

INTERANNUAL AND SPATIAL VARIATION IN THE DISTRIBUTION OF YOUNG-OF-THE-YEAR ROCKFISH (*SEBASTES* SPP.): EXPANDING AND COORDINATING A SURVEY SAMPLING FRAME

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ABSTRACT

Data on young-of-the-year rockfish, *Sebastes* spp., were analyzed from two midwater trawl surveys conducted by the National Marine Fisheries Service Southwest Fisheries Science Center Fisheries Ecology Division and the Pacific Whiting Conservation Cooperative from 2001 to 2005. Length-frequency data for *Sebastes* spp. from the two surveys showed interannual and geographic variability. Examination of side-by-side vessel paired trawls indicated a disparity in the 2001 and 2002 data, while for 2003 to 2005 the *Sebastes* spp. catch data and species richness were comparable. Comparison of the mean log-transformed catches of *Sebastes* spp. from the two surveys showed significant inter-survey differences in 2001 and 2002, but results for 2003 to 2005 were similar. Given the concordance between the two surveys from 2003 to 2005, those data were pooled and abundance patterns by latitude and year were examined for *S. entomelas*, *S. flavidus*, *S. jordani*, *S. mystinus*, *S. paucispinis*, and *S. pinniger*. Interannual shifts in latitudinal distribution were observed, with changes in abundance often associated with the biogeographic boundaries of Point Conception, Cape Mendocino, and Cape Blanco.

INTRODUCTION

Rockfish, *Sebastes* spp., comprise a substantial portion of the groundfish fishery off the west coast of North America (PFMC 2002). Since most adult *Sebastes* spp. do not recruit to the fishery until they are three or more years old (Barss and Wyllie-Echeverria 1987; He et al. et al. 2003; Lai et al. et al. 2003; Rogers 2003), an examination of earlier life history stages and their contribution towards establishing year-class strength can be useful in the fisheries management process (Ralston and Ianelli 1998). For example, Bailey and Francis (1985) and Hollowed (1992) reported that larval survival of Pacific whiting (*Merluccius productus*) was strongly correlated with recruitment success and Bailey et al. (1986) indicated that young-of-the-year (YOY) abundance estimates from midwater trawl surveys could be useful in forecasting year-class strength. Bailey and Spring (1992) reported a good correlation between survey estimates of

YOY juvenile walleye pollock (*Theragra chalcogramma*) and the numbers of age-two recruits to the fishery later estimated from a tuned virtual population analysis. Moreover, Ralston and Howard (1995) showed that year-class strength in yellowtail rockfish (*S. flavidus*) and blue rockfish (*S. mystinus*) was already established prior to the pelagic juvenile stage by comparing indices of pelagic YOY juvenile abundance from midwater trawl surveys with settled YOY juvenile SCUBA surveys.

Since 1983 the National Marine Fisheries Service (NMFS) Southwest Fisheries Science Center (SWFSC) Fisheries Ecology Division has conducted annual midwater trawl surveys off northern and central California (CA) in order to develop annual indices of abundance for YOY of commercially and recreationally significant *Sebastes* spp. Results from the surveys have been incorporated into the most recent stock assessments for such species as widow rockfish, *S. entomelas* (He et al. 2003), and chilipepper, *S. goodei* (Ralston et al. 1998). In addition, results from the NMFS surveys have been used in the assessment of *M. productus* (Sakuma and Ralston 1997; Helsen et al. 2004).

Beginning in 2001, the Pacific Whiting Conservation Cooperative (PWCC), in cooperation with the NMFS Northwest Fisheries Science Center (NWFS), began a survey patterned after the existing NMFS survey specifically targeting YOY *M. productus* with the intent of providing increased coverage in more northern areas, extending from central CA through Oregon (OR). While *M. productus* was the primary species targeted by the PWCC, the *Sebastes* spp. collected were also of interest. The NMFS and PWCC surveys sampled during the same time period each year and used similar gear and methods, allowing potential combination of the data from the two surveys. Consequently, YOY *Sebastes* spp. catches could be quantified for almost the entire west coast of the United States (fig. 1). Therefore, the purpose of this study was to compare the NMFS and PWCC surveys and to evaluate the feasibility of combining the data from the two surveys to examine temporal and spatial patterns in the abundance of YOY *Sebastes* spp. on a broad scale.

