# APPENDIX EI-1. EVALUATION OF INDICATORS FOR ECOLOGICAL INTEGRITY USING THE BONNEVILLE POWER ADMINISTRATION DATA SET

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## OVERVIEW

As currently reported within the CCIEA, the Ecological Integrity goal relies heavily (but not exclusively) on evaluations of indicators derived from time series of benthic-dwelling taxa of trophic level ≥3. All of the current Ecological Integrity indicators have been evaluated with respect to 17 separate considerations (categorized as 'theoretical', 'data', and 'other') proposed by Kershner et al. (2011) and in previous versions of the CCIEA. However, none of these evaluations has focused on indicators derived specifically from data sets collected as part of surveys of Coastal Pelagic Species (CPS). To fill this gap, we evaluated 15 candidate indicators of Ecological Integrity derivable from a CPS data set developed with funding from the Bonneville Power Administration (BPA). In this pilot evaluation, we evaluated these indicators specifically with respect to the Ecological Integrity attribute *community composition* and data available from the BPA Plume Survey, a systematic 15-year time series of surface trawls made along the Oregon and Washington coast (see description of survey methods in Brodeur et al. 2005). In each detailed indicator summary (as well as in the Table of Contents above), the name of each indicator we evaluated is listed, followed by its score in brackets [ ].

Our approach differs from previous work in that we focused specifically on indicators populated with data for CPS. The indicators we evaluated included: forage fish biomass (in aggregate), jellyfish biomass (in aggregate), squid biomass (in aggregate), Humboldt squid, euphausiid biomass (in aggregate), species richness, Shannon diversity, (ecosystem) mean trophic level, ratio of forage fish to jellyfish, ratio of piscivorous to zooplanktivorous fish biomass, ratio of finfish to crustacean biomass, zooplanktivorous fish biomass, piscivorous fish biomass, biomass of top predators (trophic level > 4), and scavenger or detritivore biomass.

We adopted a tiered approach to the evaluation of each indicator, similar to the approach used for indicator evaluations in the Groundfish section of the CCIEA:

1. Evaluate the indicator generically, without respect to taxa or data sets, for theoretical and other considerations.
2. Modify the indicator evaluation for theoretical and other considerations based on specific information related to CPS taxa.
3. Evaluate the indicator with respect to specific CPS data sets for data considerations.

For example, for the indicator *(ecosystem) mean trophic level*, in the first tier of our evaluation, we focused on the criteria listed under theoretical considerations and other considerations, without concern for the data or taxa on which this indicator would be based. After this initial evaluation, we modified the supporting documentation, references, and scoring for this indicator so that the theoretical considerations and other considerations were evaluated for CPS taxa specifically. Finally, we evaluated the data

considerations criteria with respect to a specific CPS data set (that derived from the BPA Plume survey; Brodeur et al. 2005).

The management goals outlined in the 2014 CCIEA are essentially framed by NOAA's mission to understand, conserve, and manage coastal and marine ecosystems and resources. As a result, fisheries or protected species (e.g., Groundfish, Salmon, Marine Mammals, and CPS) represent significant focal points of the assessment. One of the main roles of the Ecological Integrity goal in the CCIEA is to highlight or emphasize indicators that help us understand the web of ecosystem interactions, especially those not evaluated and reported for other CCIEA goals. While coastal pelagic species indicators, such as spatial structure, mean length (size), size structure, and age structure are potentially informative of ecosystem structure or function, we felt that they were best evaluated as candidate CPS indicators, rather than as candidate Ecological Integrity indicators. Similarly, we did not evaluate the reliability of individual coastal pelagic species as indicators of the Ecological Integrity goal, as doing so would require detailed knowledge of the relationship between each species and the Ecological Integrity attributes (ecosystem trophic structure and biodiversity), which is beyond the scope of our current expertise.

Our evaluation suggests several promising indicators of Ecological Integrity that can be derived from the BPA Plume survey data set, including aggregate biomass of forage fish, zooplanktivorous fish, and jellyfish. Of these, **jellyfish biomass is most complementary to existing Ecological Integrity indicators within the CCIEA**.

## SUMMARY OF INDICATOR EVALUATIONS

**Table 1**. Summary of indicator evaluations for the Ecological Integrity goal of the CCIEA. The numerical value that appears under each of the considerations represents the summed scores for the criteria evaluated for each type of consideration. Criteria with full support in the peer-reviewed literature received a score of 1, those with partial support received a score of 0.5, and those with little or no support received a score of 0.

| CCIEA Goal: Attribute | Indicator | Primary consider-ations (5) | Data consider-ations (7) | Other consider-ations (5) | Summary comments |
|---|---|---|---|---|---|
| Ecological Integrity: Community Composition | Forage fish biomass | 4 | 5 | 4.5 | Good indicator of changing ecosystem state and important to global fish landings and food webs. However, aggregating the biomass of all forage species may reduce its sensitivity as an indicator, and it may not respond to management actions if a threshold shift has occurred in the ecosystem. Concrete, operationally simple data, although forage fish naturally have highly variable populations (high signal:noise ratio). Changes in trends of aggregate groups will be concurrent, at best. |
| Ecological Integrity: Community Composition | Jellyfish biomass, status and trends | 4.5 | 5 | 4 | Good indicator of trophic energy transfer and pelagic community composition. Abundance can be linked to human activities, although there is contradictory guidance on reference condition or threshold. Some taxa are not sampled easily, though there is good understanding of seasonal and annual cycles for three dominant species in the CCIEA. Human problems with jellyfish have captured public attention; considered a good anticipatory indicator based on rapid growth rates and one-year life history. |

| CCIEA Goal: Attribute | Indicator | Primary consider-ations (5) | Data consider-ations (7) | Other consider-ations (5) | Summary comments |
|---|---|---|---|---|---|
| Ecological Integrity: Community Composition | Squid biomass | 3.5 | 5 | 1 | Market squid are considered part of the forage community and represent one of the most lucrative CA fisheries. Elusive as adults, squid have poor history of reporting due to sampling difficulties; this has led to a limited understanding of population dynamics, hampering assessments of stock health and related ecosystem attributes. Recent evidence suggests paralarval abundance may provide a better fishery-independent index of stock biomass. |
| Ecological Integrity: Community Composition | Seasonal migrants – e.g., Humboldt squid | 4 | 0 | 3.5 | The range expansion of seasonal migrants like Humboldt squid possibly indicates shifts in climate regimes, ocean circulation, and ecosystem-wide food webs. However, like market squid they are not well sampled in the BPA plume time-series. Increasingly appreciated as important by the public and managers, this indicator has a mixed history of reporting. Seasonal migrants are considered a good anticipatory indicator, often with short generation times and the ability to quickly respond to changes at the base of the food web. |
| Ecological Integrity: Community Composition | Euphausiid abundance | 4.5 | 0 | 3 | Euphausiids are a critical link in the food web for many commercially important taxa and considered a predictable and sensitive indicator of ocean conditions in the CA Current. They are patchily distributed and poorly sampled in the BPA plume time-series, leading to shortcomings in their reporting history and understanding by policy makers. |
| Ecological Integrity: Community Composition | Species richness | 2.5 | 6 | 3.5 | Species richness is a crucial property of ecological communities that is highly relevant to management concerns and public perception, but relationships to ecosystem function are complex. There is no support that the richness of pelagic nekton communities respond to management actions or pressures. The BPA dataset provides a useful platform for evaluating species richness of the pelagic nekton community; little evidence it could be used as an anticipatory indicator. |

| CCIEA Goal: Attribute | Indicator | Primary consider-ations (5) | Data consider-ations (7) | Other consider-ations (5) | Summary comments |
|---|---|---|---|---|---|
| Ecological Integrity: Community Composition | Shannon diversity | 3.5 | 6 | 3 | Shannon diversity estimates show habitats occupied by pelagic nekton species can expand and contract in relation to the dynamic nature of the California Current at both seasonal and interannual periodicities. However, linking Shannon diversity to targets or reference points is difficult, making this indicator difficult to interpret or contextualize. The BPA time series meets most criteria for Shannon diversity data considerations; although there is little evidence pelagic nekton Shannon diversity metrics could be used as an anticipatory indicator. |
| Ecological Integrity: Community Composition | Mean trophic level | 3.5 | 4 | 2.5 | The diet of many pelagic nekton species change on an annual basis, making trophic level assignments difficult and the data signal noisy, and often confounded by major shifts of some abundant taxa. MTL is increasingly used as an ecosystem indicator, but cannot be considered an anticipatory indicator in this context. |
| Ecological Integrity: Community Composition | Forage fish: jellyfish ratio | 4.5 | 5 | 2 | Both forage fish and jellyfish biomass score highly individually as indicators, and the data are readily obtained from the BPA data set. In addition, the conceptual underpinnings of this ratio are clear: as the biomass of forage fish increases relative to that of jellyfish, there is more production available to fisheries and to larger predatory fish, mammals, and birds. However, the statistical properties of the ratio of these 2 quantities are understudied, making it more difficult to use the ratio of forage fish to jellyfish to determine appropriate reference points, communicate to the public, and compare across ecosystems. |

| CCIEA Goal: Attribute | Indicator | Primary consider-ations (5) | Data consider-ations (7) | Other consider-ations (5) | Summary comments |
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| Ecological Integrity: Community Composition | Piscivorous: Zooplanktivorous fish ratio | 4 | 0 | 1 | The ratio of piscivorous fish to zooplanktivorous fish biomass is in theory a sound indicator, albeit with challenging statistical properties that limit ease of communication and setting of reference points. However, there are very few piscivorous fishes represented in the CPS taxa sampled by the BPA survey. Thus, this indicator is likely to be inappropriate for use with the BPA data set and most others geared to sample CPS. |
| Ecological Integrity: Community Composition | Finfish: Crustacean Biomass Ratio | 3 | 0 | 1 | The conceptual underpinnings of this indicator are clear. In general, finfish tend to be represented on a higher mean trophic level than crustaceans. Thus if fishing down or through the food web occurs, the ratio of finfish to crustacean biomass should decline. However, this indicator is usually intended to include benthic animals as part of the crustacean biomass in the denominator, and so is not well-suited to derivation from CPS data sets like the BPA survey. |
| Ecological Integrity: Community Composition | Zooplanktivorous fish biomass | 4.5 | 5 | 4.5 | Reliable indicator of changing ecosystem state and important to global fish landings and food webs. However, aggregating the biomass of all zooplanktivoroush fish species may reduce its sensitivity as an indicator, and it may not respond to management actions if a threshold shift has occurred in the ecosystem. This indicator is concrete and simple, although zooplanktivorous fishes naturally have highly variable populations (high signal:noise ratio). Changes in trends of aggregate groups will be concurrent, at best. |

| CCIEA Goal: Attribute | Indicator | Primary consider-ations (5) | Data consider-ations (7) | Other consider-ations (5) | Summary comments |
|---|---|---|---|---|---|
| Ecological Integrity: Community Composition | Piscivorous fish biomass | 3 | 0 | 3 | In principle, piscivorous fish biomass could serve as a reliable indicator of Ecological Integrity, as it is well supported theoretically as a metric that should decline if fishing down/through the food web occurs (Pauly et al. 1998, Essington et al. 2006). In addition, this indicator is reported in many ecosystems and is relatively easy to communicate. However, the representation of piscivorous fishes in CPS data sets is minimal, reference points for this indicator have yet to be established, and as an aggregate group it is unlikely to serve as a leading indicator of ecosystem changes. |
| Ecological Integrity: Community Composition | Top predator biomass (trophic level > 4) | 3 | 0 | 3 | Like piscivorous fish biomass, in principle top predator biomass could serve as a reliable indicator of Ecological Integrity, as it is well supported theoretically as a metric that should decline if fishing down/through the food web occurs (Pauly et al. 1998, Essington et al. 2006). In addition, this indicator is reported in many ecosystems and is relatively easy to communicate. However, the representation of top predator biomass in CPS data sets is minimal, reference points for this indicator have yet to be established, and as an aggregate group it is unlikely to serve as a leading indicator of ecosystem changes. |
| Ecological Integrity: Community Composition | Scavenger or detritivore biomass | 3 | 0 | 2 | Scavenger biomass is in principle a theoretically sound indicator of ecological integrity, as it is expected to increase as fisheries discards and other human pressures accumulate. However, it is probably best represented with the inclusion of benthic detritivores and is at best partially tracked within CPS data sets like the BPA survey. Furthermore, it is an indicator that is likely to respond to ecosystem changes rather than lead them and does not have a long history of reporting in previous ecosystem assessments. |

