COASTAL PELAGICS AND FORAGE FISHES

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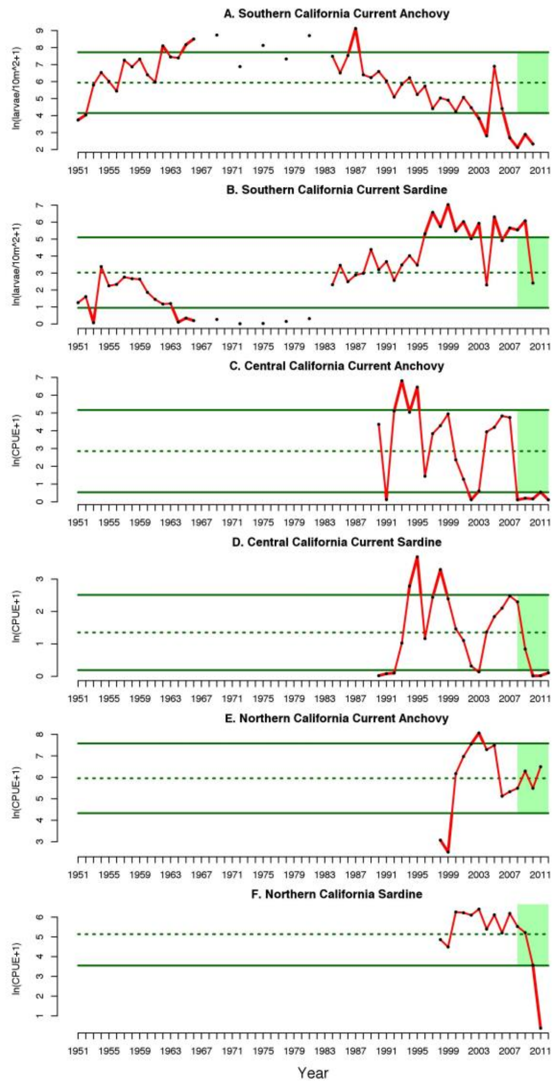
OVERVIEW

Although most assessed forage fish in the central and northern California Current regions are becoming more abundant or remained stable in recent years, sardine appear to be declining off the northern California coast. In the southern California Current region, there is an indication of recent reduction in forage production driven by the trends in anchovy, hake and the mesopelagic coolwater forage assemblage.

EXECUTIVE SUMMARY

Here, we examine trends in abundance and condition of coastal pelagic species and additional forage species throughout the California Current Large Marine Ecosystem (CCLME). Primarily we rely on the data collected from fishery independent surveys in southern California (1951-2010), central California (1990-2012), and Washington and Oregon (1998-2011). Given the differences in methods, catchability, and timing, these surveys are not directly comparable; however the intra-survey trends can be used to inform relative differences in abundance between the regions. We also utilize assessment reports of the Pacific Fisheries Management Council (1929-2011; (Crone et al. 2011, Hill et al. 2011) to estimate trends in biomass and age structure of assessed coastal pelagic species.

There is substantial regional variability in the forage base dynamics in the California Current system. Generally, in the central and northern California Current regions, the forage community became more abundant or remained stable, although sardine abundance declined in recent years. Anchovy is below average in Central California, yet stable in Northern California. Off Southern California, anchovy abundance appears to be on the same trajectory as for Central California, while sardine remain stable. However, in the context of the longer time frame (multiple decades), abundance of sardines is about average. The accompanying figure can be used to demonstrate these points.



Abundance time series for anchovy and sardine from three regions of the California Current system. Absence of red line indicates years of no survey results , green area indicates the last five years of the data series, dashed green line indicates mean and solid green lines indicate +/- 1 s.d.

DETAILED REPORT

The purpose of this chapter of the CCIEA is to examine trends in available indicators relevant to coastal pelagic species and additional forage fishes along the California Current. This is the first step in finding valuable data series that can be used to describe various aspects of the CCE and its forage community. The analysis is largely qualitative at this early stage of the CCIEA. It is important to recognize that we refer to "status" here quite differently than the Pacific Fisheries Management Council (PFMC), and any difference between our status statements and those should not be considered a conflict. We are not using similar models nor benchmarks as those traditionally used. Our purpose is to set the framework for evaluating the forage community from an ecosystem perspective. This approach starts with a simple selection of indicators and evaluation of the trends. However, in subsequent reports we will use these biological indicators in combination with indicators of environmental and anthropogenic pressures to evaluate potential risk to the forage community and develop additional assessment tools useful for ecosystem based management. Indicators for various pressures can be found in other chapters of the full CCIEA (e.g., Anthropogenic Drivers and Pressures, Oceanographic and Climatic Drivers and Pressures).

Coastal pelagic species (CPS) and forage species support important commercial fisheries as well as a number of higher trophic level species including those that are commercially exploited (e.g., rockfish, salmon) and/or legally protected (e.g., salmon, marine mammals, seabirds). In the context of this report, we consider species to be a CPS and/or forage if they are 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, as well as invertebrate species such as squid and krill). Such species are often the principal means of transferring production from primary and secondary tropic levels (typically phytoplankton and zooplankton) to larger predatory fish, marine mammals and seabirds. Although the potential dynamics between the forage base and ecosystem integrity is not the primary aim of this section, we note that recent work Smith et al. (2011) demonstrates the likely negative effects on the ecosystem caused by reductions in abundance of lower trophic level species.

Here, we define coastal pelagic species as recognized by the PFMC: northern anchovy, Pacific sardine, jack mackerel, Pacific mackerel, market squid, and krill. However, when data are available, we also include trends in other fishes that make up the forage complex including juvenile groundfish, herring, whitebait smelt, sanddabs, and selected mesopelagic assemblages.

INDICATOR SELECTION: SOUTHERN CALIFORNIA CURRENT, CALCOFI

INDICATOR EVALUATION: SOUTHERN CALIFORNIA CURRENT, CALCOFI

We considered a number of indicators to represent the coastal pelagic larval and forage assemblage in southern California. Our choice of indicators was based on relative abundances, time series length and availability. As well, the literature indicates that unexploited oceanic assemblages are more sensitive to climatic effects than coastal and/ or exploited species (Hsieh and Ohman 2006).Data sources potentially included: 1. estimates of small pelagic fish biomass from acoustics (MacLennan and Simmonds 1992, Zwolinski and Demer 2012, Zwolinski et al. 2012), 2. sardine biomass from aerial surveys (Jolly and Watson 1979, Lo et al. 1992), and 3.Daily Egg Production Method (DEPM) surveys for sardine (Lasker 1985, Lo et al. 1996). Although these series are valuable and both the acoustic surveys and the DEPM surveys produce biomass or spawning biomass estimates, results from these surveys are integrated in the sardine stock assessment (Crone et al 2011, Hill et al. 2011) , and we therefore do not use them individually in this report.

An additional data source, the California Cooperative Oceanic Fisheries Investigations (CalCOFI) provides the longest and most complete estimates of abundance of over 400 combined fish and cephalopod species (Table C1). Here we utilized CalCOFI ichthyoplankton data from 1951 to 2010 collected through oblique vertical plankton tows as described by Kramer et al (1972) and Smith and Richardson (1977).

Table C1: List of mesopelagic and coastal pelagic species from CalCOFI surveys used in this report. Subcategory lists mesopelagic species associated with warm or cool water conditions in the Southern California Bight. All species were captured as larvae and enumerated in units of mean larvae/10m^2 captured in the CalCOFI core area within three month periods (i.e., quarters) and summed over all four quarters for a year.

