APPENDIX C-1. EVALUATION OF INDICATORS FOR COASTAL PELAGIC AND FORAGE SPECIES USING THE BONNEVILLE POWER ADMINISTRATION DATA SET

Jameal F. Samhouri[1], Gregory D. Williams[1], Richard Brodeur[1], and Caren Barcelo[2]

1. NOAA FISHERIES, NORTHWEST FISHERIES SCIENCE CENTER
2. OREGON STATE UNIVERSITY, COLLEGE OF EARTH, OCEAN AND ATMOSPHERIC SCIENCE, 104 CEOAS ADMINISTRATION BUILDING, CORVALLIS, OREGON 97331

OVERVIEW

As currently reported within the CCIEA, the Coastal Pelagic and forage species (CPS) goal of the CCIEA reports on several indicators, but none have been evaluated systematically according to the same considerations suggested by Kershner et al. (2011) and in previous versions of the CCIEA (e.g., Groundfish section), or hierarchically with respect to particular attributes of the CPS goal. To fill these gaps, we evaluated 5 candidate indicators of Coastal Pelagic Species derivable from a data set developed with funding from the Bonneville Power Administration (BPA). The BPA Plume Survey has generated 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).

To initiate an indicator evaluation and selection framework that parallels the Groundfish section (and others), we evaluated 5 candidate indicators with respect to 2 CPS attributes: population size and population condition. We defined these attributes as in other CCIEA sections (e.g., see the Groundfish goal). One candidate indicator, forage fish biomass (in aggregate), was evaluated with respect to the CPS attribute of population size. The remaining four candidate indicators were evaluated with respect to the population condition attribute for CPS, and included: spatial structure, mean length (size), size structure, and age structure. In the future, it would be worth evaluating additional CPS indicators of population size, such as survey-specific biomass or abundance, and population condition, like age and size at maturity. In the Table of Contents below, the name of each indicator we evaluated is listed, followed by its score in brackets [].

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 *age structure*, 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).

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.

All 5 of the candidate CPS goal indicators received scores ≥12, suggesting that they would all serve reasonably well. However, we only evaluated one candidate indicator of the CPS population size attribute, and suspect that estimates of the biomass of individual species would perform better than forage fish biomass in aggregate (see Groundfish goal for parallel evaluation). **The highest scoring indicator of CPS population condition was age structure.**

TABLE OF CONTENTS

Overview **1**

Table of Contents *3*

Summary of Indicator Evaluations *4*

Detailed Indicator Evaluations for the Ecological Integrity Goal *6*

Forage fish abundance; in aggregate [12] 6

Spatial structure of population (center of distribution [latitude or depth]) [13] 10

Mean length (size) [12] 14

Size structure [12] 18

Age structure [13.5] 22

References *26*

SUMMARY OF INDICATOR EVALUATIONS

Table 1. Summary of indicator evaluations for the Coastal Pelagic Species 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
Coastal Pelagic Species: Population Size	Forage fish abundance; in aggregate	4	5	3	Highly important to global fish landings and food webs. Stock assessments are conducted on most important taxa to guide harvest. Aggregating the abundance of all forage species may reduce its sensitivity as an indicator, and population size may not respond to management actions if a threshold shift has occurred in the ecosystem. Changes in trends of aggregate groups will be concurrent, at best. Most commonly reported indicators involving forage species are based on biomass.
Coastal Pelagic Species: Population Condition	Spatial structure of population	3.5	5	4.5	Changing spatial distributions of pelagic nekton have been predicted with some climate change scenarios, showing corresponding impacts to associated commercial fisheries. It is difficult to specifically attribute these changes to particular causes, however. Though not necessarily anticipatory, this indicator is well understood by policymakers and compatible with a number of other ecosystem assessments.

CCIEA Goal: Attribute	Indicator	Primary consider-ations (5)	Data consider-ations (7)	Other consider-ations (5)	Summary comments
Coastal Pelagic Species: Population Condition	Mean length (size)	3	5	4	Length-based indicators receive contradictory theoretical support from the literature about population condition, unless they are tied closely to age information. The BPA survey does have size information for a 15-y time series of data in the region. Though used to assess year class strength, mean length is better for measuring medium term trends.
Coastal Pelagic Species: Population Condition	Size structure	3	5	4	Size- based indicators receive contradictory theoretical support from the literature about population condition, unless they are tied closely to age information. The BPA survey does have size information for a 15-y time series of data in the region. Though used to assess year class strength, size structure is better for measuring medium term trends.
Coastal Pelagic Species: Population Condition	Age structure	4.5	5	4	Age structure is the basis for most ecological models and stock assessments, and generally has well-defined progress targets. Age truncation is known to have severe consequences for fish population sustainability. This indicator is well understood and highly compatible, with a variety of other assessments.

