a 1 X 1 degree area to the north). To correct this problem, we created a regular 0.1-degree grid over the study area and then re-projected this grid to a Cylindrical Equal-Area projection

[6] Scavenger biomass ratio includes crab biomass but is included here since the data come from the groundfish trawl survey.

(units = meters, projection type = 3, longitude of the center of projection = -122 0' 0.00", latitude of the center of projection = 56 30' 0.00", Azimuth = 120.95, and Scale factor = 1). The new data layer had the correct area for each 0.1-degree grid cell. The total area of a given depth x region bin was calculated by summing the area of the relevant grid cells. Each depth x region bin was then assigned a weight equal to its proportion of the total area of all depth x region bins. These weights were then used to calculate the area-weighted mean for each groundfish-based indicator of ecological integrity.

Table EI 2. Depth and latitude bins uses in the area-weighted analyses showing total area of the bins, corresponding weights and total number of trawls from 2003 – 2012. See text for depth and latitude borders.

Depth zone	Latitude zone	Total area (km^2)	Weight	Trawls
Shelf	Flattery	36,394	0.231	1422
Shallow slope	Flattery	11,020	0.070	806
Deep slope	Flattery	10,916	0.069	496
Shelf	Blanco	5,407	0.034	264
Shallow slope	Blanco	2,182	0.014	200
Deep slope	Blanco	5,258	0.033	247
Shelf	Mendocino	16,689	0.106	763
Shallow slope	Mendocino	8,326	0.053	575
Deep slope	Mendocino	12,518	0.079	466
Shelf	Conception	10,176	0.064	364
Shallow slope	Conception	11,702	0.074	479
Deep slope	Conception	27,243	0.173	306

GROUNDFISH INDICATORS

Mean trophic level (MTL, Pauly and Watson 2005, 2010) was calculated as the biomass-weighted mean trophic level for each haul (Table EI 3), which was then used to calculate an area-weighted mean for the West Coast shelf and slope (see Area-weighted means, below). Information on trophic level was taken from Fishbase.org. Taxa included in the analyses were all fishes identified to the species level. Data were CPUE biomass (kg per km^2) by species per haul.

Previous analyses of MTL (Pauly et al. 2001, Essington et al. 2006, Branch et al. 2010) have generally not corrected for survey area. In part this is because many workers have focused on catch-MTL, which is derived from fisheries catch data. The data used here

are from a fishery-independent trawl survey, and therefore, represent ecosystem-MTL. To correctly evaluate the change in the trophic structure of the groundfish assemblage it is important to correct the data for survey area since the total area of various depth x latitude bins is not constant.

Area-adjusted MTL for groundfishes is presented in the results section above. For comparison, the raw MTL trend is shown below (Figure EI 42). While the overall trend is similar (a decline since 2003), there are important differences. Most importantly the absolute level of decline is quite different: 0.077 if adjusting for area versus 0.190 if not. A decrease in MTL of ~0.15 represents a decrease of 50% in the primary production required to support the assemblage. Therefore, failing to account for sample area overestimates the change in the trophic structure and energy requirements for the assemblage in question.

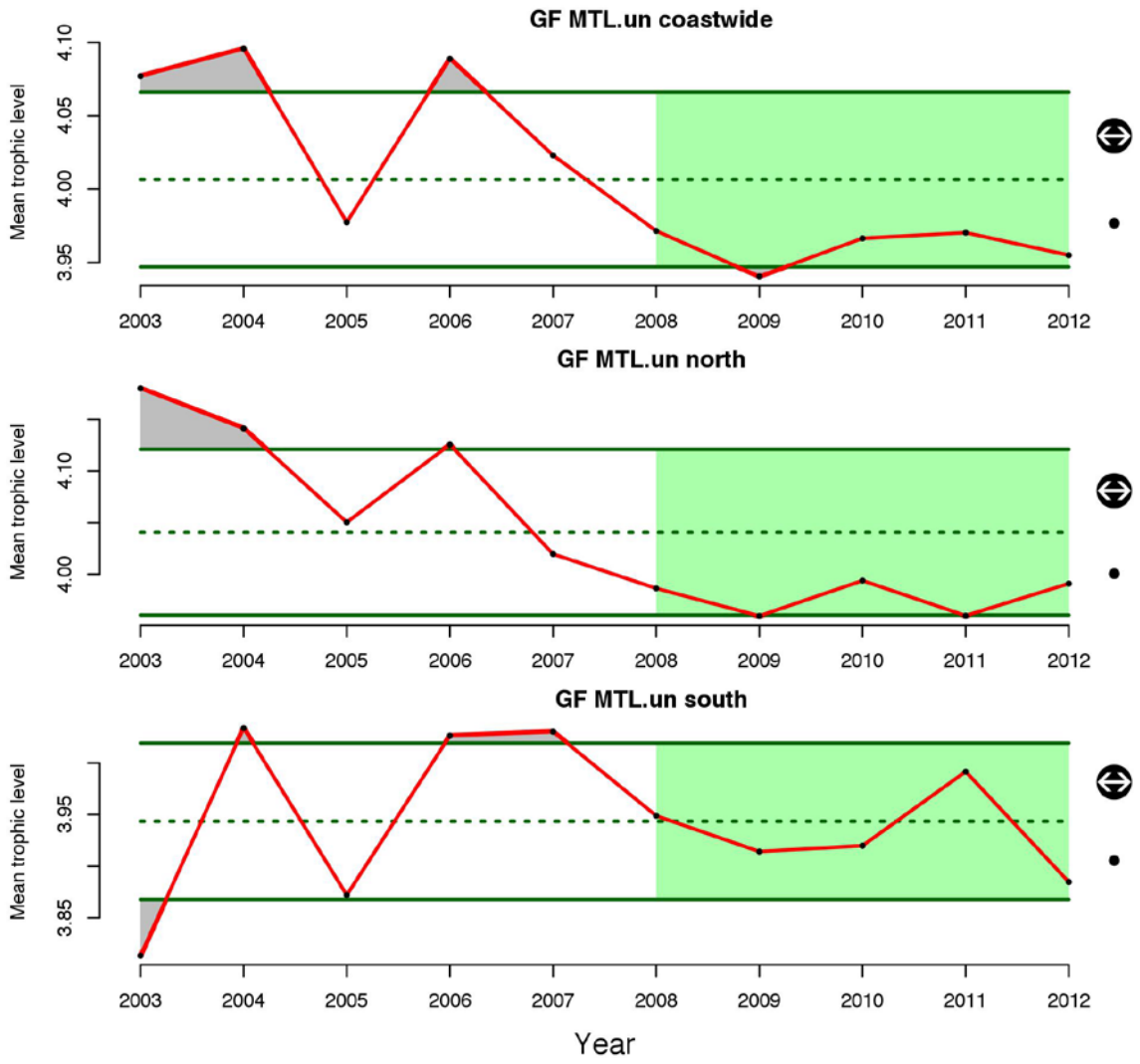

Figure EI 42a-c. Mean trophic level for West Coast groundfishes from 2003 – 2012. MTL was calculated for survey data without adjusting for sampling effort in different depth x latitude strata. The top pane shows coastwide MTL. The lower two panes show MTL for the regions north and south of Cape Mendocino (40.4° N). Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

Table EI 3. Groundfish species included in the analysis of mean trophic level. TL = Trophic level from Fishbase.org. KG = total biomass in the West Coast Groundfish Bottom Trawl Survey for 2003-2012 for depths ≤ 1200 m. Data are courtesy of Beth Horness (Beth.Horness@noaa.gov).

