Status of the California Current Ecosystem: Major EBM Components

Introduction

Our main findings are:

- The variability of seasonal upwelling onset (for example late upwelling in 2005) led to the collapse of Sacramento River fall-run Chinook salmon, Oregon coho, and Cassin's auklets (*Ptychoramphus aleuticus*) in the Gulf of the Farallones. Cumulative interactions between climate change and fishing pressure have resulted in severe CCLME salmon population declines, potentially resulting in severe societal costs in recent years.
- Groundfish assemblages on the west coast have shown changes in abundance (number per km^2) and assemblage structure from 2005 to 2009. Seventeen species were chosen to represent broad functional groups. More than half (10 of 17) of the groundfish species examined declined in abundance, while 5 showed no trend and only 2 increased. Shannon Diversity and top predator biomass of groundfish assemblages have also declined over this period.

Below we present time series of indicators associated with each of our EBM components. For primary producers, we present annual winter and summer time series while mid and upper trophic species are examined on an annual basis. For a summary of data sets included in this report, see Appendix C. Analyses of groundfish and ecosystem health were repeated for each of four NMSs north of Point Conception and these results are presented in Appendix D.

EBM Component: Central California Salmon

Pacific salmon are among the most culturally important and economically valuable commercially fished species in the CCLME. Significant fluctuations in salmon abundances and marine survival occurred throughout the CCLME during 2003–2008, leading to a number of dramatic management actions. Chinook and coho salmon that emigrate from rivers from California to Oregon reside in coastal waters for a period of time before migrating up the coast. It is in these coastal waters that the greatest mortality occurs. A poor environment can lead to reduced early growth and ultimately poor survival and recruitment to the spawning stock (Beamish and Mahnken 2001, Beamish et al. 2004, Wells et al. 2008).

Coho salmon hatchery returns (OPI) were below average in 2005 and 2006 (Figure 4), pointing to poor ocean conditions in 2004 and 2005, the years of ocean entry. These years, though demonstrating reduced returns, were not as poor as during the mid-1990s (Peterson and Schwing 2003). Juvenile coho salmon growth off the west coast of Vancouver Island in 2005 was the lowest on record since 1998 (DFO 2006).

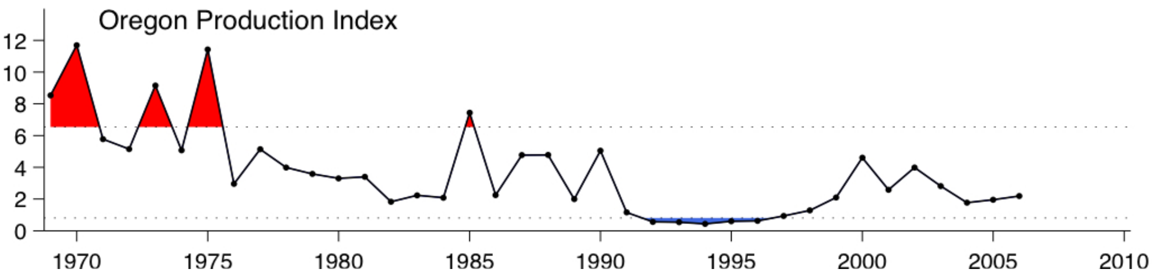


Figure 4. Coho salmon percent, smolt-adult return, 1970–2006. Dashed lines reflect 1 SD above and below the long-term mean.

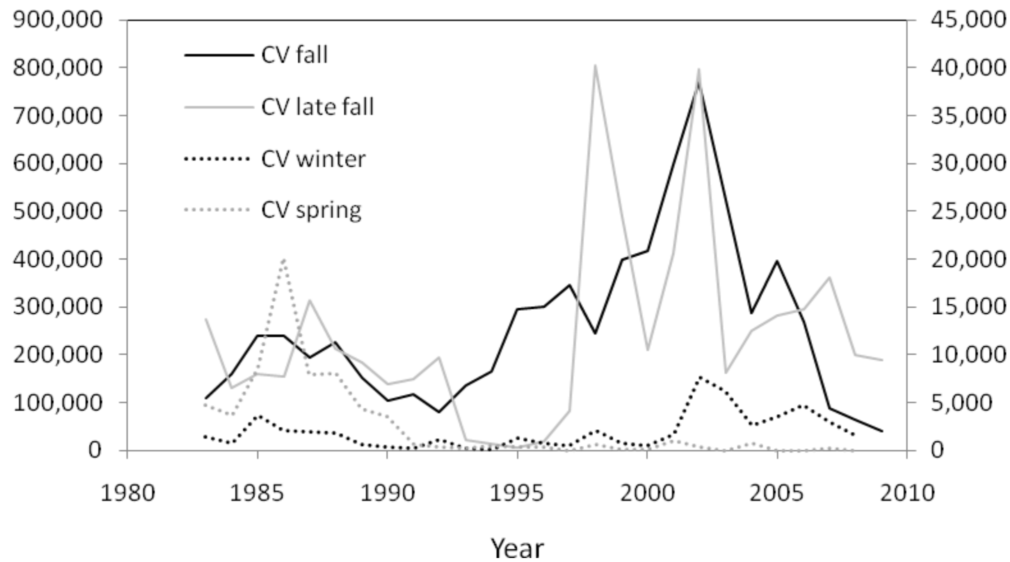
Key Attribute: Population Size

Indicator: Spawning escapement

There are four temporally segregated Chinook salmon runs in the Central Valley. Such diversity in life history buffers Chinook salmon against environmental variability. However anthropogenic impacts have resulted in an unnaturally large contribution of a fall run and three less productive runs (Lindley et al. 2009b). Estimates of Central Valley spawning escapement are used to set fishery limits to ensure that spawner numbers remain high enough for populations to remain viable.

Chinook salmon fall escapement had an increasing trend, though the values have plummeted since 2002 (Figure 5). There was also a near complete reproductive failure for the 2004 and 2005 brood years (Figure 5). As a result, there were exceptionally low adult returns to fall-run California Central Valley in 2007–2008. The fall-run Chinook salmon collapse may have been caused by climatic conditions that produced little food in the ocean (e.g., delayed upwelling in the ocean-entry year 2005) combined with a reliance on a hatchery-reared homogeneous salmon population instead of a varied wild salmon population (Lindley et al. 2009a). The Central Valley late fall-run population also experienced peak escapement in the early 2000s, but has not demonstrated the same decline experienced by the fall-run population. The Central Valley winter-run population actually had the highest escapement values in the most recent years. Finally, the Central Valley spring-run population experienced its greatest returns in the mid-1980s and has since remained relatively flat.

This asynchrony in population escapement trends indicates that the populations are likely exposed to different environmental or management forces. In fact, two of these populations are threatened or endangered (spring and winter run) and, therefore, attempts are made to avoid catches in the fishery. However, it is also important to recognize that variability in the timing of spawning, emigration, and distribution could have an effect on the ultimate production of the stocks as well, which could result in the asynchrony shown here. Unlike Central Valley populations, the Klamath River fall-run population appears to have variable spawning escapement over the last 30 years with no particular trend apparent (Figure 5). However, there does appear to be an episode to the Klamath escapement values likely related to large-scale oceanographic conditions (e.g., ENSO).



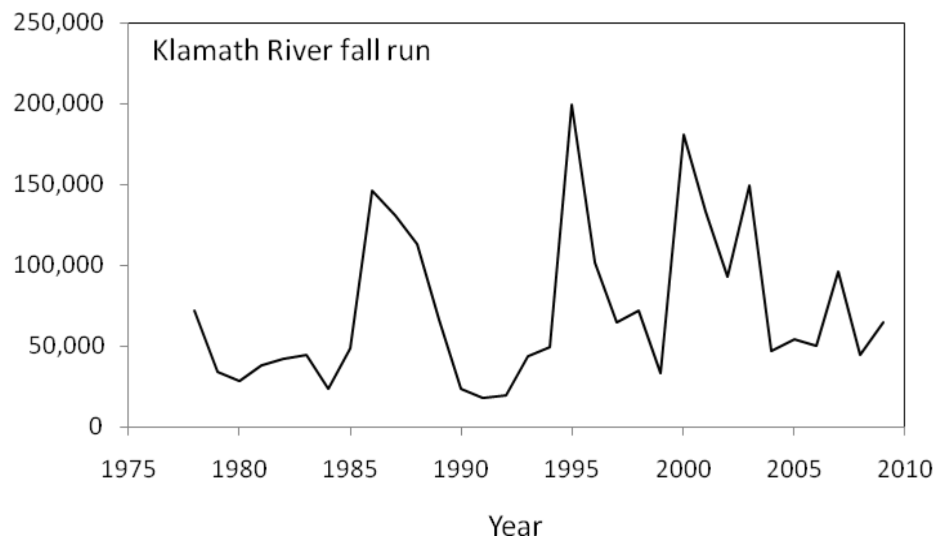


Figure 5. Spawning escapement for Central Valley (CV) populations and Klamath River fall-run populations of Chinook salmon. Data represent total returns to spawning grounds (hatchery plus natural). For the CV, fall run Chinook are plotted on the left primary vertical axis and the other stocks are plotted on the right vertical axis.

A primary goal will be to determine the natural and managerial forces driving variability within and between Chinook salmon populations from the Klamath and Sacramento rivers. Such information will help improve the utility of a spawning escapement index toward evaluating the health of both populations.

Indicator: Population growth rate

The Sacramento River fall-run Chinook salmon population has shown an average 15% decline in growth rate over the last 10 years with an exceptional 48% decline in the last 5 years (Figure 6), which could make recovery slow. Not shown in Figure 6, Sacramento winter-run and

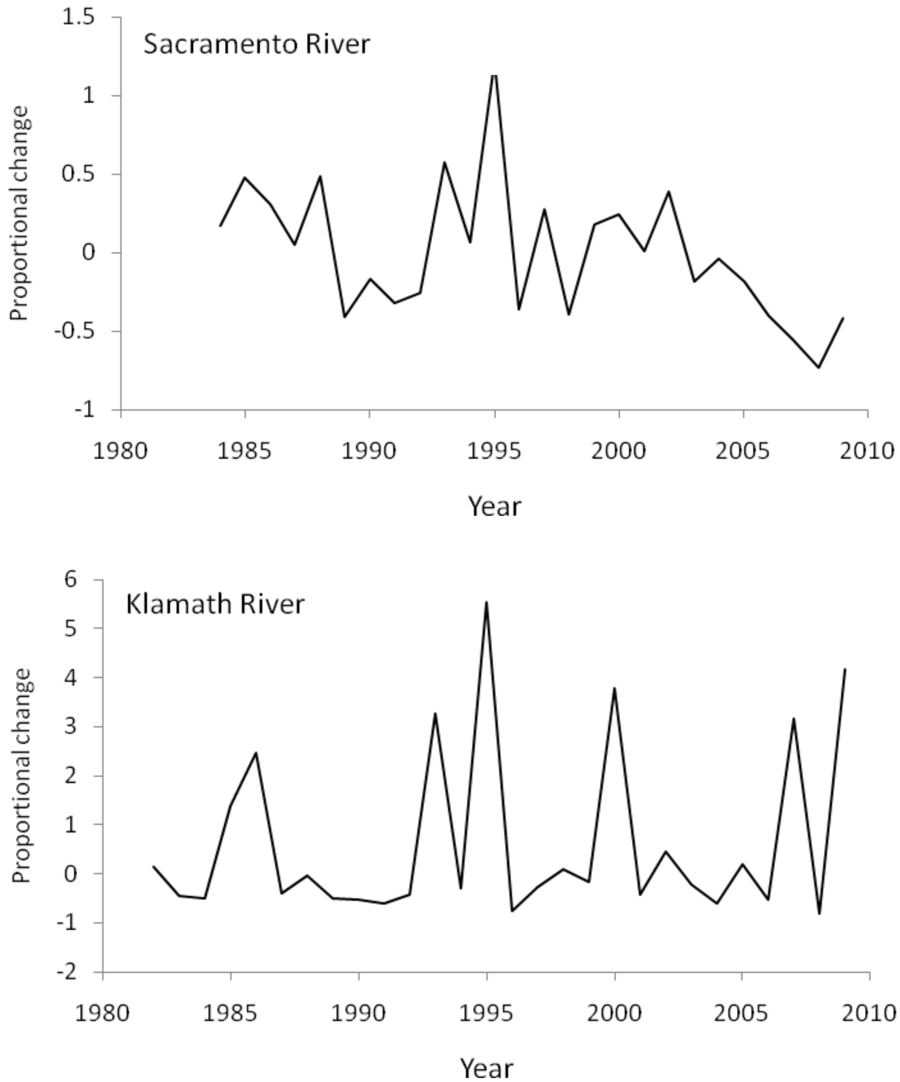


Figure 6. Population growth rates for Sacramento River fall-run Chinook salmon (the largest component of the Central Valley Chinook fall runs) and Klamath River fall-run Chinook salmon. The growth rate for the Sacramento River fall run was calculated as the proportional change in the Sacramento Index between successive years. The Sacramento Index represents the ocean abundance of age-3 fish calculated by summing later harvest and escapement values. The growth rate of the Klamath River fall run was calculated based on the ocean abundance of age-3 Klamath River fall-run fish.

spring-run Chinook salmon have also experienced precipitous declines in growth rates over the last 5 years (38% and 61%, respectively). Unlike the Sacramento River Chinook salmon, Klamath River fall-run Chinook salmon did not experience any particularly dramatic trend in growth rates over the last 5 to 10 years (Figure 6). Instead, growth rate was relatively stable but punctuated by extremely productive years. It is likely these bumps in growth rate are corrections following poor productivity years, such as during the 1983 and 1998 ENSO events. These differences between Sacramento River and Klamath River populations may be caused by a combination of managerial or environmental differences experienced by the fish.

As with the future direction for improving the spawning escapement index, a future goal will be to determine the forces driving variability within and between Chinook salmon populations from the Klamath and Sacramento rivers. Such information will help improve the utility of a growth rate index toward evaluating the health of the both populations.

Indicator: Hatchery contribution

Population viability is dependent in part on maintaining life history diversity in the population. Hatchery production is a relatively homogeneous life history type relative to naturally produced populations. If natural production is reduced, the population can be at risk during periods of increased environmental variability. In recent years, the contribution of hatchery fish to the population has increased substantially. That the number of hatchery fish produced has remained relatively stable indicates that the remaining natural spawners have diminished. Therefore the natural population is at increased risk (Lindley et al. 2007). The proportion of fall-run Chinook salmon spawning in hatcheries, a corollary to the actual contribution of hatchery fish to the population, has increased dramatically in the Central Valley over the last 5 years (Figure 7). Such an increase is indicative of a diminished production of natural populations and could indicate constriction of life history diversity. Fall-run Chinook salmon from the Klamath River did not experience any particular trend over the years and recently have not demonstrated an increase in the hatchery contribution (Figure 7).

The methodology used here to estimate hatchery contribution is flawed. Specifically, it simply calculates the proportion of fish that spawn at hatcheries with no consideration to straying rates. Therefore, it likely underestimates the contribution of hatchery fish. Improvements to the index could come from using genetic sampling, otolith chemistry, and systematic proportional tagging of hatchery fish.

Key Attribute: Population Condition

Indicator: Age structure

A diverse age structure is important to improve the viability of a population. Larger, older Chinook salmon produce more and larger eggs. Therefore, they produce a brood which may contribute proportionally more to the later spawning population than broods from younger, smaller fish. However, the diversity of ages, including younger fish, is important to accommodate variability in the environment. If mortality on any given cohort is great, there is benefit to having younger spawners. This bet hedging is a critical aspect of Chinook salmon populations that allows them to naturally mitigate year-to-year environmental variability.