DETAILED INDICATOR EVALUATIONS FOR THE ECOLOGICAL INTEGRITY GOAL

FORAGE FISH ABUNDANCE; IN AGGREGATE [12]

CCIEA Goal: Coastal Pelagic Species

Attribute: Population Size

Total score: 12

Summary: Highly important to global fish landings and food webs. Stock assessments are conducted on most important taxa to guide harvest. Aggregating the abundance of all forage species may reduce its sensitivity as an indicator, and population size may not respond to management actions if a threshold shift has occurred in the ecosystem. Changes in trends of aggregate groups will be concurrent, at best. Most commonly reported indicators involving forage species are based on biomass.

Criterion	Score	Explanation
(a) Theoretically-sound	1	Most indicators of the pelagic fish community are based on biomass, not numbers, although stock assessments of Pacific sardine and mackerel generally estimate both biomass and age-based population size (Crone et al. 2011, Hill et al. 2011) Survey abundance may be a better indicator of relative spatial distribution than population strength (Bjorkstedt et al. 2012, Song et al. 2012) Abundance surveys show distribution shifts of sardine into NW waters in the mid-1990's (Emmett et al. 2005) and Baltic Sea pelagic ecosystems appear to be driven by planktivore abundance (Casini et al. 2009).
(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) Fishery Management Plans for assessed species (e.g., sardine, CPS Fishery Management Plan; State plans for Herring assessment and management), as well as entire CalCOFI sampling program, attest to management importance.
(c) Responds predictably & is	1	Climate or regime shifts; Survey abundance of anchovy and sardine in California current represent variability in the distribution throughout the

sufficiently sensitive to changes in a specific ecosystem attribute(s)		CCE (Bjorkstedt et al. 2012, Song et al. 2012) Pelagic nekton responded to anomalous environmental conditions in CCE in 2005, including widespread onshore and poleward displacement of taxa to new geographic areas, population changes within the normal range, and reduced productivity of early life stages based on larval and juvenile surveys (Brodeur et al. 2006) Abundance surveys show distribution shifts of sardine into NW waters in the mid-1990's, likely in response to regional warming trends (Emmett et al. 2005) Between 1998 and 2002, species composition shifted from a community dominated by southern species (mackerels and hake) to one dominated by northern species (squid, smelts, and salmon) (Brodeur et al. 2005).
(d) Responds predictably & is sufficiently sensitive to changes in a specific management action(s) or pressure(s)	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 or are highly connected in the food web (Smith et al. 2011; Kaplan et al. 2013) Precautionary management will theoretically affect population, though not if threshold shift has occurred or environmental drivers have changed (Casini et al. 2009) Survey abundance of anchovy and sardine in California current is not likely to represent overall population strength as much as variability in the distribution throughout the CCE (Bjorkstedt et al. 2012, Song et al. 2012).
(e) Linkable to scientifically-defined reference points & progress targets	0.5	Most reference points are based on population biomass (Link 2005). Fishery Management Plan reference points for managed species have been applied as reference targets for sardines (Hill et al. 2011), but simulation models by Kaplan et al. (2013) show that groundfish (B25, B40) levels 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 m2 mouth opening) in the upper 18-20 m of the water column at every station. 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. To maintain catches of small fish and squids, a 6.1 m long, 0.8 cm knotless liner was sewn into the cod end. Total counts and weights are available for each nekton taxon caught.

		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. 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 deg 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. 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; 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 abundance of each component of the community is easily understood.
(p) History of reporting	0.5	Biomass is usually the most commonly reported indicator involving pelagic / zooplanktivorous fishes (Link 2005, Samhouri et al. 2009, Fulton et al. 2005) Historic time series provide relative CPUE estimates for regions of the CCE (e.g., Brodeur et al. 2005, Emmett et al. 2005).
(q) Cost-effective	1	Assessment data or other pelagic surveys are already conducted 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 Rapid response of forage fishes and other nekton (distributional anomalies) to delayed upwelling (Brodeur et al. 2006) Forage fish generally show a short 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	0	No. Most commonly reported indicators involving pelagic / zooplanktivorous fishes are based on biomass (Link 2005, Samhouri et al. 2009, Fulton et al. 2005)
TOTAL SCORE	12	

SPATIAL STRUCTURE OF POPULATION (CENTER OF DISTRIBUTION [LATITUDE OR DEPTH]) [13]

CCIEA Goal: Coastal Pelagic Species

Attribute: Population condition

Total score: 13

Summary: Changing spatial distributions of pelagic nekton have been predicted with some climate change scenarios, showing corresponding impacts to associated commercial fisheries. It is difficult to specifically attribute these changes to particular causes, however. Though not necessarily anticipatory, this indicator is well understood by policymakers and compatible with a number of other ecosystem assessments.