Order	Family	Species	Common Name	TL	KG
Pleuronectiformes	Pleuronectidae	*Microstomus pacificus*	Dover sole	3.3	285170.06
Gadiiformes	Merlucciidae	*Merluccius productus*	Pacific hake	4.3	119343.88
Scorpaeniformes	Scorpaenidae	*Sebastolobus altivelis*	longspine thornyhead	3.4	113339.45
Squaliformes	Squalidae	*Squalus acanthias*	spiny dogfish	4.3	99876.12
Scorpaeniformes	Anoplopomatidae	*Anoplopoma fimbria*	sablefish	3.8	88377.85
Pleuronectiformes	Paralichthyidae	*Citharichthys sordidus*	Pacific sanddab	3.5	72783.45

Order	Family	Species	Common Name	TL	KG
Scorpaeniformes	Scorpaenidae	*Sebastes goodei*	chilipepper	3.5	69512.06
Rajiformes	Rajidae	*Raja rhina*	longnose skate	3.8	63856.20
Pleuronectiformes	Pleuronectidae	*Atheresthes stomias*	arrowtooth flounder	4.3	61488.71
Pleuronectiformes	Pleuronectidae	*Glyptocephalus zachirus*	rex sole	3.2	59942.57
Scorpaeniformes	Scorpaenidae	*Sebastes diploproa*	splitnose rockfish	3.7	53479.68
Scorpaeniformes	Scorpaenidae	*Sebastolobus alascanus*	shortspine thornyhead	3.6	39965.62
Scorpaeniformes	Scorpaenidae	*Sebastes zacentrus*	sharpchin rockfish	3.6	34050.38
Chimaeriformes	Chiamaeridae	*Hydrolagus colliei*	spotted ratfish	3.7	32683.24
Scorpaeniformes	Hexagrammidae	*Ophiodon elongatus*	lingcod	4.3	30049.90
Gadiiformes	Macrouridae	*Coryphaenoides acrolepis*	Pacific grenadier	3.8	28005.09
Scorpaeniformes	Scorpaenidae	*Sebastes flavidus*	yellowtail rockfish	4.1	27934.79
Pleuronectiformes	Pleuronectidae	*Parophrys vetulus*	English sole	3.4	27348.26
Scorpaeniformes	Scorpaenidae	*Sebastes jordani*	shortbelly rockfish	3.2	25528.40
Scorpaeniformes	Scorpaenidae	*Sebastes saxicola*	stripetail rockfish	3.6	24686.86
Pleuronectiformes	Pleuronectidae	*Eopsetta jordani*	petrale sole	4.1	24563.38
Scorpaeniformes	Scorpaenidae	*Sebastes proriger*	redstripe rockfish	3.7	19659.21
Scorpaeniformes	Scorpaenidae	*Sebastes elongatus*	greenstriped rockfish	3.6	19280.61
Scorpaeniformes	Scorpaenidae	*Sebastes pinniger*	canary rockfish	3.8	17866.10
Gadiiformes	Macrouridae	*Albatrossia pectoralis*	giant grenadier	4.3	15871.14
Scorpaeniformes	Scorpaenidae	*Sebastes alutus*	Pacific ocean perch	3.5	15103.42
Scorpaeniformes	Scorpaenidae	*Sebastes crameri*	darkblotched rockfish	3.7	14637.72
Scorpaeniformes	Scorpaenidae	*Sebastes semicinctus*	halfbanded rockfish	3.5	12533.42
Rajiformes	Rajidae	*Raja binoculata*	big skate	3.92	11349.26
Argentiniformes	Alepocephalidae	*Alepocephalus tenebrosus*	California slickhead	3.5	10779.92
Pleuronectiformes	Pleuronectidae	*Lyopsetta exilis*	slender sole	3.4	10335.98
Pleuronectiformes	Pleuronectidae	*Hippoglossus stenolepis*	Pacific halibut	4.1	8605.01
Rajiformes	Rajidae	*Bathyraja kincaidii*	Bering skate	3.4	7826.25
Carcharhiniformes	Scyliorhinidae	*Apristurus brunneus*	brown cat shark	3.6	7661.75
Pleuronectiformes	Pleuronectidae	*Embassichthys bathybius*	deepsea sole	3.3	6613.33
Gadiiformes	Gadidae	*Gadus macrocephalus*	Pacific cod	4	6409.07
Perciformes	Zoarcidae	*Lycodes cortezianus*	bigfin eelpout	3.5	5455.26
Scorpaeniformes	Scorpaenidae	*Sebastes aurora*	aurora rockfish	3.6	4943.46
Perciformes	Sciaenidae	*Genyonemus lineatus*	white croaker	3.4	4364.22
Scorpaeniformes	Scorpaenidae	*Sebastes helvomaculatus*	rosethorn rockfish	3.6	4016.01
Scorpaeniformes	Scorpaenidae	*Sebastes paucispinis*	bocaccio	3.5	3942.88
Carcharhiniformes	Scyliorhinidae	*Parmaturus xaniurus*	filetail cat shark	3.8	3921.85
Perciformes	Zoarcidae	*Bothrocara brunneum*	twoline eelpout	3.6	3331.56
Scorpaeniformes	Scorpaenidae	*Sebastes melanostomus*	blackgill rockfish	3.7	3042.29
Scorpaeniformes	Scorpaenidae	*Sebastes entomelas*	widow rockfish	3.7	2922.55
Rajiformes	Rajidae	*Raja inornata*	California skate	3.7	2597.02
Gadiiformes	Moridae	*Antimora microlepis*	Pacific flatnose	3.5	2328.77
Scorpaeniformes	Scorpaenidae	*Sebastes chlorostictus*	greenspotted rockfish	3.7	2325.36