While Central Valley Chinook salmon stocks lack age-specific data to evaluate age structure of the population, the Klamath River fall run has sufficient data. Examination of the proportional contribution of each age to the spawning stock demonstrates that the largest fraction of the spawning population is age-3 and age-4 fish (Figure 8). In addition, there has been a declining fraction of age-2 spawning over the years. However, little should be made of this negative trend, as it seems to be driven in large part by a few extraordinary years. Overall, no recent trends are apparent in the age structure of Klamath River Chinook salmon and it actually appears relatively stable across the last 30 years. This evaluation of Klamath River Chinook

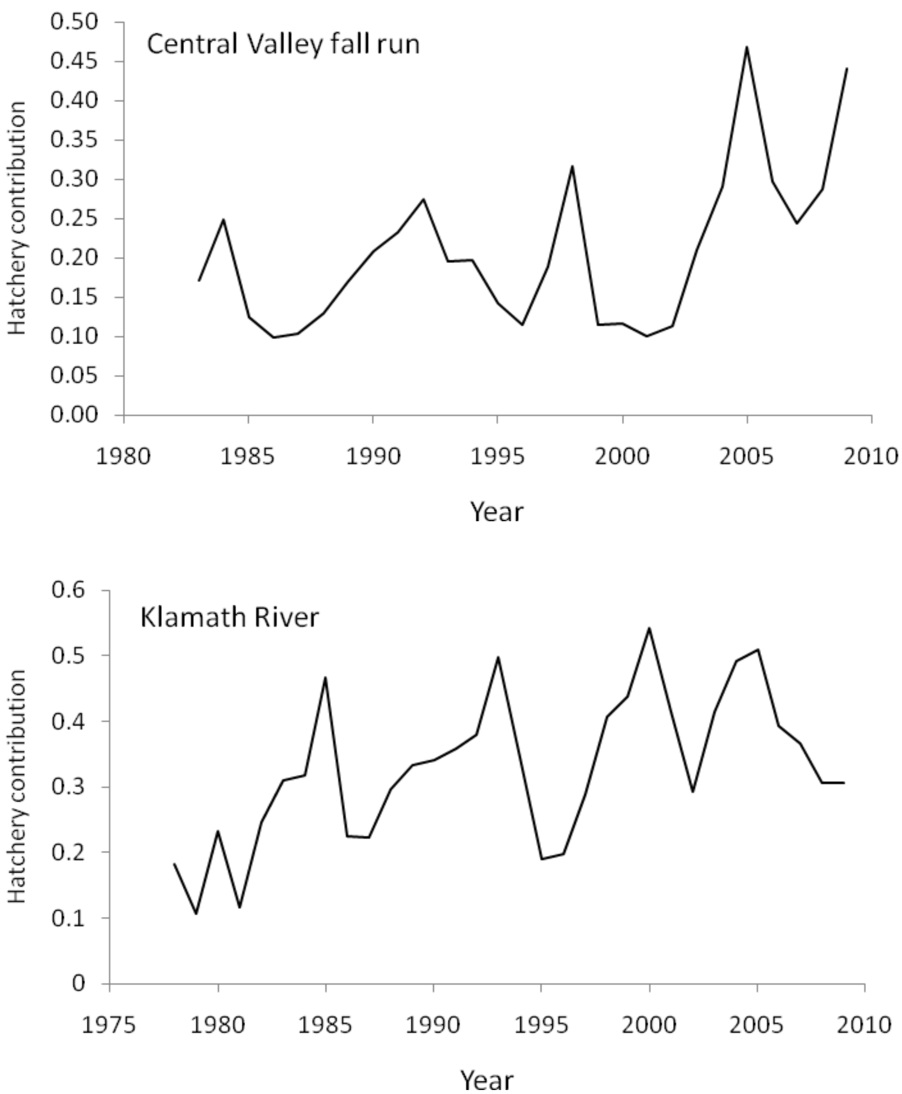


Figure 7. Proportions of Chinook salmon from the Central Valley fall-run and Klamath River fall-run populations that spawned in hatcheries. This is only an index of hatchery contribution, as estimates of hatchery fish spawning in natural areas are not available.

salmon should not be extrapolated to Central Valley Chinook salmon. As indicated in nearly every example shown here, the Central Valley Chinook populations seem not to correlate to the Klamath River population with any regularity. It is likely that fish from the Central Valley did demonstrate a change in age structure in recent years. Specifically, 2005–2008 represented consistently poor conditions; therefore, the age structure of a 3-year cohort was less likely to mitigate this lower frequency environmental event. With the recent implementation of standardized proportional tagging of hatchery fish, better estimates of age structure variability will become available for Central Valley Chinook salmon.

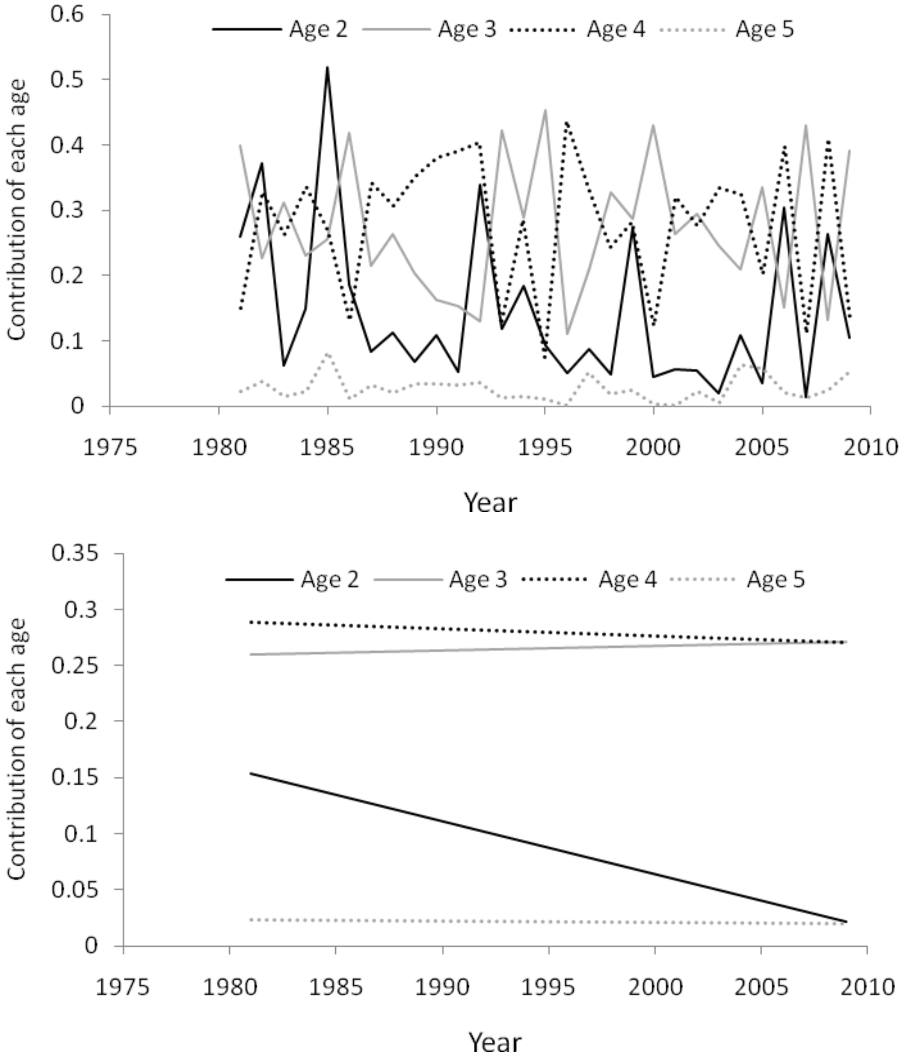


Figure 8. Time series of run size estimates for each age of returning Klamath River fall-run Chinook salmon in given years are in the upper plot. Specifically, this figure represents the age structure of the Klamath River fall-run population during any given year. As indicated by the lower plot, there was only a trend in the age-2 group; namely, the proportion of fish returning to spawn at age 2 has declined. However, examination of the time series (upper plot) shows that the trend is likely derived from a few years (e.g., 1982 and 1985) that represented enormous numbers of age-2 fish returns.

Indicator: Spatial stock structure

A more comprehensive evaluation of the spatial structure of central California salmon stocks will be completed in 2011.

Indicator: Size at age

A more comprehensive evaluation of size at age for central California salmon will be completed in 2011.

EBM Component: Sturgeon

Generally, little data are available on the abundance or condition of green sturgeon populations, yet the southern stock is considered likely to become an endangered species in the foreseeable future. This concern is based on the drastic reduction of spawning habitat above Shasta Dam on the Sacramento River and Oroville Dam on the Feather River, California (Adams et al. 2007). There has also been a large decline in the number of juveniles entrained in water diversion projects, indicating a reduction in the production of the populations. The northern population is not currently considered to be in danger of extinction (Adams et al. 2007).

Key Attribute: Population Size

Indicator: Spawning escapement

Spawning abundance was estimated systematically for the first time in 2010, using sonar and underwater video to count green sturgeon in their summer holding pools on the Sacramento, Klamath, and Rogue rivers. Over time, these surveys can be repeated to generate estimates of population growth rate.

Indicator: Juvenile abundance

Catch of juvenile green sturgeon in fish traps at large water diversions is available for the past several decades and will likely be available for some time in the future, until a planned major reorganization of water infrastructure in California's Central Valley radically alters the hydrology and operation of pumping plants. The number of Sacramento River sturgeon juveniles captured at water diversions has dropped, indicating reduced production of the population. Catches at these pumping plants may be an index of recruitment to the population, although the factors affecting the sampling performance of these pumps are unknown.

Key Attribute: Population Condition

Indicator: Age structure

This will be completed in a future IEA.

Indicator: Spatial structure

Tagging studies of green sturgeon conducted by SWFSC and NWFSC have collected a large amount of data on the habitat associations and movement of green sturgeon within and among the coastal Pacific Ocean, spawning rivers, and estuaries of nonnatal rivers. These data are being used to create dynamic models of green sturgeon distribution. A spawning river model for the Sacramento River has been completed (Mora et al. 2009) and a marine distribution model is in development.

EBM Component: Groundfishes

Because of their ecological importance and high value as recreational and commercial fisheries, groundfish are an important component of the California Current ecosystem. Time series of groundfish catch expressed as number of fish km^{-2} provide indicators of changes in abundance. Time series of size distribution provide indicators of changes in population structure (e.g., many young fish or more older fish). Changes in spatial distribution can indicate responses to climate or localized fishing effects.

The combined data from the AFSC triennial and NWFSC annual trawl surveys (see Table 7 through Table 10 for trawl survey characteristics, net details, triennial survey effort, and annual survey effort, respectively) contained more than 349 taxa identifiable to species—far too many to present here. For each of the groundfish indicators below, a subset of 17 species was chosen for analysis and presentation (Table 11). These species represent the most common species from each of the 17 functional groups used in the Horne et al. (2010) ecosystem model of the California Current. Thus the 17 groundfish that we cover are representative of groups of fish from different habitats and trophic guilds. These 17 species comprise about 80% of the total number of species captured.

Key Attribute: Population Size

Groundfish number was selected as the sole indicator for groundfish population size. Time series of groundfish abundance follow a standard format with additional statistical information presented on each figure. The triennial and NWFSC data were not combined because of differences in survey design (see Appendix C).

Ten of 17 species showed declines during the 2005–2009 period that were greater than 1 SD of the NWFSC time series for said species (Figure 9 through Figure 12). These species include: Pacific hake, stripetail rockfish (*Sebastes saxicola*) (small shallow rockfishes), Dover

Table 7. Characteristics of the triennial and NWFSC groundfish trawl surveys. (Data courtesy of Melissa Haltuch, NWFSC.)

	Triennial survey	**NWFSC survey**
Time extent	1977–2004	1998–present
1977 not used	Shelf added in 2003	
Vessel	Alaska class commercial vessels, 65–147 m	West Coast groundfish commercial vessels, 65–93 m
Survey design	Line transect survey, random trawls on same lines	Stratified random survey
Survey timing	1980–1992 later	Consistent
	1995–2004 earlier	
Depth and range	Varies over time, 55–336 m, 55–500 m, lat 36.8°N, lat 34.5°N, excludes Point Conception	Consistent, 55–1,280 m since 2003, lat 32.5°N to lat 48.17°N, includes Point Conception

Table 8. Comparison of net characteristics for the triennial and NWFSC groundfish trawl surveys. (Data courtesy of Melissa Haltuch, NWFSC.)

Triennial survey	**NWFSC survey**
High opening Nor'Eastern trawl	4 panel Aberdeen style trawl
76.2 m net to doors	62.5 m net to doors
Roller gear (37.4 m footrope)	Continuous disk footrope (32.5 m)
Bare wire bottom bridles	20.3 cm disk partway into bridles
1.8 m × 2.7 m V-door	1.5′ × 2.1′ V-door
12.7 cm mesh, 8.9 cm codend, 3.2 cm liner	13.9 cm mesh, 12.7 cm codend, 3.8 cm liner
30 minute tow	15 minute tow
3.0 knot towing speed	2.2 knot towing speed
Little or no mud cloud between doors and net due to lack of disks in wings (little herding)	Mud cloud between doors and net due to disks in wings (enhanced herding)
Strong avoidance of rocky areas	Able to tow closer to rocky areas

Table 9. Distribution of survey effort for the AFSC triennial survey among latitudes and years. (Data courtesy of Mark Wilkins, AFSC.)

Latitude	**1980**	**1983**	**1986**	**1989**	**1992**	**1995**	**1998**	**2001**	**2004**
34	—	—	—	14	13	12	12	12	13
35	—	—	—	22	11	15	16	16	12
36	6	6	2	12	10	11	11	12	9
37	27	26	27	58	53	32	33	32	26
38	25	23	26	31	29	33	32	32	20
39	13	13	14	18	16	17	18	17	16
40	12	12	10	14	14	15	16	16	14
41	16	18	15	23	23	23	23	23	20
42	10	33	8	22	20	20	21	22	17
43	77	82	38	25	28	27	30	29	27
44	66	79	46	45	46	41	44	43	36
45	21	27	34	67	66	38	39	39	33
46	82	86	54	46	47	32	31	33	26
47	35	48	105	37	32	28	29	27	29
48	50	90	127	74	73	55	66	51	17

sole (*Microstomus pacificus*), rex sole (*Glyptocephalus zachirus*) (small flatfishes), chilipepper (*Sebastes goodei*) (midwater rockfishes), spiny dogfish (small demersal sharks), shortbelly rockfish (*Sebastes jordani*), white croaker (*Genyonemus lineatus*) (miscellaeneous nearshore demersal fishes), canary rockfish, and longnose skate (*Raja rhina*) (skates and rays). Five species had stable population trends over the 5-year period: sablefish, redstripe rockfish (*Sebastes proriger*) (shallow large rockfishes), splitnose rockfish (*Sebastes diploproa*) (deep small rockfishes), darkblotched rockfish (*S. crameri*) (deep large rockfish), and yelloweye rockfish (*S. ruberrimus*). Only lingcod (*Ophiodon elongatus*) (representing large demersal predators) and arrowtooth flounder (*Atheresthes stomias*) (large flat fishes) increased.

Table 10. Distribution of trawl effort for the annual NWFSC survey. (Data courtesy of Beth Horness, NWFSC.)

Latitude	2003	2004	2005	2006	2007	2008	2009
34	30	28	41	24	33	31	41
35	12	12	11	9	17	12	18
36	7	8	14	9	10	13	6
37	18	21	27	22	20	28	36
38	18	25	29	25	25	26	25
39	11	13	19	16	5	17	8
40	13	5	14	9	14	4	8
41	20	9	19	8	14	12	20
42	28	15	21	21	16	20	16
43	10	17	30	36	31	17	25
44	18	32	46	39	39	47	39
45	18	22	26	39	44	31	34
46	15	24	27	23	32	24	27
47	33	21	19	20	29	31	28
48	38	23	21	16	20	15	18

Table 11. Groundfish functional groups and representative species (from Horne et al. 2010).

Functional group	Representative species	Scientific name
Hake	Pacific hake	*Merluccius productus*
Shallow small rockfish	Stripetail rockfish	*Sebastes saxicola*
Sablefish	Sablefish	*Anoplopoma fimbria*
Dover sole	Dover sole	*Microstomus pacificus*
Shallow large rockfish	Redstripe rockfish	*Sebastes proriger*
Deep small rockfish	Splitnose rockfish	*Sebastes diploproa*
Small flatfish	Rex sole	*Glyptocephalus zachirus*
Midwater rockfish	Chilipepper rockfish	*Sebastes goodei*
Small demersal sharks	Spiny dogfish	*Squalus acanthias*
Shortbelly rockfish	Shortbelly rockfish	*Sebastes jordani*
Large flatfish	Arrowtooth flounder	*Atheresthes stomias*
Deep large rockfish	Darkblotched rockfish	*Sebastes crameri*
Misc. nearshore demersal fish	White croaker	*Genyonemus lineatus*
Canary rockfish	Canary rockfish	*Sebastes pinniger*
Large demersal predators	Lingcod	*Ophiodon elongatus*
Skates and rays	Longnose skate	*Raja rhina*
Yelloweye rockfish	Yelloweye rockfish	*Sebastes ruberrimus*

Over longer periods, however, some species show different trends. For example, while currently stable, sablefish populations clearly declined from 2003 to the 2009 survey. For chilipepper rockfish, the 5-year trend showed a decrease in numbers per square kilometer, but the final 3 years of the trend appear to have stabilized.