Criterion	Score	Explanation
(a) Theoretically-sound	1	Spatial structure of biomass considered as attribute by Fulton et al. (2005); Reese and Brodeur (2006) used species concentration/composition to identify areas of biological activity, with flow and circulation suggested as the primary drivers of these patterns. Climate change may lead to large-scale redistribution of global catch potential, with an average of 30–70% increase in high-latitude regions and a drop of up to 40% in the tropics (Cheung et al. 2010). As an example, Barcelo et al. (in prep) show a northward shift in the center of distribution of market squid. Northward shifts in species distributions were matched by corresponding northward shifts in fisheries (Pinsky and Fogarty 2012).
(b) Relevant to management concerns	1	Fishery Management Plans of assessed CPS species like Pacific sardine and mackerel (Hill et al. 2011; Crone et al. 2011). Spatial changes may have impacts on the nature and value of these commercial fisheries (Perry et al. 2005). Changing species distributions are predicted to result in

		species extinctions on land and population extinctions in the sea (Thomas et al. 2004; Drinkwater 2005); Climate change may lead to large-scale redistribution of global catch potential, with an average of 30–70% increase in high-latitude regions and a drop of up to 40% in the tropics (Cheung et al. 2010). Northward shifts in species distributions were matched by corresponding northward shifts in fisheries, with fisheries lagging by 10-30%; lags may lead to overfishing and population declines (Pinsky and Fogarty 2012).
(c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s)	0.5	Distributional shifts are hypothesized to occur for either two reasons - climatic or exploitation - but the difference is difficult to distinguish. Dulvy et al. (2008) suggests changes in depth distribution of an assemblage of North Sea groundfish is due to climate while, latitudinal shifts may be caused by either - (similar to Coetzee 2008 & Fairweather et al. 2006). Distributions of North Sea fishes responded markedly to increases in sea temperature, with nearly two-thirds of species shifting in mean latitude or depth or both over 25 years; all but one shifted northward. Shifting species were those with faster life cycles (Perry et al. 2005). In the northern California current, models have identified significant relationships between sardine eggs and sea surface temperature, chlorophyll a concentration, and the gradient of sea surface altitude. The model accurately predicts the habitat and seasonal migration pattern of sardine, irrespective of spawning condition (Zwolinski et al. 2011). Reese and Brodeur (2006) used species composition and concentration to identified 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)	0.5	Distributional shifts are hypothesized to occur for either two reasons - climatic or exploitation - but the difference is difficult to distinguish. Perry et al. 2005 showed large latitudinal shifts correlated with changes in temperature. Dulvy et al. (2008) suggests changes in depth distribution of an assemblage of North Sea groundfish is due to climate while, latitudinal shifts may be caused by either - similar to

		Coetzee 2008 & Fairweather et al. 2006. The geographic ranges of overexploited species typically decline, and stocks are concentrated into smaller regions following population declines (Atkinson et al., 1997; Garrison & Link 2000).
(e) Linkable to scientifically-defined reference points & progress targets	0.5	Reference points for distributional shifts are not used and would be difficult to measure unless species were divided into Distinct Population Segments and shifts away from one segment triggered management actions Management should strive to preserve a minimal spawning biomass throughout the geographic range of the stock (Berkeley et al. 2004). Spatial management tools need to formulate more specific targets (Backcock et al. 2005). However, historical spatial center could serve as a straightforward reference point (Cheung et al. 2010).
(g) Concrete & Numerical	1	Large trawls (336 m2 mouth opening) in the upper 18-20 m of the water column at every station. 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. To maintain catches of small fish and squids, a 6.1 m long, 0.8 cm knotless liner was sewn into the cod end. Total counts and weights are available for each nekton taxon caught. 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. 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 deg 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. 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; 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, Dulvy et al. 2008
(p) History of reporting	1	Yes, stock assessments, bottom trawl survey, and landings by area or by location from trawl logbooks; CPS analyses generally divided by region.
(q) Cost-effective	1	Yes, stock assessments, bottom trawl survey, and landings by area or by location from trawl logbooks
(r) Anticipatory or leading indicator	0.5	Not necessarily, although some estimates of changing species distributions could be anticipatory.
(t) Regionally/ nationally/ internationally compatible	1	Yes; Perry et al. 2005, Coetzee 2008, Dulvy et al. 2008, Garrison & Link 2000.
TOTAL SCORE	13	

MEAN LENGTH (SIZE) [12]

CCIEA Goal: Coastal Pelagic Species

Attribute: Population condition

Total score: 12

Summary: Length-based indicators receive contradictory theoretical support from the literature about population condition, unless they are tied closely to age information. The BPA survey does have size information for a 15-y time series of data in the region. Though used to assess year class strength, mean length is better for measuring medium term trends.