Genus species	Common name	Subcategory
Bathylagus pacificus	slender blacksmelt	cool-water
Bathylagus wesethi	snubnose blacksmelt	warm-water
Ceratoscopelus townsend	fangtooth lanternfish	warm-water
Citharichthys sordidus	Pacific sanddab	
Diogenichthys atlanticus	longfin lanternfish	warm-water
Diogenichthys laternatus	diogenes laternfish	warm-water
Engraulis mordax	northern anchovy	
Leuroglossus stilbius	California smoothtongue	cool-water
Lipolagus ochotensis	eared blacksmelt	cool-water
Merluccius productus	hake	
Protomyctophum crockeri	California flashlightfish	cool-water
Sardinops sagax	Pacific sardine	
Sebastes jordani	shortbelly rockfish	
Stenobrachius leucopsarus	northern lampfish	cool-water
Symbolophorus californiensis	bigfin laternfish	warm-water
Tarletonbeania crenularis	blue laternfish	cool-water
Triphoturus mexicanus	Mexican lampfish	warm-water
Vinciguerria spp.	lightfishes	warm-water

We have restricted our analysis to the most abundant and potentially influential CPS and forage species for which we have data. To provide an integrated measure of large-scale responses to environmental variability, we aggregated the mesopelagic fishes into cool- and warm-water groups following Hsieh et al. (2005). These groups are likely to reflect general trends in the ecosystem better than time series for individual species, some of which are relatively data poor. The species and groups analyzed were Pacific sardine, northern anchovy, hake, jack mackerel, Pacific sanddab, shortbelly rockfish, cool-water mesopelagics, and warm-water mesopelagics (Figure C2.)

Summary of indicators: Southern California Current, CalCOFI

1. All data are from the core CalCOFI sampling area (lines 76.7-93.3, stations 28.0 – 120.0; Figure C1) for years when the core area was sampled during each quarter of the year. Mean larval abundances (larvae/10 m^2) were estimated for each 3.3-line by 10-station cell in the core area for each quarter, and then cells were summed over the year. Means across the entire time series were then calculated using the delta-lognormal distribution (Pennington 1983). This procedure standardized the data given unequal sampling effort during some cruises, many zero catches, and seasonal but variable patterns of spawning for the fishes analyzed.
2. Individual species analyzed were Pacific sardine, northern anchovy, Pacific hake, jack mackerel, Pacific sand dab, and shortbelly rockfish.
3. The cold- and warm-water associated mesopelagic species were summed for each net tow and then analyzed as groups following the same method described above for individual species.
4. Summed forage is simply the sum of the larval abundances listed in Table C1 and expressed on a log scale.

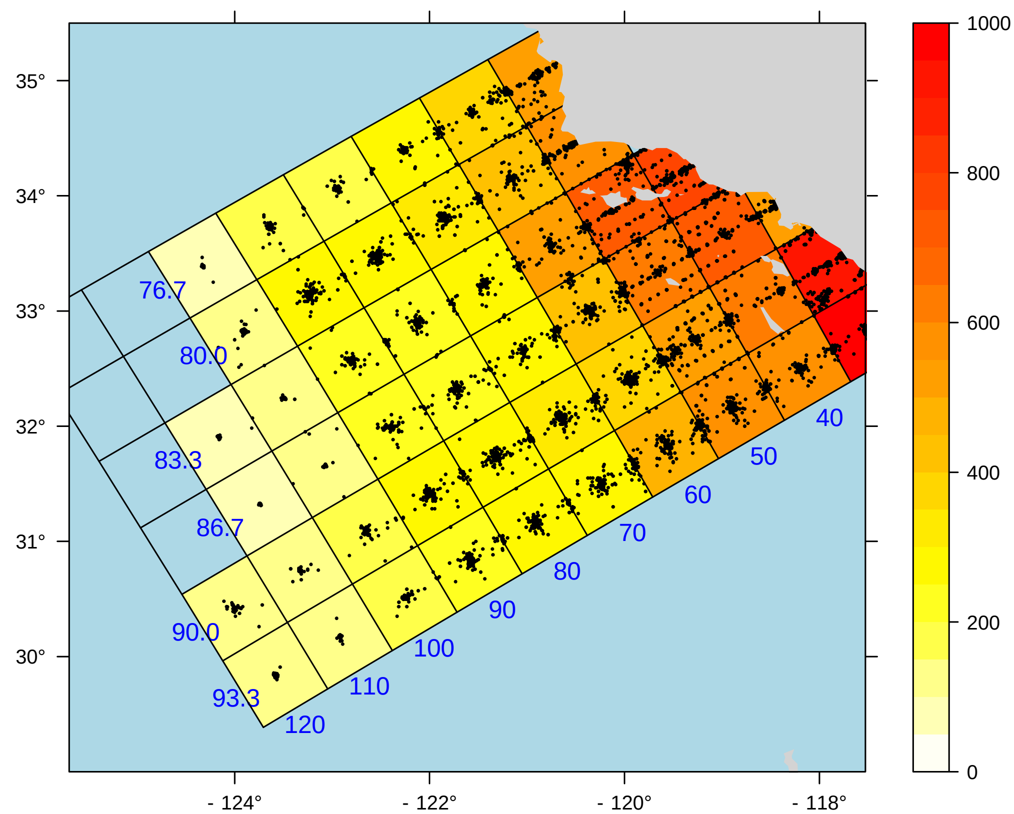
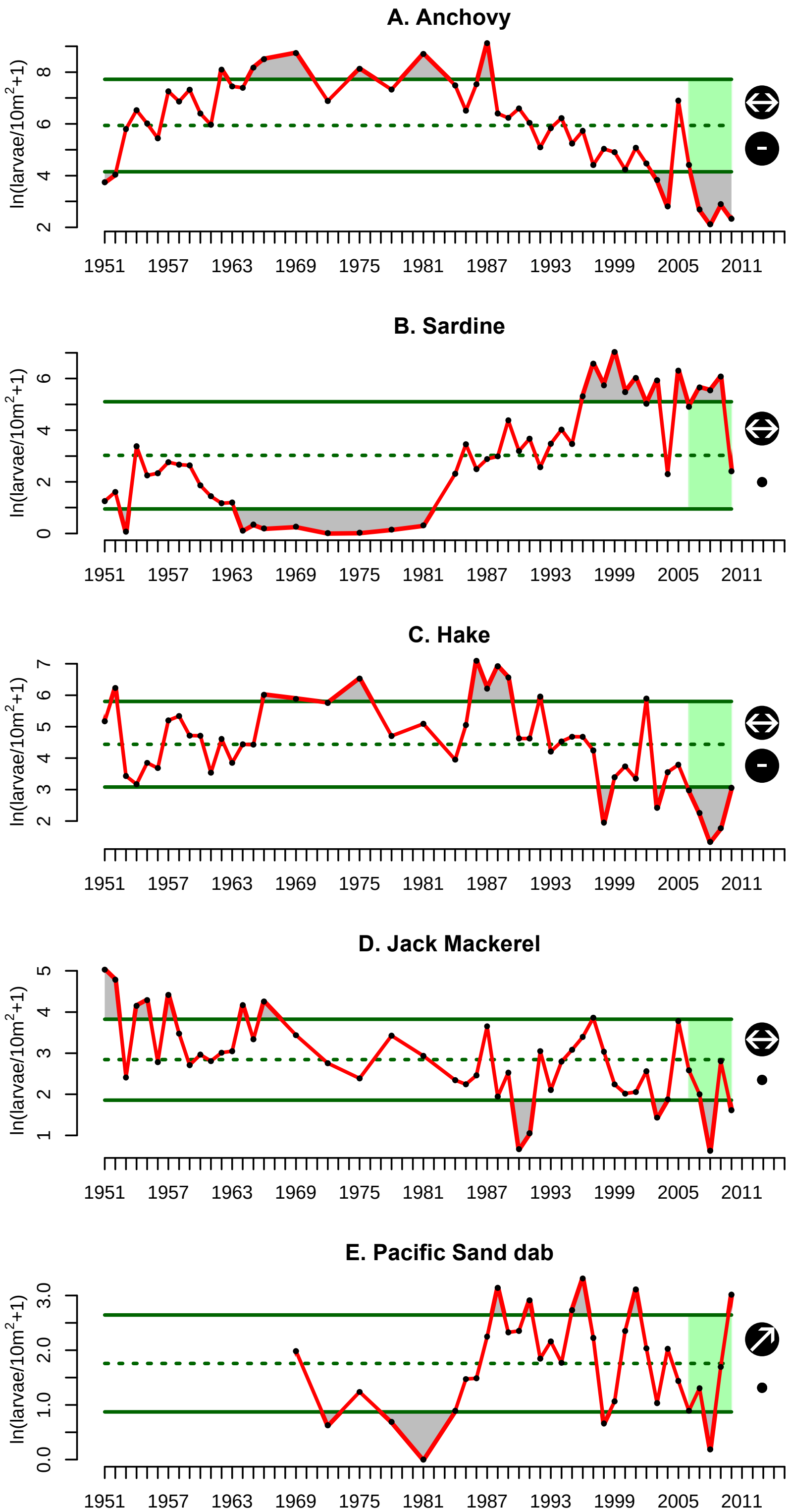


Figure C1. *CalCOFI Sampling Pattern for Oblique Net Tows*. Grid pattern of 3.3-line by 10-station cells in the core CalCOFI sampling area (lines 76.7-93.3) used for analysis of Southern California forage. Color key indicates actual number of samples collected within each cell for the period 1951-2010. Black dots indicate actual sample locations.