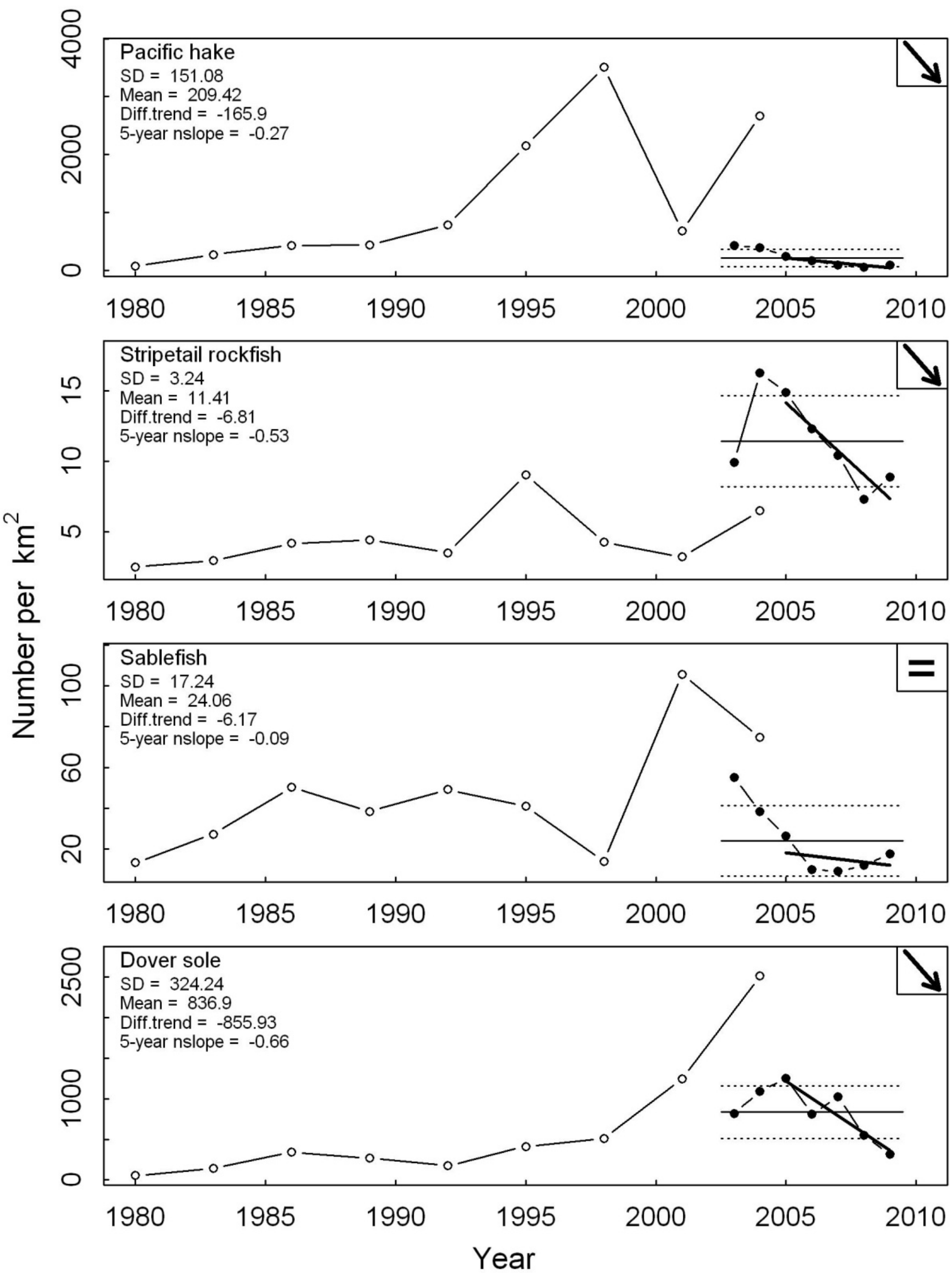
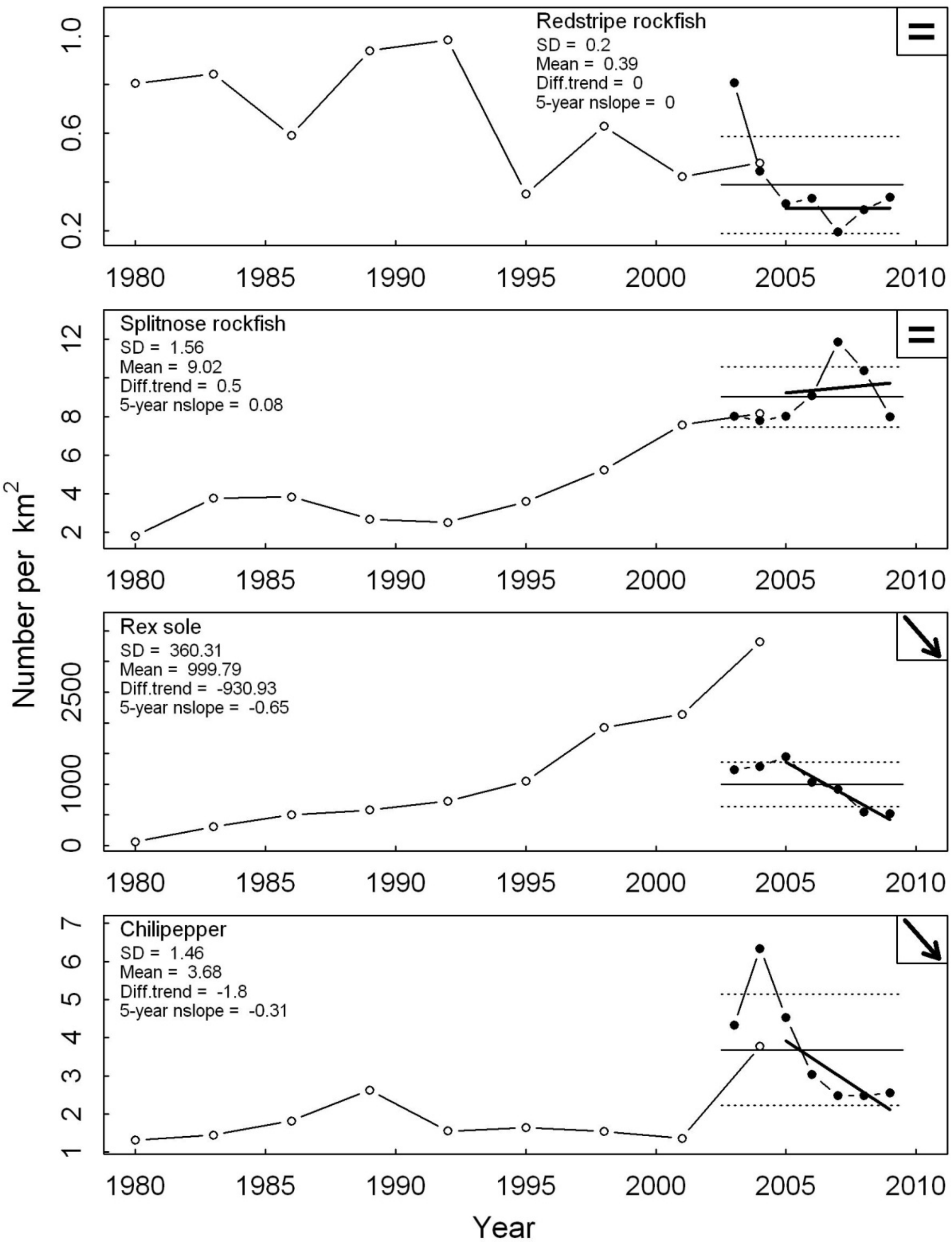


Figure 9. Catch per unit effort (CPUE) (number per km^2) for four groundfishes from 1980 to 2009 for the triennial trawl survey (open circles, data courtesy of Mark Wilkins, AFSC) and the NWFSC trawl survey (closed circle, data courtesy of Beth Horness, NWFSC). Mean and SD are the mean and standard deviation of the NWFSC time series, Diff.trend is the absolute change in the predicted trend over 5 years, and 5-year nslope is the slope of normalized data for comparison across species. The solid line is the mean for the 7-year NWFSC data. Dotted lines are ±1 SD. The trend line (thick black) is the 5-year trend. Symbols in the upper right indicate whether the 5-year trend decreased or showed no change relative to 1 SD of NWFSC data.



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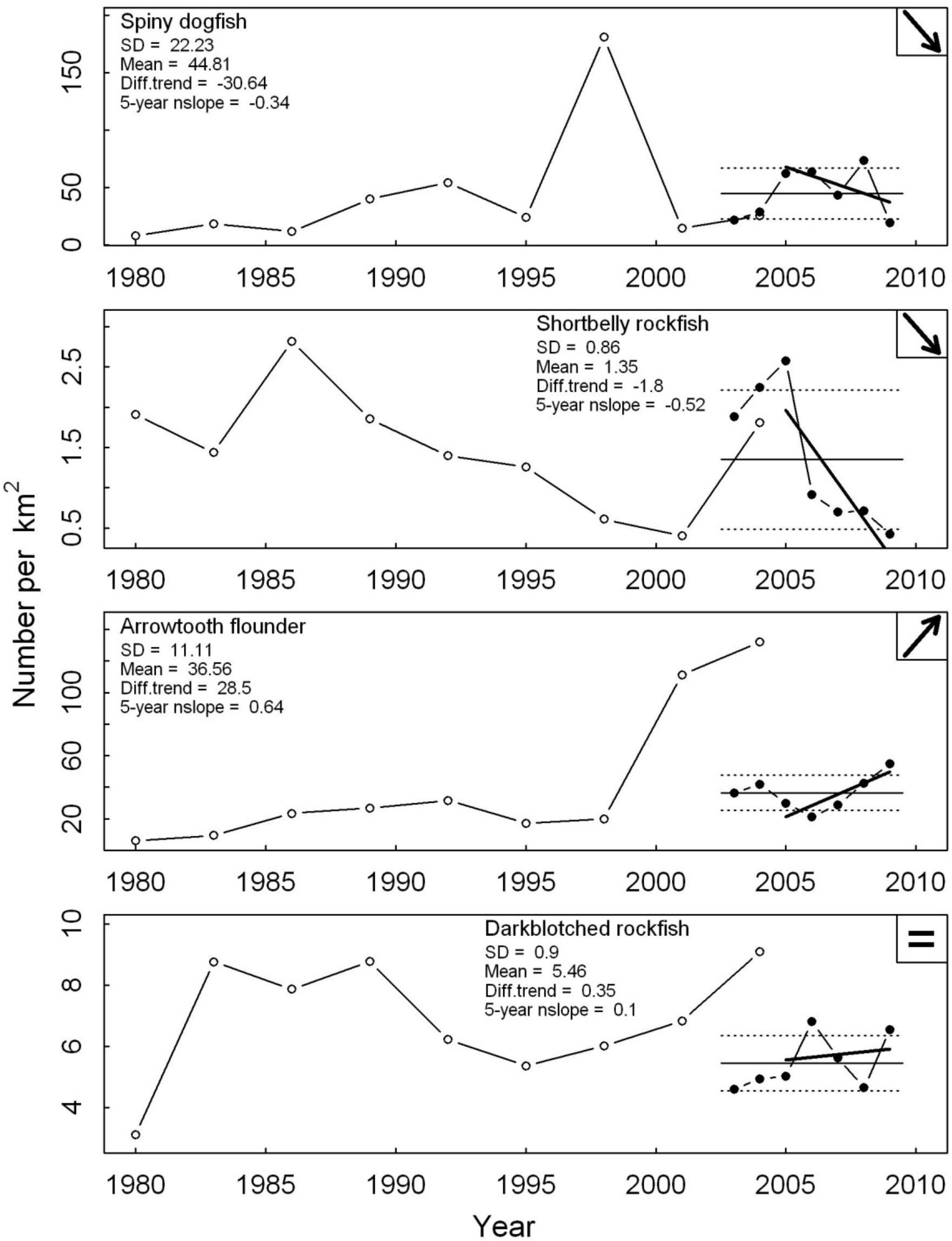

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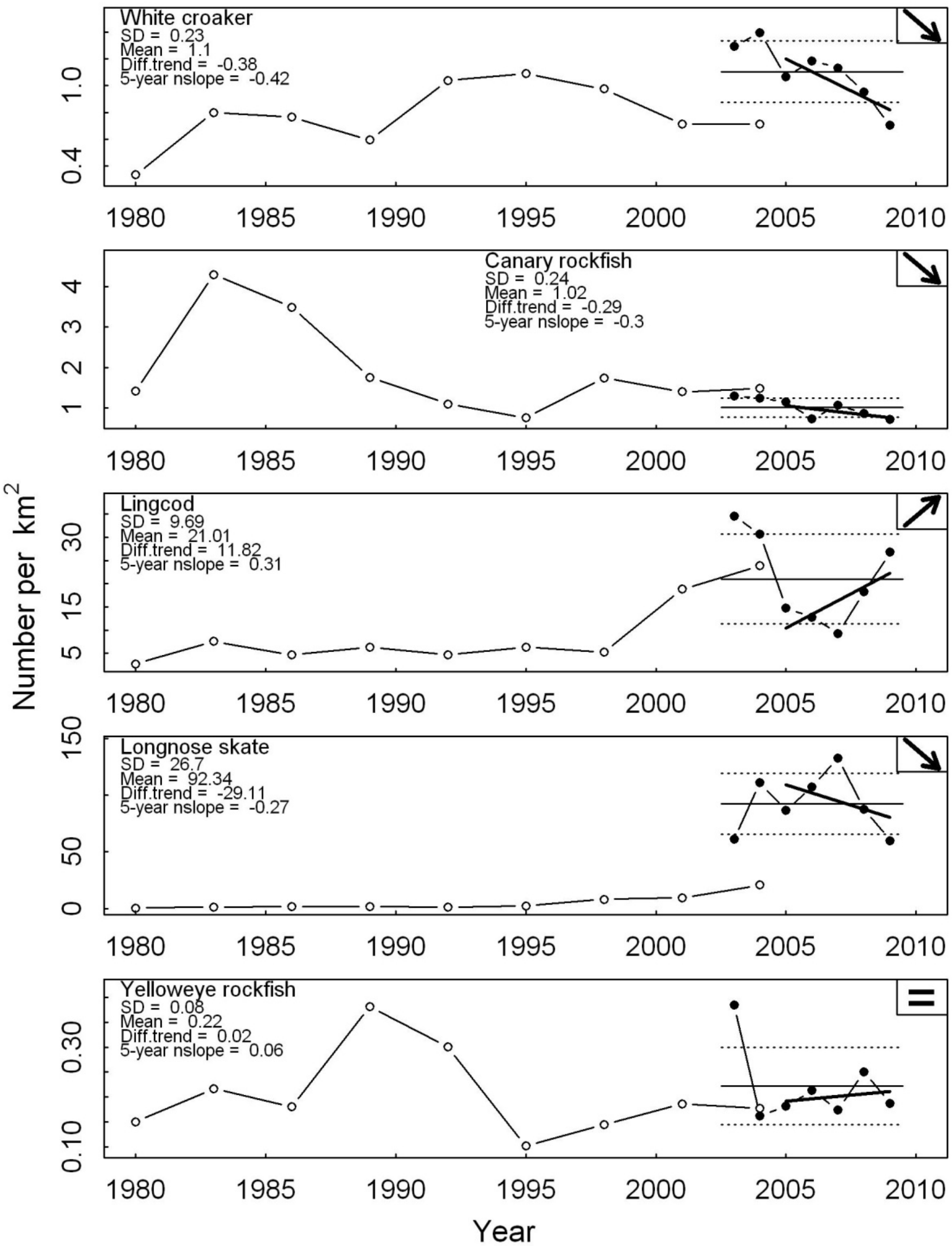


Figure 12. CPUE (number per km^2) for five groundfishes from 1980 to 2009 for the triennial trawl survey (open circles, data courtesy of Mark Wilkins, AFSC) and the NWFSC trawl survey (closed circle, data courtesy of Beth Horness, NWFSC). Mean and SD are the mean and standard deviation of the NWFSC time series, Diff.trend is the absolute change in the predicted trend over 5 years, 5-year nslope is the slope of normalized data for comparison across species. The solid line is the mean for the 7-year NWFSC data. Dotted lines are ±1 SD. The trend line (thick black) is the 5-year trend. Symbols in the upper right indicate whether the 5-year trend increased, decreased, or showed no change relative to 1 SD of NWFSC data. Data are the year effect from the GAM model and not absolute estimates of abundance.

There are three areas for potential improvement of the current indicators: 1) integration of the AFSC and NWFSC surveys, 2) development of more species-specific statistical models, and 3) the development of composite indicators.

While there are important differences in the methodologies of the two trawl surveys, future work should examine the possibility of integrating the two time series. Approaches have been developed for the integration of time series of different quality (Drake et al. 2010). Several species showed similar estimates of number per square kilometer for the overlapping year of 2004. Others showed similar overall trends, although absolute numbers differed. This integration will need to be done carefully, since different net sizes and trawl speeds are likely sampling different components (size distributions) of the relevant populations.

In the present report, abundance estimates for all species were derived from the same relatively simple statistical model using data covering the same latitudinal and depth extents and were limited to the shelf and shallow slope (shallower than 350 m). To provide better abundance estimates, it may be fruitful to develop more complex statistical models tailored to individual species.

Many species (including those not presented here) showed similar trends. Therefore, future work could focus on developing composite metrics that combine information from multiple species into one or several time lines to simplify presentation.

Key Attribute: Population Condition

Indicator: Size structure

For each species, the quartiles were calculated for length of all individuals collected during the first year of each survey (triennial survey 1980, NWFSC survey 2003). In instances when there were less than 20 individuals of a species measured during a year, the first year in which there were more than 20 individuals was used.

A number of species showed changes in size structure (Figure 13 through Figure 16). For example, the proportion of small hake increased from 2003 to 2009. For chilipepper rockfish, the proportion of older individuals increased from 2003 to 2009. Taken in conjunction with the numbers trends above, chilipepper show an aging and declining population. Note also that results from the two surveys do not match well. This is to be expected for two reasons. First, differences in trawl methodology (net size, tow duration, tow speed) mean that the two surveys sampled different components of the population. Second, quartiles in each survey are calculated relative to the first year of the survey, and the precise size ranges likely differ.

Future work should investigate the possibility of combining the two data sets to give a better understanding of long-term changes in size structure and the mechanisms causing size shifts.