Order	Family	Species	Common Name	TL	KG
Scorpaeniformes	Scorpaenidae	*Sebastes caurinus*	copper rockfish	4.1	2324.90
Perciformes	Zoarcidae	*Lycodes diapterus*	black eelpout	3.4	2021.75
Torpadiniformes	Torpedinidae	*Torpedo californica*	Pacific electric ray	4.5	1776.32
Scorpaeniformes	Scorpaenidae	*Sebastes wilsoni*	pygmy rockfish	3.5	1700.66
Batrachoidiformes	Batrachoididae	*Porichthys notatus*	plainfin midshipman	4	1681.95
Scorpaeniformes	Scorpaenidae	*Sebastes melananostictus.aleutianus*	Sebastes melanostictus or Sebastes aleutianus	3.65	1670.77
Pleuronectiformes	Pleuronectidae	*Hippoglossoides elassodon*	flathead sole	3.6	1645.74
Perciformes	Embiotocidae	*Zalembius rosaceus*	pink seaperch	3.3	1618.05
Perciformes	Zoarcidae	*Lycenchelys crotalinus*	snakehead eelpout	3.5	1495.36
Perciformes	Stromateidae	*Peprilus simillimus*	Pacific pompano	4.1	1387.61
Clupeiformes	Clupeidae	*Alosa sapidissima*	American shad	3.5	1227.52
Scorpaeniformes	Scorpaenidae	*Sebastes ensifer*	swordspine rockfish	3.6	1110.36
Perciformes	Zoarcidae	*Lycodes pacificus*	blackbelly eelpout	3.3	1094.90
Scorpaeniformes	Sebastidae	*Sebastes crocotulus.miniatus*	vermilion_sunset	3.8	1088.49
Scorpaeniformes	Scorpaenidae	*Sebastes rufus*	bank rockfish	3.7	1052.72
Scorpaeniformes	Scorpaenidae	*Sebastes ruberrimus*	Yelloweye rockfish	4.4	943.38
Scorpaeniformes	Scorpaenidae	*Sebastes hopkinsi*	squarespot rockfish	3.6	907.70
Scorpaeniformes	Scorpaenidae	*Sebastes babcocki*	redbanded rockfish	3.7	877.35
Scorpaeniformes	Liparidae	*Careproctus melanurus*	blacktail snailfish	3.4	870.58
Pleuronectiformes	Pleuronectidae	*Pleuronichthys decurrens*	curlfin sole	3.8	850.75
Pleuronectiformes	Pleuronectidae	*Lepidopsetta bilineata*	southern rock sole	3.2	780.37
Perciformes	Carangidae	*Trachurus symmetricus*	jack mackerel	3.6	725.02
Clupeiformes	Engraulidae	*Engraulis mordax*	northern anchovy	3	716.64
Scorpaeniformes	Scorpaenidae	*Sebastes brevispinis*	silvergray rockfish	3.8	692.05
Scorpaeniformes	Scorpaenidae	*Scorpaena guttata*	California scorpionfish	3.8	671.78
Scorpaeniformes	Cottidae	*Icelinus filamentosus*	threadfin sculpin	3.5	620.37
Clupeiformes	Clupeidae	*Clupea pallasi*	Pacific herring	3.2	529.82
Scorpaeniformes	Scorpaenidae	*Sebastes rosenblatti*	greenblotched rockfish	3.7	394.77
Pleuronectiformes	Pleuronectidae	*Platichthys stellatus*	starry flounder	3.3	370.27
Carcharhiniformes	Scyliorhinidae	*Apristurus kampae*	longnose cat shark	3.7	326.38
Scorpaeniformes	Scorpaenidae	*Sebastes levis*	Cowcod	3.8	292.57
Scorpaeniformes	Scorpaenidae	*Sebastes reedi*	yellowmouth rockfish	3.71	292.13
Rajiformes	Rajidae	*Raja stellulata*	starry skate	3.7	281.88
Gadiiformes	Macrouridae	*Nezumia stelgidolepis*	California grenadier	4.4	276.99
Squantiformes	Squantinidae	*Squatina californica*	Pacific angel shark	4.1	269.53
Pleuronectiformes	Paralichthyidae	*Hippoglossina stomata*	bigmouth sole	3.8	260.89
Myxiniformes	Myxinidae	*Eptatretus deani*	black hagfish	3.8	235.67
Argentiniformes	Alepocephalidae	*Talismania bifurcata*	threadfin slickhead	3.3	226.57
Rajiformes	Rajidae	*Bathyraja abyssicola*	deepsea skate	3.99	212.82
Carcharhiniformes	Triakidae	*Galeorhinus galeus*	soupfin shark	4.2	207.48
Mylobatiformes	Myliobatidae	*Myliobatis californicus*	bat Ray	3.14	201.80

Order	Family	Species	Common Name	TL	KG
Gadiiformes	Gadidae	*Microgadus proximus*	Pacific tomcod	3.6	196.07
Pleuronectiformes	Pleuronectidae	*Psettichthys melanostictus*	sand sole	4.1	192.54
Pleuronectiformes	Pleuronectidae	*Pleuronichthys verticalis*	hornyhead turbot	3.1	186.89
Scorpaeniformes	Hexagrammidae	*Zaniolepis latipinnis*	longspine combfish	3.1	179.82
Pleuronectiformes	Paralichthyidae	*Paralichthys californicus*	California halibut	4.5	155.76
Scorpaeniformes	Hexagrammidae	*Hexagrammos decagrammus*	kelp greenling	3.6	154.97
Carcharhiniformes	Triakidae	*Mustelus henlei*	brown smoothhound	3.6	148.93
Gadiiformes	Macrouridae	*Nezumia liolepis*	smooth grenadier	3.3	143.45
Scorpaeniformes	Scorpaenidae	*Sebastes maliger*	quillback rockfish	3.8	137.37
Gadiiformes	Melanonidae	*Melanonus zugmayeri*	arrowtail	3.51	134.48
Rajiformes	Rajidae	*Bathyraja aleutica*	Aleutian skate	4.14	120.36
Gadiiformes	Gadidae	*Theragra chalcogramma*	walleye pollock	3.5	119.09
Aulopiformes	Synodontidae	*Synodus lucioceps*	California lizardfish	4.5	118.90
Scorpaeniformes	Scorpaenidae	*Sebastes borealis*	shortraker rockfish	3.9	116.06
Scorpaeniformes	Scorpaenidae	*Sebastes ovalis*	speckled rockfish	3.7	114.43
Perciformes	Embiotocidae	*Cymatogaster aggregata*	shiner perch	3	114.19
Myxiniformes	Myxinidae	*Eptatretus stouti*	Pacific hagfish	4.24	111.01
Scorpaeniformes	Cottidae	*Enophrys taurina*	bull sculpin	3.2	109.05
Hexanchiformes	Hexanchidae	*Hexanchus griseus*	sixgill shark	4.3	107.35
Pleuronectiformes	Paralichthyidae	*Citharichthys xanthostigma*	longfin sanddab	3.5	106.57
Osmeriformes	Osmeridae	*Thaleichthys pacificus*	eulachon	3.3	101.24
Pleuronectiformes	Pleuronectidae	*Isopsetta isolepis*	butter sole	3.6	95.79
Perciformes	Icosteidae	*Icosteus aenigmaticus*	ragfish	4.5	94.04
Scorpaeniformes	Hexagrammidae	*Zaniolepis frenata*	shortspine combfish	3.4	85.29
Scorpaeniformes	Cottidae	*Leptocottus armatus*	Pacific staghorn sculpin	3.5	75.13
Scorpaeniformes	Scorpaenidae	*Sebastes rubrivinctus*	flag rockfish	3.7	69.46
Argentiniformes	Argentinidae	*Argentina sialis*	Pacific argentine	3.1	67.33
Carcharhiniformes	Scyliorhinidae	*Cephaloscyllium ventriosum*	swell shark	3.9	66.98
Scorpaeniformes	Liparidae	*Careproctus cypselurus*	blackfin snailfish	3.32	64.93
Ophidiiformes	Ophidiidae	*Chilara taylori*	spotted cusk-eel	4.1	62.33
Scorpaeniformes	Scorpaenidae	*Sebastes auriculatus*	brown rockfish	4	61.95
Perciformes	Anarhichadidae	*Anarrhichthys ocellatus*	wolf-eel	3.5	59.10
Perciformes	Serranidae	*Paralabrax nebulifer*	barred sand bass	3.5	59.05
Osmeriformes	Osmeridae	*Allosmerus elongatus*	whitebait smelt	3.2	56.88
Clupeiformes	Clupeidae	*Sardinops sagax*	Pacific sardine	2.4	49.71
Scorpaeniformes	Scorpaenidae	*Sebastes rosaceus*	rosy rockfish	3.6	49.49
Perciformes	Cryptacanthodidae	*Cryptacanthodes giganteus*	giant wrymouth	3.27	49.30
Gadiiformes	Macrouridae	*Coryphaenoides cinereus*	popeye grenadier	3.66	41.86
Ophidiiformes	Ophidiidae	*Lamprogrammus niger*	paperbone cusk-eel	3.72	33.48
Scorpaeniformes	Scorpaenidae	*Sebastes umbrosus*	honeycomb rockfish	3.6	33.40
Scorpaeniformes	Scorpaenidae	*Sebastes simulator*	pinkrose rockfish	3.6	32.02
Gadiiformes	Moridae	*Physiculus rastrelliger*	hundred fathom codling	3.4	30.28