Criterion	Score	Explanation
(a) Theoretically-sound	0.5	Mean size of all species caught in either fishery-independent surveys, fishery-dependent surveys, and/or landings is a useful and simple indicator to evaluate the overall effects of fishing on an ecosystem (Link 2005; Jennings & Kaiser 1998; Rochet & Trenkel 2003); Average size or distribution of sizes in catch is often taken as an indicator of population status...[but, there are] very few examples where length-based analysis leads to useful management advice (Hilborn and Walters 1992)
(b) Relevant to management concerns	0.5	Only if size representative of age. See references and notes for (a).
(c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s)	0.5	Attempts to use length-based analysis to formulate management advice for [some] species... is misguided and fundamentally hopeless (you need age information, gear selectivity and size related changes in distribution will influence data) (Hilborn and Walters 1992); Mean length (size) metrics... (Link & Brodziak 2002; Link et al. 2002; Rochet & Trenkel 2003; Nicholson & Jennings 2004). Fish size responds predictably to dietary ration and temperature.
(d) Responds predictably & is sufficiently sensitive to	0.5	Mean size (l, as length) of all species caught in either fishery-independent surveys, fishery-dependent surveys, and/or

changes in a specific management action(s) or pressure(s)		landings is a useful and simple indicator to evaluate the overall effects of fishing on an ecosystem... even if the change cannot be directly attributed to fishing, the indicator should still be monitored more closely, with initial steps taken to mitigate the change (Link & Brodziak 2002; Link et al. 2002; Rochet & Trenkel 2003; Nicholson & Jennings 2004). Attempts to use length-based analysis to formulate management advice for [some] species... is misguided and fundamentally hopeless (you need age information, gear selectivity and size related changes in distribution will influence data) - (Hilborn and Walters 1992); Length-based indicators weighted by biomass, rather than abundance, were more sensitive and specific to fishing pressure (Houle et al. 2012). Exploitation influences community structure directly through preferential removal of larger-bodied fishes and indirectly because larger-bodied fishes may exert top-down control upon other community members (Dulvy et al. 2004); A decrease of mean length in the population is expected and has been observed under the effects of fishing (Haedrich and Barnes 1997; Babcock et al. 1999). "…because of methodological difficulties and despite accumulated experience, it is currently not possible to state precisely how fishing affects size spectra" (Rochet and Trenkel 2003.)
(e) Linkable to scientifically-defined reference points & progress targets	1	If there is a decline in mean size of more than 30% between years, then a warning or precautionary threshold (30%) has been exceeded; the indicator should still be monitored more closely, with initial steps taken to mitigate the change. The limit reference point (LRP) has been set at a value of 50% decline, and the control rule would be to enlarge mesh size or to take similar action to alter fishing gear; 50% was chosen because it corresponds to an observed doubling in the time-series of l after fishing decreased (Link 2005 and references therein); Attempts to use length-based analysis to formulate management advice for [some] species... is misguided and fundamentally hopeless (you need age information, gear selectivity and size related changes in distribution will influence data) (Hilborn and Walters 1992); reference directions provide alternative medium-term

		management targets (Jennings and Dulvy 2005)
(g) Concrete & Numerical	1	Large trawls (336 m^2 mouth opening) in the upper 18-20 m of the water column at every station. 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. To maintain catches of small fish and squids, a 6.1 m long, 0.8 cm knotless liner was sewn into the cod end. Total counts and weights are available for each nekton taxon caught. 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. 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 deg 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. 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; 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. Link 2005; Fulton et al. 2005

(p) History of reporting	1	Yes. Link & Brodziak 2002
(q) Cost-effective	1	Yes, data collected, used to assess year class strength, included in stock assessments and FMPs for assessed groundfish species; http://www.pcouncil.org/wp-content/uploads/fmpthru19.pdf
(r) Anticipatory or leading indicator	0	No; better for measuring medium term (5-10 y) trends (Jennings and Dulvy 2005)
(t) Regionally/ nationally/ internationally compatible	1	Methratta & Link 2006; Fulton et al. 2005
TOTAL SCORE	12	

SIZE STRUCTURE [12]

CCIEA Goal: Coastal Pelagic Species

Attribute: Population condition

Total score: 12

Summary: Size- based indicators receive contradictory theoretical support from the literature about population condition, unless they are tied closely to age information. The BPA survey does have size information for a 15-y time series of data in the region. Though used to assess year class strength, size structure is better for measuring medium term trends.

Criterion	Score	Explanation
(a) Theoretically-sound	0.5	Population size structure has been evaluated as a good indicator of fishing by Fulton et al. (2005; L_{max}) and Coll et al. (2012, mean fish size); At large scales(ecosystems), size-based indicators show reliable responses to changes in rates of fishing mortality (Jennings and Dulvy 2005 and refs therein). Average size or distribution of sizes in catch is often taken as an indicator of population status...[but, there are] very few examples where length-based analysis leads to useful management advice (Hilborn and Walters 1992)
(b) Relevant to management concerns	0.5	Only if size representative of age. See references and notes for (a).
(c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s)	0.5	Attempts to use length-based analysis to formulate management advice for [some] species... is misguided and fundamentally hopeless (you need age information, gear selectivity and size related changes in distribution will influence data) (Hilborn and Walters 1992); (Link & Brodziak 2002; Link et al. 2002; Rochet & Trenkel 2003; Nicholson & Jennings 2004). Fish size responds predictably to dietary ration and temperature.
(d) Responds predictably & is sufficiently sensitive to	0.5	Attempts to use length-based analysis to formulate management advice for [some] species... is misguided and