## DETAILED INDICATOR EVALUATIONS FOR THE ECOLOGICAL INTEGRITY GOAL

### FORAGE FISH BIOMASS, IN AGGREGATE [13.5]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 13.5

**Summary:** Good indicator of changing ecosystem state and important to global fish landings and food webs. However, aggregating the biomass of all forage species may reduce its sensitivity as an indicator, and it may not respond to management actions if a threshold shift has occurred in the ecosystem. Concrete, operationally simple data, although forage fish naturally have highly variable populations (high signal:noise ratio). Changes in trends of aggregate groups will be concurrent, at best.

| Criterion | Score | Explanation |
|---|---|---|
| (a) Theoretically sound | 1 | • Changes in the biomass of pelagic species may indicate changes in ecosystem state as a function of fishing down the food web, predatory release of prey populations (forage fish), or insufficient forage base for top predators (Link 2005).<br>• Zooplanktivorous fish has been described as the best indicator of total biomass and net primary production in the system using 7 food web models from the North Pacific and the Baltic Sea (Samhouri et al. 2009).<br>• Threshold-like shifts in Baltic Sea pelagic ecosystems appear to be driven by planktivore abundance (sprat, *Sprattus sprattus*) that separates 2 ecosystem configurations in which zooplankton dynamics are driven by either hydroclimatic forces or predation pressure (Casini et al. 2009).<br>• CPS and/or forage species: often present in high abundance, feed on plankton for a portion of their life cycle and form dense schools or aggregations (e.g., anchovy, sardine, herring, mackerel, squid and krill) (CPS Management Plan, http://www.pcouncil.org/wp-content/uploads/CPS_FMP_as_Amended_thru_A13_current.pdf). |

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| (b) Relevant to management concerns | 1 | • Forage fish account for over 30% of global fish landings, and play an important role in marine food webs because they are the principal means of transferring production from plankton to larger predatory fish and to marine mammals and seabirds (Smith et al. 2011, Ruzicka et al. 2012, Sydeman et al. 2013).<br>• Fishery Management Plans for assessed species (e.g., sardine), as well as entire CalCOFI sampling program, attest to management importance. |
| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 0.5 | • Zooplanktivorous fish represents the best indicator of total biomass in an ecosystem based on 7 food web models from the North Pacific and the Baltic Sea (Samhouri et al. 2009).<br>• Small forage-fish biomass in the northeast Pacific appears to increase during cold ocean conditions as a result of zooplankton assemblage composition change, though there are differences between the SCC and NCC (http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/ha-under-development.cfm).<br>• Chavez et al. (2003) documented an Inverse relationship between sardines and anchovies, suggesting that aggregate forage fish biomass may make it insufficiently sensitive and predictable with respect to changes in community composition.<br>• Forage fish diets are variable from year to year, reflecting changes in the abundance of prey in the ecosystem (Hill et al. submitted JMS).<br>• Seasonal abiotic forcing predicts changes in the abundance of forage fish species (Litz et al. 2014). |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific management action(s) or pressure(s) | 0.5 | • Management action: the pressure of fishing these species at conventional maximum sustainable yield (MSY) levels can have large impacts on other parts of the ecosystem, particularly when they constitute a high proportion of the biomass in the ecosystem or are highly connected in the food web (Smith et al. 2011; Kaplan et al. 2013; Pikitch et al. 2014).<br>• Precautionary management will theoretically affect population, though not if threshold shift has occurred or environmental drivers have changed (Casini et al. 2009).<br>• There are differences between the SCC and NCC in forage fish community composition and responses to fishing pressure. |
| (e) Linkable to scientifically-defined reference points & progress targets | 1 | • Link (2005) set warning and limit reference points as follows: if $B_{pelagic} > 75\% B_{total}$, or if $B_{pelagic} < 20\% B_{total}$ in any given year, then a warning threshold has been exceeded. The LRPs are set at $B_{pelagic} > 85\% B_{total}$, and at $B_{pelagic} < 10\% B_{total}$. |

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| | | • Casini et al. 2009: Shifts in Baltic Sea pelagic ecosystems appear to be driven by planktivore abundance (the clupeid, sprat) that separates 2 ecosystem configurations in which zooplankton dynamics are driven by either hydroclimatic forces or predation pressure; identified an ecological threshold, corresponding to a planktivore abundance of 17 x $10^{10}$ individuals.<br>• Fishery Management Plan reference points for managed species ($B_{40}$ and $B_{25}$ rules) have been applied as reference targets, but simulation models by Kaplan et al. (2013) show that this level of forage species removal is likely to impact the abundance of other target species, protected species, and the structure of the ecosystem.<br>• Cury et al. 2011 demonstrated a threshold in forage fish abundance (1/3 max historic prey biomass) below which seabirds experience reduced/more variable productivity.<br>• Also see Lenfest report (cf. Pikitch et al. 2014). |
| (g) Concrete & Numerical | 1 | • Large trawls (336-$m^2$ opening) in the upper 18-20 m of the water column at every station.<br>• Mesh sizes ranged from 162.6 cm in the throat of the trawl near the jib lines to 8.9 cm in the cod end.<br>• To maintain catches of small fish and squids, a 6.1 m long, 0.8 cm knotless liner was sewn into the cod end.<br>• Total counts and weights are available for each nekton taxon caught.<br>• Length data are recorded for a subset of individuals (n=50 per station) of all species. |
| (h) Historical data or information available | 0.5 | • Since 1998; Annual systematic surveys have been conducted using consistent methodology in June and September of each year. |
| (i) Operationally simple | 1 | • Measurements of hydrography, zooplankton and pelagic fishes are made at each station.<br>• Vertical profiles of temperature, salinity, fluorescence, oxygen and turbidity are taken at each station. |
| (k) Broad spatial coverage | 0.5 | • Mid-Oregon to North WA coast (Newport to Cape Flattery; along nine transect lines at 50-55 stations, ranging from 45 to 48 °N). |
| (l) Continuous time series | 1 | • 15 y (1998-2012), in June and September. |
| (m) Spatial & temporal variation understood | 0.5 | • Annual and summer/spring variability well-understood for most taxa; seasonal less so.<br>• Sampling occurs during day or crepuscular periods so diel patterns are less clear and myctophids are not well characterized. |

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| (n) High signal-to-noise ratio | 0.5 | • Sampled taxa have naturally highly variable populations; for some of the best sampled taxa signal to noise is high or can be discerned, although poor for myctophids. |
| (o) Understood by the public & policymakers | 1 | • Yes; relative trends in biomass of each component of the community is easily understood and increasingly reported/embraced. |
| (p) History of reporting | 1 | • Reported in Status of California Current 2012 (CalCOFI). Link 2005; Samhouri 2009, Fulton et al. 2005. |
| (q) Cost-effective | 1 | • Assessment data already collected for many of these species; data mining is all that is needed. |
| (r) Anticipatory or leading indicator | 0.5 | • Changes in trends of aggregate groups will always be concurrent at best.<br>• Rapid response of forage fishes and other nekton (distributional anomalies) to delayed upwelling (Brodeur et al. 2006).<br>• forage fish generally show a between a change in ocean phase and population response (http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/ha-under-development.cfm), but this is relatively fast compared to other North Pacific fish populations (Yatsu et al. 2008) and early life history stages may respond more quickly. |
| (t) Regionally/nationally/internationally compatible | 1 | • Pikitch et al. 2014, Link 2002, Methratta & Link 2006. |
| **TOTAL SCORE** | 13.5 | |

## JELLYFISH BIOMASS, IN AGGREGATE [13.5]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 13.5

**Summary:** Good indicator of trophic energy transfer and pelagic community composition. Abundance can be linked to human activities, although there is contradictory guidance on reference condition or threshold. Some taxa are not sampled easily, though there is good understanding of seasonal and annual cycles for three dominant species in the CCIEA. Human problems with jellyfish have captured public attention; considered a good anticipatory indicator based on rapid growth rates and one-year life history.

| Criterion | Score | Explanation |
|---|---|---|
| (a) Theoretically sound | 1 | • Gelatinous zooplankton blooms are typically associated with overfishing, climate change, or eutrophication (Arai 2001, Purcell 2005, Purcell et al. 2007, Richardson et al. 2009).<br>• Jellyfish biomass can be one of the most sensitive indicators of changing ecosystem status (Richardson et al. 2009).<br>• Median biovolume of gelatinous zooplankton included in list of indicators translated into decision criteria (Link et al. 2005).<br>• Jellyfish should be reliable indicators of trophic energy transfer and pelagic community composition. For example, modeling exercises by Ruzicka et al. (2013) showed that in the Northern California Current large scyphozoan jellyfish are important consumers of plankton production, but can divert energy from the rest of the food web when abundant.<br>• Lower trophic level, high productivity functional groups like jellyfish biomass showed 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). |
| (b) Relevant to management concerns | 1 | • Yes, jellyfish biomass and abundance is likely to be particularly relevant to understanding community composition and species interactions; often integrated into ecosystem models (Brand et al. 2007; Pauly et al. 2009, Ruzicka et al. 2012).<br>• Numerous negative effects on human enterprise; specifically, they interfere with tourism by stinging swimmers, fishing by clogging nets, aquaculture by killing fish in net-pens and power plants by clogging cooling-water intake screens (Purcell et al. 2007).<br>• In the NCC, early stages of euphausiids, gelatinous taxa, and cladocerans were particularly vulnerable to predation by jellyfish (Suchman et al. 2008).<br>• Overfishing of small pelagic fishes in the northern Benguela Current may have promoted jellyfish abundance and possibly led to irreversible jellyfish dominance (Flynn et al. 2012, Roux et al. 2013). |

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| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 1 | • Jellyfish biomass served as the best proxy for ecosystem attributes related to community energetics using 7 food web models from the North Pacific and the Baltic Sea (Samhouri et al. 2009).<br>• Increases in jellyfish are generally associated with negative impacts on ecosystem attributes, models offer opportunity to investigate this problem (Pauly et al. 2009, Ruzicka et al. 2012).<br>• Highest catches of medusae in the NCC correlated with cool spring–summer conditions, or negative anomalies of the Pacific Decadal Oscillation, and low winter–summer runoff from the Columbia River (Suchman et al. 2012).<br>• Jellyfish increased steeply and then declined precipitously in the Eastern Bering Sea in the 1990s and 2000s, coinciding with wide-scale climate regime shifts (Brodeur et al. 2008c). |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific management action(s) or pressure(s) | 1 | • Jellyfish abundance can be linked to fishing impacts, eutrophication, habitat modification (shoreline armoring), and several other human activities (Purcell et al. 2007; Richardson et al. 2009, Pauly et al. 2009, Purcell et al. 2012).<br>• Overfishing of small pelagic fishes in the northern Benguela Current may have promoted jellyfish abundance and possibly led to irreversible jellyfish dominance (Flynn et al. 2012, Roux et al. 2013). |
| (e) Linkable to scientifically-defined reference points & progress targets | 0.5 | • Link (2005) set warning thresholds of 100% above the median biovolume for gelatinous zooplankton ($V_{jelly\text{-}med}$) and a limit reference point of 200% above $V_{jelly\text{-}med}$<br>• Condon et al. (2013) suggest there is no robust evidence for global increase in jellyfish; rather, jellyfish populations undergo larger, worldwide oscillations with an approximate 20-y periodicity. |
| (g) Concrete & Numerical | 0.5 | • Top three species individually; mesh size too large for smaller taxa. |
| (h) Historical data or information available | 0.5 | • Since 1998; Annual systematic surveys have been conducted using consistent methodology in June and September of each year. |
| (i) Operationally simple | 1 | • Measurements of hydrography, zooplankton and pelagic fishes are made at each station.<br>• Vertical profiles of temperature, salinity, fluorescence, oxygen and turbidity are taken at each station. |
| (k) Broad spatial coverage | 0.5 | • Mid-Oregon to North WA coast (Newport to Tatoosh Island).<br>• Along nine transect lines at 50-55 stations, ranging from 45 to 48 °N). |