A. Anchovy
ln(larvae/10m^2+1)
2
4
6
8
1951
1957
1963
1969
1975
1981
1987
1993
1999
2005
2011
B. Sardine
ln(larvae/10m^2+1)
0
2
4
6
1951
1957
1963
1969
1975
1981
1987
1993
1999
2005
2011
C. Hake
ln(larvae/10m^2+1)
2
3
4
5
6
7
1951
1957
1963
1969
1975
1981
1987
1993
1999
2005
2011
D. Jack Mackerel
ln(larvae/10m^2+1)
1
2
3
4
5
1951
1957
1963
1969
1975
1981
1987
1993
1999
2005
2011
E. Pacific Sand dab
ln(larvae/10m^2+1)
0.0
1.0
2.0
3.0
1951
1957
1963
1969
1975
1981
1987
1993
1999
2005
2011

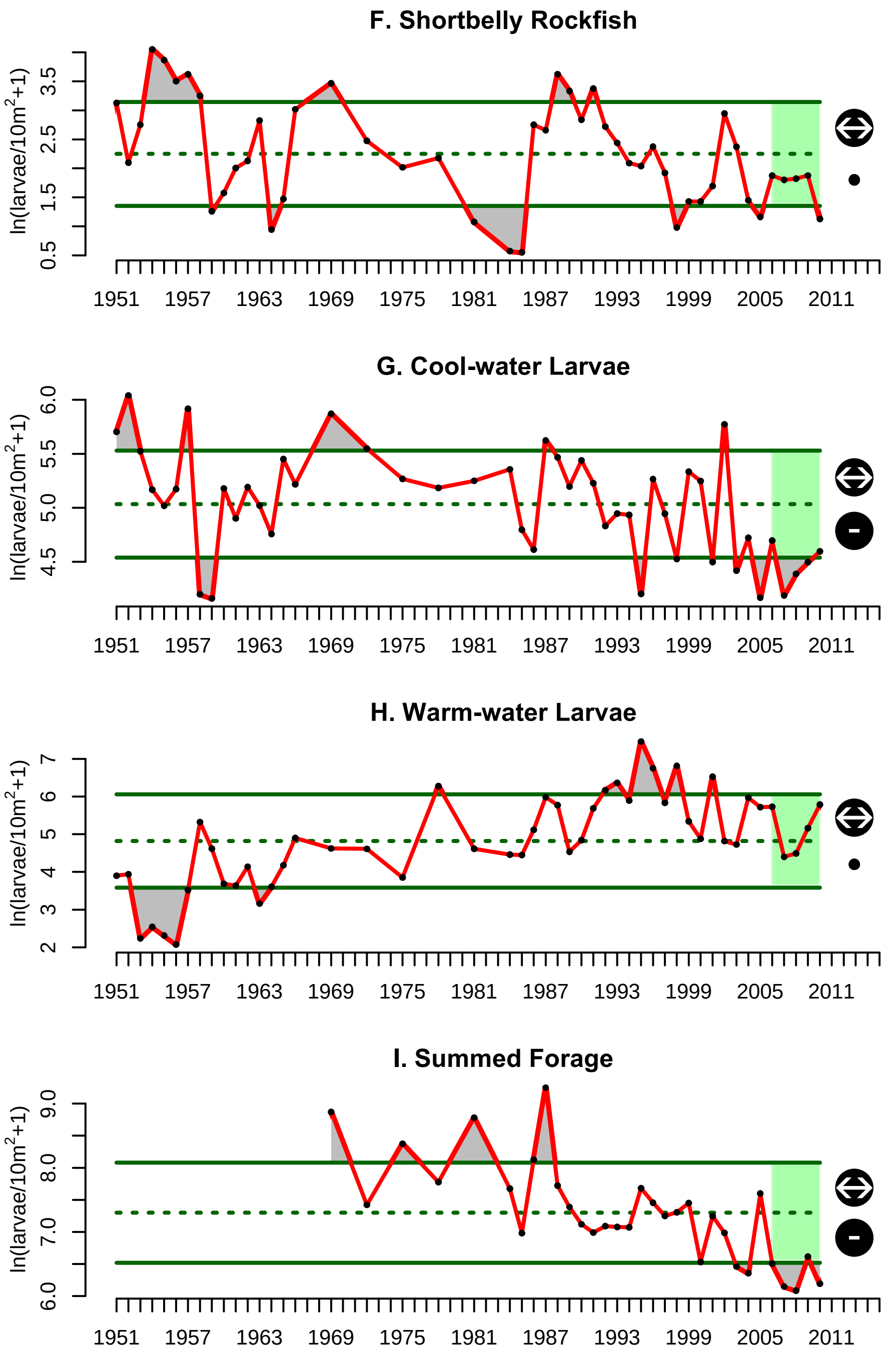


Figure C2. *Southern California Forage, CalCOFI.* Most time series are plotted in a standard format. Dark green horizontal lines show the mean (dotted) and ± 1.0 s.d. (solid line) of the full time series. The shaded green area is the last 5-years of the time series, which is analyzed to produce the symbols to the right of the plot. The upper symbol indicates whether the trend over the last 5-years increased, or decreased by more than 1.0 s.d. , or was within one 1.0 s.d of the long-term trend. The low symbol indicates whether the mean of the last 5 years was greater than (+), less than (-)or within (·) one s.d. of the long-term mean

STATUS AND TRENDS: SOUTHERN CALIFORNIA CURRENT, CALCOFI

MAJOR FINDINGS: SOUTHERN CALIFORNIA CURRENT, CALCOFI

Since 1951 the 6 species indicators and 2 species group indicators have shown high variability and limited covariation. The trends presented here are a simple, qualitative examination of major patterns, but we are testing additional ways to examine these data series including: 1) separation of the secular from the shorter time scale variability 2) examining trends in variance over time since there are indications in these series of large changes in variance over the time series, and 3) elucidating the autocorrelation structure of the time series to determine if sudden shifts in abundance occurred.

SUMMARY AND STATUS OF TRENDS: SOUTHERN CALIFORNIA CURRENT, CALCOFI

We report both long-term means and recent trends in this status review. Under the current framework, an indicator is considered to have changed in the short-term if there are significant increasing or decreasing trends over the last five years. An indicator is considered to be above or below long-term norms if the mean of the last five years of the time series differs from the mean of the full time series by more than 1.0 standard deviation.

Anchovy, hake, and cool-water mesopelagics have generally decreased over the last 30 years (Figure C2). The current decline followed a long-term increase in anchovy larvae in the previous 30 years (1950s-70s) (Fig. C2). Such long-term changes hint at a multidecadal fluctuations in abundance, but this cannot be definitively assessed with the relatively short 65-year CalCOFI time series (McClatchie 2012). Summed forage species show the same pattern as anchovy, but that is because anchovy drive the forage fish time series (Fig. C2). Sardine larvae show an entirely different trend to anchovy, and it has been postulated (Chavez et al. 2003) that abundance peaks of these species alternate at decadal time scales (although the CalCOFI time series is too short to evaluate this hypothesis). Sardine larvae in the 1980s and 90s increased from the collapse of the stock in the 1950s. Although there has been a minor decline in sardine larval abundance since 2000, sardine abundance has generally remained above the mean of the last 60 years (Fig. C2). The warm water and cool water-associated oceanic mesopelagic larval assemblages show episodic, strong fluctuations about a mean value that has been relatively stable over the past 60 years.