Order	Family	Species	Common Name	TL	KG
Perciformes	Scombridae	*Scomber japonicus*	chub mackerel	3.1	30.20
Scorpaeniformes	Psychrolutidae	*Psychrolutes phrictus*	blob sculpin	3.5	26.34
Carcharhiniformes	Triakidae	*Mustelus californicus*	gray smoothhound	3.5	26.31
Argentiniformes	Microstomatidae	*Leuroglossus stilbius*	California smoothtounge	3.26	26.28
Scorpaeniformes	Scorpaenidae	*Sebastes emphaeus*	Puget Sound rockfish	3.23	25.36
Scorpaeniformes	Scorpaenidae	*Sebastes dalli*	calico rockfish	3.53	24.01
Carcharhiniformes	Carcharhinidae	*Prionace glauca*	blue shark	4.2	22.95
Stomiiformes	Stomiidae	*Tactostoma macropus*	longfin dragonfish	4.2	22.79
Lampriformes	Trachipteridae	*Trachipterus altivelis*	king-of-the-salmon	3.9	21.29
Squaliformes	Etmopteridae	*Centroscyllium nigrum*	combtooth dogfish	3.9	21.03
Scorpaeniformes	Agonidae	*Bathyagonus nigripinnis*	blackfin poacher	3.25	20.70
Argentiniformes	Microstomatidae	*Bathylagus milleri*	robust blacksmelt	3.21	19.39
Scorpaeniformes	Scorpaenidae	*Sebastes constellatus*	starry rockfish	3.7	18.92
Stomiiformes	Stomiidae	*Stomias atriventer*	blackbelly dragonfish	4	18.48
Perciformes	Uranoscopidae	*Kathetostoma averruncus*	smooth stargazer	4.3	17.59
Argentiniformes	Microstomatidae	*Bathylagus pacificus*	Pacific blacksmelt	3.3	13.60
Osmeriformes	Osmeridae	*Spirinchus starksi*	night smelt	3.5	11.97
Scorpaeniformes	Scorpaenidae	*Sebastes nigrocinctus*	tiger rockfish	3.5	11.65
Pleuronectiformes	Pleuronectidae	*Pleuronichthys ritteri*	spotted turbot	3.2	10.50
Gadiiformes	Macrouridae	*Malacocephalus laevis*	softhead grenadier	4.2	8.76
Scorpaeniformes	Scorpaenidae	*Sebastes macdonaldi*	Mexican rockfish	3.7	8.02
Scorpaeniformes	Scorpaenidae	*Sebastes mystinus*	blue rockfish	2.8	7.85
Scorpaeniformes	Scorpaenidae	*Sebastes lentiginosus*	freckled rockfish	3.5	7.71
Pleuronectiformes	Paralichthyidae	*Xystreurys liolepis*	fantail sole	3.5	7.59
Scorpaeniformes	Triglidae	*Prionotus stephanophrys*	lumptail searobin	3.5	7.39
Scorpaeniformes	Liparidae	*Paraliparis dactylosus*	red snailfish	3.46	7.19
Perciformes	Trichiuridae	*Lepidopus xantusi*	silver scabbardfish	3.85	5.92
Pleuronectiformes	Pleuronectidae	*Lepidopsetta polyxystra*	northern rock sole	3.29	5.90
Scorpaeniformes	Agonidae	*Xeneretmus latifrons*	blacktip poacher	3.2	5.79
Scorpaeniformes	Cottidae	*Hemilepidotus spinosus*	brown Irish lord	3.5	5.70
Perciformes	Embiotocidae	*Hyperprosopon anale*	spotfin surfperch	3.3	5.62
Stomiiformes	Stomiidae	*Aristostomias scintillans*	shining loosejaw	3.5	5.58
Beryciformes	Anoplogastridae	*Anoplogaster cornuta*	fangtooth	4	5.53
Scorpaeniformes	Agonidae	*Bathyagonus pentacanthus*	bigeye poacher	3.2	5.39
Scorpaeniformes	Liparidae	*Elassodiscus caudatus*	humpback snailfish	3.31	5.05
Scorpaeniformes	Cottidae	*Scorpaenichthys marmoratus*	cabezon	3.6	4.95
Myctophiformes	Myctophidae	*Stenobrachius leucopsarus*	northern lampfish	3.2	4.70
Scorpaeniformes	Cottidae	*Bolinia euryptera*	broadfin sculpin	3.45	4.60
Scorpaeniformes	Cottidae	*Hemilepidotus hemilepidotus*	red Irish lord	3.5	4.50
Scorpaeniformes	Cottidae	*Icelinus fimbriatus*	fringed sculpin	3.7	4.47
Stephanoberyciformes	Melamphaidae	*Poromitra crassiceps*	crested bigscale	3.1	4.33
Scorpaeniformes	Agonidae	*Chesnonia verrucosa*	warty poacher	3.2	4.25