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| (l) Continuous time series | 1 | • 15 y (1998-2012), in June and September. |
| (m) Spatial & temporal variation understood | 0.5 | • Limited to spring / summer samples.<br>• Annual and seasonal cycles described by Suchman et al. (2012), Brodeur et al. (in review). |
| (n) High signal-to-noise ratio | 1 | • High signal to noise ratio for 3 top jellyfish species (Suchman et al. 2012). |
| (o) Understood by the public & policymakers | 1 | • Increasingly regarded as a keystone species/group in some systems (Pauly et al. 2009).<br>• Raft of recent studies/reviews suggest they have increased in abundance throughout world.<br>• Human problems with jellyfish have increased and have captured public attention (Purcell et al. 2007, Richardson et al. 2009). |
| (p) History of reporting | 0.5 | • The paucity of long-term data makes it difficult to draw definitive conclusions on the status of jellyfish populations (Purcell et al. 2007).<br>• But see Brodeur et al. 2002 (Bering Sea), Pauly et al. (2009), Mackas et al. (2001), Suchman et al. (2012), and Brodeur et al. (in review MEPS) for evidence of changing trend.<br>• Recent analyses of thirty-seven datasets between 1790 and 2011, representing 1,140 observation-years of jellyfish abundance, with a mean length of 31 y, show jellyfish populations undergo larger, worldwide oscillations with an approximate 20-y periodicity (Condon et al. 2013, JEDI database). |
| (q) Cost-effective | 0.5 | • There are a variety of survey techniques available, some of which are more costly to implement than others (evaluated by Bamstedt et al. 2006).<br>• Several sampling challenges make quantifying populations of large medusae particularly difficult (Purcell, 2009). |
| (r) Anticipatory or leading indicator | 1 | • Jellyfish populations can grow quickly in response to abundant prey, producing jellyfish "blooms."<br>• Because of fast growth rates and one-year life cycle, 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).<br>• Autocorrelation among years in jelly abundance can be high (Richardson and Gibbons 2008). |

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| (t) Regionally/nationally/internationally compatible | 1 | • Yes (Link et al. 2005; Pauly et al. 2009). |
| **TOTAL SCORE** | 13.5 | |

## SQUID BIOMASS, IN AGGREGATE [9.5]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 9.5

**Summary:** Market squid are considered part of the forage community and represent one of the most lucrative CA fisheries. Elusive as adults, squid have poor history of reporting due to sampling difficulties; this has led to a limited understanding of population dynamics, hampering assessments of stock health and related ecosystem attributes. Recent evidence suggests paralarval abundance may provide a better fishery-independent index of stock biomass.

| Criterion | Score | Explanation |
|---|---|---|
| (a) Theoretically sound | 1 | • Can be considered part of the forage/pelagic community (see Forage Fish Biomass section, above).<br>• Changes in the biomass of pelagic species may indicate changes in ecosystem state as a function of fishing down the food web, predatory release of prey populations (forage species), or insufficient forage base for top predators (Link 2005).<br>• However, little is known about the present size, age structure, or status of the market squid population.<br>• At present, no direct, statistically valid population estimates are available (PFMC 2010).<br>• Historically, abundance/biomass estimates estimated from commercial landings, but new research shows that paralarval abundance (CalCOFI) provides a fishery-independent index |

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| | | of stock biomass (Koslow and Allen 2011).<br>• Model simulations suggest, however, that squids are able to benefit from a general increase in fishing pressure, mainly due to predation release, and quickly respond to changes triggered by the environment.<br>• Squids may thus be very sensitive to the effects of fishing and climate change (Coll et al. 2013). |
| (b) Relevant to management concerns | 1 | • As a forage species they play an important role in marine food webs as the principal means of transferring production from plankton to larger predatory fish and to marine mammals and seabirds (Smith et al. 2011).<br>• CPS Management Plans, attest to management importance, however there is large variation in relative abundance of squid between NCC and SCC.<br>• One of the largest and most lucrative California fisheries.<br>• In the mid-1990s, market squid became the largest California fishery in terms of both landings and revenue. (Koslow and Allen 2011).<br>• Key component of marine food webs and of increasing economic importance as evidenced by rapid rise in global landings (Hunsicker et al. 2010).<br>• Humboldt squid *Dosidicus gigas* range expansion into CCLME coincided with declines in valuable target species such as Pacific hake *Merluccius productus* and other top predators (Zeidberg and Robison 2007). |
| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 0.5 | • Paralarval abundance provides a fishery-independent index of stock biomass, and these statistical relationships suggest that the ENSO and PDO indices can be used for adaptive management of the market squid fishery (Koslow and Allen 2011).<br>• However there is still limited understanding of market squid population dynamics, which would hamper assessing the status (health) of related ecosystem attributes (PFMC 2010).<br>• New evidence suggests that the market squid center of biomass shifted northward between 1999-2012 (Barcelo et al. in prep). |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific management action(s) or pressure(s) | 0.5 | • Unclear, except from ecological model simulations.<br>• The role of squids in open ocean and upwelling ecosystems appear more constrained to a bottom-up impact on their predators, suggesting large removals of squids will likely have large-scale effects on marine ecosystems (Coll et al. 2013).<br>• Simulations confirm that squids are able to benefit from a general increase in fishing pressure, mainly due to predation release, and quickly respond to changes triggered by |

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| | | the environment. Squids may thus be very sensitive to the effects of fishing and climate change.<br>• CPUE seems to have deficiencies as an index of stock biomass because the fishery is carried out on spawning aggregations (Koslow and Allen 2011).<br>• Owing to the shorter life cycle of cephalopods, and rapid turnover, and lower standing stocks than for longer-lived taxa; strong circumstantial evidence that fishing pressure has changed ecological conditions and cephalopod stocks have increased as predatory fish have declined (Caddy and Rodhouse 1998).<br>• Interconnectedness of commercial cephalopods and fishes is only recently being recognized - may help promote sustainable fishing in these ecosystems under increased levels of exploitation (Hunsicker et al. 2010). |
| (e) Linkable to scientifically-defined reference points & progress targets | 0.5 | • There is a limited understanding of market squid population dynamics, which has hampered assessing the status (health) of this valuable marine resource (PFMC 2010).<br>• The fishery is therefore "monitored" without a formal stock assessment to guide management; catch limits are based on the approximate maximum landings obtained in three seasons since 1998–2000 (107,048 mt; 118,000 st), but landings over the past decade have been mostly about half the total allowable catch.<br>• Catch per unit effort (CPUE) has been relatively steady, but CPUE is generally unreliable as a proxy for stock biomass, particularly for a fishery with evolving gear technology and that targets spawning aggregations (Koslow and Allen 2011).<br>• For pelagic species, Link (2005) set warning and limit reference points as follows: if $B_{pelagic} > 75\% B_{total}$, or if $B_{pelagic} < 20\% B_{total}$ in any given year, then a warning threshold has been exceeded.<br>• The LRPs are set at $B_{pelagic} > 85\% B_{total}$, and at $B_{pelagic} < 10\% B_{total}$; Fishery Management Plan reference points for managed species ($B_{40}$ and $B_{25}$ rules) have been applied as reference targets, but simulation models by Kaplan et al. (2013) show that this level of forage species removal is likely to impact the abundance of other target species, protected species, and the structure of the ecosystem. |
| (g) Concrete & Numerical | 1 | • Large trawls (336 $m^2$ mouth opening) in the upper 18-20 m of the water column at every station.<br>• Mesh sizes ranged from 162.6 cm in the throat of the trawl near the jib lines to 8.9 cm in the cod end.<br>• To maintain catches of small fish and squids, a 6.1 m long, 0.8 cm knotless liner was sewn |

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| | | into the cod end.<br>• Total counts and weights are available for each nekton taxon caught.<br>• Length data are recorded for a subset of individuals (n=50 per station) of all species. |
| (h) Historical data or information available | 0.5 | • Since 1998; Annual systematic surveys have been conducted using consistent methodology in May, June, and September of each year. |
| (i) Operationally simple | 1 | • Measurements of hydrography, zooplankton and pelagic fishes are made at each station.<br>• Vertical profiles of temperature, salinity, fluorescence, oxygen and turbidity are taken at each station. |
| (k) Broad spatial coverage | 0.5 | • Mid-Oregon to North WA coast (Newport to Cape Flattery; along nine transect lines at 50-55 stations, ranging from 45 to 48 °N). |
| (l) Continuous time series | 1 | • 15 y (1998-2012), in June and September. |
| (m) Spatial & temporal variation understood | 0.5 | • Annual and summer/spring variability well-understood; seasonal (winter) less so.<br>• Appear to be similarly abundant during day and night (C. Barcelo personal communication).<br>• Sampled during day or crepuscular periods and not during winter.<br>• New evidence suggests that market squid center of biomass shifted northward between 1999-2012 (Barcelo et al. in prep). |
| (n) High signal-to-noise ratio | 0.5 | • Often difficult to sample, resulting in high noise.<br>• Patchily distributed. |
| (o) Understood by the public & policymakers | 0.5 | • Yes, but perhaps not as resonant for their ecosystem integrity value as other indicators.<br>• Relative trends in biomass of squid are easily understood by the public and policymakers.<br>• Abundance/biomass estimates were once determined from commercial landings, but new research shows that paralarval abundance (CalCOFI) can provide a fishery-independent index of stock biomass (Koslow and Allen 2011). |
| (p) History of reporting | 0 | • Not extensive because squid biomass estimates have been notoriously difficult to determine.<br>• Information about the effects of fishing and the environment on squid populations is especially lacking, probably because they are difficult to sample, and they have complex life cycles and distribution patterns (Coll et al. 2013).<br>• Historically, abundance/biomass estimates were determined from commercial landings, but new research shows that paralarval abundance (CalCOFI) provides a fishery- |

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| | | independent index of stock biomass (Koslow and Allen 2011) and acoustic methods may prove promising (Zeidberg,, personal communication). |
| (q) Cost-effective | 0 | • Stock assessments of market squid are unlikely due to sampling difficulties; more likely to rely on data already collected by CalCOFI on paralarva abundance, which has been correlated with stock biomass (Koslow and Allen 2011). |
| (r) Anticipatory or leading indicator | 0.5 | • The market squid lives only 6–9 months (Butler et al. 1999), and the population fluctuates markedly from year to year, largely in apparent response to environmental factors.<br>• However, limited understanding of market squid population dynamics (PFMC 2010) hampers understanding of its potential role as leading indicator. |
| (t) Regionally/nationally/internationally compatible | 0 | • Few compatible indicators found in use elsewhere to reflect ecosystem integrity. |
| **TOTAL SCORE** | 9.5 | |

## SEASONAL MIGRANTS - HUMBOLDT SQUID [7.5]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 7.5

This is an example of how an individual species could be evaluated as an indicator for the Ecological Integrity goal. It is the only individual CPS we evaluated this year for the Ecological Integrity goal.