Indicator: Spatial structure

Annual variation in the distribution of groundfishes was examined by comparing abundances (CPUE estimated as number per km^2) in 1° latitudinal bins at lat 34–48°N along the

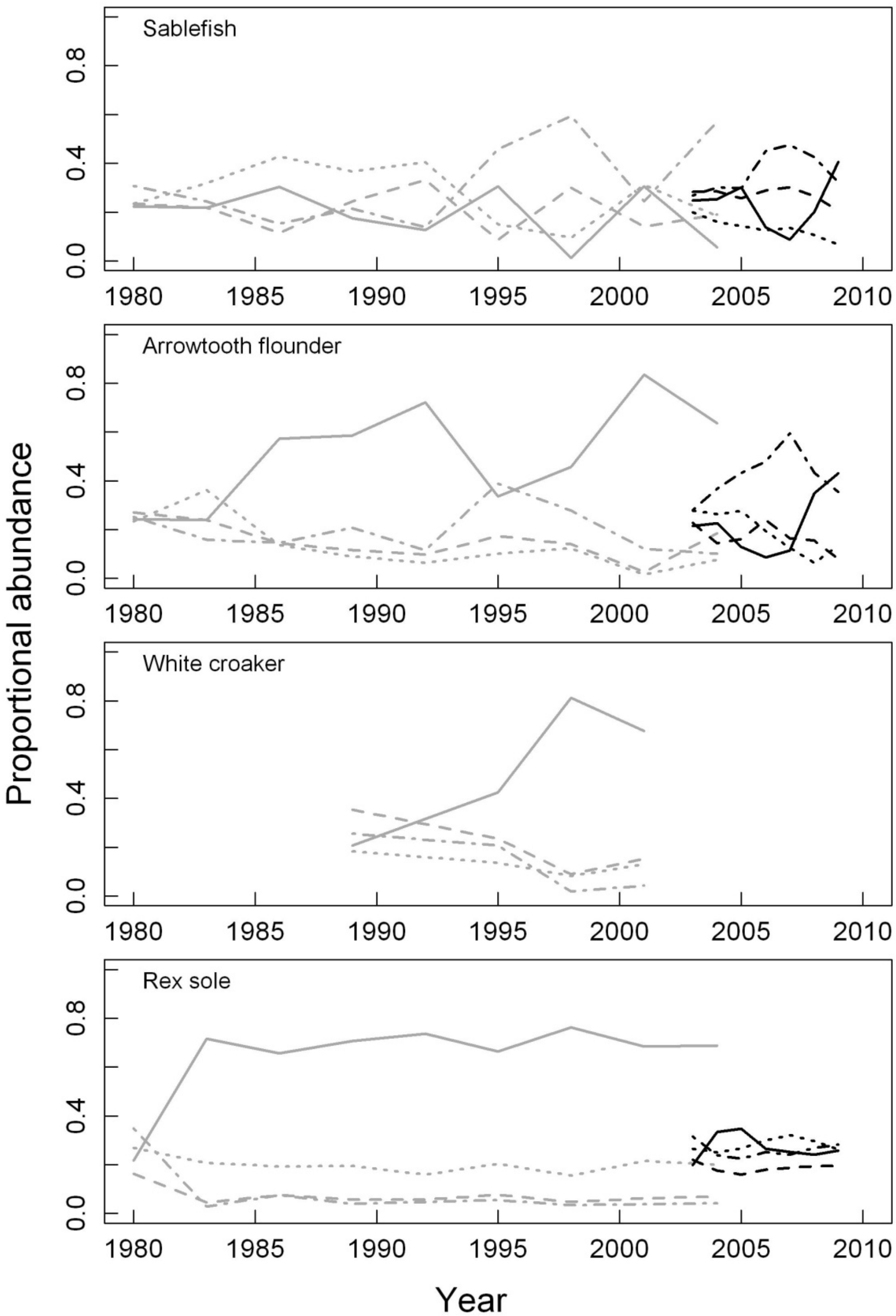


Figure 13. Size distribution for four groundfishes from 1980 to 2009. Plots show the proportion of fish in the first (solid), second (dashed), third (dotted), and fourth (dot-dash) quartiles. Gray lines are triennial survey data (courtesy of Mark Wilkins, AFSC), and black lines are NWFSC survey data (courtesy of Beth Horness, NWFSC). To show change in size structure through time, size cutoffs for the quartiles were established based on the first year in each time series (1980 and 2003). Subsequent years show proportion of fishes in those size classes.

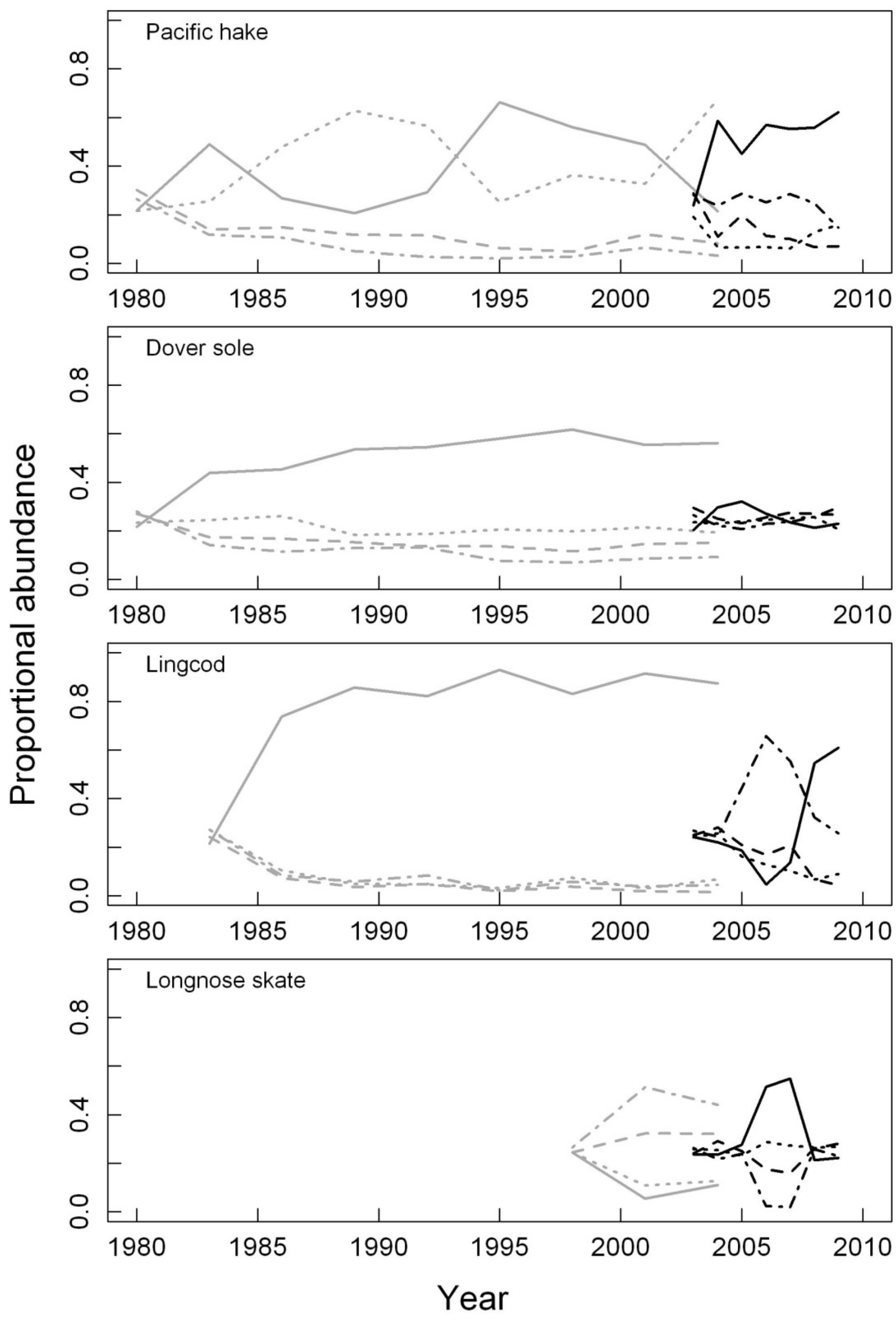


Figure 14. Size distribution for four groundfishes from 1980 to 2009. Plots show the proportion of fish in the first (solid), second (dashed), third (dotted), and fourth (dot-dash) quartiles. Gray lines are triennial survey data (courtesy of Mark Wilkins, AFSC), and black lines are NWFSC survey data (courtesy of Beth Horness, NWFSC). To show change in size structure through time, size cutoffs for the quartiles were established based on the first year in each time series (1980 and 2003). Subsequent years show proportion of fishes in those size classes.

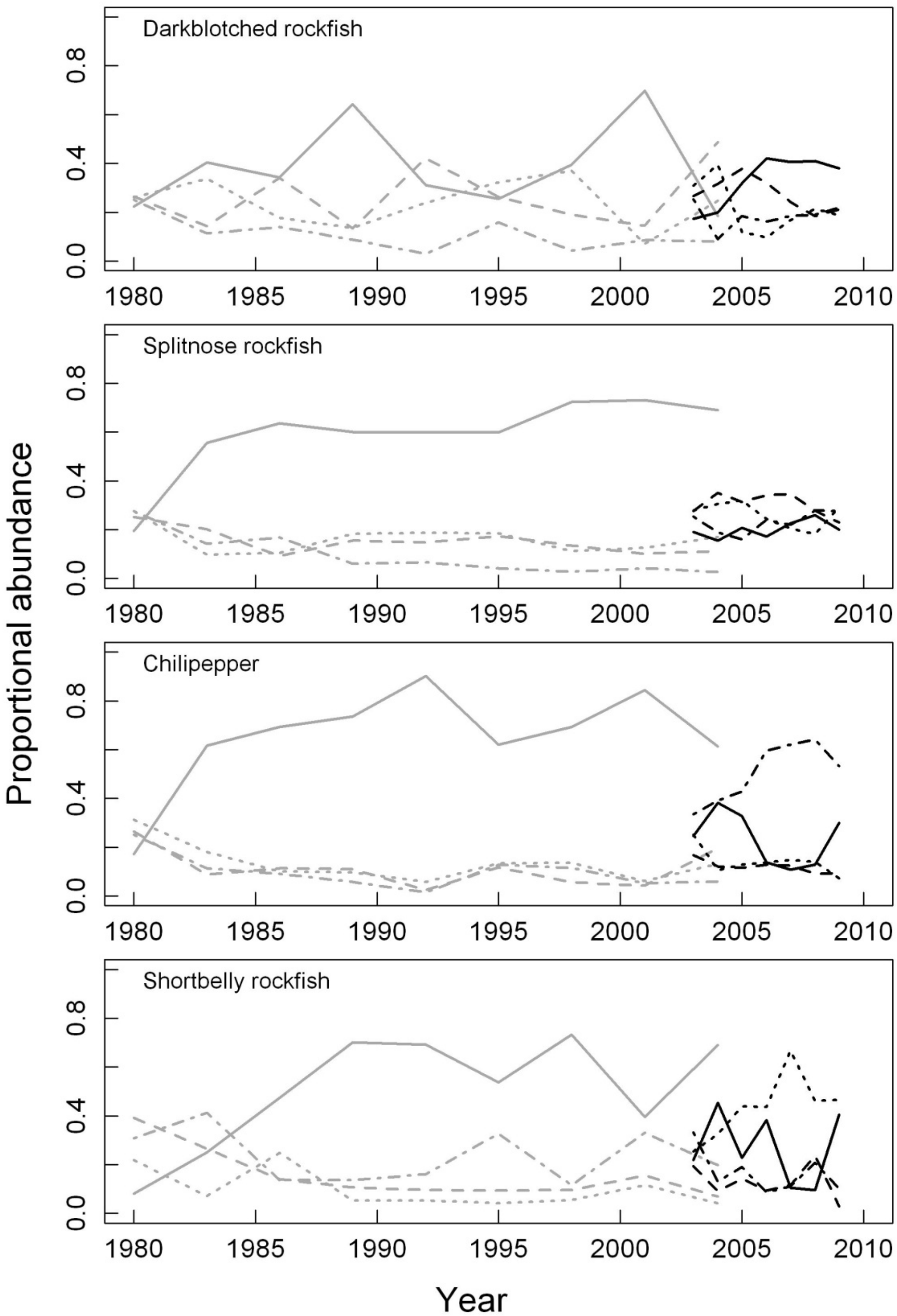


Figure 15. Size distribution for four groundfishes from 1980 to 2009. Plots show the proportion of fish in the first (solid), second (dashed), third (dotted), and fourth (dot-dash) quartiles. Gray lines are triennial survey data (courtesy of Mark Wilkins, AFSC), and black lines are NWFSC survey data (courtesy of Beth Horness, NWFSC). To show change in size structure through time, size cutoffs for the quartiles were established based on the first year in each time series (1980 and 2003). Subsequent years show proportion of fishes in those size classes.

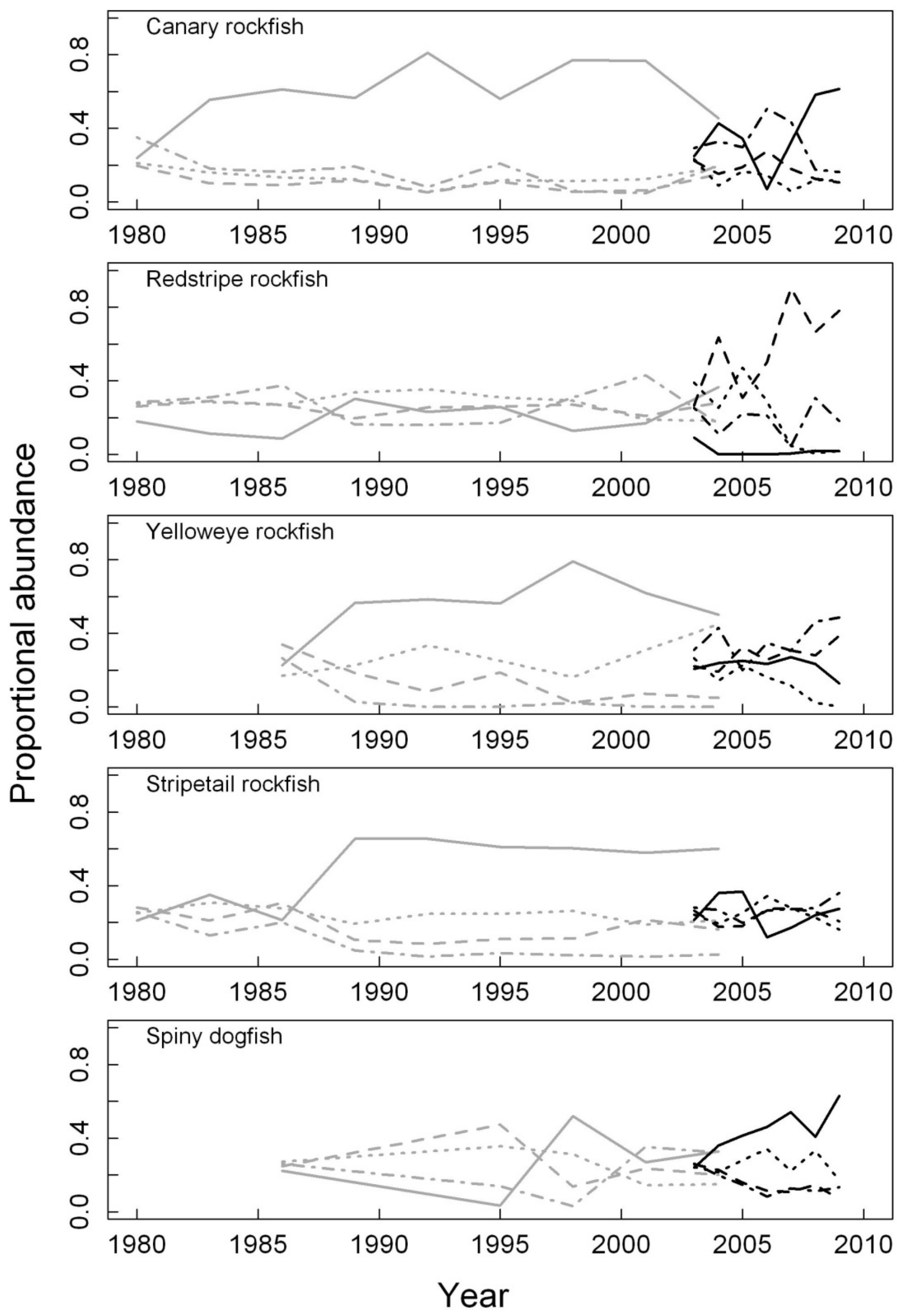


Figure 16. Size distribution for five groundfishes from 1980 to 2009. Plots show the proportion of fish in the first (solid), second (dashed), third (dotted), and fourth (dot-dash) quartiles. Gray lines are triennial survey data (courtesy of Mark Wilkins, AFSC), and black lines are NWFSC survey data (courtesy of Beth Horness, NWFSC). To show change in size structure through time, size cutoffs for the quartiles were established based on the first year in each time series (1980 and 2003). Subsequent years show proportion of fishes in those size classes.

West Coast. The data selection in terms of latitude and depth ranges followed that use in groundfish numbers above.

As with groundfish numbers, results for both the triennial and NWFSC surveys are presented on the same figures. However, given differences between the two surveys, they should not be directly compared. As such, trends are interpreted within time series. When examining triennial survey results, note that the 34° and 35°N latitude bins were not sampled from 1980 to 1986, so southern expansions (e.g., stripetail rockfish) into these latitudes in the triennial survey are not real.

Many species showed some variation in their spatial distributions through time (Figure 17 through Figure 20). For example in the triennial survey, Pacific hake show a northerly shift from 1980 to 1992 and a more bimodal distribution in 1995. In the NWFSC survey, hake are distributed to the north in 2003 but farther south in 2008, then back north in 2009. Spiny dogfish have also shown recent changes in distribution. Both surveys show a generally northern distribution through 2004, after which dogfish were more abundant in the southern half of the sampled range. Other species have shown relatively stable spatial distributions. Arrowtooth flounder maintained a northern distribution across both time series, although in the NWFSC surveys their relative abundance at midlatitudes has fluctuated. For example, rex sole were distributed primarily to the north across both time series.