Order	Family	Species	Common Name	TL	KG
Tetradontiformes	Molidae	*Mola mola*	ocean sunfish	4	4.15
Scorpaeniformes	Scorpaenidae	*Sebastes melanops*	black rockfish	4.4	4.11
Rajiformes	Rhinobatidae	*Zapteryx exasperata*	bandedguitarfish	3.5	4.10
Osmeriformes	Osmeridae	*Hypomesus pretiosus*	surf smelt	3.4	3.90
Scorpaeniformes	Liparidae	*Careproctus gilberti*	smalldisk snailfish	3.3	3.72
Scorpaeniformes	Liparidae	*Paraliparis rosaceus*	rosy snailfish	3.7	3.56
Scorpaeniformes	Cottidae	*Chitonotus pugetensis*	roughback sculpin	3.5	3.41
Argentiniformes	Platytroctidae	*Sagamichthys abei*	shining tubeshoulder	3.1	3.35
Scorpaeniformes	Cottidae	*Enophrys bison*	buffalo sculpin	3.3	3.23
Scorpaeniformes	Scorpaenidae	*Sebastes gilli*	bronzespotted rockfish	3.8	3.20
Scorpaeniformes	Cottidae	*Radulinus asprellus*	slim sculpin	3.4	3.08
Perciformes	Trichiuridae	*Aphanopus carbo*	black scabbardfish	4.48	3.08
Scorpaeniformes	Scorpaenidae	*Sebastes carnatus*	gopher rockfish	3.6	2.97
Perciformes	Embiotocidae	*Amphistichus argenteus*	barred surfperch	3.5	2.85
Perciformes	Centrolphidae	*Icichthys lockingtoni*	medusafish	3.7	2.79
Stomiiformes	Stomiidae	*Idiacanthus antrostomus*	Pacific blackdragon	3.8	2.75
Ophidiiformes	Bythitidae	*Cataetyx rubrirostris*	rubynose brotula	3.5	2.74
Perciformes	Embiotocidae	*Phanerodon furcatus*	White Surfperch	3.4	2.67
Scorpaeniformes	Cottidae	*Gymnocanthus tricuspis*	arctic staghorn sculpin	3.46	2.35
Perciformes	Zoarcidae	*Lycodapus fierasfer*	blackmouth eelpout	3.3	2.32
Scorpaeniformes	Cottidae	*Clinocottus acuticeps*	sharpnose sculpin	3.5	2.26
Perciformes	Bathymasteridae	*Ronquilus jordani*	northern ronquil	3.1	2.26
Argentiniformes	Opisthoproctidae	*Macropinna microstoma*	barreleye	3.3	2.22
Ophidiiformes	Bythitidae	*Brosmophycis marginata*	red brotula	3.5	2.21
Perciformes	Embiotocidae	*Damalichthys vacca*	pile perch	3.68	2.12
Scorpaeniformes	Psychrolutidae	*Malacocottus kincaidi*	blackfin sculpin	3.39	1.97
Scorpaeniformes	Agonidae	*Odontopyxis trispinosa*	pygmy poacher	3.2	1.97
Anguilliformes	Serrivomeridae	*Serrivomer sector*	sawtooth eel	3.8	1.95
Argentiniformes	Microstomatidae	*Leuroglossus schmidti*	northern smoothtongue	3.12	1.91
Chimaeriformes	Rhinochimaeridae	*Harriotta raleighana*	Pacific longnose chimaera	3.55	1.80
Scorpaeniformes	Cottidae	*Icelinus burchami*	dusky sculpin	3.5	1.73
Scorpaeniformes	Cottidae	*Jordania zonope*	longfin sculpin	3.4	1.63
Perciformes	Chiasmodontidae	*Chiasmodon niger*	black swallower	4.2	1.54
Scorpaeniformes	Liparidae	*Paraliparis cephalus*	swellhead snailfish	3.38	1.50
Anguilliformes	Nemichthyidae	*Avocettina infans*	blackline snipe eel	3.5	1.40
Osmeriformes	Osmeridae	*Spirinchus thaleichthys*	longfin smelt	3.2	1.32
Aulopiformes	Paralepididae	*Magnisudis atlantica*	duckbill barracudina	4.1	1.27
Scorpaeniformes	Liparidae	*Paraliparis pectoralis*	broadfin snailfish	3.6	1.23
Petromyzontiformes	Petromyzontidae	*Lampetra tridentata*	Pacific lamprey	4.5	1.23
Perciformes	Zoarcidae	*Bothrocara molle*	soft eelpout	3.4	1.20
Stomiiformes	Stomiidae	*Borostomias panamensis*	Panama snaggletooth	3.1	1.20

Order	Family	Species	Common Name	TL	KG
Stomiiformes	Sternoptychidae	*Argyropelecus affinis*	slender hatchetfish	3.1	1.18
Anguilliformes	Nettastomatidae	*Facciolella gilbertii*	dogface witch-eel	3.4	1.16
Scorpaeniformes	Agonidae	*Agonopsis vulsa*	northern spearnose poacher	3.3	1.12
Perciformes	Zoarcidae	*Lycodapus endemoscotus*	deepwater eelpout	3.3	1.10
Squaliformes	Somniosidae	*Scymnodon squamulosus*	velvet dogfish	4	1.00
Argentiniformes	Alepocephalidae	*Bajacalifornia burragei*	sharpchin slickhead	3.3	0.99
Lophiiformes	gigantactinidae	*Gigantactis vanhoeffeni*	whipnose	4.51	0.96
Myctophiformes	Lampanyctinae	*Nannobrachium ritteri*	broadfin lampfish	4.4	0.92
Aulopiformes	Scopelarchidae	*Benthalbella dentata*	northern pearleye	4.5	0.89
Pleuronectiformes	Pleuronectidae	*Pleuronichthys coenosus*	C-O sole	3.2	0.85
Myctophiformes	Neoscopelidae	*Scopelengys tristis*	blackchin	3.1	0.78
Stephanoberyciformes	Melamphaidae	*Melamphaes lugubris*	highsnout bigscale	3.8	0.78
Gadiiformes	Moridae	*Halargyreus johnsoni*	slender codling	3.38	0.68
Anguilliformes	Nemichthyidae	*Nemichthys scolopaceus*	slender snipe eel	3.5	0.67
Scorpaeniformes	Triglidae	*Bellator xenisma*	splitnose searobin	3.4	0.62
Osmeriformes	Osmeridae	*Osmerus mordax*	rainbow smelt	3	0.61
Scorpaeniformes	Cottidae	*Icelinus tenuis*	spotfin sculpin	3.6	0.60
Perciformes	Zoarcidae	*Lycenchelys camchatica*	Kamchatka eelpout	3.3	0.57
Perciformes	Embiotocidae	*Phanerodon atripes*	sharpnose surfperch	3.4	0.56
Scorpaeniformes	Liparidae	*Rhinoliparis attenuatus*	slim snailfish	3.36	0.52
Perciformes	Trichiuridae	*Lepidopus fitchi*	scabbardfish	4.1	0.50
Perciformes	Zoarcidae	*Lycodapus mandibularis*	pallid eelpout	3.3	0.49
Myctophiformes	Myctophidae	*Tarletonbeania crenularis*	blue lanternfish	3.1	0.48
Gadiiformes	Macrouridae	*Coryphaenoides filifer*	filamented grenadier	4.5	0.47
Scorpaeniformes	Liparidae	*Rhinoliparis barbulifer*	longnose snailfish	3.31	0.46
Perciformes	Embiotocidae	*Rhacochilus toxotes*	rubberlip Surfperch	3.41	0.41
Gadiiformes	Macrouridae	*Coelorinchus scaphopsis*	shoulder spot grenadier	3.55	0.40
Perciformes	Caristiidae	*Caristius macropus*	manefish	4.2	0.40
Scorpaeniformes	Agonidae	*Xeneretmus leiops*	smootheye poacher	3.3	0.39
Argentiniformes	Microstomatidae	*Nansenia candida*	bluethroat argentine	3.3	0.38
Scorpaeniformes	Scorpaenidae	*Sebastes variegatus*	harlequin rockfish	3.6	0.38
Myctophiformes	Myctophidae	*Symbolophorus californiensis*	California lanternfish	3.1	0.37
Perciformes	Sciaenidae	*Seriphus politus*	queenfish	3.7	0.35
Anguilliformes	Nettastomatidae	*Venefica tentaculata*	Venefica tentaculata	3.48	0.34
Stomiiformes	Sternoptychidae	*Sternoptyx diaphana*	longspine hatchetfish	3.4	0.34
Anguilliformes	Nemichthyidae	*Nemichthys larseni*	pale snipe eel	3.42	0.32
Lophiiformes	Oneirodidae	*Chaenophryne draco*	smooth dreamer	3.86	0.32
Scorpaeniformes	Agonidae	*Podothecus acipenserinus*	sturgeon poacher	3.39	0.30
Scorpaeniformes	Hemitripteridae	*Nautichthys oculofasciatus*	sailfin sculpin	4.1	0.28
Lophiiformes	Oneirodidae	*Oneirodes acanthias*	spiny dreamer	3.1	0.28
Aulopiformes	Paralepididae	*Arctozenus risso*	ribbon barracudina	3.2	0.27