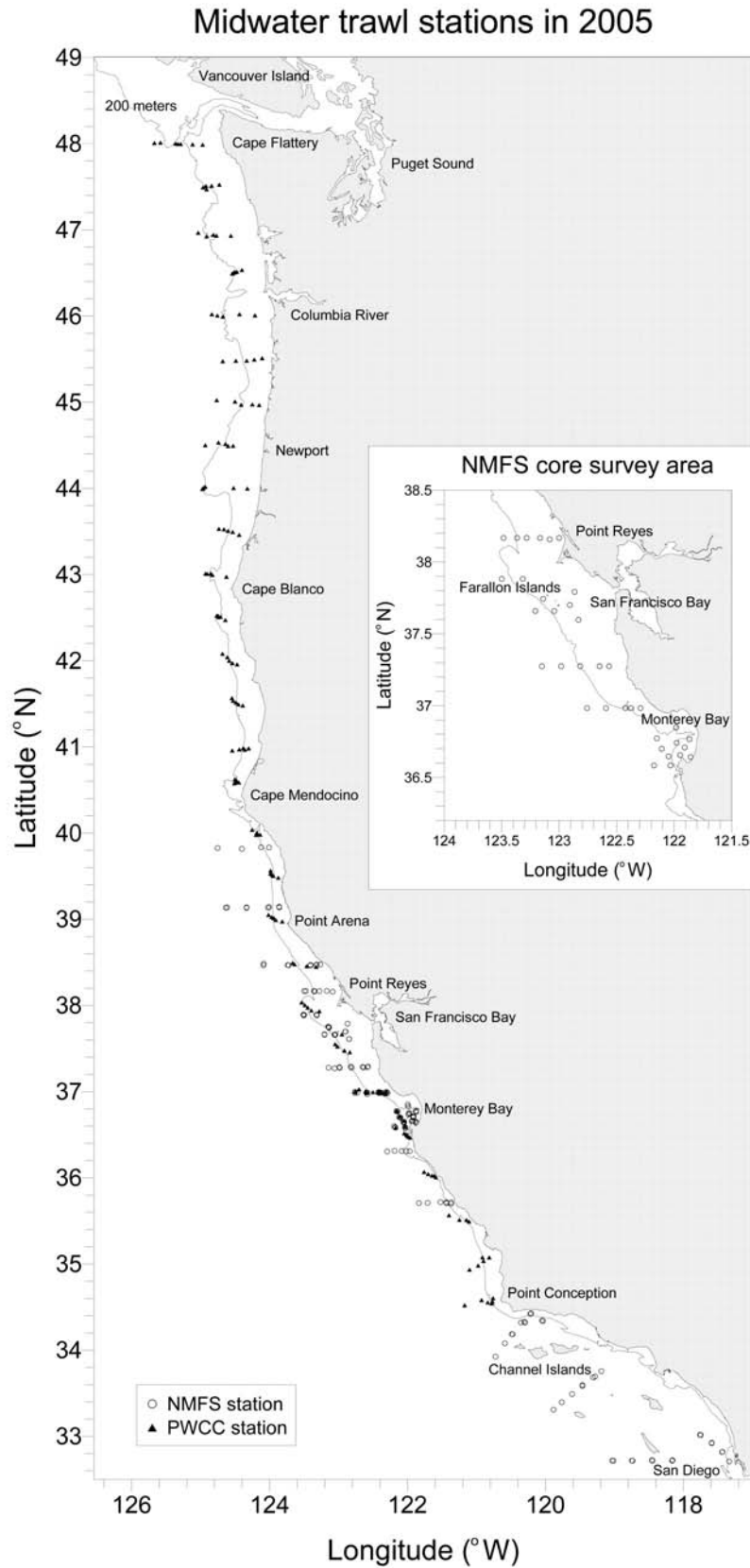


Figure 1. Spatial coverage of stations sampled by the NMFS and PWCC surveys in 2005 and the locations of the fixed standard stations within the NMFS core survey area (inset).