There are two potential areas for improvement of present analyses. First, at present a relatively simple statistical approach standardized for all species was used to estimate the CPUE by latitude bin. Future improvements may seek to implement more complex estimation approaches (e.g., delta-generalized linear model) and tailor models to each indicator species. Second, the current presentation of spatial distribution is complex and difficult to interpret. It may be necessary to maintain a similar presentation to fully understand species distributions. However, it would be beneficial to produce a more simplified metric for each species that would be more easily visually interpreted. Integration of data sources and improved statistical approaches will improve the utility of this indicator.

EBM Component: Ecosystem Health

As noted in the Selecting and Evaluating Indicators for the California Current section, the concept of ecosystem health is technically problematic, but the term has become part of EBM and thus we use it here. In our framework, ecosystem health is defined specifically by the key attributes we developed in that section.

Note on the figures that presentation of the time series of most indicators follows a standard format with additional statistical information displayed on each figure. When groundfish data were used, statistics pertain only to the NWFSC data because of differences in survey design (see Appendix C). In these cases, the relationship of the mean of the final 5 years of the time series was not compared to the mean of the NWFSC time series because the latter was only 7 years long.

Indicators of ecosystem health necessarily cover diverse taxa and require data from broad geographic areas. Time constraints prevented us acquiring and integrating data representing

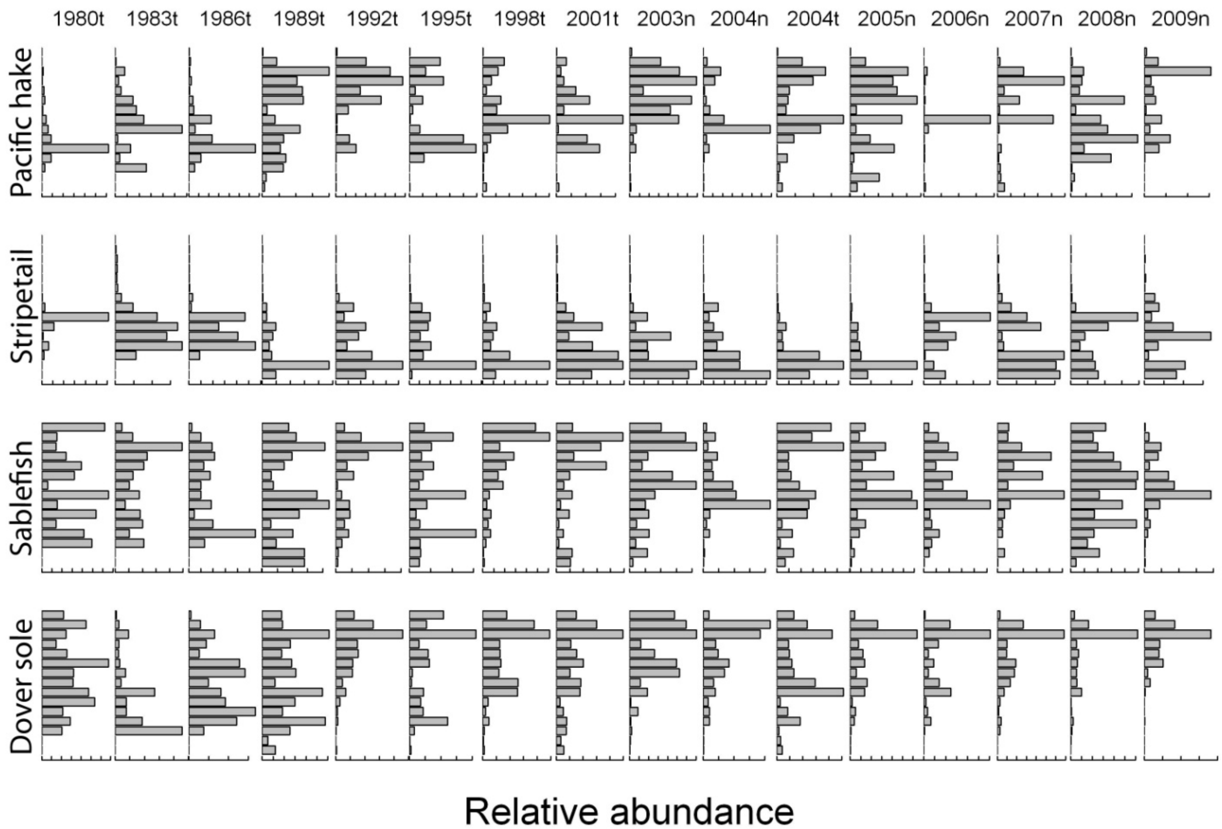


Figure 17. Spatial distribution of four groundfish from 1980 to 2009. Data are CPUE (number per km^2) presented in 10 latitude bins from lat 34°N (y-axis minimum) to lat 48°N (y-axis maximum). Data are relative within years and absolute values should not be compared across years as axes may vary. Letters following year headings indicate triennial (t, data courtesy of Mark Wilkins, AFSC) or NWFSC (n, data courtesy of Beth Horness, NWFSC) surveys. Due to difference between the two surveys, trends between the two should be made with caution. Both surveys were conducted in 2004.

some components of the ecosystem for this year's report. Throughout this section, we note crucial data gaps that will be filled in the coming year and incorporated into subsequent iterations of the California Current IEA.

Key Attribute: Community Composition

Indicator: Diversity

Shannon Diversity—The Shannon Diversity Index takes into account the number of species and the evenness of those species in a sample (Magurran 1988). The index increases with the addition of unique species or with more even representation of species (greater evenness).

Shannon Diversity ($\log_e$) for West Coast groundfishes was estimated from the triennial survey and the NWFSC survey. A subset of the available data was used including trawls

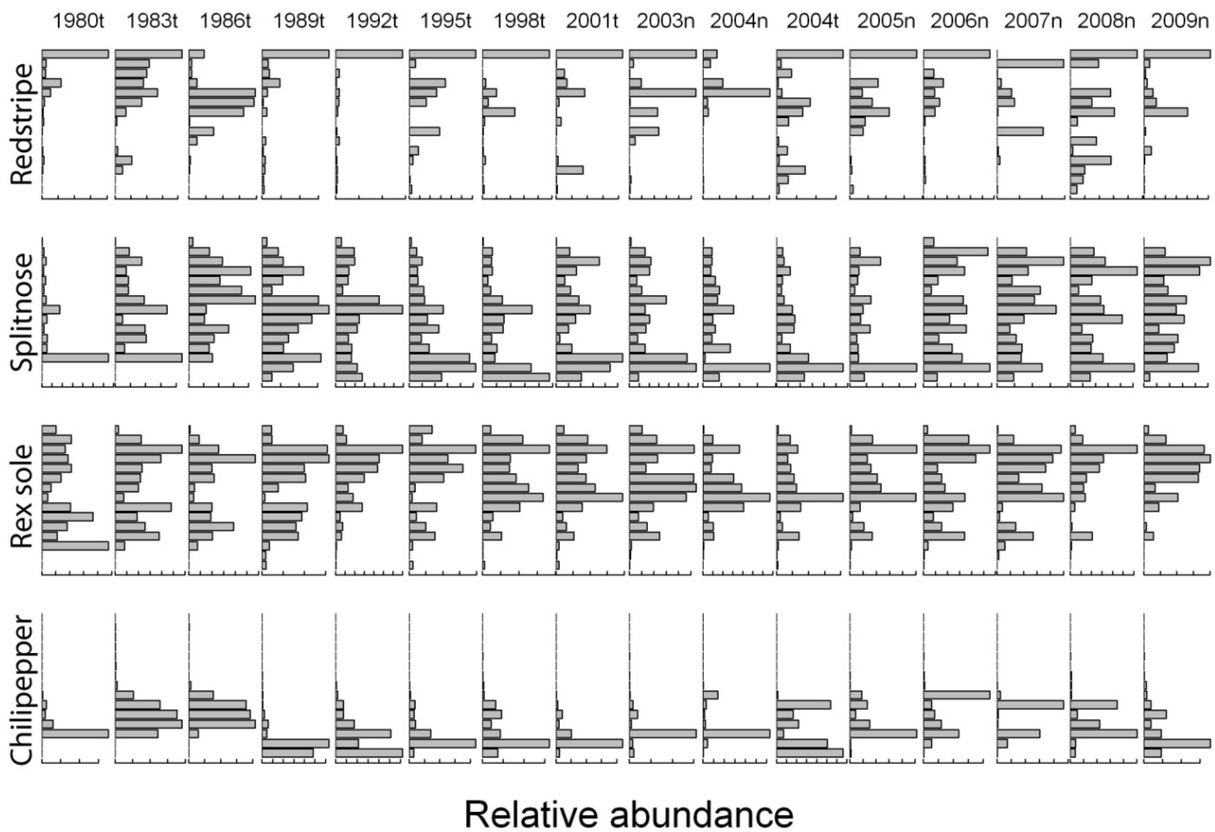


Figure 18. Spatial distribution of four groundfish from 1980 to 2009. Data are CPUE (number per km^2) presented in 10 latitude bins from lat 34°N (y-axis minimum) to lat 48°N (y-axis maximum). Data are relative within years and absolute values should not be compared across years as axes may vary. Letters following year headings indicate triennial (t, data courtesy of Mark Wilkins, AFSC) or NWFSC (n, data courtesy of Beth Horness, NWFSC) surveys. Due to difference between the two surveys, trends between the two should be made with caution. Both surveys were conducted in 2004.

between 50–350 m and 34–38°N latitude. AFSC data included the years 1980–2004 (every third year), while NWFSC data included 2003–2009 data. See Appendix C for further details.

The 5-year trend for Shannon Diversity showed a decrease from 2005 to 2009 (Figure 21), indicating some change in assemblage structure for West Coast groundfishes. Notably the 2009 estimate was similar to the 2003 value, suggesting a return to an earlier state. Future monitoring will need to determine whether Shannon Diversity continues to decline or levels off.

Estimates of Shannon Diversity are not easily comparable between the triennial data and the NWFSC data. Shannon Diversity in 2004 was higher in the NWFSC surveys than in the triennial surveys.

Taxonomic distinctness—TD is a diversity metric that quantifies the relatedness of species in a sample based on the distance between species pairs in a taxonomic tree (see

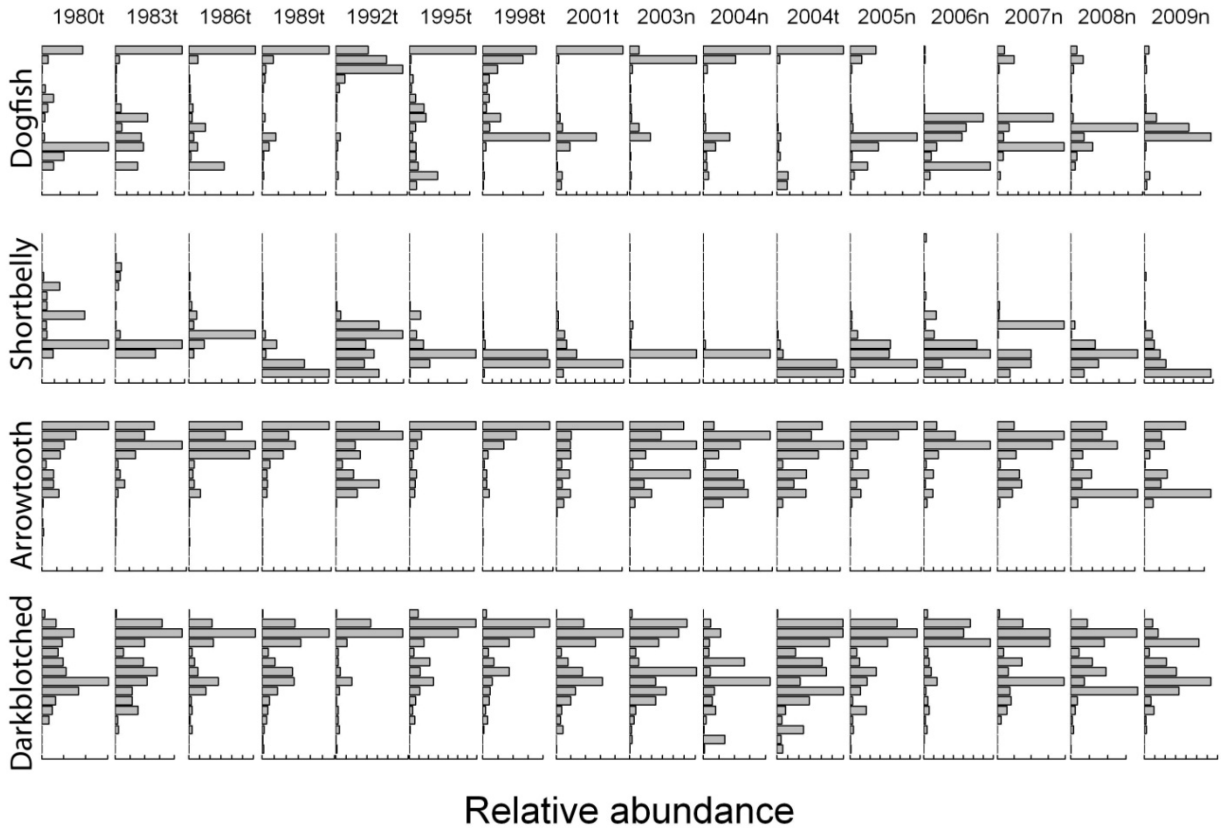


Figure 19. Spatial distribution of four groundfish from 1980 to 2009. Data are CPUE (number per km^2) presented in 10 latitude bins from lat 34°N (y-axis minimum) to lat 48°N (y-axis maximum). Data are relative within years and absolute values should not be compared across years as axes may vary. Letters following year headings indicate triennial (t, data courtesy of Mark Wilkins, AFSC) or NWFSC (n, data courtesy of Beth Horness, NWFSC) surveys. Due to difference between the two surveys, trends between the two should be made with caution. Both surveys were conducted in 2004.

Appendix C). Changes in TD indicate changes in the deeper evolutionary makeup of the community, not just the number or evenness of species in a system. High AvTD values indicate low relatedness of species or taxa in the sample. VarTD is a measure of the regularity of branch lengths within the taxonomic tree for that sample, not the variance of AvTD among samples. See Appendix C for more details.

AvTD and VarTD (Clarke and Warwick 1998a, Clarke and Warwick 2001b) for West Coast groundfishes were estimated from the triennal survey and the NWFSC trawl survey (see Appendix C for further details). A subset of the available data was used: trawls between 50–350 m and 34–38°N latitude. Triennial data included the years 1980–2004 (every third year), while NWFSC data included 2003–2009 data. Yearly estimates were derived separately for each time series.

AvTD (Figure 22) increased slightly but steadily from 1980 to 1998. The trend over the last 5 years of the NWFSC time series was for a decline in AvTD, but this decline was based

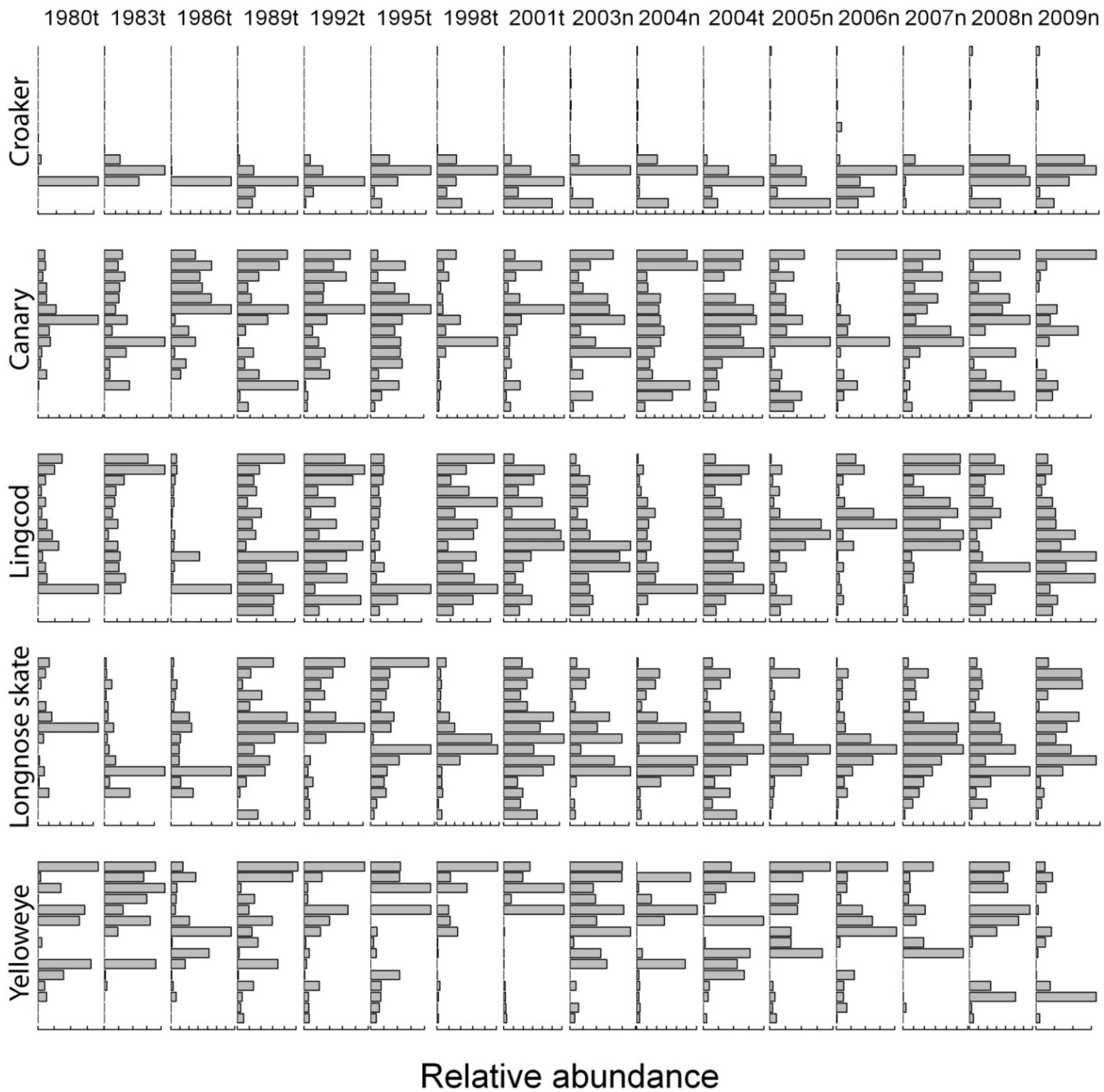


Figure 20. Spatial distribution of five groundfish from 1980 to 2009. Data are CPUE (number per km^2) presented in 10 latitude bins from lat 34°N (y-axis minimum) to lat 48°N (y-axis maximum). Data are relative within years and absolute values should not be compared across years as axes may vary. Letters following year headings indicate triennial (t, data courtesy of Mark Wilkins, AFSC) or NWFSC (n, data courtesy of Beth Horness, NWFSC) surveys. Due to difference between the two surveys, trends between the two should be made with caution. Both surveys were conducted in 2004.