INDICATOR SELECTION: CENTRAL CALIFORNIA CURRENT, MIDWATER TRAWL SURVEY

INDICATOR EVALUATION: CENTRAL CALIFORNIA CURRENT, MIDWATER TRAWL SURVEY

General description: Central California, midwater trawl survey

We evaluated a number of indicators to represent the coastal pelagic larval abundance in central California. Data are based on mid-water trawl collections. CPS and forage species data series that could potentially be included are krill (Euphausiids*)*, market squid, anchovy, and sardine. In addition, numerous other members of the forage community are available including juvenile salmon, juvenile sanddabs, octopus, juvenile hake, mesopelagics, and juvenile winter-spawned rockfishes (Santora et al. 2012). Each of these data series have been collected since 1990 and some as early as 1983. However, we focus here on the most abundant, continuously present, and available species: anchovy, sardine, market squid, krill, juvenile rockfishes, juvenile sand dabs, and juvenile hake (Table C2). As well, we sum these (minus krill) to represent an index of total forage abundance. Four of these, anchovy, sardine, market squid and krill represent the CPS.

Importantly, the abundance of anchovy and sardine from this survey in central California is not likely to represent overall population strengths as much as it represents variability in the distribution throughout the CCE (Bjorkstedt et al. 2012, Song et al. 2012). As a consequence, unlike the overall trend in CCE, anchovy and sardine are positively correlated for the majority of the time series. We did not include juvenile salmon because the net is inefficient at collecting salmon. Future reports will include additional results for mesopelagic species.

Table C2. Species collected and enumerated in the mid-water trawl survey along Central California.

Genus species	**Common name**	**Stage**	**Units**
Citharichthys sordidus	Pacific sanddab	juvenile	CPUE individuals*
Engraulis mordax	northern anchovy	adult	CPUE individuals
Euphausiids	krill	adult	CPUE individuals
Loligo opalescens	market squid	juvenile, adult	CPUE individuals
Merluccius productus	Pacific hake	juvenile	CPUE individuals
Sardinops sagax	Pacific sardine	adult	CPUE individuals
Sebastes spp.	rockfishes	juvenile	CPUE individuals

*CPUE is catch per unit of effort

This data is based on midwater trawl surveys that have operated annually during May-June from 1983-present. However, all the data used here has been taken only since 1990 as methodology has been consistent since. Samples were collected using a modified Cobb midwater trawl, with a head rope depth of 30 m (the average depth of the thermocline in the region) at a speed of ~2 knots for 15 minutes at depth, with the exception of stations that were too shallow (< ~60m) such as those in the Gulf of the Farallones for which the headrope depth was 10 m (Sakuma et al. 2006). In all cases, samples represent catch per standard 15 minute trawl (CPUE). The data was log-transformed data because it was log-normally distributed .

Appropriate indicators: Central California Current, midwater trawl survey

We examined trends in anchovy and Pacific sardine. Along the CCE northern anchovy abundance variability tends to be positively related to warmer, less productive conditions. In central California, temporal dynamics of northern anchovy abundance likely reflect abundance likely a change in the distribution relative to CCE as a whole (for the May-June period in which the survey is conducted) rather than overall changes in the stock. However, while the anchovy abundance variability is poorly correlated to ocean temperatures in central California, during times of low productivity across the CCE northern anchovy make up a greater proportion of the diets of seabirds locally and, therefore, their relative abundance in the forage community can indicate overall productivity conditions. Along the CCE Pacific sardine abundance variability is positively related to cooler, more productive conditions. In central California, Pacific sardine abundance likely represents a change in the average distribution.

As well, we examined trends in a number of additional fishes that during a period of their life cycle are important contributors to the forage community, including: juvenile Pacific hake, juvenile rockfish, and juvenile Pacific sanddabs. Currently the factors that drive variability in Pacific hake abundance in this survey are not entirely clear as high numbers may represent a strong year class or a shift in the distribution of young-of-the-year. Juvenile and sub-adult hake are an important prey for many other higher trophic level predators. Juvenile rockfish captured in this data series represent juveniles spawned in the current winter (e.g., age 0 individuals). While pelagic, they represent a critical prey resource for predators such as Common murre, rhinoceros auklets and Chinook salmon, and there is a significant relationship between juvenile rockfish abundance and breeding success of seabirds ((Wells et al. 2008a, Field et al. 2010). Pacific sanddabs, when juveniles, are pelagic and represent a moderately important prey resource for many predators in the region.

Krill is a reasonable indicator of local environmental quality. Krill abundance is known to increase during productive conditions with optimal winds (Cury and Roy 1989). Central California represents a krill hot spot (Santora et al. 2011) where seabirds, mammals, salmon (adult and juveniles), juvenile rockfishes and a number of other species feed on krill. Wells et al. (2008b) and Wells et al (2012)demonstrate the critical role of krill on seabirds, rockfish and salmon. Here, we do not separate the two dominant species of krill in central California (*Euphausia pacifica* and *Thysanoessa spinifera*) because they were not identified to the species level until 2002. However, the two species generally occupy different habitats (inner-shelf vs outer-shelf, (Santora et al. 2012))and have different life-histories. Predators tend to rely on one of the two species more than the other. For example, juvenile rockfish prey primarily on *E. pacifica* (Reilly et al. 1992) and juvenile salmon on *T. spinifera* (Wells et al. 2012). In the future, as these series continue, we will analyze each species separately.

Monterey Bay is a spawning ground for market squid, and this species forms one of the largest and most lucrative California fisheries. Both juvenile and adult squid make up a significant proportion of the diets of many predators. High market squid abundance is generally positively associated with cool, productive conditions. Data series is log-normally distributed so in these analyses we log-transformed the data.

Summed forage is simply the sum of the fish abundances listed above in Table CPS2. There are clear problems with this data series: not all fish are the same size, the data have not been weighted for seasonality of spawning, and responses to environmental variability may affect the relative abundance of species. We envision this indicator as a first step toward truer measures of forage biomass and suggest this be a gap to be filled in future IEAs.