METHODS

General Survey

Annual midwater trawl surveys were conducted by the NMFS SWFSC aboard the National Oceanic and Atmospheric Administration (NOAA) research vessel R/V *David Starr Jordan* using a modified anchovy midwater trawl with a 26 m headrope and 9.5 mm codend mesh (Wyllie-Echeverria et al. 1990). Trawls were conducted at night (2100 to 0600 hrs) with a trawl duration of 15 minutes at a target headrope depth of 30 m. At stations with shallow bottom depths the target headrope depth was decreased to 7 m. Prior to 2003, realized headrope depths were determined by attaching a temperature depth recorder (TDR) to the headrope. Beginning in 2003, a Simrad integrated trawl instrumentation (ITI) system was used in addition to the TDR. Using data from the Simrad ITI system, target headrope depth was maintained in real time by altering vessel speed while holding constant the amount of wire out. Trawls were conducted at a set of standard fixed stations in a core survey area between southern Monterey Bay, CA (36°35'N latitude), and 38°10'N latitude, just north of Point Reyes, CA (38°00'N latitude) (fig. 1 inset). One occupation of these standard stations consisted of one sweep through the core survey area. From 1986 to 2003, three successive sweeps through the core survey area were completed every year during May to mid-June, with each sweep lasting approximately 10 days. Beginning in 2004, the spatial coverage was expanded northward to Delgada, CA (39°50'N latitude), just south of Cape Mendocino and southward to 32°43'N latitude just off San Diego, CA. The expansion of the survey area to the south was of particular interest given that Point Conception, CA (34°27'N latitude), is a well-known biogeographic boundary for many species (Horn and Allen 1978; Wares et al. 2001; Blanchette et al. 2002), including *Sebastes* spp. (Love et al. 2002), and also given the different oceanographic conditions south of Point Conception that can have a major effect on year-class strength (Parrish et al. 1981). While stations within the core survey area were still sampled three times, the new stations within the expanded survey area were only sampled twice. All *Sebastes* spp. were sorted, identified to species or species group, enumerated, and then frozen aboard the vessel. Frozen samples were transferred to the NMFS SWFSC Fisheries Ecology Division shoreside facility where species identifications and catch numbers were confirmed. Standard lengths (SL) were recorded from up to 100 specimens per species per trawl. SL measurements were expanded to the total number of fish caught and length frequencies for the 2001 to 2005 surveys were plotted for all *Sebastes* spp. combined collected within the northern/central CA area north of Point

Conception and also from southern CA south of Point Conception.

PWCC surveys were conducted aboard the fishing vessel F/V *Excalibur* using trawl gear and methods patterned after the NMFS surveys with some minor differences. Since the PWCC surveys began in 2001, a Furuno wireless net sounder system was used to determine the target headrope depth, which was maintained by keeping vessel speed constant and altering the amount of wire out. While the NMFS surveys sampled standard stations at fixed locations, the PWCC surveys sampled stations at non-fixed locations centered on the shelf break (~200 m bottom depth). Sampling was centered around the shelf break because that was where YOY *M. productus* were most likely to occur (Bailey 1981; Bailey et al. 1982; Saunders and McFarlane 1997). Each year the surveys began sampling at Newport, OR (44°30'N latitude), and then sampled at approximately 55.6 km (30 nautical mile) intervals down the coast to 34°30'N latitude, just north of Point Conception, with the survey area encompassing the known biogeographic boundaries of Cape Mendocino, CA (40°30'N latitude), and Cape Blanco, OR (42°50'N latitude) (Parrish et al. 1981; Barth et al. 2000; Williams and Ralston 2002; Cope 2004; Field and Ralston 2005). As time allowed, additional sampling was conducted along the vessel's northward return trackline to Newport, OR. Given that the latitudinal distribution of adult spawning and larvae for *M. productus* can vary from year to year (Bailey et al. 1982; Hollowed 1992; Horne and Smith 1997), the spatial coverage of the PWCC surveys was expanded in 2004 to 46°30'N latitude, just north of the Columbia River (46°00'N latitude), and then again in 2005 up to 48°00'N latitude, just south of Cape Flattery, WA (48°23.5'N latitude). All *Sebastes* spp. taken in PWCC midwater trawls were sorted, enumerated, and then frozen aboard the vessel. Frozen samples were then transferred to the shore-side facility at the NMFS SWFSC Fisheries Ecology Division for individual species identification and SL measurement. Length frequencies for the 2001 to 2005 surveys were plotted for all *Sebastes* spp. collected within the northern/central CA area north of Point Conception to Cape Mendocino and also from the northern CA/OR/WA area north of Cape Mendocino.

Paired Trawl Comparisons

To compare sampling between the two surveys, the NMFS and the PWCC spent a minimum of two nights each year starting in 2001 conducting side-by-side vessel paired trawls at the same stations. From 2001 through 2003, all paired trawls were conducted within Monterey Bay, whereas in 2004 they were conducted north of Monterey Bay up to San Francisco Bay. In 2005, paired trawling was conducted in the area north of Monterey