Order	Family	Species	Common Name	TL	KG
Aulopiformes	Notosudidae	*Scopelosaurus harryi*	scaly paperbone	3.1	0.26
Scorpaeniformes	Psychrolutidae	*Dasycottus setiger*	spinyhead sculpin	3.54	0.25
Lophiiformes	Melanocetidae	*Melanocetus johnsonii*	common blackdevil	4.1	0.24
Anguilliformes	Serrivomeridae	*Serrivomer jesperseni*	crossthroat Snipe Eel	3.69	0.24
Osmeriformes	Opostoproctidae	*Dolichopteryx longipes*	brownsnout spookfish	3	0.24
Perciformes	Zoarcidae	*Lycodema barbatum*	bearded eelpout	3.3	0.24
Argentiniformes	Platytroctidae	*Maulisia mauli*	Maulisia mauli	3.25	0.22
Perciformes	Embiotocidae	*Amphistichus rhodoterus*	redtail surfperch	3.4	0.22
Perciformes	Tetragonuridae	*Tetragonurus cuvieri*	smalleye squaretail	3.8	0.22
Perciformes	Stichaeidae	*Poroclinus rothrocki*	whitebarred prickleback	3.1	0.20
Pleuronectiformes	Cynoglossidae	*Symphurus atricauda*	California toungefish	3.39	0.20
Perciformes	Zoarcidae	*Lycodes palearis*	wattled eelpout	3.48	0.19
Ophidiiformes	Ophidiidae	*Dicrolene filamentosa*	threadfin cusk-eel	3.61	0.19
Lophiiformes	Ceratiidae	*Cryptopsaras couesii*	triplewart sea devil	4.5	0.18
Scorpaeniformes	Rhamphocottidae	*Rhamphocottus richardsoni*	grunt sculpin	3.42	0.17
Scorpaeniformes	Agonidae	*Agonopsis sterletus*	southern spearnose poacher	3.2	0.16
Ophidiiformes	Ophidiidae	*Ophidion scrippsae*	basketweave cusk-eel	3.5	0.16
Scorpaeniformes	Cottidae	*Triglops macellus*	roughspine sculpin	3.32	0.15
Aulopiformes	Paralepididae	*Lestidiops ringens*	slender barracudina	4.1	0.15
Perciformes	Chiasmodontidae	*Kali indica*	shortnose swallower	3.47	0.15
Lophiiformes	Oneirodidae	*Oneirodes thompsoni*	Oneirodes thompsoni	4.2	0.14
Stomiiformes	Stomiidae	*Bathophilus flemingi*	highfin dragonfish	3.5	0.14
Lophiiformes	Caulophrynidae	*Caulophryne jordani*	fanfin seadevil	4.02	0.12
Scorpaeniformes	Scorpaenidae	*Sebastes serriceps*	tree rockfish	3.6	0.10
Scorpaeniformes	Liparidae	*Careproctus colletti*	Alaska snailfish	3.34	0.10
Perciformes	Sciaenidae	*Cheilotrema saturnum*	black croaker	3.6	0.10
Perciformes	Embiotocidae	*Embiotoca lateralis*	striped surfperch	3.4	0.09
Perciformes	Zoarcidae	*Melanostigma pammelas*	midwater eelpout	3.1	0.09
Scorpaeniformes	Liparidae	*Elassodiscus tremebundus*	blacklip snailfish	3.57	0.09
Scorpaeniformes	Liparidae	*Liparis fucensis*	slipskin snailfish	3.5	0.08
Perciformes	Trichodontidae	*Trichodon trichodon*	Pacific sandfish	3.7	0.08
Perciformes	Ammodytidae	*Ammodytes hexapterus*	Pacific sand lance	3.1	0.07
Pleuronectiformes	Paralichthyidae	*Citharichthys stigmaeus*	speckled sanddab	3.4	0.06
Perciformes	Chiasmodontidae	*Kali normani*	needletooth swallower	3.43	0.06
Scorpaeniformes	Cottidae	*Radulinus taylori*	spinynose sculpin	3.25	0.06
Perciformes	Cryptacanthodidae	*Lyconectes aleutensis*	dwarf wrymouth	3	0.06
Scorpaeniformes	Scorpaenidae	*Sebastes serranoides*	olive rockfish	3.9	0.05
Argentiniformes	Opisthoproctidae	*Bathylychnops exilis*	javelin spookfish	4.1	0.04
Scorpaeniformes	Cottidae	*Paricelinus hopliticus*	thornback sculpin	3.4	0.04
Osmeriformes	Platytroctidae	*Platytroctes apus*	legless searsid	3.2	0.04
Perciformes	Trichiuridae	*Benthodesmus pacificus*	North-Pacific frostfish	4.3	0.04

Order	Family	Species	Common Name	TL	KG
Scorpaeniformes	Hexagrammidae	*Oxylebius pictus*	painted greenling	3.4	0.04
Perciformes	Chaenopsidae	*Neoclinus blanchardi*	sarcastic fringehead	2.2	0.04
Lampriformes	Trachipteridae	*Desmodema lorum*	whiptail ribbonfish	4.2	0.04
Scorpaeniformes	Liparidae	*Nectoliparis pelagicus*	tadpole snailfish	3.3	0.03
Argentiniformes	Alepocephalidae	*Bajacalifornia erimoensis*	Bajacalifornia erimoensis	3.35	0.02
Perciformes	Zoarcidae	*Lycodapus dermatinus*	looseskin eelpout	3.2	0.02
Stomiiformes	Sternoptychidae	*Argyropelecus lychnus*	tropical hatchetfish	3	0.02
Perciformes	Percichthyidae	*Howella sherborni*	Howella sherborni	3.1	0.02
Scorpaeniformes	Psychrolutidae	*Psychrolutes paradoxus*	tadpole sculpin	3.17	0.02
Scorpaeniformes	Cottidae	*Icelinus borealis*	northern sculpin	3.6	0.02
Perciformes	Howellidae	*Howella brodiei*	pelagic basset	3.23	0.02
Perciformes	Clinidae	*Gibbonsia metzi*	striped kelpfish	3.39	0.02
Perciformes	Stichaeidae	*Plectobranchus evides*	bluebarred prickleback	3.1	0.02
Perciformes	Zoarcidae	*Maynea californica*	persimmon eelpout	3.285	0.01
Perciformes	Zoarcidae	*Lycodes brevipes*	shortfin eelpout	4.01	0.01
Lophiiformes	Oneirodidae	*Chaenophryne longiceps*	Chaenophryne longiceps	4.1	0.01
Atheriniformes	Atherinopsidae	*Atherinops affinis*	topsmelt	2.8	0.01

Ratio of scavenger biomass to total biomass was calculated from the West Coast Bottom Trawl Survey (WCBTS), which provides quantitative biomass data for groundfishes, as well as for several crab species for 2003-2011. We followed Brand et al. (2007) and Horne et al. (2010) in defining large crabs, large demersal sharks and grenadiers as scavengers (Table EI4). Further detail was taken from Yeh and Drazen (2011) who used baited-cameras to evaluate scavenger ecology on the California slope, and from Buckley et al. (1999) who examine food habits of several groundfishes. Scavengers are generally defined as active foragers of carrion (Britton and Morton 1994). Many of the species on the list are predators that responded strongly to baited cameras (grenadiers) or had large amounts of fisheries offal in their diet (thornyheads and sablefish). While carrion may not normally make up a substantial portion of the diets of these animals in the absence of anthropogenic influences, part of the objective of monitoring scavenger biomass is to track the effects of fisheries on the ecosystem. Therefore, it is relevant to include taxa that respond strongly to these activities. Scavenger biomass ratio was calculated for each haul by dividing the sum of scavenger biomass by the sum of total biomass for each haul. This ratio was then used to calculate the area-weighted mean scavenger: total biomass as for other groundfish indicators (see above).