changes in a specific management action(s) or pressure(s)		fundamentally hopeless (you need age information, gear selectivity and size related changes in distribution will influence data) - (Hilborn and Walters 1992); Size-based metrics would better support medium-term rather than year-on-year management evaluation, because (1.) they are unlikely to be appropriate for detecting responses to management action on time scales <5 years, and (2.) the response to management action cannot be quantitatively decomposed in the contributing causal factors without extensive additional research (Jennings and Dulvy 2005). Population size structure has been evaluated as a good indicator of fishing by Fulton et al. (2005; Lmax) and Coll et al. (2012, mean fish size); at large scales (ecosystems), size-based indicators show reliable responses to changes in rates of fishing mortality (Jennings 2005 and refs therein). Length-based indicators weighted by biomass, rather than abundance, were more sensitive and specific to fishing pressure (Houle et al. 2012). Exploitation influences community structure directly through preferential removal of larger-bodied fishes and indirectly because larger-bodied fishes may exert top-down control upon other community members (Dulvy et al. 2004)
(e) Linkable to scientifically-defined reference points & progress targets	1	If there is a decline in mean size of more than 30% between years, then a warning or precautionary threshold (30%) has been exceeded; the indicator should still be monitored more closely, with initial steps taken to mitigate the change. The limit reference point (LRP) has been set at a value of 50% decline, and the control rule would be to enlarge mesh size or to take similar action to alter fishing gear; 50% was chosen because it corresponds to an observed doubling in the time-series of l after fishing decreased (Link 2005 and references therein); Attempts to use length-based analysis to formulate management advice for [some] species... is misguided and fundamentally hopeless (you need age information, gear selectivity and size related changes in distribution will influence data) (Hilborn and Walters 1992); Reference directions provide alternative medium-term management targets (Jennings and Dulvy 2005)

(g) Concrete & Numerical	1	Large trawls (336 m^2 mouth opening) in the upper 18-20 m of the water column at every station. 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. To maintain catches of small fish and squids, a 6.1 m long, 0.8 cm knotless liner was sewn into the cod end. Total counts and weights are available for each nekton taxon caught. 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. 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 deg 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. 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; 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, used to assess year class strength, included in stock assessments and FMPs for assessed groundfish species; http://www.pcouncil.org/wp-content/uploads/fmpthru19.pdf

(p) History of reporting	1	Yes, used to assess year class strength, included in stock assessments and FMPs for assessed groundfish species; http://www.pcouncil.org/wp-content/uploads/fmpthru19.pdf
(q) Cost-effective	1	Yes, data collected, used to assess year class strength, included in stock assessments and FMPs for assessed groundfish species; http://www.pcouncil.org/wp-content/uploads/fmpthru19.pdf
(r) Anticipatory or leading indicator	0	No; better for measuring medium term (5-10 y) trends (Jennings and Dulvy 2005)
(t) Regionally/ nationally/ internationally compatible	1	Celtic Sea (Blanchard et al. 2005); Northeastern groundfish stocks (Link 2005), Eastern Bering Sea community size structure (AFSC 2009)
TOTAL SCORE	12	

AGE STRUCTURE [13.5]

CCIEA Goal: Coastal Pelagic Species

Attribute: Population condition

Total score: 12.5

Summary: Age structure is the basis for most ecological models and stock assessments, and generally has well-defined progress targets. Age truncation is known to have severe consequences for fish population sustainability. This indicator is well understood and highly compatible, with a variety of other assessments.

Criterion	Score	Explanation
(a) Theoretically-sound	1	Sardine (Hill et al. 2011, McClatchie et al. in prep) and Pacific mackerel (Crone et al. 2011) (and theoretically, all other) stock assessments; Atlantis is based on age-structured models - Fulton et al. 2005; Age truncation commonly induced by fisheries may have severe consequences for long-term sustainability of fish populations (Berkeley et al. 2004). Clupeids (e.g. Pacific sardine, herring), smelts [e.g. eulachons, and other forage fishes such as northern lampfish and Pacific sandlance, are short-lived with a small body size and size at maturation, low fecundity, high growth rates and small eggs. They are also surface and mid-water pelagic species that exhibit little if any parental investment and are planktivores or lower-order carnivores - considered opportunistic strategists; population responses tend to be large in amplitude and species grouped according to this life history strategy have been classified as having either cyclical, irregular, or spasmodic population patterns (King and MacFarlane 2003);
(b) Relevant to management concerns	1	Fishery Management Plans for sardine - Stock assessments have been performed for sardine since 1982 by using an age-structured population model incorporating both fishery-dependent and fishery-independent data (U.S. Department of Commerce, Technical Memorandum NOAA-