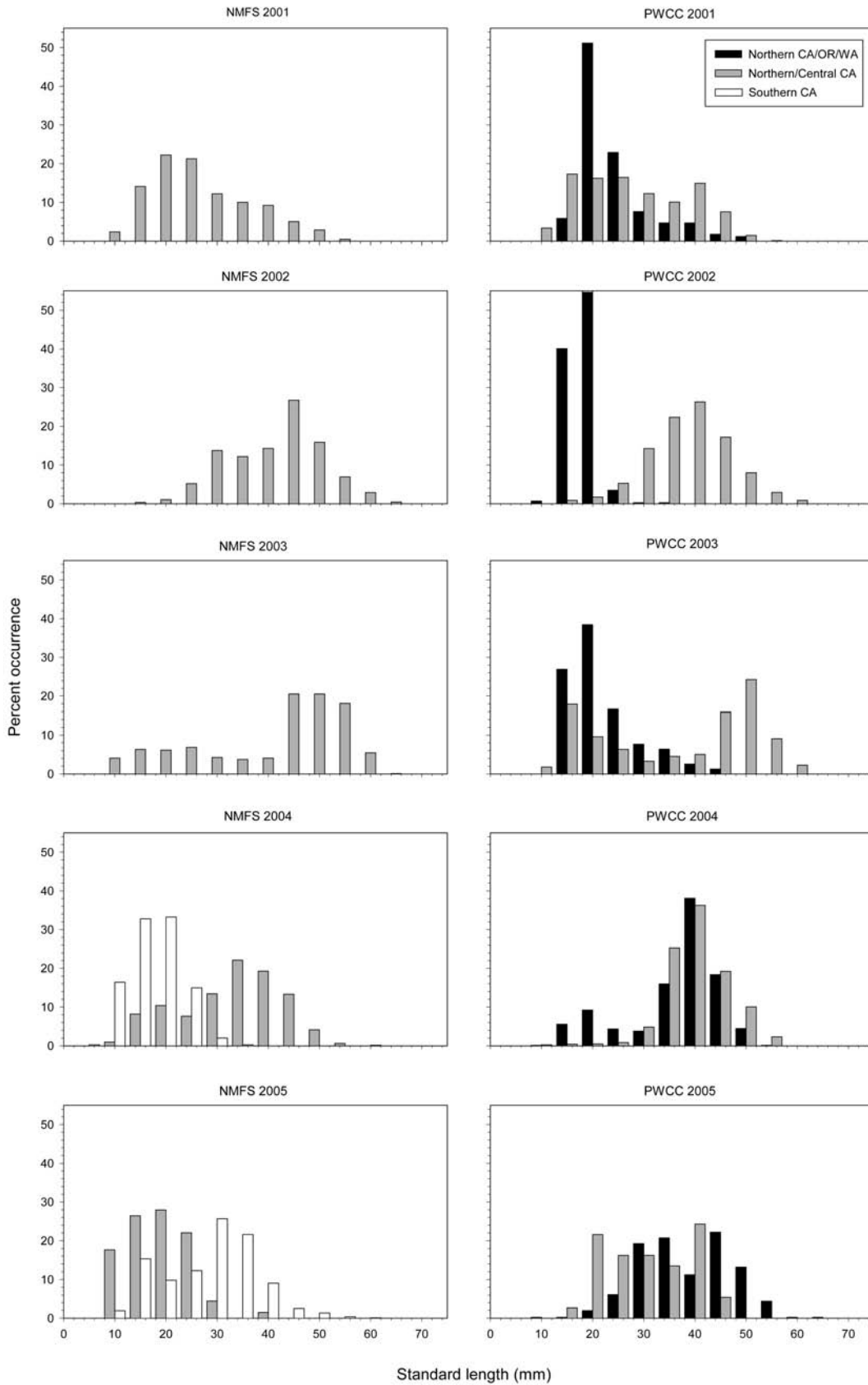


Figure 2. Length frequency plots for *Sebastes* spp. collected by the NMFS and PWCC surveys.

Bay, as well as within Monterey Bay. The two vessels attempted to trawl within 0.46 km (0.25 nautical miles) of each other and to start and end each trawl at approximately the same time. The actual distance between the two vessels as well as the depth of the bottom recorded by each vessel at the beginning of each paired trawl was examined to determine if the two vessels were indeed trawling within the same area. Catches of *Sebastes* spp. (number per trawl) and species richness (numbers of different species caught in each trawl) from the paired trawls were compared.

NMFS Core Survey Area Comparisons

As both the NMFS and PWCC surveys consistently sampled within the NMFS core survey area each year (36°30' to 38°20'N latitude), the mean log-transformed catches of all *Sebastes* spp., as well as those of individual species including widow rockfish (*S. entomelas*), yellowtail rockfish (*S. flavidus*), shortbelly rockfish (*S. jordani*), blue rockfish (*S. mystinus*), bocaccio (*S. paucispinis*), and canary rockfish (*S. pinniger*) were compared using data collected from within the core area of overlap. To ascertain the appropriateness of these comparisons the sampling dates and the number of overlapping sampling days within the NMFS core survey area were tabulated. For years and species that showed large discrepancies between the two surveys, catch size (number per trawl) and location were plotted to reveal spatial factors that may have contributed to the observed differences.