**Summary:**

The range expansion of seasonal migrants like Humboldt squid (*Dosidicus gigas*) possibly indicates shifts in climate regimes, ocean circulation, and ecosystem-wide food webs. However, like market squid they are not well sampled in the BPA plume time-series. Increasingly appreciated as important by the public and managers, this indicator has a mixed history of reporting. Seasonal migrants

are considered a good anticipatory indicator, often with short generation times and the ability to quickly respond to changes at the base of the food web.

| Criterion | Score | Explanation |
|---|---|---|
| (a) Theoretically sound | 1 | • Unusual occurrences of marine life such as Humboldt squid can be an indicator of changing ocean conditions.<br>• Considered as upper level predator that quickly responds to changing ocean conditions with distributional shifts (Field et al. 2013).<br>• Zeidberg & Robison 2007: Range expansion related to changes in climate and correlated with reduction in top predators; correlative information only.<br>• Caddy & Rodhouse 1998: cephalopod landings have increased as groundfish landings decreased.<br>• Modeling by Rosas-Luis et al. 2008 for the Gulf of California suggest the effects of Humboldt squid can be substantial..<br>• Tolerant of oxygen minimum zones, which appear to greatly favor *D. gigas* (Gilly et al. 2012).<br>• The CPS management plan considers Humboldt squid as an indicator (PFMC 2010). |
| (b) Relevant to management concerns | 1 | • Yes. Zeidberg & Robison 2007.<br>• Considered to have an important ecological role in pelagic ecosystems due to its high abundance and wide distribution (Rosas-Luis et al. 2008).<br>• Presence indicates shifts in climate regimes, ocean circulation and potentially ecosystem wide food webs.<br>• Cephalopod predation is an important variable affecting natural mortality and recruitment success of many fish stocks, particularly clupeids, scombrids, and gadoids in continental shelf ecosystems (Rodhouse and Nigmatullin 1996). Also see Miller et al. (2013) and Field et al. (2013) for predation data relevant to northern California Current.<br>• Though predators of commercially important species, they are principally prey to the same in the Eastern Tropical Pacific (Field et al. 2007).<br>• NCC invasion coincident with decline in Pacific hake - the most important commercial groundfish species off western North America (Coll et al. 2013). |

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| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 1 | • Range expansion (distribution shifts) related to changes in climate and correlated with reduction in top predators (Zeidberg & Robison 2007, Stewart et al. 2014).<br>• Thermal tolerance and plastic life history of *D. gigas* provide a parsimonious explanation of both the squid's historical visits to waters off central California and its range expansion (Watters et al. 2008).<br>• Growth and physiological challenges may be related to climate change, changing $CO_2$ levels, and ocean acidification (Rosas-Luis et al. 2008).<br>• Coincidence of poleward range expansions of Humboldt squid in both hemispheres suggests a physically-induced forcing mechanism (Field et al. 2007).<br>• Tolerance of oxygen minimum zone appears to greatly favor *D. gigas*, and it is clearly an environment that this species inhabits and utilizes (Gilly et al. 2012, Stewart et al. 2014). |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific management action(s) or pressure(s) | 0.5 | • Unclear, except from ecological model simulations.<br>• Current variation in population appears to be physically-based (Field et al. 2007).<br>• Results from a model for the eastern equatorial Pacific suggest that squids are controlled more by bottom-up forcing than by top-down cascades from tuna fishing (Watters et al. 2003).<br>• The role of squids in open ocean and upwelling ecosystems appeared more constrained to a bottom-up impact on their predators, suggesting large removals of squids will likely have large-scale effects on marine ecosystems (Coll et al. 2013).<br>• Simulations confirm that squids are able to benefit from a general increase in fishing pressure, mainly due to predation release, and quickly respond to changes triggered by the environment.<br>• The impact of the fishery on the population is not understood, and there are concerns about overexploitation during the periodic downturns of the population (Koslow and Allen 2011). |
| (e) Linkable to scientifically-defined reference points & progress targets | 0.5 | • Generally characterized by presence/absence in time-series data from Zeidberg & Robison (2007) and Field et al. (2007).<br>• No scientifically defined reference points or progress targets, per se. |
| (g) Concrete & Numerical | 0 | • No data available from BPA surveys. |
| (h) Historical data or information available | 0 | • No data available from BPA surveys. |

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| (i) Operationally simple | 0 | • No data available from BPA surveys. |
| (k) Broad spatial coverage | 0 | • No data available from BPA surveys. |
| (l) Continuous time series | 0 | • No data available from BPA surveys. |
| (m) Spatial & temporal variation understood | 0 | • No data available from BPA surveys.<br>• Highly mobile.<br>• Poorly characterized with gear. |
| (n) High signal-to-noise ratio | 0 | • No data available from BPA surveys.<br>• Notoriously difficult to sample, resulting in high noise. |
| (o) Understood by the public & policymakers | 1 | • Yes. See recent articles in press and Scientific American (2010) and videos by BBC/National Geographic; focus on low oxygen zones and competition with other commercial species (salmon, tuna). |
| (p) History of reporting | 0.5 | • Currently, lack of abundance/biomass information and incomplete knowledge of how movement and food habits may differ across seasons and between inshore and offshore waters (Field et al. 2007).<br>• Trends in abundance estimated using landings information from commercial and recreational fisheries, resource surveys, food habits studies, discussions with fishermen (Field et al. 2007).<br>• Unique and long time series of video observations over 16 y (Zeidberg and Robison 2007). |
| (q) Cost-effective | 0.5 | • Currently data from existing surveys and landings are probably sufficient to describe regime shift type effects (Field et al. 2007, Zeidberg & Robison 2007).<br>• Better biomass estimates would be desired if it becomes an established indicator. |
| (r) Anticipatory or leading indicator | 1 | • Short generation times make it sensitive to change (Zeidberg & Robison 2007), but more of a concurrent indicator than an anticipatory one.<br>• Modeling results illustrate that squids have the ability to quickly respond to changes at the base of the food web that may be triggered by environmental changes (Coll et al. 2013).<br>• Considered as upper level predator that quickly responds to changing ocean conditions with distributional shifts. |
| (t) Regionally/nationally/internationally compatible | 0.5 | • West Coast only.<br>• Could be considered regionally compatible as upper level predator (invasive species?) that |

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| | | quickly responds to changing ocean conditions with distributional shifts. |
| **TOTAL SCORE** | 7.5 | |

## EUPHAUSIID BIOMASS, IN AGGREGATE [7.5]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 7.5

**Summary:** Euphausiids are a critical link in the food web for many commercially important taxa and considered a predictable and sensitive indicator of ocean conditions in the CA Current. They are patchily distributed and poorly sampled in the BPA plume time-series, leading to shortcomings in their reporting history and understanding by policy makers

| Criterion | Score | Explanation |
|---|---|---|
| (a) Theoretically sound | 1 | • Can be considered part of the forage/pelagic community (see forage section, above; Smith et al. 2012).<br>• Species can be found well poleward of their usual range during strong El Niño events, some because they are transported by anomalously poleward geostrophic currents, and some because normally cool areas warm and become habitable (Keister et al. 2005).<br>• Biomass anomalies for the euphausiid *Nyctiphanes simplex* in the California Current System as an indicator of plankton biomass (deYoung et al. 2008).<br>• Changes in southern California Current are characterized by an increase in the abundance of southern and tropical euphausiid species in the southern California Bight, and a decreased abundance of a northern species (Peterson 2009).<br>• Euphausiids also constitute an important part of the diet of cod larvae and juveniles. In particular, euphausiids have a high-energy content and constitute an important source of vitamin A for fish such as cod, which cannot synthesize this vitamin (Beaugrand et al. 2003) |

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| | | (Mackas and Beaugrand 2010).<br>• Euphausiid abundance data from broadly based California Cooperative Oceanic Fisheries Investigation surveys in California and Baja California sectors of the California Current provided a time series distinguishing periodic, rhythmic and irregular species patterns (Brinton and Townsend 2003). |
| (b) Relevant to management concerns | 1 | • Critical link in food web.<br>• PFMC preemptively outlawed a krill fishery because they recognized the importance of krill as forage for other fishery species (groundfish, HMS, CPS).<br>• Many fish, mammals, and birds depend on krill directly or indirectly as a primary food resource, e.g. Pacific hake *Merluccius productus*, juvenile rockfish *Sebastes* spp., salmonids, whales, and auklets (Sydeman et al. 2011; Beaugrand et al. 2003).<br>• Grouped in large carnivorous zooplankton group of Atlantis ecosystem model of CCS, based on densities from Newport line (Brand et al. 2007; Horne et al. 2009) or DFO surveys in Barkley Sound (Sydeman et al. 2011).<br>• Major predators of mesozooplankton (Mackas and Beaugrand 2010).<br>• Field and Francis (2006) reported that a large proportion of the energy flux in the CCE flows through krill, underscoring the critical role krill play in regulating ecosystem productivity (Croll 2005). |
| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 1 | • Yes - Community composition related to climate or regime shifts (Peterson 2009; Mackas and Beaugrand 2010, Gomez-Gutierrez et al. 2005), although understanding of the spatio-temporal dynamics of krill populations remains fragmentary.<br>• Comparisons with environmental indexes indicate significant correlations with biomass of warmwater species, most notably in coastal *Nyctiphanes simplex* (Brinton and Townsend 2003; deYoung et al. 2008).<br>• Positive euphausiid anomalies were correlated with anomalously weak summer upwelling off of Vancouver Island (Mackas et al. 2001). |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific management action(s) or pressure(s) | 1 | • Ecosystem models suggest impacts of harvesting krill (large zooplankton) to be medium to high among global marine systems (Smith et al. 2011; Kaplan and Leonard 2012). |
| (e) Linkable to scientifically-defined reference points & progress targets | 0.5 | • Yes. Tropical warm-species vs. cold-species relative abundance / ratio (anomaly).<br>• Lower counts and higher patchiness of euphausiids in samples may increase variability.<br>• Fishery Management Plan reference points for managed pelagic species ($B_{40}$ and $B_{25}$ rules) |

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| | | have been applied as reference targets, but simulation models by Kaplan et al. (2013) and Kaplan and Leonard (2012) show that this level of forage species removal is likely to impact the abundance of other target species, protected species, and the structure of the ecosystem and suggest an alternative. |
| (g) Concrete & Numerical | 0 | • Poorly sampled in BPA Plume survey. |
| (h) Historical data or information available | 0 | • Poorly sampled in BPA Plume survey. |
| (i) Operationally simple | 0 | • Poorly sampled in BPA Plume survey. |
| (k) Broad spatial coverage | 0 | • Poorly sampled in BPA Plume survey. |
| (l) Continuous time series | 0 | • Poorly sampled in BPA Plume survey. |
| (m) Spatial & temporal variation understood | 0 | • Mesh size too large; poorly characterized with gear. |
| (n) High signal-to-noise ratio | 0 | • Poorly sampled, resulting in high noise. |
| (o) Understood by the public & policymakers | 0.5 | • Equivocal. Relative importance of krill/euphausiids seems to be rising among scientists and policy-makers, in part due to improved acoustic sampling methods of this patchily distributed species, but public likely unaware of food-web links. |
| (p) History of reporting | 0.5 | • Reporting not as extensive as copepods; perhaps related to poor sampling methods (Hewitt and Demer 2000).<br>• Copepods appear to be focus of most zooplankton sampling, although CalCOFI has tracked euphausiids for decades, and there is information available in the NCC (Mackas et al 2001). |
| (q) Cost-effective | 0.5 | • Patchily distributed - requiring acoustic surveys.<br>• Data mining from relatively new large-scale hydroacoustic surveys (Santora et al. 2011) and older, station-based zooplankton net samples (e.g., CalCOFI) has been the best source of data.<br>• Capture efficiency of euphausiids is believed to differ between day and night samples due to visual avoidance of the net (e.g., Shaw and Robinson 1998).<br>• Existing samples from BPA trawls in northern CC use large mesh sizes that do not adequately sample euphausiids well (R. Brodeur, pers. obs.). |

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| (r) Anticipatory or leading indicator | 0.5 | • Possibly, due to position in food web and rapid response to environmental / ocean conditions (e.g., Miller et al. 2010). |
| (t) Regionally/nationally/internationally compatible | 1 | • Korean Peninsula (Rebstock and Kang 2003); N. Atlantic (Beaugrand et al. 2003); Alaska (AFSC 2010); Antarctic (Reid et al. 2005); British Columbia (Mackas et al. 2001). |
| **TOTAL SCORE** | 7.5 | |

## DIVERSITY INDICES – SPECIES RICHNESS [12]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 12

**Summary:** Species richness is a crucial property of ecological communities that is highly relevant to management concerns and public perception, but relationships to ecosystem function are complex. There is no support that the richness of pelagic nekton communities responds to management actions or pressures. The BPA dataset provides a useful platform for evaluating species richness of the pelagic nekton community; little evidence it could be used as an anticipatory indicator.

| Criterion | Score | Explanation |
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| (a) Theoretically sound | 0.5 | • Substantial literature on biodiversity and ecosystem function.<br>• Species diversity is a crucial property of ecological communities: it is the primary descriptor of community structure, and it is generally believed to be a major determinant of the functioning and the dynamics of ecological communities (Wilson 1999 and others). Therefore, diversity measurement is often a first step in characterizing an ecological community (e.g., Magurran 2004).<br>• Species richness is the number of different species represented in a particular ecological community, landscape, or region. Often requires correction for sampling effort |