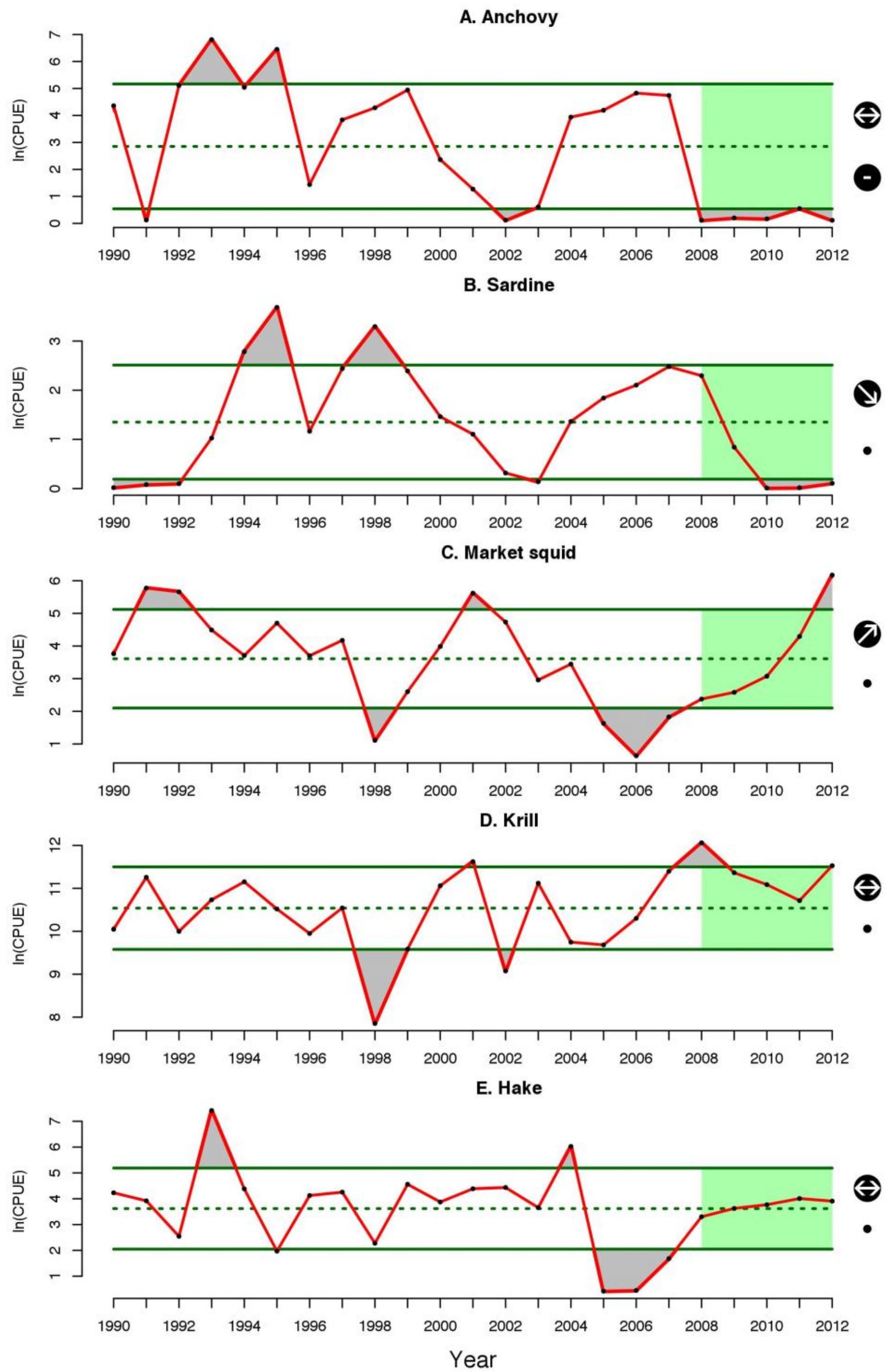
STATUS AND TRENDS: CENTRAL CALIFORNIA CURRENT, MIDWATER TRAWL SURVEY

MAJOR FINDINGS: CENTRAL CALIFORNIA CURRENT, MIDWATER TRAWL SURVEY

2005 and 2006 were poor production years for rockfish, sanddabs, squid and hake; consistent with observations of anomalous ocean conditions and poor reproductive success of higher trophic levels reported elsewhere. In the last five years all but anchovy and sardine abundance were within 1 s.d. of long-term mean (Figure C3). Notably, high abundance of krill over the past five years, and the greatest abundance on record of market squid was found in the last year (Figure C3). Overall, these data series suggest that recent years have been conducive to more production and stable or improved forage abundance, in agreement with Bjorkstedt et al. (2012)

SUMMARY AND STATUS OF TRENDS: CENTRAL CALIFORNIA CURRENT, MID-WATER TRAWL SURVEY

Anchovy are currently below their long-term average and there is no obvious recent trend (Figure C3). Similarly, sardine recently fell below average abundance following a negative trend since 2007. However, the remaining indicators are within 1 s.d. of their long-term means. Rockfish and sanddabs have recovered from the poor years of 2005 and 2006 (Figure C3). Likewise, krill abundance achieved record levels in 2008 and has maintained relatively high abundance in recent years (Figure C3). Finally, market squid is presently experiencing the greatest of the three boom periods of the last 20 years (Figure C3).


A. Anchovy
B. Sardine
C. Market squid
D. Krill
E. Hake
ln(CPUE)
Year
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012

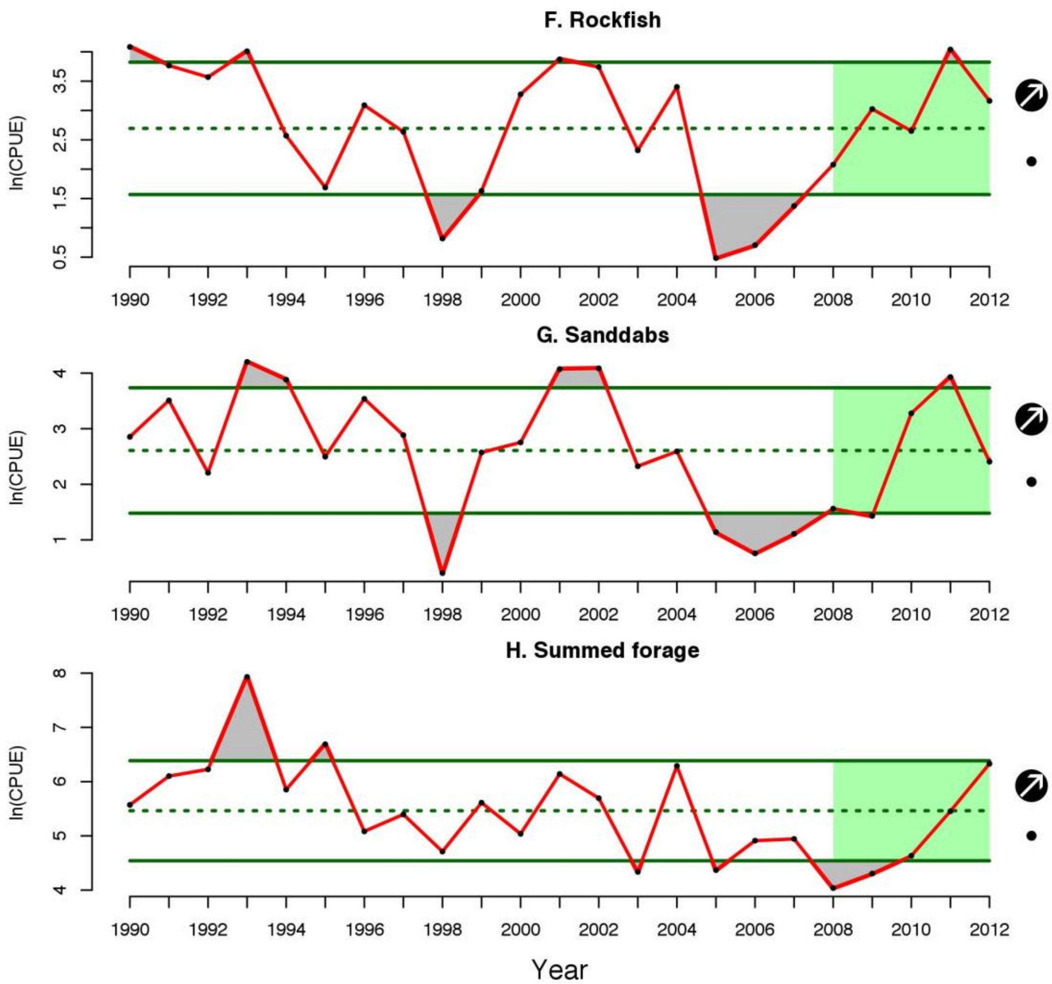


Figure C3. *Central California Forage, mid-water trawl.* Most time series are plotted in a standard format. Dark green horizontal lines show the mean (dotted) and ± 1.0 s.d. (solid line) of the full time series. The shaded green area is the last 5-years of the time series, which is analyzed to produce the symbols to the right of the plot. The upper symbol indicates whether the trend over the last 5-years increased, or decreased by more than 1.0 s.d. , or was within one 1.0 s.d of the long-term trend. The low symbol indicates whether the mean of the last 5 years was greater than (+), less than (-)or within (·) one s.d. of the long-term mean.

INDICATOR SELECTION: NORTHERN CALIFORNIA CURRENT, PREDATOR SURVEY

INDICATOR EVALUATION: NORTHERN CALIFORNIA CURRENT, PREDATOR SURVEY

General description: Northern California Current, predator survey

Forage fish data were collected by the NWFSC-NOAA predator surveys along two transects off the Columbia River and Willapa Bay, WA every two weeks from May through August (8-10 cruises a year starting in 1998 (Emmett et al. 2005). However, because the survey was scaled back to just the Willapa Line in 2011 we analyze only samples from this line. All tows were made at the surface to the upper 20 m of the water column during the night. Numbers of individuals were recorded for each species caught in each haul and standardized by the horizontal distance traveled by the towed net. Yearly abundance data was obtained by combining (summing) the standardized count data of each species captured during all cruises for each year.

Appropriate indicators: Northern California Current, predator survey

Table C3. Species collected in the surface trawl of the northern California Current predator survey.