Combined Survey Data

For years in which the NMFS and PWCC surveys were shown to be similar and/or comparable, the catch data from the two surveys were combined. Mean log-transformed catches summarized by degree of latitude were then plotted for *S. entomelas*, *S. flavidus*, *S. mystinus*, and *S. pinniger*, which have a northern distribution as adults (Love et al. 2002), as well as *S. jordani* and *S. paucispinis*, which have a more southern distribution (Love et al. 2002), in order to reveal interannual spatial variability in relation to the biogeographic boundaries of Point Conception, Cape Mendocino, and Cape Blanco.

RESULTS

General Survey

YOY *Sebastes* spp. from the NMFS surveys were smaller in the northern/central California area in 2001 and 2005 than in 2002 to 2004 (fig. 2). In addition, in 2004 YOY *Sebastes* spp. captured in the southern CA area were substantially smaller than those taken in the northern/central CA area. Conversely, in 2005 the opposite pattern occurred, i.e., fish in the southern CA area were larger than those in the northern/central CA area.

The YOY *Sebastes* spp. from the PWCC surveys showed similar patterns to the NMFS surveys for the northern/central CA area with some minor differences (fig. 2). While the fish from the PWCC surveys were generally smaller in 2001 and 2005 compared to 2002 to 2004, there were noticeable numbers of larger fish observed in 2005, much more so than in the NMFS surveys. From 2001 to 2003 YOY *Sebastes* spp. from the PWCC surveys in the northern CA/OR/WA area were smaller than those in the northern/central CA area. However, in 2004 fish in the northern CA/OR/WA area were almost as large as those in the northern/central CA area and in 2005 the northern CA/OR/WA fish were larger.

Paired Trawl Comparisons

In 2001 and 2002, less than half of the paired trawls (3 of 10 and 1 of 7, respectively) were within 0.46 km of each other, while in subsequent years at least half (5 out of 10 for 2003, 15 out of 18 for 2004, and 5 out of 10 for 2005) of the paired trawls were within 0.46 km of each other. A Tukey's studentized range test ($\alpha = 0.05$, $df = 50$) indicated that the mean distance between the NMFS and PWCC survey vessels was significantly greater in 2002 than in the other years (tab. 1). Likewise, the inter-vessel distance in 2001 was significantly greater than in 2004, but was not significantly different from 2003 and 2005, and there were no significant differences between 2003, 2004, and 2005. In addition, a Tukey's studentized range test ($\alpha = 0.05$, $df = 50$) indicated that mean absolute differences in bottom depths were not significantly different amongst any of the years (tab. 1). However, in general, greater differences in bottom depths were observed in 2001 to 2003 compared with 2004 to 2005. In addition, the lack of a statistically significant result in this instance was probably influenced by high within-year variability.

Comparisons of the catches of *Sebastes* spp. taken during the paired trawls are shown in Figure 3. The upper panel includes all five years of data and the lower panel excludes the first two years from the comparison. By excluding 2001 and 2002 (the two years with significantly larger vessel distances and where less than 50% of the trawls were within 0.46 km) the concordance in *Sebastes* spp. catch between the two vessels was much improved, with the r^2 going from 0.66 to 0.81. Similarly, the comparison of the species richness from the paired trawls was much improved by excluding 2001 and 2002 with the r^2 going from 0.30 to 0.66 (fig. 4).

NMFS Core Survey Area Comparisons

Sampling dates within the NMFS core survey area for the two surveys are shown in Table 2. In 2002 and 2004 the PWCC offset in starting day was greater than

TABLE 1
 Mean distance between the NMFS and PWCC vessels and the mean absolute difference
 in the bottom depths from side-by-side paired trawls.

Year	Mean distance (km)	Standard deviation	Coefficient of variation	Mean bottom depth difference (m)	Standard deviation	Coefficient of variation
2001	0.7159	0.3308	46.2	114.2	154.3	135.1
2002	1.1226	0.3745	33.4	121.0	154.1	127.4
2003	0.4932	0.2103	42.6	139.1	170.1	122.3
2004	0.3334	0.2128	63.8	34.8	53.4	153.4
2005	0.5060	0.2339	46.2	42.8	41.0	95.8