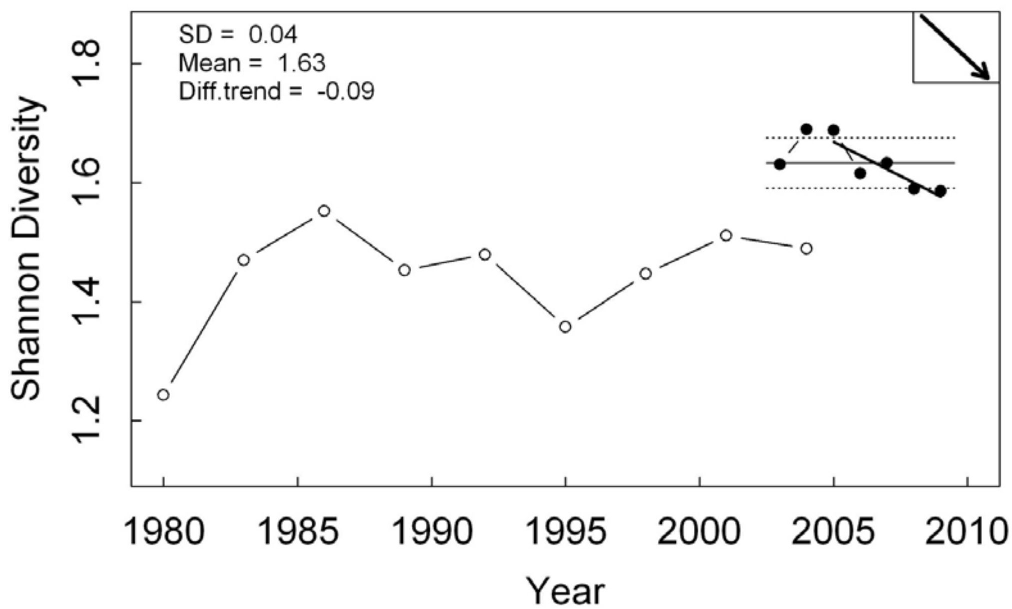
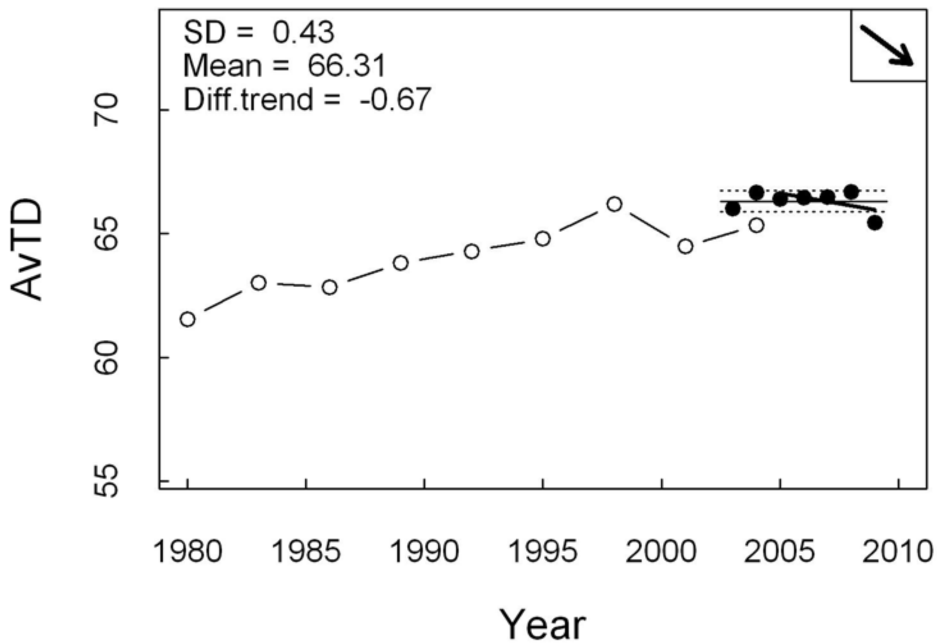


Figure 21. Annual mean Shannon Diversity for lat 34–48°N and 50–350 m bottom depth. Open circles show yearly averages calculated from triennial trawl survey (data courtesy of Mark Wilkins, AFSC). Closed circles show results for the NWFSC trawl survey (data courtesy of Beth Horness, NWFSC). Mean and SD are the mean and standard deviation of the NWFSC time series, Diff.trend is the absolute change in the predicted trend over 5 years. The solid line is the mean for the NWFSC data. Dotted lines are ±1 SD. The trend line (thick black) is the 5-year trend. Symbol in the upper right indicates that the 5-year trend decreased relative to 1 SD of NWFSC data. Data are the year effect from the GAM model and not absolute estimates of diversity.

largely on one data point. VarTD (Figure 22) showed an overall increase from the early 1990s, but the 5-year trend is presently stable.

TD of zooplankton in the California Current was largely stable over the last 5 years except during the winter (Figure 23 and Figure 24). Winter values during the last 5 years have trended up for AvTD. For both metrics, the 5-year mean was within 1 SD of the long-term mean in all cases.

The trend in TD indicates that the structure of the groundfish assemblage has changed since 1980 to some degree. Caution should be used in interpreting the results and further investigation of the data is necessary to fully understand the significance of the change. Higher diversity (usually measured as richness but here measured as AvTD) is generally considered good because of biodiversity-ecosystem function relationships (Stachowicz et al. 2007). However, the West Coast groundfish assemblage contains many closely related rockfishes (*Sebastes*), which leads to low AvTD values and high VarTD (Tolimieri and Anderson 2010). A reduction in the frequency of occurrence of rockfishes would cause the reverse trend—an increase in AvTD, as the species present would be less related, and a decrease in VarTD, as branch lengths between species became more regular.



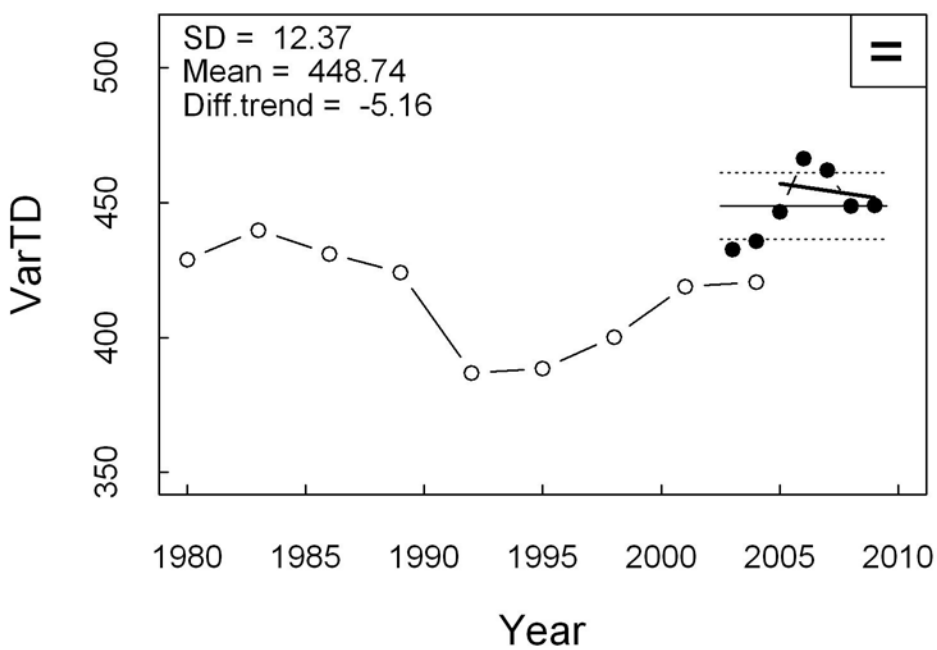


Figure 22. AvTD and VarTD for West Coast groundfishes from 1980 to 2009 for lat 34–48°N and 50–350 m bottom depth. Closed circles show results for the NWFSC trawl survey (data courtesy of Beth Horness, NWFSC). Mean and SD are the mean and standard deviation of the NWFSC time series, Diff.trend is the absolute change in the predicted trend over 5 years. The solid line is the mean for the NWFSC data. Dotted lines are ±1 SD. The trend line (thick black) is the 5-year trend. Symbols in the upper right indicates whether the 5-year trend decreased or showed no change relative to 1 SD of NWFSC data. Data are the year effect from the GAM model and not absolute estimates of the metrics.

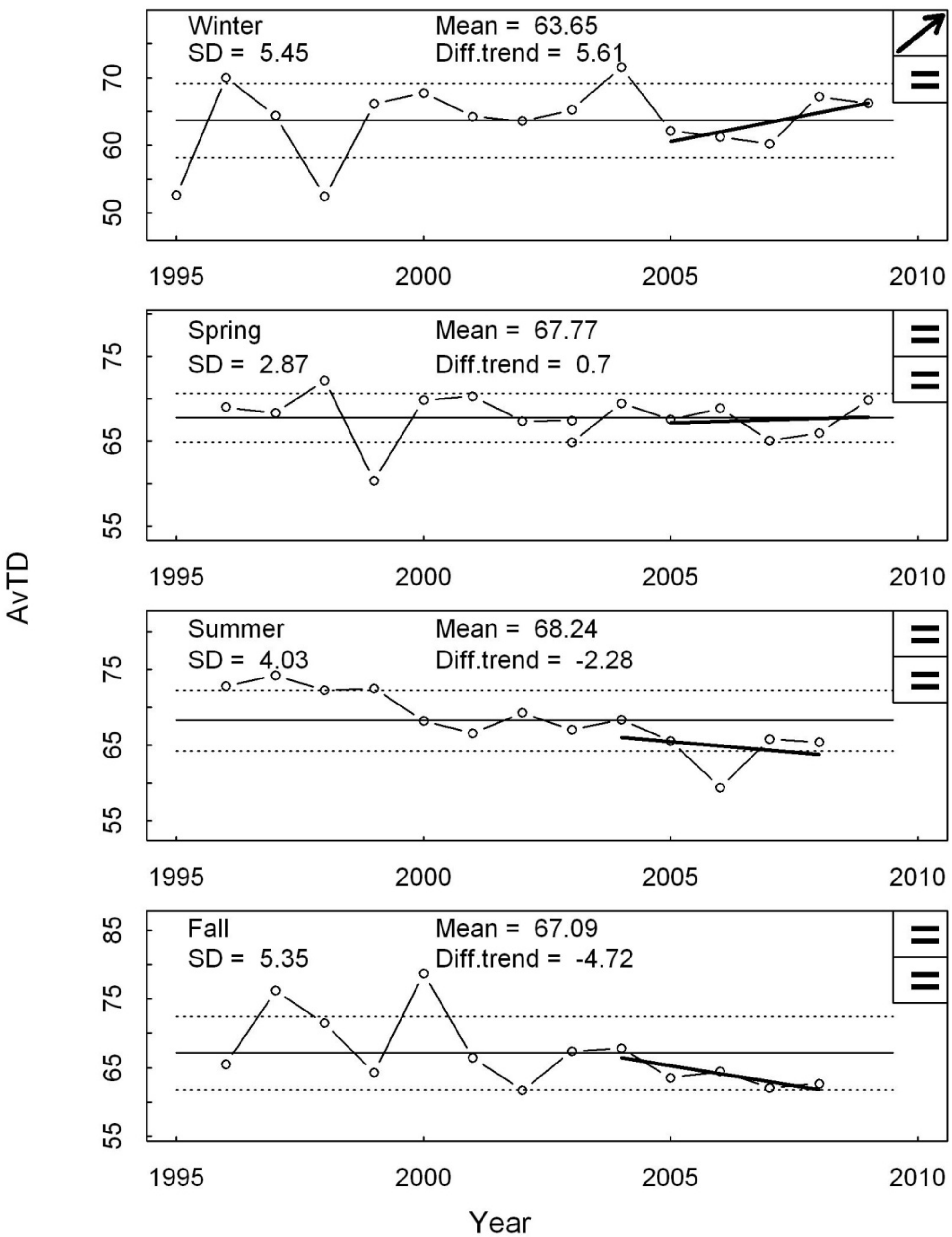


Figure 23. AvTD of California Current zooplankton from 1996 to 2008 in four seasons. Mean and SD are the mean and standard deviation of the NWFSC time series, Diff.trend is the absolute change in the predicted trend over 5 years. Dotted lines are ±1 SD. The trend line (thick black) is the 5-year trend. Symbols in the upper right box indicate whether the 5-year trend increased or showed no change relative to 1 SD of NWFSC data. Symbols in the lower right box indicate that the 5-year mean showed no change relative to the long-term mean. Data are the year effect from the GAM model and not absolute estimates of the metrics.

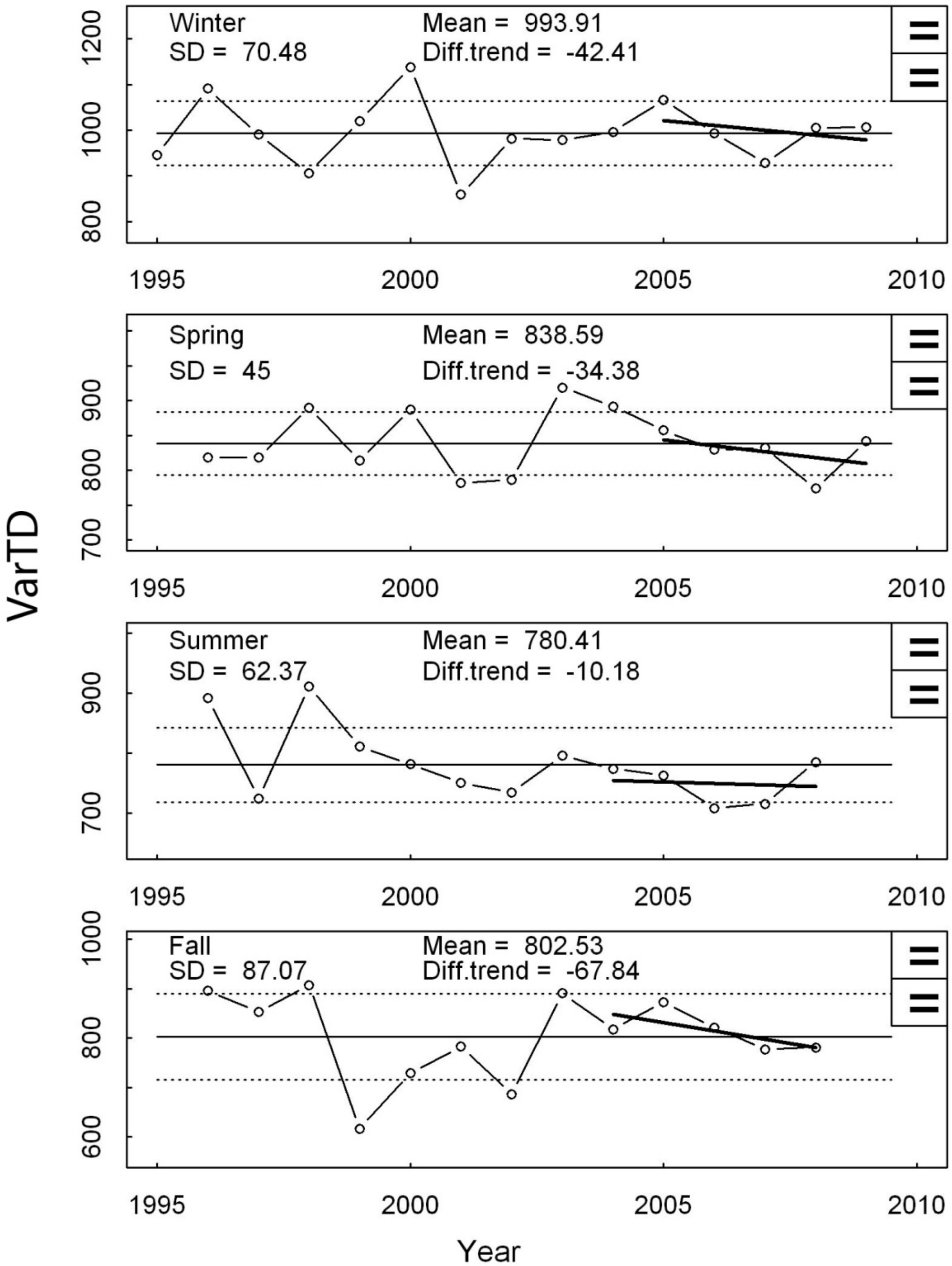


Figure 24. VarTD of California Current zooplankton from 1996 to 2008 in four seasons. Mean and SD are the mean and standard deviation of the NWFSC time series, Diff.trend is the absolute change in the predicted trend over 5 years. Dotted lines are ±1 SD. The trend line (thick black) is the 5-year trend. Symbols in the upper right box indicate that the 5-year trend showed no change relative to 1 SD of NWFSC data. Symbols in the lower right box indicate that the 5-year mean showed no change relative to the long-term mean. Data are the year effect from the GAM model and not absolute estimates of the metrics.