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| | | (rarefaction).<br>• Stachowicz et al. 2007 note that relationships between richness and ecosystem function are complex, but that communities are more stable at higher richness. Populations can be more variable but community level processes are more stable.<br>• Suggested from microbial communities that one cannot reliably estimate the absolute and relative number of species present in a community without making unsupported assumptions about species abundance distributions because sample data do not contain information about the number of rare species in the tail of abundance distributions (Haegeman et al. 2013). |
| (b) Relevant to management concerns | 1 | • Yes. Biodiversity, composed of Richness and Evenness, is often a stated goal of ecosystem management (Palumbi et al. 2009; Gislason et al. 2000; Samhouri et al. 2009)<br>• World leaders committed to reduce biodiversity loss via the Convention on Biological Diversity (CBD) in 2002. |
| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 0.5 | • May not be highly sensitive to change.<br>• Species-sampling intensity relationships require rarefraction because a decrease in abundance of all spp will lead to lower richness per sample (e.g., haul).<br>• In Gulf of Maine, changes in species diversity (both Shannon's and richness) were greatest on interannual scales, intermediate on seasonal scales, and smallest across regions, in contrast to abundance patterns, suggesting that zooplankton diversity may be a more sensitive indicator of ecosystem response to interannual climate variation than zooplankton abundance (Johnson et al. 2011).<br>• Richness was used by Reese and Brodeur (2006) to identify areas of biological activity, with flow and circulation suggested as the primary drivers of these patterns. |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific management action(s) or pressure(s) | 0 | • Little support for this in the literature related to CPS.<br>• Other studies on benthic invertebrate communities do show relationship between species richness and fishing /dredging (Reiss et al 2009, Gaspar et al 2009). |
| (e) Linkable to scientifically-defined reference points & progress targets | 0.5 | • Both Link (2005) and Dulvy et al. (2006) note linking diversity indices to targets or reference points is difficult.<br>• Link et al. 2005 give a criterion for linking Richness to Reference Points but the choice is somewhat arbitrary.<br>• Natural/base-line levels of richness may vary so absolute values may not be comparable in terms of thresholds. |

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| (g) Concrete & Numerical | 1 | • Large trawls (336 $m^2$ mouth opening) in the upper 18-20 m of the water column at every station.<br>• Mesh sizes ranged from 162.6 cm in the throat of the trawl near the jib lines to 8.9 cm in the cod end.<br>• To maintain catches of small fish and squids, a 6.1 m long, 0.8 cm knotless liner was sewn into the cod end.<br>• Total counts and weights are available for each nekton taxon caught.<br>• Length data are recorded for a subset of individuals (n=50 per station) of all species. |
| (h) Historical data or information available | 0.5 | • Since 1998; annual systematic surveys have been conducted using consistent methodology in May, June, and September of each year. |
| (i) Operationally simple | 1 | • Measurements of hydrography, zooplankton and pelagic fishes are made at each station.<br>• Vertical profiles of temperature, salinity, fluorescence, oxygen and turbidity are taken at each station. |
| (k) Broad spatial coverage | 0.5 | • Mid-Oregon to North WA coast (Newport to Tatoosh Island; along nine transect lines at 50-55 stations, ranging from 45 to 48 °N). |
| (l) Continuous time series | 1 | • 15 y (1998-2012), in June and September. |
| (m) Spatial & temporal variation understood | 1 | • Brodeur et al. 2005, Thompson et al. in review. |
| (n) High signal-to-noise ratio | 1 | • Brodeur et al. 2005, Thompson et al. in review. |
| (o) Understood by the public & policymakers | 1 | • Yes. Thompson and Starzomski 2007 provide a general review that shows a general understanding and positive impression towards 'biodiversity' among the public.<br>• World leaders committed to reduce biodiversity loss via the Convention on Biological Diversity (CBD) in 2002. |
| (p) History of reporting | 0.5 | • Biodiversity measures have been widely used as indicators of ecosystem response/state (e.g., Chesapeake Bay index of biotic integrity, Australia's state of the environment, etc.), but CPS are generally not the focal species group of these reporting efforts. |
| (q) Cost-effective | 1 | • Can be calculated from current data sets and monitoring programs. |
| (r) Anticipatory or leading indicator | 0.5 | • Uncertain.<br>• Could be monitored annually to detect change.<br>• Changes in species diversity were greatest on interannual scales, intermediate on |

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| | | seasonal scales, and smallest across regions, in contrast to abundance patterns, suggesting that zooplankton diversity may be a more sensitive indicator of ecosystem response to interannual climate variation than zooplankton abundance (Johnson et al. 2011). |
| (t) Regionally/nationally/internationally compatible | 0.5 | • Yes. Species richness used worldwide as an indicator of ecosystem health, though often used in combination with other measures of diversity (e.g., evenness) (http://www.environment.gov.au/soe/2011/report/biodiversity/index.html). Few regions, however, focus on pelagic nekton (but see Johnson et al. 2011, Gulf of Maine); rather, benthic invertebrate (e.g., Chesapeake Bay; http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/benthic_index/) are generally used. |
| **TOTAL SCORE** | 12 | |

## DIVERSITY INDICES – SHANNON DIVERSITY [12.5]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 12.5

**Summary:** Shannon diversity estimates show habitats occupied by pelagic nekton species can expand and contract in relation to the dynamic nature of the California Current at both seasonal and interannual periodicities. However, linking Shannon diversity to targets or reference points is difficult, making this indicator difficult to interpret or contextualize. The BPA time series meets most criteria for Shannon diversity data considerations; although there is little evidence pelagic nekton Shannon diversity metrics could be used as an anticipatory indicator.

| Criterion | Score | Explanation |
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| (a) Theoretically sound | 0.5 | • Substantial literature on biodiversity and ecosystem function<br>• Species diversity is a crucial property of ecological communities: it is the primary descriptor of community structure, and it is generally believed to be a major determinant of the functioning and the dynamics of ecological communities (Wilson 1999 and others). Therefore, diversity measurement is often a first step in characterizing an ecological community (e.g., Magurran 2004).<br>• Shannon Diversity is a diversity measure that incorporates both richness and evenness.<br>• Modeling results from seven different Ecopath models in different systems showed detrivore, adult sablefish, and marine mammal biomass were positively correlated with consumption and negatively correlated with Shannon Diversity (Samhouri et al 2009). |
| (b) Relevant to management concerns | 1 | • Biodiversity, composed of Richness and Evenness, is often a stated goal of ecosystem management (Palumbi et al 2009; Gislason et al 2000; Samhouri et al. 2009).<br>• World leaders committed to reduce biodiversity loss via the Convention on Biological Diversity (CBD) in 2002. |
| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 1 | • Brodeur et al. (2008a) showed ichthyoplankton species composition/diversity was an indicator of warm and cold phases in northeast Pacific Ocean.<br>• Analysis of diversity / species composition showed habitats occupied by pelagic nekton species expand and contract in relation to the dynamic nature of the California Current and are affected by changing ocean conditions at both seasonal and interannual periodicities (Brodeur et al. 2005).<br>• In Gulf of Maine, changes in species diversity (both Shannon's and richness) were greatest on interannual scales, intermediate on seasonal scales, and smallest across regions, in contrast to abundance patterns, suggesting that zooplankton diversity may be a more sensitive indicator of ecosystem response to interannual climate variation than zooplankton abundance (Johnson et al. 2011). |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific | 0.5 | • Samhouri et al. (2010) used ecological modeling to show Shannon diversity declined with increasing fishing pressur<br>• However, Samhouri et al. note that the indicator-attribute relationship can switch |

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| management action(s) or pressure(s) | | depending upon the type of fishing pressure used in the model. This result might make the indicator-attribute relationship unpredictable in the real world. |
| (e) Linkable to scientifically-defined reference points & progress targets | 0.5 | • Samhouri et al. (2010) discuss identifying thresholds based on the relationship between the indicator or attribute and fishing pressure<br>• Samhouri et al. (2010) did not find nonlinearity in the relationship between Shannon diversity and nearshore habitat pressure, but did find nonlinearity in the relationship between Shannon diversity and fishing.<br>• Both Link (2005) and Dulvy et al (2006) note linking diversity indices to targets or reference points is difficult. |
| (g) Concrete & Numerical | 1 | • Large trawls (336-$m^2$ mouth opening) in the upper 18-20 m of the water column at every station.<br>• Mesh sizes ranged from 162.6 cm in the throat of the trawl near the jib lines to 8.9 cm in the cod end.<br>• To maintain catches of small fish and squids, a 6.1-m long, 0.8-cm knotless liner was sewn into the cod end.<br>• Total counts and weights are available for each nekton taxon caught.<br>• Length data are recorded for a subset of individuals (n=50 per station) of all species. |
| (h) Historical data or information available | 0.5 | • Since 1998; Annual systematic surveys have been conducted using consistent methodology in May, June, and September of each year |
| (i) Operationally simple | 1 | • Measurements of hydrography, zooplankton and pelagic fishes are made at each station.<br>• Vertical profiles of temperature, salinity, fluorescence, oxygen and turbidity are taken at each station. |
| (k) Broad spatial coverage | 0.5 | • Mid-Oregon to North WA coast (Newport to Tatoosh Island; along nine transect lines at 50-55 stations, ranging from 45 to 48° N.) |
| (l) Continuous time series | 1 | • 15 y (1998-2012), in June and September |

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| (m) Spatial & temporal variation understood | 1 | • Brodeur et al. 2005, Thompson et al. in review MEPS |
| (n) High signal-to-noise ratio | 1 | • Brodeur et al. 2005, Thompson et al. in review MEPS |
| (o) Understood by the public & policymakers | 0.5 | • Somewhat understood; Biodiversity has entered the common lexicon.<br>• While widely used by ecologists, Shannon diversity is influenced by both richness (# of spp) and evenness making the interpretation of specific changes difficult without further analyses or context.<br>• Moreover, the numerical value is dependent upon the log-base used in calculation and other factors. The result is that the numerical value has meaning only within the context of the data set and the log-base used and is not directly interpretable to the general public.<br>• World leaders committed to reduce biodiversity loss via the Convention on Biological Diversity (CBD) in 2002. |
| (p) History of reporting | 0.5 | • Biodiversity measures have been widely used as indicators of ecosystem response/state (e.g., Chesapeake Bay index of biotic integrity, Australia's state of the environment, etc.), but CPS are generally not the focal species group of these reporting efforts. |
| (q) Cost-effective | 1 | • Can be calculated from current data sets and monitoring programs |
| (r) Anticipatory or leading indicator | 0.5 | • Uncertain.<br>• Could be monitored annually to detect change.<br>• Changes in species diversity were greatest on interannual scales, intermediate on seasonal scales, and smallest across regions, in contrast to abundance patterns, suggesting that zooplankton diversity may be a more sensitive indicator of ecosystem response to interannual climate variation than zooplankton abundance (Johnson et al. 2011). |
| (t) Regionally/nationally/internationally compatible | 0.5 | • Yes. Shannon diversity is used worldwide as an indicator of ecosystem health, though often used in combination with other measures of diversity (e.g., richness) (http://www.environment.gov.au/soe/2011/report/biodiversity/index.html). Few |

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| | | regions, however, focus on pelagic nekton (but see Johnson et al., Gulf of Maine); rather, benthic invertebrates (e.g., Chesapeake Bay; http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2012/indicators/benthic_index/) are generally used. |
| **TOTAL SCORE** | 12.5 | |

## (ECOSYSTEM) MEAN TROPHIC LEVEL [10]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 10

**Summary:** The diet of many pelagic nekton species change on an annual basis, making trophic level assignments difficult and the data signal noisy, and often confounded by major shifts of some abundant taxa. MTL is increasingly used as an ecosystem indicator, but cannot be considered an anticipatory indicator in this context.

| Criterion | Score | Explanation |
|---|---|---|
| (a) Theoretically sound | 0.5 | • Theoretically could be done, may be especially informative when integrating pelagic estimates with other ecosystem components (e.g., demersal / benthic community).<br>• Ecosystem MTL is calculated from Fisheries Independent data, including surveys and assessments; in a worldwide review of multiple ecosystems, survey MTL and assessment MTL were generally higher than catch MTL, reflecting the greater focus of surveys and stock assessments on bottom-dwelling high-trophic-level fish species that account for only a moderate proportion of total catch weight (Branch et al. 2010)<br>• Average trophic level showed potential as an indicator if, and only if, good diet data |