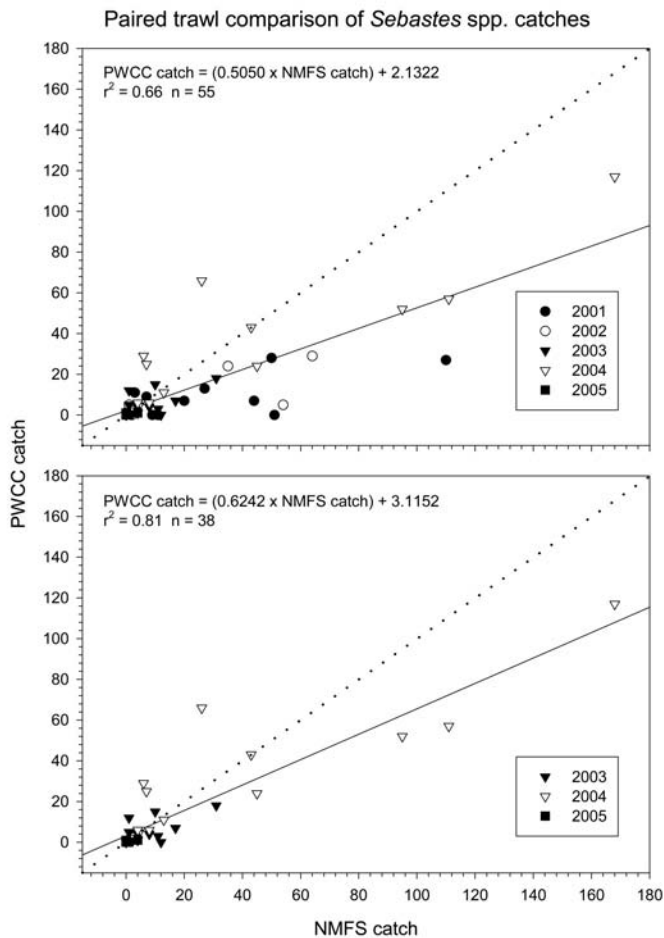


Figure 3. Comparison of *Sebastes* spp. catches from side-by-side paired trawls between the NMFS and PWCC surveys. The dotted line represents the line of equality, while the solid line is the regression line.

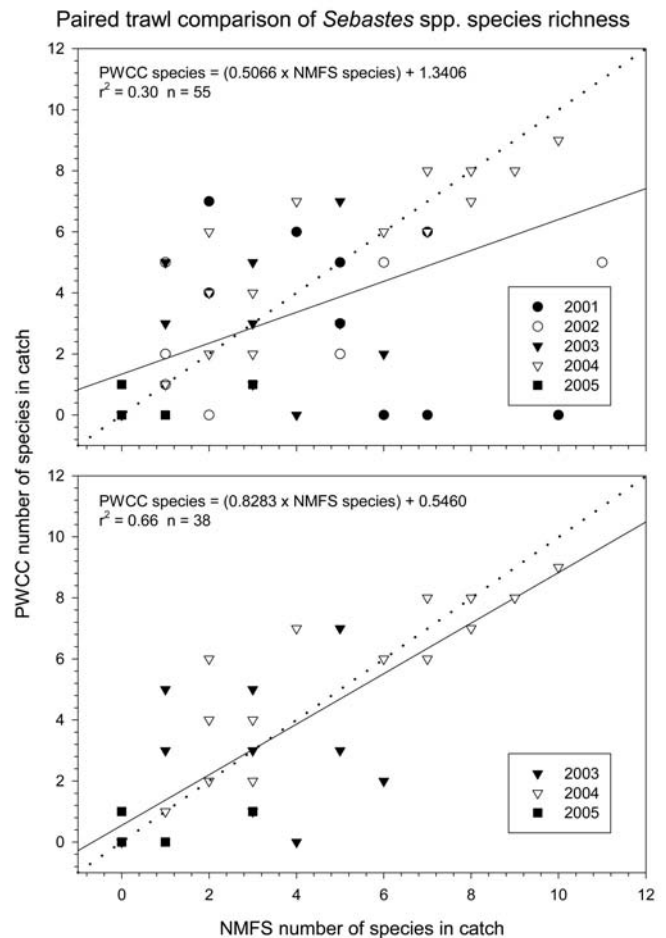


Figure 4. Comparison of *Sebastes* spp. species richness (number of different species per trawl) from side-by-side paired trawls between the NMFS and PWCC surveys. The dotted line represents the line of equality, while the solid line is the regression line.

TABLE 2
 Sampling dates for the NMFS and PWCC surveys, the starting day offset for the PWCC surveys relative to the NMFS surveys, and the number of PWCC sampling days within the NMFS core survey area. Starting day offset is the lag time between when the NMFS started sampling in the core survey area and when the PWCC began sampling in that area.