Indicator: Seabird reproduction indices

While there are a handful of seabird colonies with long-term monitoring programs in place (Appendix C), no single coast-wide indicator has been developed. Future work will endeavor to develop a coast-wide seabird reproductive index based on a multivariate approach (Frederiksen et al. 2007) that integrates data sets from a variety of long-term seabird colony monitoring programs along the Pacific coast.

Indicator: The northern copepod biomass anomaly

The northern copepod biomass anomaly measures whether copepod species from northern waters are more or less common than normal off the Oregon coast. It is responsive to climate effects such as El Niño or PDO. The anomaly indicates change in the structure of the zooplankton community. Importantly, because northern species of copepods are lipid rich, a high value of the northern copepod index is suggestive of good feeding conditions at the base of the food web and may help to predict changes in fish populations (Beamish and Mahnken 2001).

Over the last 5 years (2005–2009), the northern copepod anomaly has followed an increasing trend (Figure 25), although the 5-year mean is within 1 SD of the long-term mean for the time series. This increasing trend suggests the increasing prevalence of cold water copepods in the system. This increase may be temporary, however, as the overall time series suggests long-term cycling.

Several long-term zooplankton monitoring programs, representing seven subregions spanning the entire California Current system from Baja California to Vancouver Island, now provide zooplankton time series of various lengths from 1969 to the present. Although differences in processing and sampling zooplankton time series introduce a variety of biases that often prevent comparisons between data sets, many major questions can still be answered, because an individual data set can be presented and analyzed as a time series of log-scale anomalies relative to the local long-term average seasonal climatology. Anomalies are primarily used to separate interannual variability from the often large annual seasonal cycle of zooplankton stock size (Mackas and Beaugrand 2010).

The specific species associated with these anomalies vary regionally, but can generally be classified as resident versus nonresident species. Here we propose to combine these regional anomalies into a single index that can be used to represent coast-wide responses of zooplankton communities to regional climate signals. This coast-wide zooplankton index indicator will combine regionally specific community composition anomalies into a single index using multivariate techniques (i.e., principal component analysis) in similar fashion to the calculation of regional climate indices, such as the MEI (Wolter and Timlin 1993). This index can then be tested for use as a leading indicator of regional climate signals, such as ENSO or PDO, using existing time series from the last 20 years, during which time the California Current saw at least two major climate regime shifts.

Indicator: Top predator biomass

Data sources, data selection, and statistical procedures follow those for the estimation of groundfish numbers (see Evaluating Potential Indicators for the California Current: Groundfish

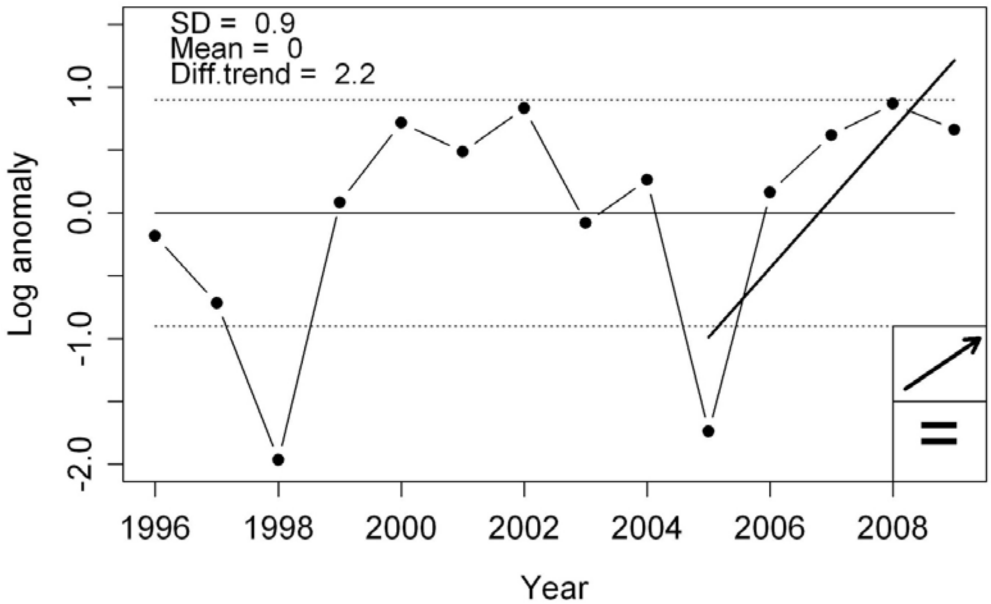


Figure 25. The northern copepod anomaly off Oregon from 1996 to 2009. Biomass values are mg carbon m^{-3} in log10. Values above zero indicate a higher than normal abundance of northern copepod species. Symbol in the upper right box indicates that the 5-year trend increased relative to 1 SD of the long-term mean. Symbol in the lower right box indicates that the 5-year mean showed no change relative to the long-term mean. (Data courtesy of Bill Peterson, NWFSC.)

and Ecosystem Health subsection above and Appendix C). While similar generalized additive models (GAMs) were used to produce annual means, top predator data were transformed (log(x+0.1)) prior to analysis.

Top predator biomass (kg per km^2) per trawl for groundfishes was calculated by summing the biomass of all groundfish species listed in FishBase.org with trophic levels of 4.0 or higher (Table 12). Top predator biomass declined from 2003 to 2009 (Figure 26) by more than 2 SD of the full NWFSC time series. Over the last 5 years, biomass has continued to decline by more than 1 SD of the full NWFSC time series.

Time constraints prevented us from collating and analyzing appropriate data for other apex predators. Future efforts will expand this indicator so that it includes a breadth of top predator species.

Key Attribute: Energetics and Material Flows

Indicator: Nutrient levels

In developed nearshore regions of the California Current, nutrient concentrations have been more or less continuously measured for decades in many rivers, estuaries, beaches, and other drinking water supplies. In contrast for offshore regions, nutrient levels in the upper layers of the water column have generally been poorly characterized in space and time (Hill and Wheeler 2002). Some exceptions to this pattern include intensive sampling at individual regions:

Table 12. Species used in the estimation of top predator biomass. Trophic level from FishBase.org.

Common name	**Scientific name**	**Trophic level**
Giant grenadier	*Albatrossia pectoralis*	4.3
Longnose lancetfish	*Alepisaurus ferox*	4.1
Thresher shark	*Alopias vulpinus*	4.5
Fangtooth	*Anoplogaster cornuta*	4.0
North Pacific daggertooth	*Anotopterus nikparini*	4.5
Black scabbardfish	*Aphanopus carbo*	4.5
Arrowtooth flounder	*Atheresthes stomias*	4.3
Javelin spookfish	*Bathylychnops exilis*	4.1
Deepsea skate	*Bathyraja abyssicola*	4.0
Aleutian skate	*B. aleutica*	4.1
White skate	*B. spinosissima*	4.0
Roughtail skate	*B. trachura*	4.0
Northern pearleye	*Benthalbella dentata*	4.5
Pacific pomfret	*Brama japonica*	4.4
Manefish	*Caristius macropus*	4.2
Can-opener smoothdream	*Chaenophryne longiceps*	4.1
Pacific viperfish	*Chauliodus macouni*	4.1
Black swallower	*Chiasmodon niger*	4.2
Spotted cusk-eel	*Chilara taylori*	4.1
Filamented grenadier	*Coryphaenoides filifer*	4.5
Triplewart sea devil	*Cryptopsaras couesii*	4.5
Petrale sole	*Eopsetta jordani*	4.1
Pacific hagfish	*Eptatretus stoutii*	4.2
Umbrellamouth gulper	*Eurypharynx pelecanoides*	4.1
Pacific cod	*Gadus macrocephalus*	4.0
Soupfin shark	*Galeorhinus galeus*	4.2
Whipnose	*Gigantactis vanhoeffeni*	4.5
Sixgill shark	*Hexanchus griseus*	4.3
Pacific halibut	*Hippoglossus stenolepis*	4.1
Ragfish	*Icosteus aenigmaticus*	4.5
Smooth stargazer	*Kathetostoma averruncus*	4.3
Pacific lamprey	*Lampetra tridentata*	4.5
Pacific scabbardfish	*Lepidopus fitchi*	4.1
Slender barracudina	*Lestidiops ringens*	4.1
Shortfin eelpout	*Lycodes brevipes*	4.0
Duckbill barracudina	*Magnisudis atlantica*	4.1
Softhead grenadier	*Malacocephalus laevis*	4.2
Common blackdevil	*Melanocetus johnsonii*	4.1
Pacific hake	*Merluccius productus*	4.3
Ocean sunfish	*Mola mola*	4.0
Sailfin sculpin	*Nautichthys oculofasciatus*	4.1
Glowingfish	*Neoscopelus macrolepidotus*	4.2
California grenadier	*Nezumia stelgidolepis*	4.4
Pink salmon	*Oncorhynchus gorbuscha*	4.2
Coho salmon	*O. kisutch*	4.2
Chinook salmon	*O. tshawytscha*	4.4
[No common name]	*Oneirodes thompsoni*	4.2
Lingcod	*Ophiodon elongatus*	4.3

Table 12 continued. Species used in the estimation of top predator biomass. Trophic level from FishBase.org.

Common name	Scientific name	Trophic level
California halibut	*Paralichthys californicus*	4.5
Pacific pompano	*Peprilus simillimus*	4.1
[No common name]	*Photonectes margarita*	4.0
Plainfin midshipman	*Porichthys notatus*	4.0
Blue shark	*Prionace glauca*	4.2
Pacific sand sole	*Psettichthys melanostictus*	4.1
Brown rockfish	*Sebastes auriculatus*	4.0
Copper rockfish	*S. caurinus*	4.1
Yellowtail rockfish	*S. flavidus*	4.1
Black rockfish	*S. melanops*	4.4
Yelloweye rockfish	*S. ruberrimus*	4.4
Pacific sleeper shark	*Somniosus pacificus*	4.3
Spiny dogfish	*Squalus acanthias*	4.3
Pacific angel shark	*Squatina californica*	4.1
Blackbelly dragonfish	*Stomias atriventer*	4.0
California lizardfish	*Synodus lucioceps*	4.5
Longfin dragonfish	*Tactostoma macropus*	4.2
Pacific electric ray	*Torpedo californica*	4.5

the southern California Current via the CalCOFI program (Figure 27 through Figure 29, McClatchie et al. 2009) and portions of the northern California Current via GLOBEC cruises.

Most nutrient levels (nitrate, phosphate, silicate) are characterized in the CalCOFI region from 1984 to present based on concentration anomalies in the mixed layer depth, calculated using a density criterion set either to 12 m or to the halfway point between the 2 sampling depths where the gradient first reaches values larger than 0.002 per million, whichever is larger. Annual averages and the climatological mean are also graphed (McClatchie et al. 2009).

Preliminary comparisons are shown between existing nearshore (e.g., Washington State's ORHAB program, Monterey Bay National Marine Sanctuary Program) and offshore sampling programs by presenting data on seasonal averages (January-March = Win; April-June = Spr; July-September = Sum; October-December = Fall) of three nutrient levels (nitrate, phosphate, silicate) in the surface 5 m of the water column.

Future iterations of this indicator will seek to standardize these values using concentration anomalies in the mixing layer relative to annual and climatological means for each region.

Indicator: Chlorophyll *a*

High values of chl *a* levels indicate increased abundance of primary producers at the water surface. Satellite chl *a* values since 2002 were low in 2005 at locations B and C and in 2009 at locations A and B. In winter 2010, they were above 1 SD for all three locations (Figure 30). In the summers of 2003 and 2004, there were peaks at locations B and C, respectively.

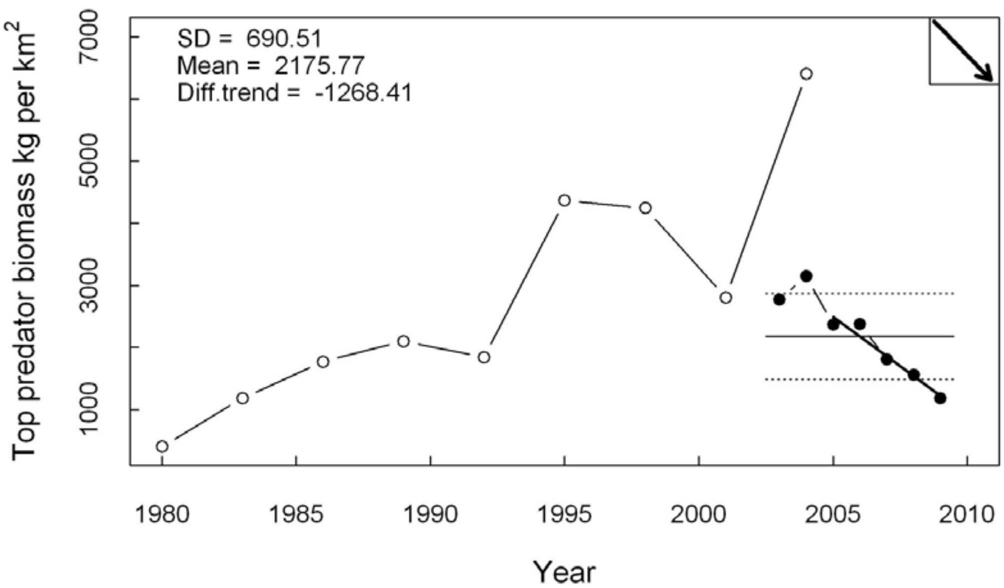


Figure 26. Top predator biomass. Closed circles show results for the NWFSC trawl survey (data courtesy of Beth Horness, NWFSC). Mean and SD are the mean and standard deviation of the NWFSC time series, Diff.trend is the absolute change in the predicted trend over 5 years. The solid line is the mean for the NWFSC data. Dotted lines are ±1 SD. The trend line (thick black) is the 5-year trend. Symbol in the upper right indicates that the 5-year trend decreased relative to 1 SD of NWFSC data. Data were log(x+0.1) transformed prior to analysis and back-transformed for presentation. Data are the year effect from the GAM model and not absolute estimates of abundance.

Chl *a* values at all three locations were low in 2010 and showed a decline over the past 5 years at locations B and C. Spatial patterns show chl *a* greater near the coast particularly in estuaries such as San Francisco Bay, Puget Sound, and the Columbia River mouth. Overall chl *a* values were greater in summer than winter.

In the past several years, surface chlorophyll concentrations in Monterey Bay have been anomalously high (Kahru and Mitchell 2008, Kahru et al. 2009), consistent with the PDO shift in late 1998 and subsequent cooler state of the CCLME (Peterson and Schwing 2003, Chavez et al. 2003). Surface chlorophyll concentrations on the Oregon continental shelf have also been high in recent years, with summer averages nearly double values from 1997 to 2000 (Figure 30).

EBM Component: Forage Fish

This EBM component will be developed for the 2011 report. We have included existing data on trends below as a precursor to more thorough treatment in FY2011.