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| | | are available; i.e., high potential but sensitive to data quality; alternatively, size-based indicators of MTL are easily collected and less error-prone (Fulton et al. 2005)<br>• Shown to be a good indicator for demersal fish (Samhouri et al. 2009)<br>• MTL was an ambiguous measure of invertebrate exploitation compared to indicators of mortality rate or biomass (Caddy & Garibaldi 2000)<br>• Furthermore, diet/trophic level assignment of many forage (pelagic nekton) species change from year to year - attributed to variations in a few key prey species due to environmental variability (McFarlane and Beamish 2001, Brodeur and Pearcy 1992). |
| (b) Relevant to management concerns | 0.5 | • Ecosystem models used to examine systemic effects of fishing LTL species found variation in impact of harvest has potentially important management implications.<br>• Generic properties that explain and predict the variation in response were primarily relative abundance of the group in the ecosystem and connectivity of the group in the food web, whereas trophic level was NOT a good predictor (Smith et al. 2011).<br>• MTL is probably more relevant to management concerns for conservationists than for fisheries concerns. |
| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 1 | • Diet/trophic level assignment of many forage species change from year to year - attributed to variations in a few key prey species due to environmental drivers (McFarlane and Beamish 2001, Brodeur and Pearcy 1992).<br>• Debate continues over the best means of calculating MTL in an effort to minimize data requirements (Rochet and Trenkel 2003).<br>• While the metric tracks changes in trophic structure it is often necessary to distinguish between changes in high and low TL taxa. For example, a decrease in MTL could be the result of a decrease in high TL fishes or a increase in the abundance of low TL fishes or both (Pauly et al. 1998, Pauly & Watson 2005, Essington 2006, Branch et al. 2010, Stergiou & Tsikliras 2011, Tolimieri et al. 2013). |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific management action(s) or pressure(s) | 0.5 | • No consistency in comparisons between catch, survey and assessment MTL in individual ecosystems. Catch MTL is negatively correlated with survey MTL for 13 of 29 surveys, and negatively correlated with assessment MTL in 4 of 9 ecosystems (Branch et al. 2010).<br>• While the metric tracks changes in trophic structure it is often necessary to |

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| | | distinguish between changes in high and low TL taxa. For example, a decrease in MTL could be the result of a decrease in high TL fishes or a increase in the abundance of low TL fishes or both (Pauly et al. 1998, Pauly & Watson 2005, Essington 2006, Branch et al. 2010, Stergiou & Tsikliras 2011).<br>• Diet/trophic level assignment of many forage species change from year to year - attributed to variations in a few key prey species due to environmental variability (McFarlane and Beamish 2001, Brodeur and Pearcy 1992, Tolimieri et al. 2013). |
| (e) Linkable to scientifically-defined reference points & progress targets | 1 | • Essington et al. 2006 indicate that a 0.1 change in MTL indicates a 50% change in the primary production required to support a given level of fisheries harvest (also see Christensen and Pauly 1995, Pauly et al. 1998, Pauly & Watson 2005, Essington 2006, Branch et al. 2010, Stergiou & Tsikliras 2011). |
| (g) Concrete & Numerical | 1 | • Large trawls (336-$m^2$ mouth opening) in the upper 18-20 m of the water column at every station.<br>• Mesh sizes ranged from 162.6 cm in the throat of the trawl near the jib lines to 8.9 cm in the cod end.<br>• To maintain catches of small fish and squids, a 6.1-m long, 0.8-cm knotless liner was sewn into the cod end.<br>• Total counts and weights are available for each nekton taxon caught.<br>• Length data are recorded for a subset of individuals (n=50 per station) of all species. |
| (h) Historical data or information available | 0.5 | • Since 1998; Annual systematic surveys have been conducted using consistent methodology in May, June, and September of each year. |
| (i) Operationally simple | 1 | • Measurements of hydrography, zooplankton and pelagic fishes are made at each station.<br>• Vertical profiles of temperature, salinity, fluorescence, oxygen and turbidity are taken at each station. |
| (k) Broad spatial coverage | 0.5 | • Mid-Oregon to North WA coast (Newport to Tatoosh Island; along nine transect lines at 50-55 stations, ranging from 45 to 48° N.) |

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| (l) Continuous time series | 1 | • 15 y (1998-2012), in June and September |
| (m) Spatial & temporal variation understood | 0 | • trophic levels vary inter-annually and seasonally and spatially, difficult to assign |
| (n) High signal-to-noise ratio | 0 | • difficult to distinguish signal from noise because of uncertainty in TL assignment |
| (o) Understood by the public & policymakers | 1 | • MTL included in Convention of Biological Diversity list of indicators (Pauly & Watson 2005, Stergiou & Tsikliras 2011) |
| (p) History of reporting | 0.5 | • Increasingly used as an ecosystem indicator, although catch MTL (not ecosystem MTL) was the primary marine index chosen by the Convention on Biological Diversity to measure global biodiversity, and has been applied widely to report on the state of the marine environment (Pauly & Watson 2005, Stergiou & Tsikliras 2011, Branch et al. 2010)<br>• MTL generally based on demersal trawl surveys or assessments, not pelagic community components. |
| (q) Cost-effective | 0.5 | • Some existing pelagic surveys could be used (e.g., CalCOFI, Field et al., Brodeur et al.), though most existing calculations based on groundfish data from Stock Assessments and Keller et al. 2008 (NWFSC trawl survey, 1998-present), Weinberg et al. 2002 (AFSC triennial survey, 1977-2001); REEF.org (for data at diver depths.)<br>• Would need to evaluate diets of species by age class, as well as relative biomass of survey. |
| (r) Anticipatory or leading indicator | 0 | • Diet/trophic level assignment of many forage (pelagic nekton) species change from year to year - attributed to variations in a few key prey species due to environmental variability (McFarlane and Beamish 2001, Brodeur and Pearcy 1992)<br>• However, understanding the anticipatory nature of dietary changes is somewhat different than understanding the nature of MTL classification. |
| (t) Regionally/nationally/internationally compatible | 0.5 | • Catch MTL (not ecosystem MTL) included in Convention of Biological Diversity list of indicators (Pauly & Watson 2005, Stergiou & Tsikliras 2011) but exact values will depend on local food web. Global comparison of various ecosystem MTL values |

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| | | completed by Branch et al. (2010). |
| **TOTAL SCORE** | 10 | |

## FORAGE FISH / JELLYFISH RATIO [11.5]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 11.5

**Summary:** Both forage fish and jellyfish biomass score highly individually as indicators, and the data are readily obtained from the BPA data set. In addition, the conceptual underpinnings of this ratio are clear: as the biomass of forage fish increases relative to that of jellyfish, there is more production available to fisheries and to larger predatory fish, mammals, and birds. However, the statistical properties of the ratio of these 2 quantities are understudied, making it more difficult to use the ratio of forage fish to jellyfish to determine appropriate reference points, communicate to the public, and compare across ecosystems.

| Criterion | Score | Explanation |
|---|---|---|
| (a) Theoretically sound | 1 | • As the biomass of forage fish increases relative to that of jellyfish, there is more production available to fisheries and to larger predatory fish, mammals, and birds.<br>• Fulton et al. 2005; Samhouri et al. 2009; Kaplan et al. 2011; Shannon et al. 2009; Daskalov et al. 2007 |
| (b) Relevant to management concerns | 1 | • Caddy 2000; Fulton et al. 2003; De Leiva Moreno et al 2000<br>• Also, forage fish account for over 30% of global fish landings, and play an important role in marine food webs because they are the principal means of transferring |

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| | | production from plankton to larger predatory fish and to marine mammals and seabirds (Smith et al. 2011)<br>• Fishery Management Plans for assessed species (e.g., sardine), as well as entire CalCOFI sampling program, attest to management importance. |
| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 1 | • Forage fish/jellyfish ratio was highly correlated with Simpson diversity, mean trophic level, target group biomass (Samhouri et al. 2009; Kaplan et al. 2011; Daskalov et al. 2007). |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific management action(s) or pressure(s) | 1 | • Changes in the ratio of forage fish to jellyfish biomass across seven food web models (six in the north Pacific Ocean) were correlated with measures of diversity after perturbing the systems with various levels of fishing pressure (Samhouri et al. 2009). Also see Purcell 2012; Kaplan et al. 2011; Richardson et al. 2009. |
| (e) Linkable to scientifically-defined reference points & progress targets | 0.5 | • Changes in the ratio of these biomass groups could be used as a target, but none have been used to date |
| (g) Concrete & Numerical | 1 | • Large trawls (336-$m^2$ mouth opening) in the upper 18-20 m of the water column at every station.<br>• Mesh sizes ranged from 162.6 cm in the throat of the trawl near the jib lines to 8.9 cm in the cod end.<br>• To maintain catches of small fish and squids, a 6.1-m long, 0.8-cm knotless liner was sewn into the cod end.<br>• Total counts and weights are available for each nekton taxon caught.<br>• Length data are recorded for a subset of individuals (n=50 per station) of all species. |
| (h) Historical data or information available | 0.5 | • Since 1998; Annual systematic surveys have been conducted using consistent methodology in May, June, and September of each year |
| (i) Operationally simple | 1 | • Measurements of hydrography, zooplankton and pelagic fishes are made at each station.<br>• Vertical profiles of temperature, salinity, fluorescence, oxygen and turbidity are taken at each station. |

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| (k) Broad spatial coverage | 0.5 | • Mid-Oregon to North WA coast (Newport to Tatoosh Island; along nine transect lines at 50-55 stations, ranging from 45 to 48° N.) |
| (l) Continuous time series | 1 | • 15 y (1998-2012), in June and September |
| (m) Spatial & temporal variation understood | 0.5 | • Annual and summer/spring variability well-understood for most taxa; seasonal less so.<br>• Sampling occurs during day or crepuscular periods so diel patterns are less clear and myctophids are not well characterized. |
| (n) High signal-to-noise ratio | 0.5 | • Sampled taxa have naturally highly variable populations<br>• For some of the best sampled taxa signal to noise is high or can be discerned. Poor for myctophids. |
| (o) Understood by the public & policymakers | 0 | • Ratios of groups are not easily understood |
| (p) History of reporting | 0 | • No |
| (q) Cost-effective | 1 | • Data mining by group is all that is needed. Forage fishes and jellyfishes often caught in surveys by identical gear (Brodeur et al. 2004, 2006). |
| (r) Anticipatory or leading indicator | 0.5 | • Evidence exists suggesting that forage fish and jellyfish individually could be leading indicators, though this ratio indicator is understudied (Anderson and Piatt 1999) |
| (t) Regionally/nationally/internationally compatible | 0.5 | • This ratio and its constituent parts are increasingly reported around the world (Pauly et al. 2009, Condon et al. 2013) |
| **TOTAL SCORE** | 11.5 | |

## PISCIVOROUS FISH / ZOOPLANKTIVOROUS FISH RATIO [5]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 5

**Summary:** The ratio of piscivorous fish to zooplanktivorous fish biomass is in theory a sound indicator, albeit with challenging statistical properties that limit ease of communication and setting of reference points. However, there are very few piscivorous fishes represented in the CPS taxa sampled by the BPA survey. Thus, this indicator is likely to be inappropriate for use with the BPA data set and most others geared to sample CPS.

| Criterion | Score | Explanation |
|---|---|---|
| (a) Theoretically sound | 0.5 | • Fulton et al. 2005; Samhouri et al. 2009; Kaplan et al. 2011.<br>• CPS data sets could include the following piscivorous fish species: hake, dogfish, adult salmon, jack mackerel, and sharks (Brodeur et al. 2006).<br>• However, the representation of piscivorous fishes in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be piscivores, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to piscivory. |
| (b) Relevant to management concerns | 1 | • The zooplanktivores and piscivores included in some CPS data sets are of critical management importance, as evidenced by their inclusion in PFMC Fishery Management Plans (hake, salmon, etc.; www.pcouncil.org) |
| (c) Responds predictably & is sufficiently sensitive to changes in a specific | 1 | • Changes in the ratio of piscivorous to zooplanktivorous biomass will obviously affect community composition, but variation in overall community composition may not be detected by variation in the ratio of these two groups alone (Fulton et al. 2005; |