Year	NMFS dates	PWCC dates	Starting day offset	PWCC sample days
2001	11 May to 8 June	15 May to 20 May	4 days	6 days
2002	9 May to 3 June	20 May to 23 May	11 days	4 days
2003	14 May to 11 June	21 May to 25 May	7 days	5 days
2004	9 May to 6 June	24 May to 30 May	15 days	7 days
2005	8 May to 11 June	18 May to 29 May	10 days	6 days

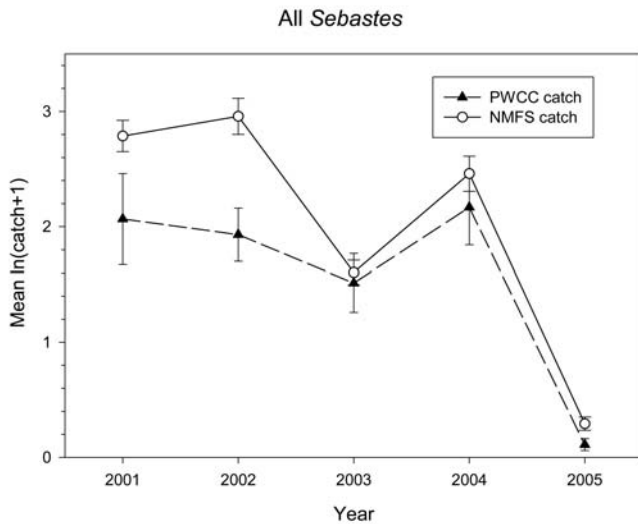


Figure 5. Mean log-transformed *Sebastes* spp. catches for the NMFS and PWCC surveys from the NMFS core survey area. Error bars represent the standard error of the mean.

the 10 days that it typically takes for the NMFS to complete one sweep through the core survey area stations. In addition, the PWCC spent the fewest sampling days in 2002 and the most sampling days in 2004 within the NMFS core survey area. Examining the mean log-transformed catches in the core survey area from both surveys (fig. 5) using an ANOVA indicated that there was a significant vessel and year interaction ($n = 566$, $df = 9$, $r^2 = 0.38$, $P < 0.0001$). The least-squares mean log-transformed catches were significantly different between the NMFS and PWCC surveys for 2001 ($P = 0.0316$) and 2002 ($P = 0.0012$), but not for 2003 ($P = 0.7339$), 2004 ($P = 0.3106$), and 2005 ($P = 0.5082$). Noticeable discrepancies in the mean log-transformed catches between the two surveys were observed for *S. entomelas* and *S. mystinus* in 2002 as well as for *S. jordani* in 2004 (fig. 6). *Sebastes jordani* also showed less prominent disparities in the comparisons for 2001 and 2002.

The disparity between the NMFS and the PWCC surveys in 2002 could be attributed to the fact that the NMFS survey had large catches of *S. entomelas* and *S. mystinus* on the shelf, particularly at some of the most nearshore stations, while the PWCC survey trawls were conducted along the shelf break with low observed catches for these two species (fig. 7). Likewise, in 2001 and 2002 the NMFS surveys had large catches of *S. jordani* around the Farallon Islands offshore of the San Francisco Bay area, while the PWCC surveys conducted trawls on either side of this area with moderate catches in 2001 and low catches in 2002 (fig. 8). The NMFS survey's largest catch of 995 *S. jordani* in 2001 occurred at the most nearshore station just north of Monterey Bay on 1 June 2001, which was well after the PWCC sur-

vey had already finished sampling within the NMFS core survey area (fig. 8 and tab. 2). In 2004, while the PWCC survey had broader spatial coverage over the shelf, catches of *S. jordani* were low, and the NMFS survey collected the majority of the fish in the Monterey Bay area where the PWCC survey did not conduct any trawls.

Combined Survey Data

Since the mean log-transformed catches from the NMFS and PWCC surveys were not significantly different from 2003 to 2005 (fig. 5), the data were combined for these three years. *Sebastes entomelas*, *S. flavidus*, and *S. mystinus*, which are all northern species, had a similar interannual northward shift in distribution, with catches occurring between Point Conception and Cape Mendocino in 2003, between Point Conception and Cape Blanco in 2004, and from Cape Mendocino up to Cape Flattery in 2005 (fig. 9). In 2005 there was a dramatic decline in catches in the area south of Cape Mendocino (an area where fish were most abundant in the previous two years). Noticeable changes in catches for these species consistently occurred within the vicinity of the biogeographic boundaries of Cape Mendocino and Cape Blanco. Similarly, the other northern species, *S. pinniger*, had a northward shifting pattern with an abrupt change in catch rate within the vicinity of Cape Mendocino and Cape Blanco. However, *S. pinniger* appeared to be even more northerly distributed than *S. entomelas*, *S. flavidus*, and *S. mystinus*. Similar to the northern species, the two southern species, *S. jordani* and *S. paucispinis*, showed a decline in catch between Point Conception and Cape Mendocino in 2005. However, the changes in catch for these two southern species primarily occurred within the vicinity of Point Conception, with catches dramatically increasing south of that location.