Table EI 4. Groundfish and decapod taxa included in the quantification of scavenger biomass 2003-2012. Data are from the West Coast Groundfish Bottom Trawl Survey, courtesy of Beth Horness (Beth.Horness@noaa.gov).

Species	Family	Order	Class	Total catch (kg)
Albatrossia pectoralis	Macrouridae	Gadiiformes	Actinopterygii	19451.3
Coelorinchus scaphopsis	Macrouridae	Gadiiformes	Actinopterygii	0.4
Coryphaenoides acrolepis	Macrouridae	Gadiiformes	Actinopterygii	33158.8
Coryphaenoides cinereus	Macrouridae	Gadiiformes	Actinopterygii	42.3
Coryphaenoides filifer	Macrouridae	Gadiiformes	Actinopterygii	0.5
Macrouridae	Macrouridae	Gadiiformes	Actinopterygii	0.0
Malacocephalus laevis	Macrouridae	Gadiiformes	Actinopterygii	8.8
Nezumia liolepis	Macrouridae	Gadiiformes	Actinopterygii	149.9
Nezumia stelgidolepis	Macrouridae	Gadiiformes	Actinopterygii	277.0
Antimora microlepis	Moridae	Gadiiformes	Actinopterygii	2951.1
Anoplopoma fimbria	Anoplopomatidae	Scorpaeniformes	Actinopterygii	88740.3
Bolinia euryptera	Cottidae	Scorpaeniformes	Actinopterygii	4.6
Chitonotus pugetensis	Cottidae	Scorpaeniformes	Actinopterygii	3.4
Clinocottus acuticeps	Cottidae	Scorpaeniformes	Actinopterygii	2.3
Enophrys bison	Cottidae	Scorpaeniformes	Actinopterygii	3.2
Enophrys taurina	Cottidae	Scorpaeniformes	Actinopterygii	109.0
Gymnocanthus tricuspis	Cottidae	Scorpaeniformes	Actinopterygii	2.4
Hemilepidotus hemilepidotus	Cottidae	Scorpaeniformes	Actinopterygii	4.5
Hemilepidotus spinosus	Cottidae	Scorpaeniformes	Actinopterygii	5.7
Icelinus borealis	Cottidae	Scorpaeniformes	Actinopterygii	0.0
Icelinus burchami	Cottidae	Scorpaeniformes	Actinopterygii	1.7
Icelinus filamentosus	Cottidae	Scorpaeniformes	Actinopterygii	620.4
Icelinus fimbriatus	Cottidae	Scorpaeniformes	Actinopterygii	4.5
Icelinus tenuis	Cottidae	Scorpaeniformes	Actinopterygii	0.6
Jordania zonope	Cottidae	Scorpaeniformes	Actinopterygii	1.6
Leptocottus armatus	Cottidae	Scorpaeniformes	Actinopterygii	75.1
Paricelinus hopliticus	Cottidae	Scorpaeniformes	Actinopterygii	0.0
Radulinus asprellus	Cottidae	Scorpaeniformes	Actinopterygii	3.1
Radulinus taylori	Cottidae	Scorpaeniformes	Actinopterygii	0.1
Scorpaenichthys marmoratus	Cottidae	Scorpaeniformes	Actinopterygii	5.0
Triglops macellus	Cottidae	Scorpaeniformes	Actinopterygii	0.2
Sebastolobus alascanus	Scorpaenidae	Scorpaeniformes	Actinopterygii	40274.5
Sebastolobus altivelis	Scorpaenidae	Scorpaeniformes	Actinopterygii	114933.6
Sebastolobus sp.	Scorpaenidae	Scorpaeniformes	Actinopterygii	0.0
Hexanchus griseus	Hexanchidae	Hexanchiformes	Chondrichthyes	107.4
Scymnodon squamulosus	Somniosidae	Squaliformes	Chondrichthyes	2
Eptatretus deani	Myxinidae	Myxiniformes	Myxini	239.2
Eptatretus sp.	Myxinidae	Myxiniformes	Myxini	2.0

Species	Family	Order	Class	Total catch (kg)
Eptatretus stouti	Myxinidae	Myxiniformes	Myxini	111.2
Cancer magister	Canceridae	Decapoda	Malacostraca	47360.4
Chionoecetes bairdi	Oregoniidae	Decapoda	Malacostraca	16.1
Chionoecetes tanneri	Oregoniidae	Decapoda	Malacostraca	30716.5

Simpson Diversity (1-λ, Gini-Simpson index) was calculated (using the vegan package in R 2.15 (R Development Core Team 2012)) for each haul and then used to calculate an area-weighted mean for the West Coast shelf and slope. Taxa included in the analyses were all fishes identified to the species level (324 species). Data were number of individuals by species per haul.

Species Richness and Species Density were calculated for each depth x latitude bin and then used to derive the area-weighted mean for the combined West Coast shelf and slope. Because the number of species per sample will increase non-linearly in relation to sampling effort (either area or number of individuals), the groundfish data required rarefaction to standardize annual estimates of species richness and species density (Gotelli and Colwell 2001). Individual based rarefaction assumes that individuals are randomly distributed in space or time (Gotelli and Colwell 2001), and is, therefore, not the best approach for fishes since many species school. Individual-based rarefaction will tend to overestimate species richness when individuals are patchily distributed (Colwell et al. 2004). Instead, sample-based rarefaction was used to calculate species density curves by pooling samples (trawls) in depth x latitude bins. Rarefaction was conducted using the 'specaccum' function in the 'vegan' package for R 2.15 (Mao Tau, Colwell et al. 2004, R Development Core Team 2012).

Sample-based rarefaction curves initially produce estimates of species density (species per area) and not species richness (species *per capita*), and data need to be re-scaled to the number of species per some number of individuals based on the mean number of individuals per trawl (Gotelli and Colwell 2001). Since the purpose was not to estimate mechanism, a high-order polynomial was chosen to maximize fit (minimum $r^2 = 0.9988$ for all regressions) and to achieve the best fits at the lower end of the data range where more mechanistic models overestimate the number of species. Rarefaction by samples produced an estimated number of species per cumulative number of samples from one to the total number of samples for each depth x latitude bin. For each depth x latitude bin, the mean number of individuals per haul was calculated and multiplied by the number of samples (1 to total) to give the cumulative expected number of individuals per total samples. This number of individuals per total samples was then used in the regression analysis to predict richness. Rarefied data were rescaled to the number of species per 3900 individuals. The

reference value of 3900 individuals was chosen based on two criteria. First, it was larger than the smallest mean number of individuals per sample for all depth x latitude bins so that all predicted values were from within the range of the data. Second, it was just smaller than the number of individuals (3991) from the depth x latitude bin with the lowest total number of individuals per 12 samples (the lowest number of samples from a depth x latitude bin by year). Species richness for a given year was then calculated as the area-weighted mean richness for that year.