Genus species	Common name	Stage	Units
Allosmerus elongatus	whitebait smelt	juvenile, adult	CPUE individuals
Clupea pallasii	Pacific herring	juvenile, adult	CPUE individuals
Engraulis mordax	northern anchovy	juvenile, adult	CPUE individuals
Sardinops sagax	Pacific sardine	juvenile, adult	CPUE individuals

Time series plots of standardized yearly abundance data are presented for each of the four most dominant and consistently collected forage species (Pacific sardine, northern anchovy, Pacific herring and whitebait smelt; Table C3). Although other forage species are caught in these surveys, these four species represent the bulk of the forage fish catch in surface waters at night. They include migratory (sardines and some anchovies) species that may spawn off the Pacific Northwest or migrate from California (Emmett et al. 2005, Litz et al. 2008). Herring and whitebait smelt are likely spawned locally. These species may have seasonal trends in abundance (Emmett et al. 2005) so may have different trends than taken twice a year but over a broader geographical area. The data are log-normally distributed therefore was log-transformed for this analysis.

Summed forage is simply the sum of the fish abundances listed above in Table C3. There are clear problems with this data series: not all fish are the same size, the data have not been weighted for seasonality of spawning, and responses to environmental variability may affect the relative abundance of species. We envision this indicator as a first step toward truer measures of forage biomass and suggest this be a gap to be filled in future IEAs Data series is log-normally distributed so in these analyses we log-transformed the data. Data series are log-normally distributed so in these analyses we log-transformed the data.

STATUS AND TRENDS: NORTHERN CALIFORNIA CURRENT, PREDATOR SURVEY

MAJOR FINDINGS: NORTHERN CALIFORNIA CURRENT, PREDATOR SURVEY

Sardines appear to be undergoing a decline in the northern California Current since their peak levels in 2000-2003 (Fig. C4). Whitebait smelt and summed forage fish are increasing in recent years (Fig. C4).

SUMMARY AND STATUS OF TRENDS: NORTHERN CALIFORNIA CURRENT, PREDATOR SURVEY

Over the last decade, anchovy showed a broad peak in above average abundance lasting 2-3 years, followed by a decline to much lower abundance that has remained relatively stable over the last 5 years. Herring showed a similar pattern to anchovy with higher abundances developing two years earlier than anchovy (Fig. C4). Sardine showed a similar pattern to herring, but declined more slowly and with greater variation. Notably, the sardine decline continued in the last 5 years, and did not stabilize as did anchovy and herring (Fig. C4). Cooler ocean conditions since the El Niño of 2010 may have resulted in decreased abundance or survival of sardines but may be conducive to higher survival in whitebait smelt which displayed a positive recent trend. The summed forage also demonstrated a modest but significant upward trend.

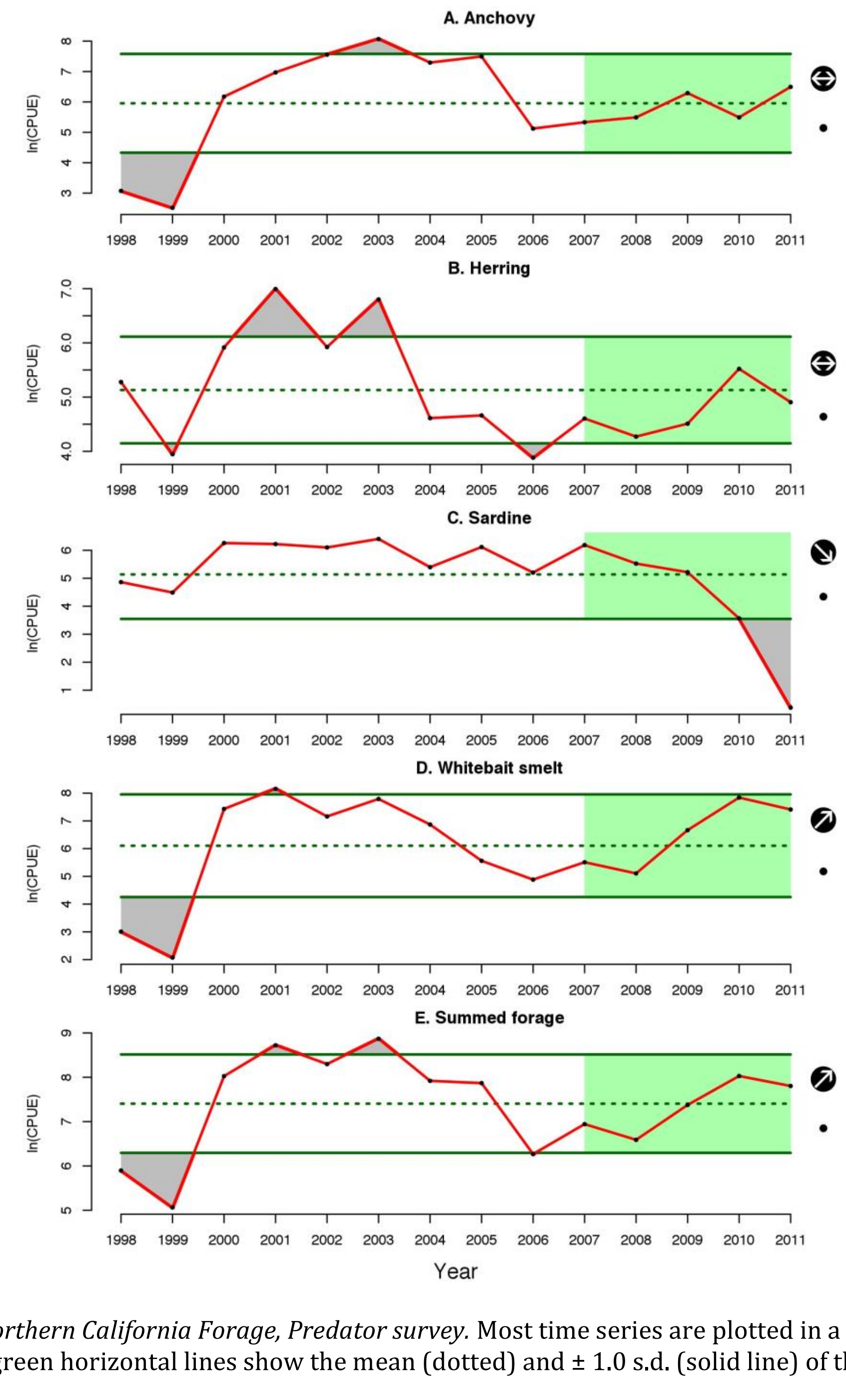


Figure C4. *Northern California Forage, Predator survey.* Most time series are plotted in a standard format. Dark green horizontal lines show the mean (dotted) and ± 1.0 s.d. (solid line) of the full time series. The shaded green area is the last 5-years of the time series, which is analyzed to produce the symbols to the right of the plot. The upper symbol indicates whether the trend over the last 5-years increased, or decreased by more than 1.0 s.d. , or was within one 1.0 s.d of the long-term trend. The low symbol indicates whether the mean of the last 5 years was greater than (+), less than (-)or within (·) one s.d. of the long-term mean.

INDICATOR SELECTION: NORTHERN CALIFORNIA CURRENT, COLUMBIA RIVER PLUME

INDICATOR EVALUATION: NORTHERN CALIFORNIA CURRENT, COLUMBIA RIVER PLUME

General description: Northern California Current, Columbia River plume

Pelagic nekton catch data were collected by the NWFSC-NOAA Bonneville Power Administration survey surface trawls on standard transects and stations between Tatoosh Island, WA and Cape Perpetua, OR in June and September from 1998 to 2011. All tows were made during the day at predetermined locations along transects extending off the coast to the shelf break (Brodeur et al. 2005). Numbers of individuals were recorded for each species caught in each haul and were standardized by the horizontal distance sampled by the towed net as CPUE (no. km^{-1} towed). Yearly abundance data were obtained by combining (summing) the standardized count data of each species captured during June and September for each year.

Appropriate indicators: Northern California Current, Columbia River plume

Table C4. Species collected din the surface trawl of the Northern California Current Columbia River plume survey.