		TM-NMFS-SWFSC-396) (Hill et al. 2011); "A full and stable age distribution indicates that a population has had recruitment successfully for a number of years, older large fish are present in the population, and the fishery may be less prone to collapse. However following a few years of reduced recruitment (and typically lower biomass) the age structures can be weighted more toward older fish. Likewise, when there is a boom year the vast majority of the biomass will shift to younger fish that could destabilize the age structure for a number of years following (McClatchie et al. *in prep*); Age truncation commonly induced by fisheries may have severe consequences for long-term sustainability of fish populations (Berkeley et al. 2004). Opportunistic strategists (like most pelagic nekton) should be managed to maintain a critical minimum spawning biomass; Spawning stock biomass is the basis of management targets and "spawning-stock" is based on age of fish (King and MacFarlane 2003)
(c) Responds predictably & is sufficiently sensitive to changes in a specific ecosystem attribute(s)	1	Asymmetrical age structure may also be a sign of extended period of poor recruitment. Annual recruitment is estimated using a cohort analysis of aged fish; full and stable age distribution indicates that a population has had recruitment successfully for a number of years, older large fish are present in the population, and the fishery may be less prone to collapse ; broad age distribution can also reduce recruitment variability (All stock assessments, Berkeley et al. 2004); Abundance and distribution of opportunistic strategists (e.g. Pacific sardine and Pacific herring) are known to fluctuate concurrently with climate–ocean regimes (McFarlane & Beamish 2001). Population responses tend to be large in amplitude and species grouped according to this life history strategy have been classified as having either cyclical, irregular or spasmodic population patterns (King and MacFarlane 2003).
(d) Responds predictably & is sufficiently sensitive to changes in a specific	0.5	One of the more predictable effects of fishing is the reduction or removal of the older age classes, i.e., age truncation. Age truncation commonly induced by fisheries

management action(s) or pressure(s)		may have severe consequences for long-term sustainability of fish populations (Berkeley et al. 2004). However, this may be more relevant to species with different life history strategy (e.g., long-lived groundfish). In CCE, Pacific herring represent one of the only forage species for which fishing is considered to be contributing to truncated age structure (Pikitch et al. 2014)
(e) Linkable to scientifically-defined reference points & progress targets	1	All stock assessments, Spawning stock biomass is the basis of management targets and "spawning-stock" is based on age of fish.
(g) Concrete & Numerical	1	Large trawls (336 m^2 mouth opening) in the upper 18-20 m of the water column at every station. 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. To maintain catches of small fish and squids, a 6.1 m long, 0.8 cm knotless liner was sewn into the cod end. Total counts and weights are available for each nekton taxon caught. 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. 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 deg 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. 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; 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	Sardine stock assessment and FMP
(p) History of reporting	1	Sardine stock assessment and FMP; Even if not all CPS have age structure reported historically, the concept is highly familiar to the PFMC
(q) Cost-effective	0.5	Sardine stock assessment and FMP
(r) Anticipatory or leading indicator	0.5	Concurrent; (Jennings and Dulvy 2005)
(t) Regionally/ nationally/ internationally compatible	1	Celtic Sea (Blanchard et al. 2005); Northeastern groundfish stocks (Link 2005), Eastern Bering Sea community size structure (AFSC 2009)
TOTAL SCORE	13.5	

REFERENCES

AFSC. 2009. Ecosystem considerations for 2010. Alaska Fisheries Science Center, Appendix C, Report for the North Pacific Fishery Management Council.

Atkinson, D. B., G. A. Rose, E. F. Murphy, and C. A. Bishop. 1997. Distribution changes and abundance of northern cod (*Gadus morhua*), 1981–1993. Canadian Journal of Fisheries and Aquatic Science **54 (Suppl 1)**:132-138.

Babcock, E. A., E. K. Pikitch, M. K. McAllister, P. Apostolaki, and C. Santora. 2005. A perspective on the use of spatialized indicators for ecosystem-based fishery management through spatial zoning. ICES Journal of Marine Science **62**:469-476.

Babcock, R. C., S. Kelly, N. T. Shears, J. W. Walker, and T. J. Willis. 1999. Changes in community structure in temperate marine reserves. Marine Ecology-Progress Series **189**:125-134.

Berkeley, S. A., M.A. Hixon, R.J. Larson, and M.S. Love. 2004. Fisheries sustainability via protection of age structure and spatial distribution of fish populations. Fisheries **29**:23-32.

Bjorkstedt, E. P., R. Goericke, S. McClatchie, E. Weber, W. Watson, N. Lo, W. T. Peterson, R. D. Brodeur, T. Auth, J. Fisher, C. Morgan, J. Peterson, J. Largier, S. J. Bograd, R. Durazo, G. Gaxiola-Castro, B. Lavaniegos, F. P. Chavez, C. A. Collins, B. Hannah, J. Field, K. Sakuma, W. Satterthwaite, M. O'Farrell, S. Hayes, J. Harding, W. J. Sydeman, S. A. Thompson, P. Warzybok, R. Bradley, J. Jahncke, R. T. Golightly, S. R. Schneider, R. M. Suryan, A. J. Gladics, C. A. Horton, S. Y. Kim, S. R. Melin, R. L. DeLong, and J. Abell. 2012. State of the California Current 2011-2012: Ecosystems Respond to Local Forcing as La Nina Wavers and Wanes. California Cooperative Oceanic Fisheries Investigations Reports **53**:41-76.