For background the raw number of species per trawl is presented here (Figure EI 43) and could be considered analogous to species density since the data are species per area (trawls of more or less consistent swept area). Raw species density declined around 2007-2008 but then subsequently increased by more than 1.0 s.d. of the long-term mean over the last five years.

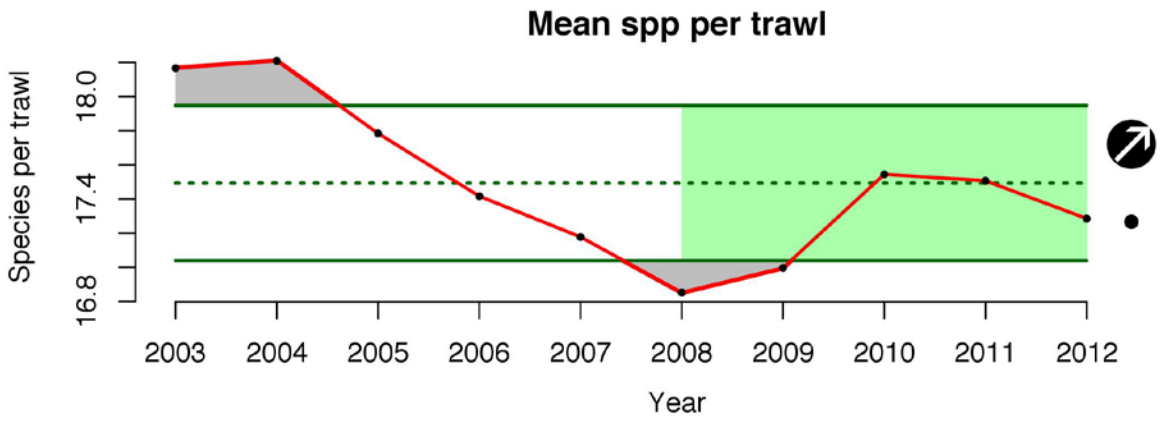

Figure EI 43. Mean number of groundfish species per trawl for 2003-2011 from the West Coast Groundfish Bottom Trawl Survey. Species number values were not subjected to rarefaction. Data courtesy of Beth Horness (Beth.Horness@noaa.gov).

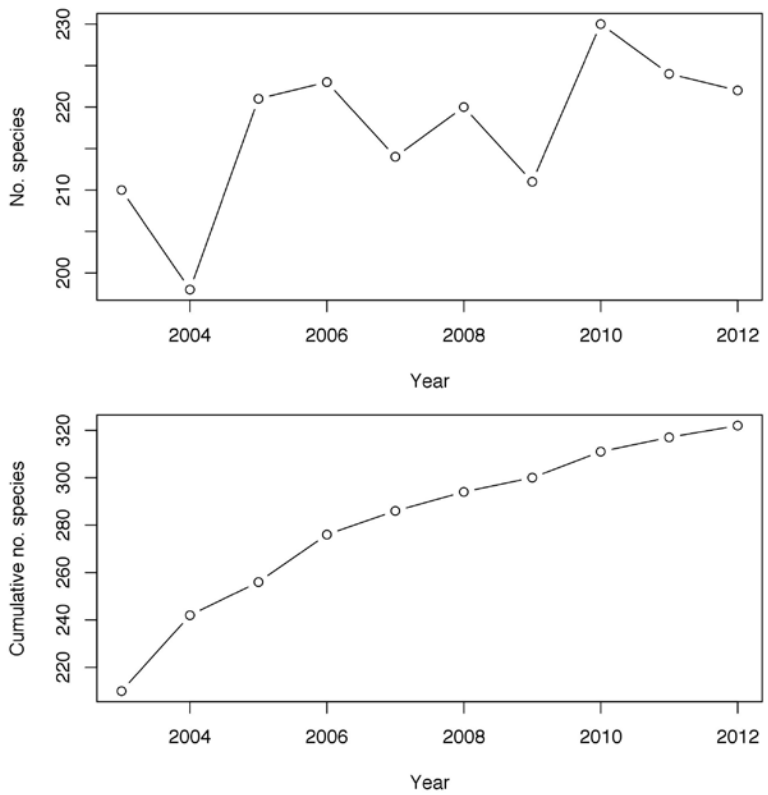

Figure EI 44. (A) Number of species identified in any given year by the trawl survey, (B) cumulative number of species identified by the trawl survey.

The initial decrease in species per trawl is probably related to a decline in the number of individuals per trawl (see Species Richness & Species Density - Groundfishes). The increase in species richness later in the time series may be attributable to better species identification. The number of species identified in any given year has increased over the time series by about 25-30 species from 2003 to 2012 (Figure EI 44a). The total number of species recorded by the trawl survey has steadily increased as expected by species-area relationships (Figure EI 44b).

ICHTHYOPLANKTON

We analyzed ichthyoplankton samples collected along two and six transects running perpendicular to shore in Oregon and California, respectively, between 2004 and 2011 in spring and summer. Stations within the Oregon lines were separated by between 8 and 20 km, while the California stations were separated by between 5 and 60 km (shoreward stations are closer together than seaward stations). The California samples comprised the suite of 66 stations sampled quarterly by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program (Hewitt 1988). Spring samples were collected in April and May in California and Oregon, respectively, and summer samples in August in both regions. Due to weather and logistic constraints, not each targeted station was sampled in

each year. On average, 9 stations per season per year were sampled in Oregon and 64 stations were sampled in California.

Obliquely-towed bongo nets were used to collect ichthyoplankton following standard CalCOFI protocols (Kramer D. et al. 1972, Smith and Richardson 1977). The nets had 71-cm diameter openings in California and 60-cm diameter openings in Oregon with 0.505-mm mesh in both regions. Nets were fished to 100 m (or 5 m from the bottom at shallow stations) and 212 m (or 15 m from the bottom) in Oregon and California, respectively. Although the discrepancy in tow depth among regions potentially biases inter-region comparisons of assemblage structure, depth-stratified ichthyoplankton distributions in both Oregon and California showed that most individuals are found in the upper 100 m, thus likely minimizing impact of the different methodologies (Ahlstrom 1959, Moser and Smith 1993, Auth et al. 2007). Nets were equipped with flowmeters to determine the amount of water filtered during each tow.

Ichthyoplankton samples were preserved at sea in buffered formalin and identified to the lowest possible taxonomic level in the laboratory. Most taxa were identified to the species level but a few were only discernible to genus. For example, all rockfishes (*Sebastes* spp.) in Oregon were identified only to genus, but in California, a few were taken to species (*S. aurora*, *S. diploproa*, *S. goodei*, *S. jordani*, *S. levis*, and *S. paucispinis*), while the rest fell into the *Sebastes* spp. category. Second, although two species of sanddabs are found in both Oregon and California, they were not consistently identified to species and were thus termed *Citharichthys* spp.

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