Most mesopelagic fishes decreased in abundance during cool phases of the PDO and increased during warm phases from CalCOFI data up to 2002 (Hsieh et al. 2005, 2009). Because these species are not commercially fished and are highly linked to primary productivity, they can serve as a potential proxy for tracking changes in environmental forcing that could cascade through the pelagic food web. Market squid in the southern ecoregion were below normal in

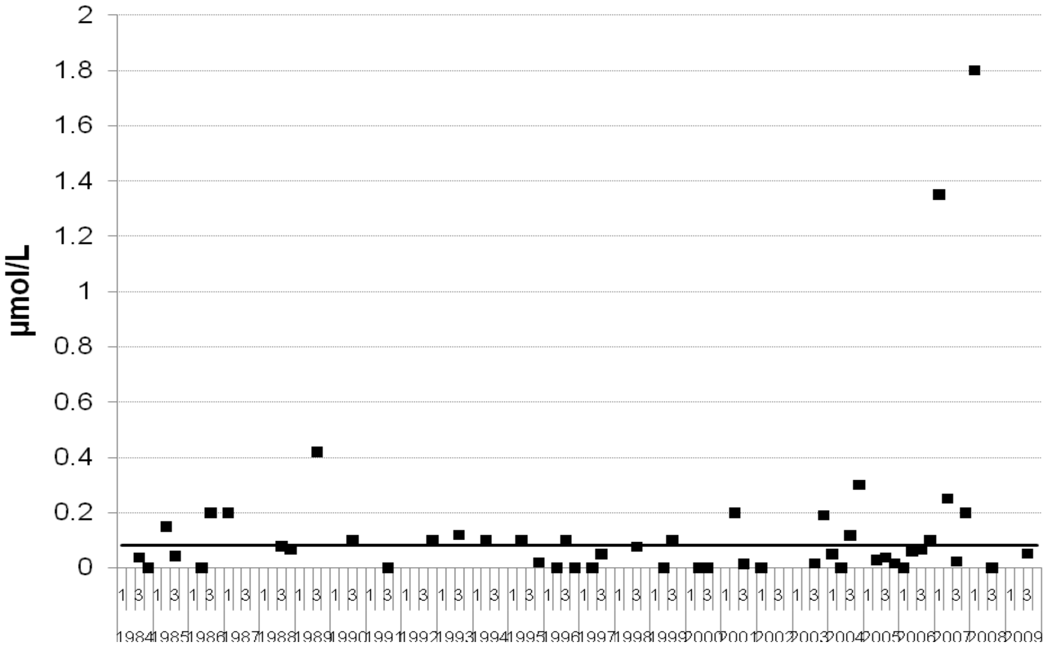


Figure 27. Mean nitrate (NO_3) concentrations (μmol/L) by season (1 = Win = Jan–Mar; 2 = Spr = Apr–Jun; 3 = Sum = Jul–Sep; 4 = Fall = Oct–Dec), from 1984 to 2009 at depths less than 6 m. Long-term mean indicated by the thick horizontal line. Geographic range encompasses station grid 66.7 (CalCOFI north) through grid 136.7 (IMECOCAL–Baja California). Data accessible in the CCE LTER data repository supported by the Division of Ocean Sciences, NSF Grant OCE-0417616. Data set 82: Conductivity temperature depth bottle data–Survey cruise data set (CalCOFI–SIO).

2005 and 2006, as evidenced by both landing data and California sea lion (*Zalophus californianus*) diets (Figure 31).

Of the key coastal species, northern anchovy is often characterized as being favored during cool periods and Pacific sardine during warm periods (Chavez et al. 2003). However, it has been a cool period for the past 5 years and the abundance of sardine larvae has remained relatively high, but anchovy abundance has remained low. Northern anchovy and Pacific sardine egg counts in spring (April) 2005 and 2006 were very low, especially in comparison with the 2001–2003 period (Bograd et al. 2010). The relative increases and decreases in anchovy versus sardine eggs between years may be attributed to temperature and upwelling (Lluch-Belda et al. 1991).

The composition of the forage fish community in 2005 and 2006 was most similar to that observed during the 1998 El Niño, with very low abundances of young-of-year groundfish and market squid, but with relatively high catch rates of anchovies and sardines. However, since 2006 the midwater trawl assemblage has trended back towards a species composition more characteristic of the cool, productive period of 2002. The abundance of juvenile age-0 rockfish (*Sebastes* spp.) was exceptionally low in 2005. Essentially, complete recruitment failure in the central ecoregion was observed (Bograd et al. 2010).

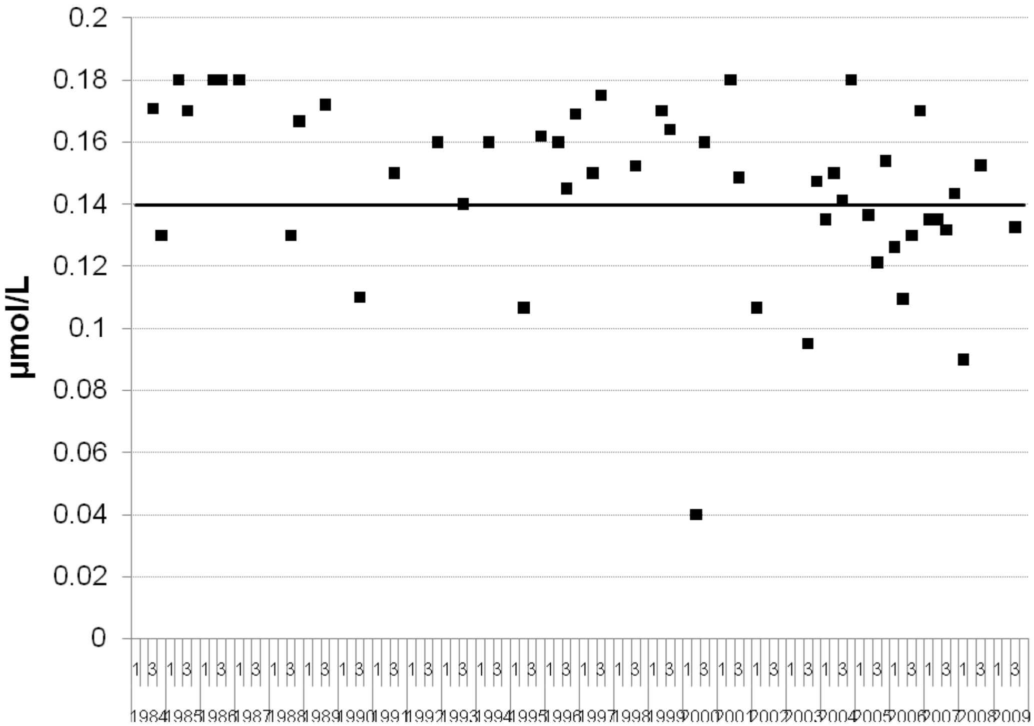


Figure 28. Mean phosphate (PO_4) concentrations (µmol/L) by season (1 = Win = Jan–Mar; 2 = Spr = Apr–Jun; 3 = Sum = Jul–Sep; 4 = Fall = Oct–Dec), from 1984 to 2009 at depths less than 6 m. Long-term mean indicated by a thick horizontal line. Geographic range encompasses station grid 66.7 (CalCOFI north) through grid 136.7 (IMECOCAL–Baja California). Data accessible in the CCE LTER data repository supported by the Division of Ocean Sciences, NSF Grant OCE-0417616. Data set 82: Conductivity temperature depth bottle data–Survey cruise data set (CalCOFI–SIO).

EBM Component: Vibrant Coastal Communities

Work will commence on this EBM component in FY2011.

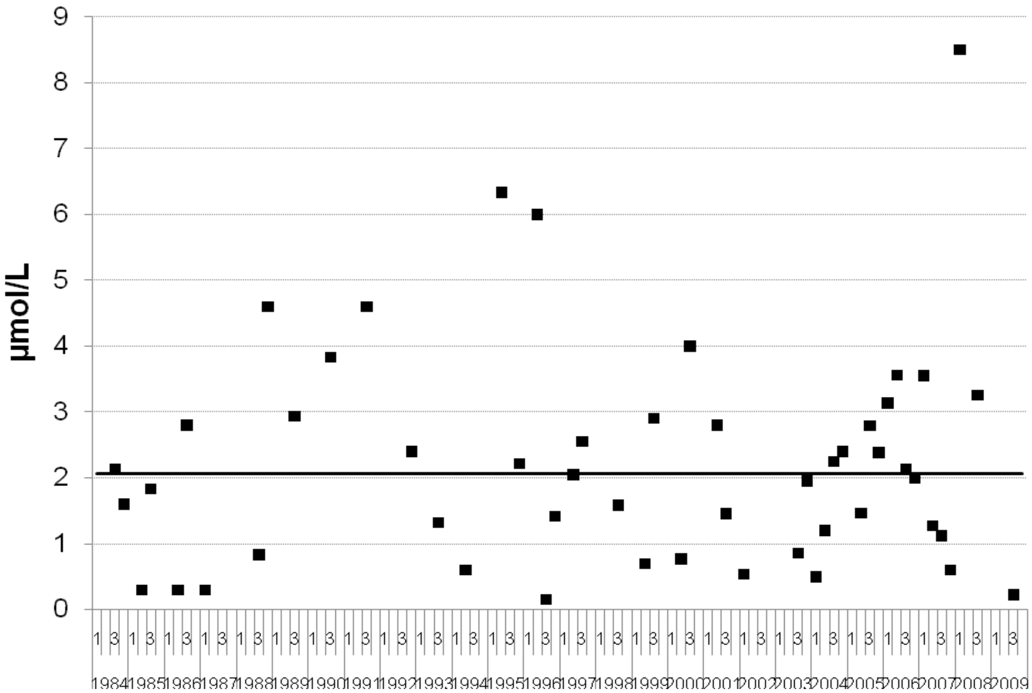


Figure 29. Mean silicate (SiO_3) concentrations (µmol/L) by season (1 = Win = Jan–Mar; 2 = Spr = Apr–Jun; 3 = Sum = Jul–Sep; 4 = Fall = Oct–Dec), from 1983 to 2009 at depths less than 6 m. Long-term mean indicated by a thick horizontal line. Geographic range encompasses station grid 66.7 (CalCOFI north) through grid 136.7 (IMECOCAL–Baja California). Data accessible in the CCE LTER data repository supported by the Division of Ocean Sciences, NSF Grant OCE-0417616. Data set 82: Conductivity temperature depth bottle data–Survey cruise data set (CalCOFI–SIO).

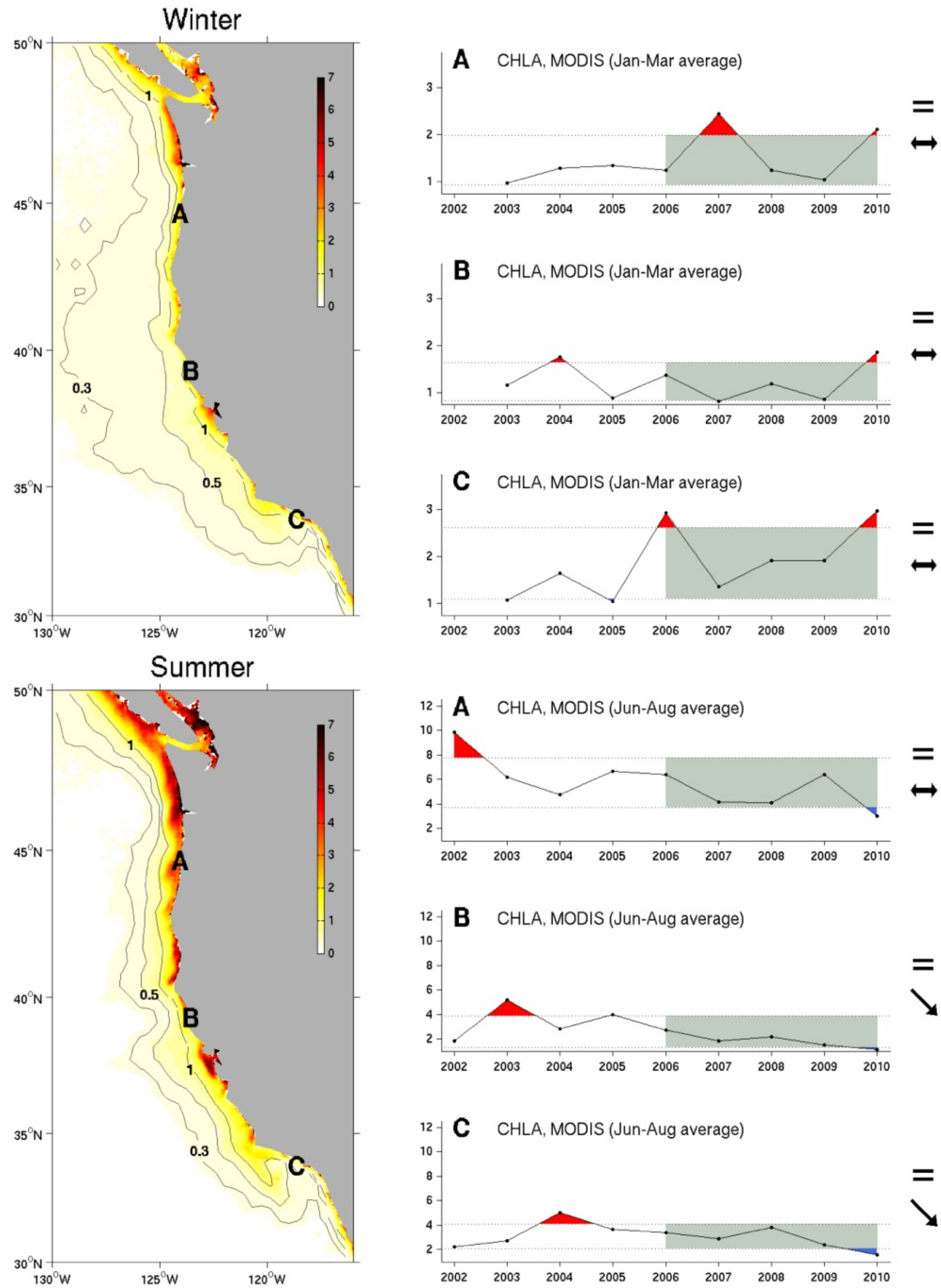


Figure 30. Winter and summer spatial means of SeaWiFS chl *a* (1999–2008) and MODIS chl *a* time series from NDBC buoys. The MODIS time series are area averages of 2 degree x 50 km boxes for north-south and east-west, respectively, and centered on locations A, B, and C. All values on the figures have units of milligrams per cubic meter. On the right side of each line chart, the equal sign indicates that the 2006–2010 mean is within the long-term SD; the down and horizontal arrows indicate whether the 2006–2010 trend is below or within 1 SD.

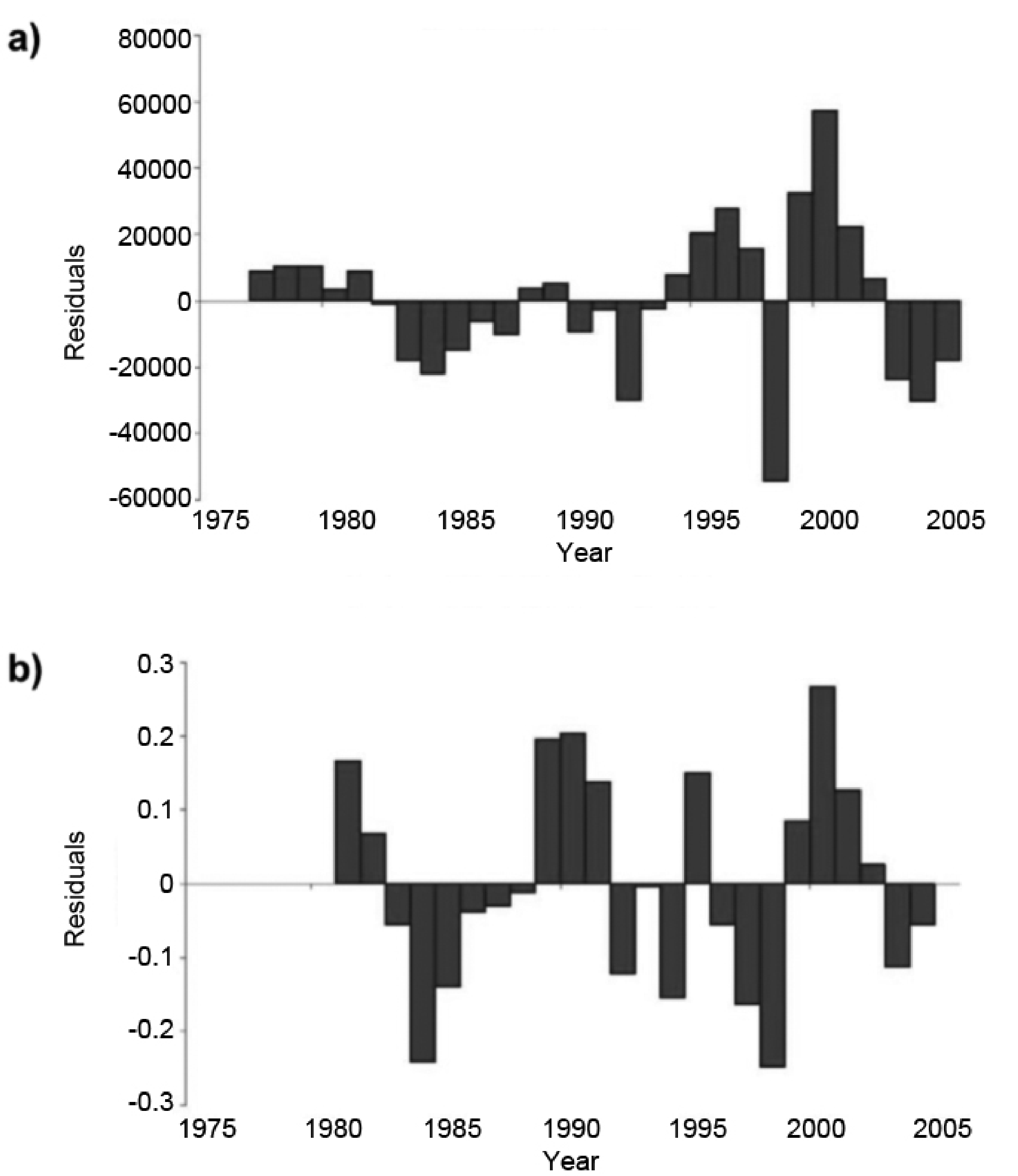


Figure 31. Market squid indices from landings data (panel a) and California sea lion diets (panel b). Note that the trend of increasing catch due to increasing fishing effort has been removed by quadratic regression. Bars represent residuals after detrending. (Catch data courtesy of Dale Sweetnam, California Department of Fish and Game, and marine mammal data courtesy of Mark Lowry, SWFSC.)

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Technical background for an Integrated Ecosystem Assessment of the California Current

Groundfish, Salmon, Green Sturgeon, and Ecosystem Health

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