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| ecosystem attribute(s) | | Samhouri et al. 2009; Kaplan et al. 2011). |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific management action(s) or pressure(s) | 1 | • Changes in the ratio of Piscivorous to Zooplanktivorous fish biomass across seven food web models (six in the north Pacific Ocean) were correlated with measures of diversity after perturbing the systems with various levels of fishing pressure (Fulton et al. 2005; Samhouri et al. 2009; Kaplan et al. 2011). |
| (e) Linkable to scientifically-defined reference points & progress targets | 0.5 | • Changes in the ratio of these biomass groups could be used as a target, but none have been used to date |
| (g) Concrete & Numerical | 0 | • The representation of piscivorous fishes in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be piscivores, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to piscivory. |
| (h) Historical data or information available | 0 | • The representation of piscivorous fishes in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be piscivores, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to piscivory. |
| (i) Operationally simple | 0 | • The representation of piscivorous fishes in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be piscivores, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to piscivory. |
| (k) Broad spatial coverage | 0 | • The representation of piscivorous fishes in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be piscivores, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to piscivory. |
| (l) Continuous time series | 0 | • The representation of piscivorous fishes in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be piscivores, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to piscivory. |

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| (m) Spatial & temporal variation understood | 0 | • poorly characterized with gear<br>• tow speeds are too slow to capture most highly mobile, top predators |
| (n) High signal-to-noise ratio | 0 | • poorly sampled, resulting in high noise; |
| (o) Understood by the public & policymakers | 0 | • Ratios of groups are not easily understood |
| (p) History of reporting | 0 | • No |
| (q) Cost-effective | 0.5 | • Data mining by group is needed. However, ideally different gear types would be used to survey pelagic piscivores and pelagic zooplanktivores, which would make comprehensive surveys expensive. |
| (r) Anticipatory or leading indicator | 0 | • Unknown |
| (t) Regionally/nationally/internationally compatible | 0.5 | • This ratio and its constituent parts are increasingly reported around the world (Caddy and Garibaldi 2000, Fulton et al. 2005, Kaplan et al. 2011) |
| **TOTAL SCORE** | 5 | |

## FINFISH / CRUSTACEAN BIOMASS RATIO [4]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 4

**Summary:** The conceptual underpinnings of this indicator are clear. In general, finfish tend to be represented on a higher mean trophic level than crustaceans. Thus if fishing down or through the food web occurs, the ratio of finfish to crustacean biomass should

decline. However, this indicator is usually intended to include benthic animals as part of the crustacean biomass in the denominator, and so is not well-suited to derivation from CPS data sets like the BPA survey.

| Criterion | Score | Explanation |
|---|---|---|
| (a) Theoretically sound | 0 | • The conceptual underpinnings of this indicator are clear. In general, finfish tend to be represented on a higher mean trophic level than crustaceans. Thus if fishing down or through the food web occurs (Pauly et al. 1998, Essington et al. 2006), the ratio of finfish to crustacean biomass should decline.<br>• This indicator is usually intended to include benthic animals as part of the crustacean biomass in the denominator (Kaplan et al. 2011), and so is not well-suited to derivation from CPS data sets. |
| (b) Relevant to management concerns | 0.5 | • This indicator is usually intended to include benthic animals as part of the crustacean biomass in the denominator (Kaplan et al. 2011), and so derivation from CPS data sets would only be relevant if larval stages of crabs, lobsters, etc were included in the samples and known to be related to benthic population dynamics.<br>• However, krill (and pink shrimp) are obviously important forage/pelagic crustaceans that are not mentioned here; though there is little evidence in the literature comparing the relative biomass of these groups to pelagic finfish. |
| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 1 | • Changes in the ratio of finfish to crustacean biomass will obviously affect community composition, but variation in overall community composition may not be detected by variation in these groups alone (Kaplan et al. 2011, Worm and Myers 2003, Zhang and Chen 2007). |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific management action(s) or pressure(s) | 1 | • The ratio of finfish to crustacean biomass can be dynamic and related to human pressures on the ecosystem, such as fishing (Kaplan et al. 2011, Worm and Myers 2003, Zhang and Chen 2007). |
| (e) Linkable to scientifically-defined | 0.5 | • Changes in the ratio of these biomass groups could be used as a target, but none have |

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| reference points & progress targets | | been used to date |
| (g) Concrete & Numerical | 0 | • This indicator is usually intended to include benthic animals as part of the crustacean biomass in the denominator (Kaplan et al. 2011), and so derivation from CPS data sets would only be relevant if larval stages of crabs, lobsters, etc were included in the samples and known to be related to benthic population dynamics. |
| (h) Historical data or information available | 0 | • This indicator is usually intended to include benthic animals as part of the crustacean biomass in the denominator (Kaplan et al. 2011), and so derivation from CPS data sets would only be relevant if larval stages of crabs, lobsters, etc were included in the samples and known to be related to benthic population dynamics. |
| (i) Operationally simple | 0 | • This indicator is usually intended to include benthic animals as part of the crustacean biomass in the denominator (Kaplan et al. 2011), and so derivation from CPS data sets would only be relevant if larval stages of crabs, lobsters, etc were included in the samples and known to be related to benthic population dynamics. |
| (k) Broad spatial coverage | 0 | • This indicator is usually intended to include benthic animals as part of the crustacean biomass in the denominator (Kaplan et al. 2011), and so derivation from CPS data sets would only be relevant if larval stages of crabs, lobsters, etc were included in the samples and known to be related to benthic population dynamics. |
| (l) Continuous time series | 0 | • This indicator is usually intended to include benthic animals as part of the crustacean biomass in the denominator (Kaplan et al. 2011), and so derivation from CPS data sets would only be relevant if larval stages of crabs, lobsters, etc were included in the samples and known to be related to benthic population dynamics. |
| (m) Spatial & temporal variation understood | 0 | • mesh size too large; poorly characterized with gear |
| (n) High signal-to-noise ratio | 0 | • poorly sampled, resulting in high noise; |
| (o) Understood by the public & | 0.5 | • Rose 2007 citing Worm & Myers 2003, but ratios of biomass are a little obscure to the general public |

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| policymakers | | |
| (p) History of reporting | 0 | • No |
| (q) Cost-effective | 0 | • Because the crustacean groups of interest are largely sampled using different gear than is used for surveying pelagic finfish, sampling would likely be expensive. |
| (r) Anticipatory or leading indicator | 0 | • Unknown |
| (t) Regionally/nationally/internationally compatible | 0.5 | • This ratio and its constituent parts are increasingly reported around the world (Myers and Worm 2003, Zhang and Chen 2007, Kaplan et al. 2011) |
| **TOTAL SCORE** | 4 | |

## ZOOPLANKTIVOROUS FISH BIOMASS [14]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 14

**Summary:** Reliable indicator of changing ecosystem state and important to global fish landings and food webs. However, aggregating the biomass of all zooplanktivorous fish species may reduce its sensitivity as an indicator, and it may not respond to management actions if a threshold shift has occurred in the ecosystem. This indicator is concrete and simple, although zooplanktivorous fishes naturally have highly variable populations (high signal:noise ratio). Changes in trends of aggregate groups will be concurrent, at best.

| Criterion | Score | Explanation |
|---|---|---|
| (a) Theoretically sound | 1 | • Changes in the biomass of pelagic species may indicate changes in ecosystem state as a function of fishing down the food web, predatory release of prey populations (forage fish), or insufficient forage base for top predators (Link 2005).<br>• Zooplanktivorous fish has been described as the best indicator of total biomass and net primary production in the system using 7 food web models from the North Pacific and the Baltic Sea (Samhouri et al. 2009)<br>• Threshold-like shifts in Baltic Sea pelagic ecosystems appear to be driven by planktivore abundance (the clupeid, sprat) that separates 2 ecosystem configurations in which zooplankton dynamics are driven by either hydroclimatic forces or predation pressure (Casini et al. 2009). |
| (b) Relevant to management concerns | 1 | • Many zooplanktivorous fish are forage fish, accounting for over 30% of global fish landings, playing an important role in marine food webs because they are the principal means of transferring production from plankton to larger predatory fish and to marine mammals and seabirds (Smith et al. 2011)<br>• Fishery Management Plans for assessed species (e.g., sardine), as well as entire CalCOFI sampling program, attest to management importance. |
| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 1 | • Zooplanktivorous fish represents the best indicator of total ecosystem biomass based on 7 food web models from the North Pacific and Baltic Sea (Samhouri et al. 2009)<br>• Change in zooplanktivorous fish biomass may be a result of incremental changes in all species groups, but a change (or no change) in a single species may not be indicative of the community as a whole<br>• The biomass of small, zooplanktivorous forage fish in the northeast Pacific appears to increase during cold ocean conditions as a result of zooplankton assemblage composition change (http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/ha-under-development.cfm) |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific | 0.5 | • Mgt. action: the pressure of fishing these species at conventional maximum sustainable yield (MSY) levels can have large impacts on other parts of the ecosystem, particularly when they constitute a high proportion of the biomass in the ecosystem |

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| management action(s) or pressure(s) | | or are highly connected in the food web (Smith et al. 2011)<br>• Precautionary management will theoretically affect population, though not if threshold shift has occurred or environmental drivers have changed. |
| (e) Linkable to scientifically-defined reference points & progress targets | 1 | • Link (2005) set warning and limit reference points as follows: if $B_{pelagic} > 75\% B_{total}$, or if $B_{pelagic} < 20\% B_{total}$ in any given year, then a warning threshold has been exceeded. The LRPs are set at $B_{pelagic} > 85\% B_{total}$, and at $B_{pelagic} < 10\% B_{total}$.<br>• Casini et al. 2009: Shifts in Baltic Sea pelagic ecosystems appear to be driven by planktivore abundance (the clupeid, sprat) that separates 2 ecosystem configurations in which zooplankton dynamics are driven by either hydroclimatic forces or predation pressure; identified an ecological threshold, corresponding to a planktivore abundance of $17 \times 10^{10}$ individuals.<br>• Fishery Management Plan reference points for managed species (B40 and B25 rules) have been applied as reference targets, but simulation models by Kaplan et al. (2013) show that this level of forage species removal is likely to impact the abundance of other target species, protected species and the structure of the ecosystem. |
| (g) Concrete & Numerical | 1 | • Large trawls (336-$m^2$ mouth opening) in the upper 18-20 m of the water column at every station.<br>• Mesh sizes ranged from 162.6 cm in the throat of the trawl near the jib lines to 8.9 cm in the cod end.<br>• To maintain catches of small fish and squids, a 6.1-m long, 0.8-cm knotless liner was sewn into the cod end.<br>• Total counts and weights are available for each nekton taxon caught.<br>• Length data are recorded for a subset of individuals (n=50 per station) of all species. |
| (h) Historical data or information available | 0.5 | • Since 1998; Annual systematic surveys have been conducted using consistent methodology in May, June, and September of each year |
| (i) Operationally simple | 1 | • Measurements of hydrography, zooplankton and pelagic fishes made at each station.<br>• Vertical profiles of temperature, salinity, fluorescence, oxygen and turbidity are taken at each station. |

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| (k) Broad spatial coverage | 0.5 | • Mid-Oregon to North WA coast (Newport to Tatoosh Island; along nine transect lines at 50-55 stations, ranging from 45 to 48° N.) |
| (l) Continuous time series | 1 | • 15 y (1998-2012), in June and September |
| (m) Spatial & temporal variation understood | 0.5 | • Annual and spring/summer variation well-understood for most taxa; seasonal less so.<br>• Sampling occurs during day or crepuscular periods so diel patterns are less clear and myctophids are not well characterized. |
| (n) High signal-to-noise ratio | 0.5 | • Sampled taxa have naturally highly variable populations<br>• For some of the best sampled taxa signal to noise is high or can be discerned, although poor for myctophids. |
| (o) Understood by the public & policymakers | 1 | • Yes; relative trends in biomass of each component of the community are easily understood. |
| (p) History of reporting | 1 | • Link 2005; Samhouri 2009, Fulton et al. 2005; |
| (q) Cost-effective | 1 | • Assessment data already collected for many of these species; data mining is all that is needed |
| (r) Anticipatory or leading indicator | 0.5 | • Changes in trends of aggregate groups will always be concurrent at best;<br>• Rapid response of zooplanktivorous fishes and other nekton (distributional anomalies) to delayed upwelling (Brodeur et al. 2006); zooplanktivorous fishes generally show a 1-yr lag between a change in ocean phase and population response (http://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/ha-under-development.cfm), but this is relatively fast compared to other North Pacific fish populations (Yatsu et al. 2008). |
| (t) Regionally/nationally/internationally compatible | 1 | • Link 2002, Methratta & Link 2006 |
| **TOTAL SCORE** | 14 | |