Blanchard, J. L., N. K. Dulvy, S. Jennings, J. R. Ellis, J. K. Pinnegar, A. Tidd, and L. T. Kell. 2005. Do climate and fishing influence size-based indicators of Celtic Sea fish community structure? ICES Journal of Marine Science **62**:405-411.

Brodeur, R. D., J. P. Fisher, R. L. Emmett, C. A. Morgan, and E. Casillas. 2005. Species composition and community structure of pelagic nekton off Oregon and Washington under variable oceanographic conditions. Marine Ecology Progress Series **298**:41-57.

Brodeur, R. D., S. Ralston, R. L. Emmett, M. Trudel, T. D. Auth, and A. J. Phillips. 2006. Anomalous pelagic nekton abundance, distribution, and apparent recruitment in the northern California Current in 2004 and 2005. Geophysical Research Letters **33**.

Casini, M., J. Hjelm, J. C. Molinero, J. Lovgren, M. Cardinale, V. Bartolino, A. Belgrano, and G. Kornilovs. 2009. Trophic cascades promote threshold-like shifts in pelagic marine ecosystems. Proceedings of the National Academy of Sciences of the United States of America **106**:197-202.

Cheung, W. W. L., V. W. Y. Lam, J. L. Sarmiento, K. Kearney, R. Watson, D. Zeller, and D. Pauly. 2010. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Global Change Biology **16**:24-35.

Coetzee, J. C., C. C. van der Lingen, L. Hutchings, and T. P. Fairweather. 2008. Has the fishery contributed to a major shift in the distribution of South African sardine? ICES Journal of Marine Science **65**:1676-1688.

Coll, M., J. Navarro, R. J. Olson, and V. Christensen. 2012. Assessing the trophic position and ecological role of squids in marine ecosystems by means of food-web models. Deep Sea Res. http://dx.doi.org/10.1016/j.dsr2.2012.08.020.

Crone, P. R., K. T. Hill, J. D. McDaniel, and K. Lynn. 2011. Pacific mackerel (*Scomber japonicus*) stock assessment for USA management in the 2011-12 fishing year. Pacific Fishery Management Council, Portland, Oregon 97220, USA. 99 p.

Drinkwater, K. F. 2005. The response of Atlantic cod (*Gadus morhua*) to future climate change. ICES Journal of Marine Science **62**:1327-1337.

Dulvy, N. K., N. V. C. Polunin, A. C. Mill, and N. A. J. Graham. 2004. Size structural change in lightly exploited coral reef fish communities: evidence for weak indirect effects. Canadian Journal of Fisheries and Aquatic Sciences **61**:466-475.

Dulvy, N. K., S. I. Rogers, S. Jennings, V. Stelzenmuller, S. R. Dye, and H. R. Skjoldal. 2008. Climate change and deepening of the North Sea fish assemblage: A biotic indicator of warming seas. Journal of Applied Ecology **45**:1029-1039.

Emmett, R. L., R. D. Brodeur, T. W. Miller, S. S. Pool, G. K. Krutzikowsky, P. J. Bentley, and J. McCrae. 2005. Pacific sardine (Sardinops sagax) abundance, distribution, and ecological relationships in the Pacific Northwest. California Cooperative Oceanic Fisheries Investigations Reports **46**:122-143.

Fairweather, T. P., C. D. van der Lingen, A. J. Booth, L. Drapeau, and J. J. van der Westhuizen. 2006. Indicators of sustainable fishing for South African sardine *Sardinops sagax* and anchovy *Engraulis encrasicolus*. African Journal of Marine Science **28**:661-680.

Fulton, E. A., A. D. M. Smith, and A. E. Punt. 2005. Which ecological indicators can robustly detect effects of fishing? ICES Journal of Marine Science **62**:540-551.

Garrison, L. P. and J. S. Link. 2000. Fishing effects on spatial distribution and trophic guild structure of the fish community in the Georges Bank region. ICES Journal of Marine Science **57**:723-730.

Haedrich, R. L. and S. M. Barnes. 1997. Changes over time of the size structure in an exploited shelf fish community. Fisheries Research **31**:229-239.

Hilborn, R. and C. J. Walters. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Kluwer Academic Publishers, Boston, MA.

Hill, K. T., P. R. Crone, N. C. H. Lo, B. J. Macewicz, E. Dorval, J. D. McDaniel, and Y. Gu. 2011. Assessment of the Pacific sardine resource in 2011 for U.S. management in 2012. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SWFSC-487, 260 p.

Houle, J. E., K. D. Farnsworth, A. G. Rossberg, and D. G. Reid. 2012. Assessing the sensitivity and specificity of fish community indicators to management action. Canadian Journal of Fisheries and Aquatic Sciences **69**:1065-1079.