Genus species	Common name	Stage	Units
Allosmerus elongatus	whitebait smelt	juvenile, adult	CPUE individuals
Clupea pallasii	Pacific herring	juvenile, adult	CPUE individuals
Engraulis mordax	northern anchovy	juvenile, adult	CPUE individuals
Sardinops sagax	Pacific sardine	juvenile, adult	CPUE individuals
Trachurus symmetricus	Jack mackerel	juvenile, adult	CPUE individuals

Time series plots of standardized yearly abundance data are presented for each of the five most dominant and consistently collected forage species measured (jack mackerel, Pacific sardine, northern anchovy, Pacific herring and whitebait smelt; Table C4). Although other forage species are caught in these surveys, these five species represent the bulk of the forage fish catch in surface waters at night. They include migratory species (sardines and some anchovies) that may spawn off the Pacific Northwest or migrate from California (Emmett et al. 2005, Litz et al. 2008). Jack mackerel can be a forage fish at younger ages but off Oregon and Washington are too large to be fed upon by a number of predators such as seabirds or adult rockfishes. They spawn off southern California and arrive during summer to feed off Oregon and Washington. Herring and whitebait smelt are likely spawned locally. A number of these species may have seasonal trends in abundance (Emmett et al. 2005) so may have different trends than taken twice a year but over a broader geographical area. Because the data are log-normally distributed they were log-transformed for this analysis.

Summed forage is simply the sum of the fish abundances listed above in Table C4. There are clear problems with this data series: not all fish are the same size, the data have not been weighted for seasonality of spawning, and responses to environmental variability may affect the relative abundance of species. We envision this indicator as a first step toward truer measures of forage biomass and suggest this be a gap to be filled in future IEAs.

STATUS AND TRENDS: NORTHERN CALIFORNIA CURRENT, COLUMBIA RIVER PLUME

MAJOR FINDINGS: NORTHERN CALIFORNIA CURRENT, COLUMBIA RIVER PLUME

The environment has fluctuated during the period since 1998 between relatively cool years (2008, 2011) to warm El Niño years (2010) (Bjorkstedt et al. 2012), likely leading to great variability in jack mackerel, Pacific herring, and sardine.

SUMMARY AND STATUS OF TRENDS: NORTHERN CALIFORNIA CURRENT, COLUMBIA RIVER PLUME

Jack mackerel also show episodic outbreaks early in the decade, followed by a decline in the last 7 years to recent below average abundance (Figure C5). Herring shows a consistent, if non-monotonic declining trend over the last decade (Figure C5). The smelt population appears to be stable recently following two periods in 1999/2000 and 2006 of below average values (Figure C5). Anchovy has remained near above average abundance for much of the last ten years following well below average values in the late 90's and early 2000's (Figure C5). By contrast, sardine abundance was below average in 2008 and 2010 but there is apparent significant trend in recent years.

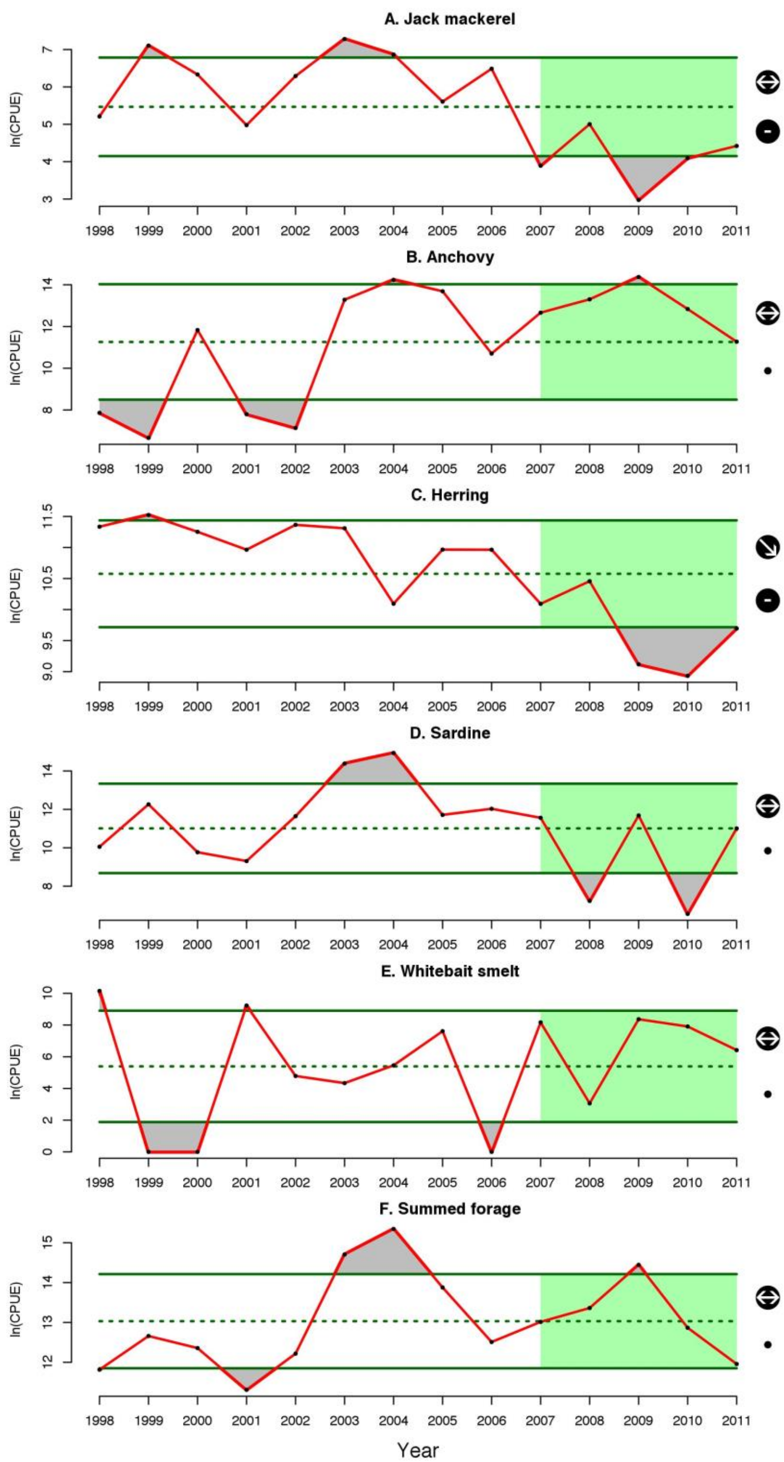


Figure C5. Northern California Forage, Columbia River plume. Most time series are plotted in a standard format. Dark green horizontal lines show the mean (dotted) and ± 1.0 s.d. (solid line) of the full time series. The shaded green area is the last 5-years of the time series, which is analyzed to produce the symbols to the right of the plot. The upper symbol indicates whether the trend over the last 5-years increased, or decreased by more than 1.0 s.d. , or was within one 1.0 s.d of the long-term trend. The low symbol indicates whether the mean of the last 5 years was greater than (+), less than (-)or within (.) one s.d. of the long-term mean

INDICATOR SELECTION: ASSESSMENTS

INDICATOR EVALUATION: ASSESSMENTS

General description: Assessments

Pacific mackerel (Crone et al. 2011) and sardine (Hill et al. 2011) assessments are prepared for the PFMC annually to be used for developing harvest rules. These assessments incorporate data from a number of sources and determine the biomass and age distribution of the populations along the coast. They represent the most complete analysis of the abundance trends across the CCE. Therefore, we use these assessments to guide our estimation of population trends of abundance and condition for these two species.

The Pacific mackerel assessment is an age-structured model incorporating information on catch, length and age distributions, and recreational fishery surveys (Crone et al. 2011). Full model details, problems and uncertainties are disclosed at http://www.pcouncil.org/coastal-pelagic-species/stock-assessment-and-fishery-evaluation-safe-documents/ and in Crone et al. (2011).

The sardine assessment includes fishery and survey data, egg production, aerial survey estimates of biomass, and acoustic estimates of biomass. Full model details, problems, uncertainties are disclosed at http://www.pcouncil.org/coastal-pelagic-species/stock-assessment-and-fishery-evaluation-safe-documents/ and in Hill et al. (2011).