## PISCIVOROUS FISH BIOMASS [6]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 6

**Summary:** In principle, piscivorous fish biomass could serve as a reliable indicator of Ecological Integrity, as it is well supported theoretically as a metric that should decline if fishing down/through the food web occurs (Pauly et al. 1998, Essington et al. 2006). In addition, this indicator is reported in many ecosystems and is relatively easy to communicate. However, the representation of piscivorous fishes in CPS data sets is minimal, reference points for this indicator have yet to be established, and as an aggregate group it is unlikely to serve as a leading indicator of ecosystem changes.

| Criterion | Score | Explanation |
|---|---|---|
| (a) Theoretically sound | 0.5 | • Fulton et al. 2005; Samhouri et al. 2009; Kaplan et al. 2011.<br>• CPS data sets could include the following piscivorous fish species: hake, dogfish, adult salmon, jack mackerel, and sharks (Brodeur et al. 2006, Brodeur et al. in prep).<br>• However, the representation of piscivorous fishes in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be piscivores, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to piscivory. |
| (b) Relevant to management concerns | 1 | • The piscivores included in some CPS data sets are of critical management importance, as evidenced by their inclusion in PFMC Fishery Management Plans (hake, salmon, etc.; www.pcouncil.org) |

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| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 0.5 | • Piscivorous fish biomass tends to be more strongly correlated with a narrower range of ecosystem attributes than other indicators that have been tested using ecosystem model simulations (Fulton et al. 2005; Samhouri et al. 2009; Kaplan et al. 2011). |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific management action(s) or pressure(s) | 0.5 | • As the majority of piscivorous fishes are the targets of fisheries, their biomass is expected to decline as fishing pressure increases. Similarly, as higher trophic level predators, bioaccumulation of toxins can lead to population declines (Fulton et al. 2005; Samhouri et al. 2009; Kaplan et al. 2011). |
| (e) Linkable to scientifically-defined reference points & progress targets | 0.5 | • It is feasible to identify thresholds, but none have been defined to date in the California Current.<br>• Samhouri et al. 2010 showed that the biomass of a dominant piscivore was linkable to ecosystem thresholds;<br>• Micheli et al. 2004 suggested a threshold time to recovery for pisicvores in no-take areas |
| (g) Concrete & Numerical | 0 | • No data available in BPA data set |
| (h) Historical data or information available | 0 | • No data available in BPA data set |
| (i) Operationally simple | 0 | • No data available in BPA data set |
| (k) Broad spatial coverage | 0 | • No data available in BPA data set |
| (l) Continuous time series | 0 | • No data available in BPA data set |
| (m) Spatial & temporal variation understood | 0 | • poorly characterized with gear;<br>• tow speeds are too slow to capture most highly mobile, top predators |
| (n) High signal-to-noise ratio | 0 | • poorly sampled, resulting in high noise; |
| (o) Understood by the public & | 1 | • Yes; relative trends in biomass of each component of the community is easily |

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| policymakers | | understood, and a focus on predators like piscivores is particularly compelling. |
| (p) History of reporting | 0.5 | • Top predator measures like piscivore biomass have been widely used as indicators of ecosystem response/state (e.g., Branch et al. 2010, Estes et al. 2011, Fulton et al. 2005, Samhouri et al. 2009, Kaplan et al. 2011), although the representation of piscivorous fishes in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be piscivores, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to piscivory. |
| (q) Cost-effective | 0.5 | • Data mining by group is needed.<br>• However, ideally multiple gear types would be used to survey pelagic piscivores, which could make comprehensive surveys expensive. |
| (r) Anticipatory or leading indicator | 0 | • Changes in trends of aggregate groups likely to be coincident at best; piscivores tend to be larger bodied and often longer lived, slower responders. |
| (t) Regionally/nationally/internationally compatible | 1 | • Methratta & Link 2006, Fulton et al. 2005, Kaplan et al. 2011 |
| **TOTAL SCORE** | 6 | |

## TOP PREDATOR BIOMASS (TROPHIC LEVEL > 4) [6]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 6

**Summary:** Like piscivorous fish biomass, in principle top predator biomass could serve as a reliable indicator of Ecological Integrity, as it is well supported theoretically as a metric that should decline if fishing down/through the food web occurs (Pauly et al. 1998, Essington et al. 2006). In addition, this indicator is reported in many ecosystems and is relatively easy to communicate. However, the representation of top predator biomass in CPS data sets is minimal, reference points for this indicator have yet to be established, and as an aggregate group it is unlikely to serve as a leading indicator of ecosystem changes.

| **Criterion** | **Score** | **Explanation** |
|---|---|---|
| (a) Theoretically sound | 0.5 | • The removal of top predators from ecosystems can result in a trophic cascade in which consumers are released from pressure and decrease the abundance of heterotrophs in the system, altering community composition (Samhouri et al. 2009; Estes et al. 2011).<br>• CPS data sets could include the following predatory species: hake, dogfish, adult salmon, jack mackerel, and sharks (Brodeur et al. 2006).<br>• However, the representation of top predators in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be top predators, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to top predator status. |
| (b) Relevant to management concerns | 1 | • Top predators have strong effects in marine ecosystems, and tend to be the targets of fisheries, making them highly relevant to management concerns (Jennings et al. 1995, Estes et al. 2011). |
| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 0.5 | • Top predator response times can be slow because of long lifespans (Estes et al. 2011).<br>• However, sometimes top predators are sensitive indicators (Pauly et al. 1998; Ward & Myers 2005). |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific | 0.5 | • Top predator response times can be slow because of long lifespans (Estes et al. 2011).<br>• However, some times top predators are sensitive indicators (Pauly et al. 1998; Ward |

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| management action(s) or pressure(s) | | & Myers 2005). |
| (e) Linkable to scientifically-defined reference points & progress targets | 0.5 | • Link (2005): thresholds in top predator biomass could be used as a target, but none has been used to date in the California Current |
| (g) Concrete & Numerical | 0 | • The representation of top predators in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be top predators, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to top predator status. |
| (h) Historical data or information available | 0 | • The representation of top predators in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be top predators, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to top predator status. |
| (i) Operationally simple | 0 | • The representation of top predators in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be top predators, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to top predator status. |
| (k) Broad spatial coverage | 0 | • The representation of top predators in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be top predators, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to top predator status. |
| (l) Continuous time series | 0 | • The representation of top predators in CPS data sets is not likely to be great for 2 reasons: (i) sampling gears not typically intended to target larger bodies pelagic fishes that may be top predators, and (ii) many of the CPS sampled will be younger and smaller individuals that have not made the ontogenetic shift to top predator status. |
| (m) Spatial & temporal variation understood | 0 | • poorly characterized with gear;<br>• tow speeds are too slow to capture most highly mobile, top predators |

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| (n) High signal-to-noise ratio | 0 | • poorly sampled, resulting in high noise; |
| (o) Understood by the public & policymakers | 1 | • Yes; trends in biomass of each component of the community is easily understood, and a focus on top predators is particularly compelling (Estes et al. 2011). |
| (p) History of reporting | 0.5 | • see above; Link 2005; Pauly et al. 1998 |
| (q) Cost-effective | 0.5 | • Data mining by group is all that is needed |
| (r) Anticipatory or leading indicator | 0 | • Top predator response times can be slow because of long lifespans (Estes et al. 2011).<br>• Even when top predators are sensitive indicators (Pauly et al. 1998; Ward & Myers 2005) they are likely to be coincident, not anticipatory indicators. |
| (t) Regionally/nationally/internationally compatible | 1 | • Link 2005, Fay et al. 2013 |
| **TOTAL SCORE** | 6 | |

## SCAVENGER OR DETRITIVORE BIOMASS [5]

**CCIEA Goal:** Ecological integrity

**Attribute:** Community composition

**Total score:** 5

**Summary:** Scavenger biomass is in principle a theoretically sound indicator of ecological integrity, as it is expected to increase as fisheries discards and other human pressures accumulate. However, it is probably best represented with the inclusion of benthic detritivores and is at best partially tracked within CPS data sets like the BPA survey. Furthermore, it is an indicator that is likely to respond to ecosystem changes rather than lead them and does not have a long history of reporting.

| Criterion | Score | Explanation |
|---|---|---|
| (a) Theoretically sound | 0 | • This indicator probably best represented with the inclusion of benthic detritivores (Ramsay et al. 1998, Samhouri et al. 2009).<br>• Jellyfish, sampled in some CPS data sets, eat detritus (Ruzicka et al. 2007, Pauly et al. 2009), but it is not their primary dietary item (Brodeur et al. 2008), which is also the case for other CPS.<br>• Therefore, while scavenger biomass is in principle a theoretically sound indicator of ecological integrity, it is at best partially tracked within CPS data sets. |
| (b) Relevant to management concerns | 1 | • Scavenger biomass is expected to increase as fisheries discards and other human pressures accumulate.<br>• reviewed by Britton and Morton 1994, and by Purcell et al. 2007, 2012 for jellyfish |
| (c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s) | 0.5 | • Changes in scavenger biomass will obviously affect community composition, but variation in overall community composition may not be detected by variation in this trophic level alone. |
| (d) Responds predictably & is sufficiently sensitive to changes in a specific management action(s) or pressure(s) | 1 | • Acute increases in scavenger population after fishing activities are reasonably well documented and there is also some evidence that fishing activities induce chronic increases in scavenger populations.<br>• Ramsay et al. 1998 or Purcell 2012 for jellyfish specifically. |
| (e) Linkable to scientifically-defined reference points & progress targets | 0.5 | • It is feasible to identify thresholds, but none have been defined to date in the California Current.<br>• Samhouri et al. (2010) showed jellyfish biomass was linkable to ecosystem thresholds using an ecosystem model for British Columbia |
| (g) Concrete & Numerical | 0 | • Scavenger biomass is at best partially tracked within CPS data sets, as these data sets do not include benthic detritivores. |

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| (h) Historical data or information available | 0 | • Scavenger biomass is at best partially tracked within CPS data sets, as these data sets do not include benthic detritivores. |
| (i) Operationally simple | 0 | • Scavenger biomass is at best partially tracked within CPS data sets, as these data sets do not include benthic detritivores. |
| (k) Broad spatial coverage | 0 | • Scavenger biomass is at best partially tracked within CPS data sets, as these data sets do not include benthic detritivores. |
| (l) Continuous time series | 0 | • Scavenger biomass is at best partially tracked within CPS data sets, as these data sets do not include benthic detritivores. |
| (m) Spatial & temporal variation understood | 0 | • Scavenger biomass is at best partially tracked within CPS data sets, as these data sets do not include benthic detritivores. |
| (n) High signal-to-noise ratio | 0 | • Scavenger biomass is at best partially tracked within CPS data sets, as these data sets do not include benthic detritivores. |
| (o) Understood by the public & policymakers | 0.5 | • Relative trends in biomass of each component of the community is easily understood, though pelagic scavengers may be a more challenging concept to communicate. |
| (p) History of reporting | 0 | • No |
| (q) Cost-effective | 1 | • Data mining by group is all that is needed |
| (r) Anticipatory or leading indicator | 0 | • No, scavengers usually respond to a change in the ecosystem that has occurred (Britton and Morton 1994, Ramsay et al. 1998), rather than anticipating one. |
| (t) Regionally/nationally/internationally compatible | 0.5 | • Changes in scavenger biomass are increasingly reported around the world (eg, due to fisheries discards, ghostfishing, competitive and predatory release). |
| **TOTAL SCORE** | 5 | |

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