Jennings, S. and N. K. Dulvy. 2005. Reference points and reference directions for size-based indicators of community structure. ICES Journal of Marine Science **62**:397-404.

Jennings, S. and M. J. Kaiser. 1998. The effects of fishing on marine ecosystems. Pages 201-+ Advances in Marine Biology, Vol 34.

Kaplan, I. C., C. J. Brown, E. A. Fulton, I. A. Gray, J. C. Field, and A. D. M. Smith. 2013. Impacts of depleting forage species in the California Current. Environmental Conservation **40**: 380–393**a.**

King, J. R. and G. A. McFarlane. 2003. Marine fish life history strategies: applications to fishery management. Fisheries Management and Ecology **10**:249-264.

Link, J. S. 2005. Translating ecosystem indicators into decision criteria. ICES Journal of Marine Science **62**:569-576.

Link, J. S. and J. K. T. Brodziak, editors. 2002. Status of the Northeast U.S. Continental Shelf Ecosystem: a report of the Northeast Fisheries Science Center's Ecosystem Status Working Group. National Marine Fisheries Service, Northeast Fish. Sci. Cent. Ref. Doc. 02-11, Woods Hole, MA.

Link, J. S., J. K. T. Brodziak, S. F. Edwards, W. J. Overholtz, D. Mountain, J. W. Jossi, T. D. Smith, and M. J. Fogarty. 2002. Marine ecosystem assessment in a fisheries management context. Canadian Journal of Fisheries and Aquatic Sciences **59**:1429-1440.

McClatchie, S., et al. *In preparation*. California Current IEA: Coastal Pelagic Species.

McFarlane, G. A. and R. J. Beamish. 2001. The re-occurrence of sardines off British Columbia characterises the dynamic nature of regimes. Progress in Oceanography **49**:151-165.

Methratta, E. T. and J. S. Link. 2006. Evaluation of quantitative indicators for marine fish communities. Ecological Indicators ***6***:575-588

Nicholson, M. D. and S. Jennings. 2004. Testing candidate indicators to support ecosystem-based management: the power of monitoring surveys to detect temporal trends in fish community metrics. ICES Journal of Marine Science **61**:35-42.

Perry, A. L., P. J. Low, J. R. Ellis, and J. D. Reynolds. 2005. Climate change and distribution shifts in marine fishes. Science **308**:1912-1915.

Pikitch, E. K., K. J. Rountos, T. E. Essington, C. Santora, D. Pauly, R. Watson, U. R. Sumaila, P. D. Boersma, I. L. Boyd, D. O. Conover, P. Cury, S. S. Heppell, E. D. Houde, M. Mangel, É. Plagányi, K. Sainsbury, R. S. Steneck, T. M. Geers, N. Gownaris, and S. B. Munch. 2014. The global contribution of forage fish to marine fisheries and ecosystems. Fish and Fisheries **15**:43–64.

Pinsky, M. L. and M. Fogarty. 2012. Lagged social-ecological responses to climate and range shifts in fisheries. Climatic Change **115**:883-891.

Reese, D. C. and R. D. Brodeur. 2006. Identifying and characterizing biological hotspots in the northern California Current. Deep-Sea Research Part Ii-Topical Studies in Oceanography **53**:291-314.

Rochet, M. J. and V. M. Trenkel. 2003. Which community indicators can measure the impact of fishing? A review and proposals. Canadian Journal of Fisheries and Aquatic Sciences **60**:86-99.

Samhouri, J. F., P. S. Levin, and C. J. Harvey. 2009. Quantitative evaluation of marine ecosystem indicator performance using food web models. Ecosystems **12**:1283-1298.

Smith, A. D. M. 2011. Impacts of fishing low-trophic level species on marine ecosystems. Science **334**:39-39.

Song, H., A. J. Miller, S. McClatchie, E. D. Weber, K. M. Nieto, and D. M. Checkley. 2012. Application of a data-assimilation model to variability of Pacific sardine spawning and survivor habitats with ENSO in the California Current System. Journal of Geophysical Research-Oceans **117,** C03009.

Thomas, C. D., A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus, M. F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A. S. v. Jaarsveld, G. F. Midgley, L. Miles, M. A. Ortega-Huerta, A. T. Peterson, O. L. Phillips, and S. E. Williams. 2004. Extinction risk from climate change. Nature **427**:145-148.

Yatsu, A., K. Y. Aydin, J. R. King, G. A. McFarlane, S. Chiba, K. Tadokoro, M. Kaeriyama, and Y. Watanabe. 2008. Elucidating dynamic responses of North Pacific fish populations to climatic forcing: Influence of life-history strategy. Progress In Oceanography **77**:252-268.

Zwolinski, J. P., R. L. Emmett, and D. A. Demer. 2011. Predicting habitat to optimize sampling of Pacific sardine (*Sardinops sagax*). ICES Journal of Marine Science **68**:867-879.