Appropriate indicators: Assessments

We focus on three indicators representing abundance and condition of Pacific mackerel and sardine. To estimate abundance trends we evaluate the biomasses of the two species.

1. Biomass of sardine is the most recent estimate provided by a member of the stock assessment team (Hill et al. 2011) in June 2012. Units are log-transformed metric tons.

2. Biomass of Pacific mackerel is the most recent estimate provided by a member of the stock assessment team (Crone et al. 2011) in June 2012. Units are log-transformed metric tons.

3. We evaluate the condition of sardine by examining their age distribution. 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. A gap in our analysis is to develop a more appropriate and interpretable index of condition.

STATUS AND TRENDS: ASSESSMENTS

MAJOR FINDINGS: ASSESSMENTS

In recent years the biomasses of Pacific mackerel and sardine have been average relative to the long-term mean yet, for sardine, the recent values are greater than the period following the population crash between 1950 and the early 1990s.

SUMMARY AND STATUS OF TRENDS: ASSESSMENTS

In the first half of the 20th century both Pacific mackerel and sardine were relatively abundant. In the late 1970s and 1980s Pacific mackerel demonstrated above average production but production has declined in the past two decades. In the last five years population estimates of biomass are within 1 s.d. of the long-term mean and there is no apparent trend (Figure C6). Similarly, sardine experienced near-above average production in the past 10-20 years yet the estimates of biomass are with 1 s.d. of the long-term mean suggesting that, while the abundance in greater in recent years, it is still only a portion of that observed in the earlier part of the 20th century (Figure C7).

Sardine can live to greater than 10 years (we grouped 10+ into the 10 age category). The age structure is heavily weighted by the youngest ages, as is typical, but following major recruitment events (such as 2004) the age range can be quite large (Figure C7). During 1999-2001 recruitment was somewhat low relative to the other years shown as can be observed by the age structure being more heavily weighted by three and four year olds. Following a number of poor recruitment years as the older fish died out the biomass dropped to a low in 2003. In 2004 a larger recruitment event occurred and the biomass rebounded by 2006.

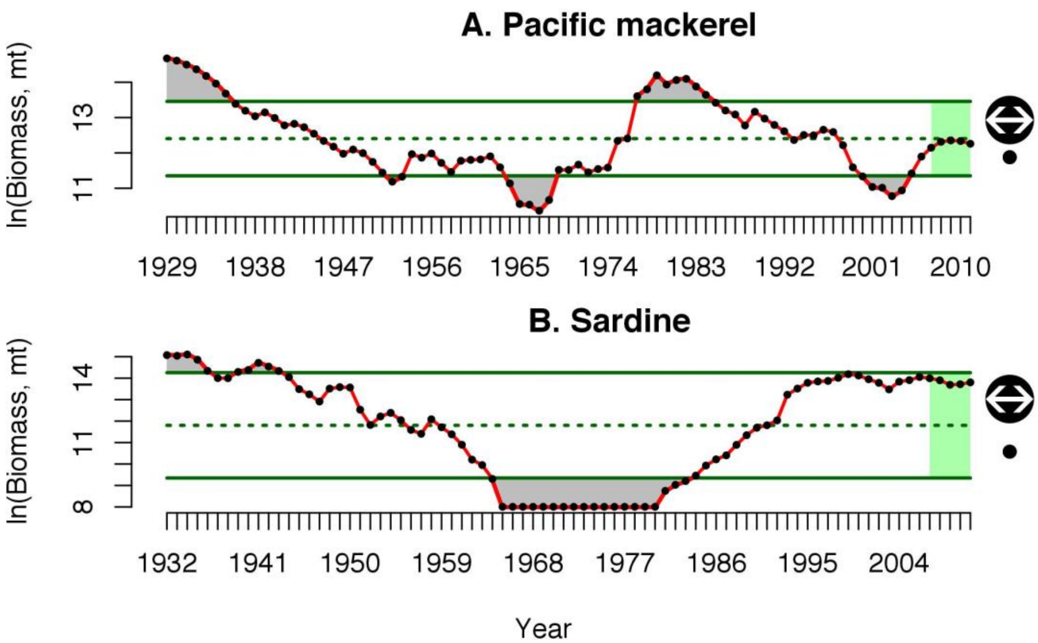


Figure C6. *Assessment biomasses.* Most time series are plotted in a standard format. Dark green horizontal lines show the mean (dotted) and ± 1.0 s.d. (solid line) of the full time series. The shaded green area is the last 5-years of the time series, which is analyzed to produce the symbols to the right of the plot. The upper symbol indicates whether the trend over the last 5-years increased, or decreased by more than 1.0 s.d. , or was within one 1.0 s.d of the long-term trend. The low symbol indicates whether the mean of the last 5 years was greater than (+), less than (-)or within (·) one s.d. of the long-term mean.

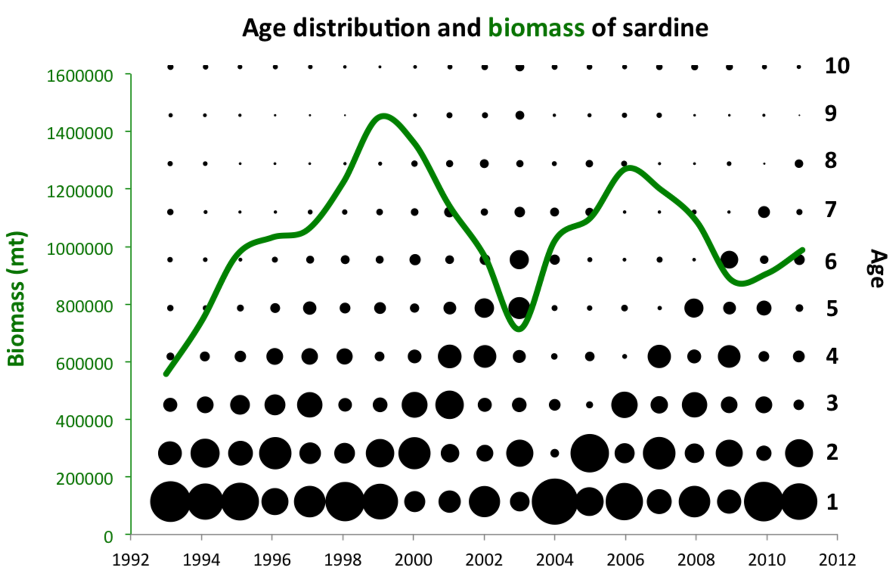


Figure C7. *Assessed age structure*. Shown are the biomass of sardines and the proportions of various ages (y-axis) in the population of sardine from 1993 to 2011.

RISK

We are not directly evaluating risk in this IEA. In the future, we will put efforts toward quantifying the relationships between environmental conditions and CPS responses (e.g., Brodeur et al. 2005, Song et al. 2012) and exposure to fishing and other anthropogenic impacts in such a way as to represent the potential risk posed to the CPS and forage community.

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Integrated Ecosystem Assessment of the California Current

Phase II Report 2012

August 2013

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

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Full report :

Levin, P.S., B.K. Wells, M.B. Sheer (Eds). 2013. California Current Integrated Ecosystem Assessment: Phase II Report. Available from ***http://www.noaa.gov/iea/CCIEA-Report/index***.

Chapter (example):

K.S. Andrews, G.D. Williams, and V.V. Gertseva. 2013. Anthropogenic drivers and pressures, In: Levin, P.S., Wells, B.K., and M.B. Sheer, (Eds.), California Current Integrated Ecosystem Assessment: Phase II Report. Available from ***http://www.noaa.gov/iea/CCIEA-Report/index***.

Appendix, example for MS5:

Gray, I.A., I.C. Kaplan, I.G. Taylor, D.S. Holland, and J. Leonard. 2013. Biological and economic effects of catch changes due to the Pacific Coast Groundfish individual quota system, Appendix MS5, Appendix to: Management testing and scenarios in the California Current, In: Levin, P.S., Wells, B.K., and M.B. Sheer (Eds.). California Current Integrated Ecosystem Assessment: Phase II Report. Available from ***http://www.noaa.gov/iea/CCIEA-Report/index***.