DISCUSSION

The geographic and interannual differences in the length–frequency distributions observed in this study (fig. 2) could have been due to variability in the survival of YOY *Sebastes* spp. released at different times during the spawning season. Woodbury and Ralston (1991) reported interannual differences in birthdate distributions for YOY *Sebastes* spp., suggesting differential survival depending on the date of birth within the spawning season. There also could have been interannual differences in species composition, as some species spawn later than others, which could have led to a preponderance of smaller fish. Differences in species composition could also have led to the geographic differences in the observed length frequencies. Wyllie-Echeverria (1987) noted that parturition occurred earlier in the southern portion of the range and later in the northern portion for several *Sebastes* spp. This latitudinal effect on spawn-

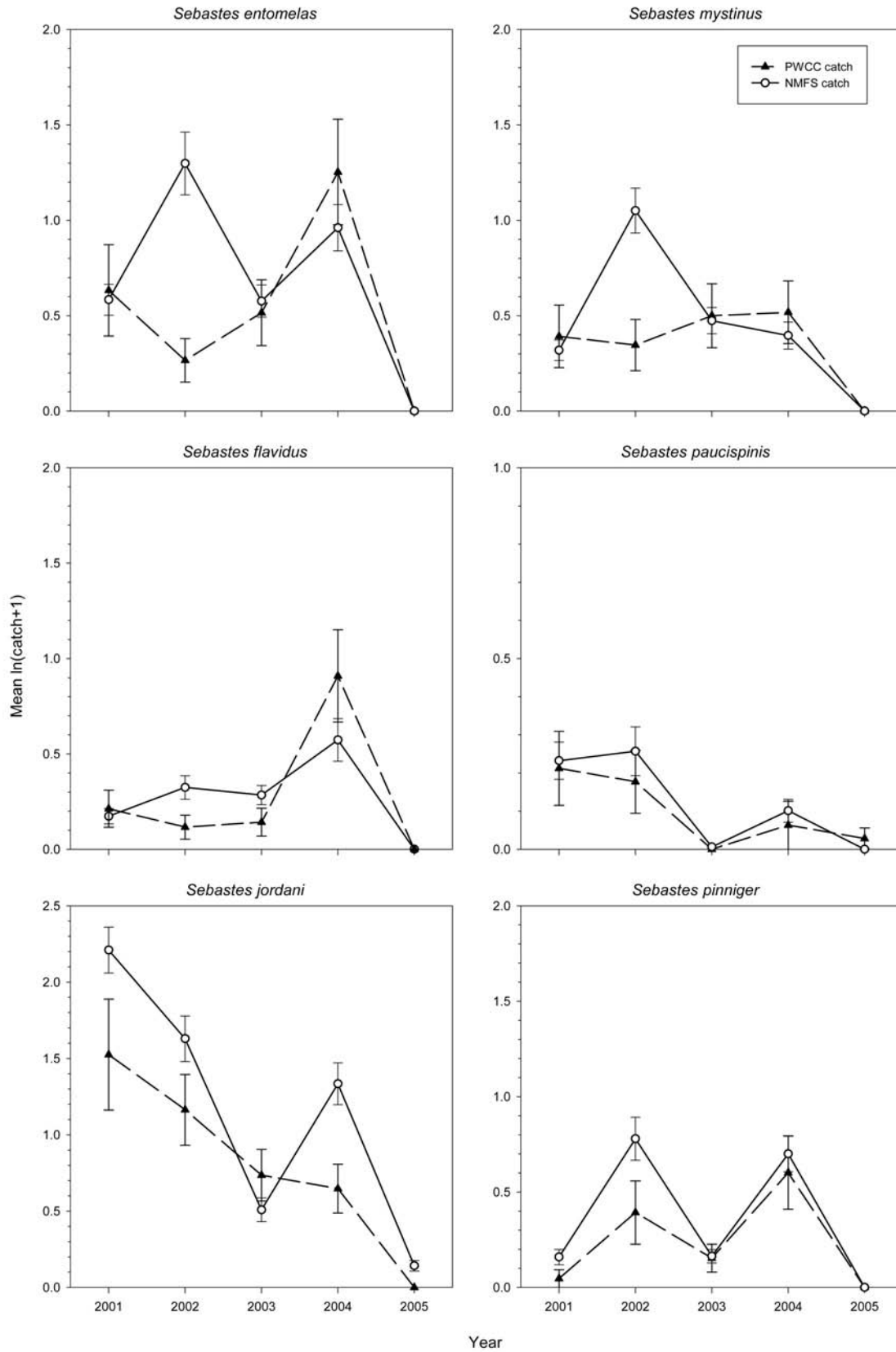


Figure 6. Mean log-transformed catches for individual *Sebastes* spp. for the NMFS and PWCC surveys from the NMFS core survey area. Error bars represent the standard error of the mean.

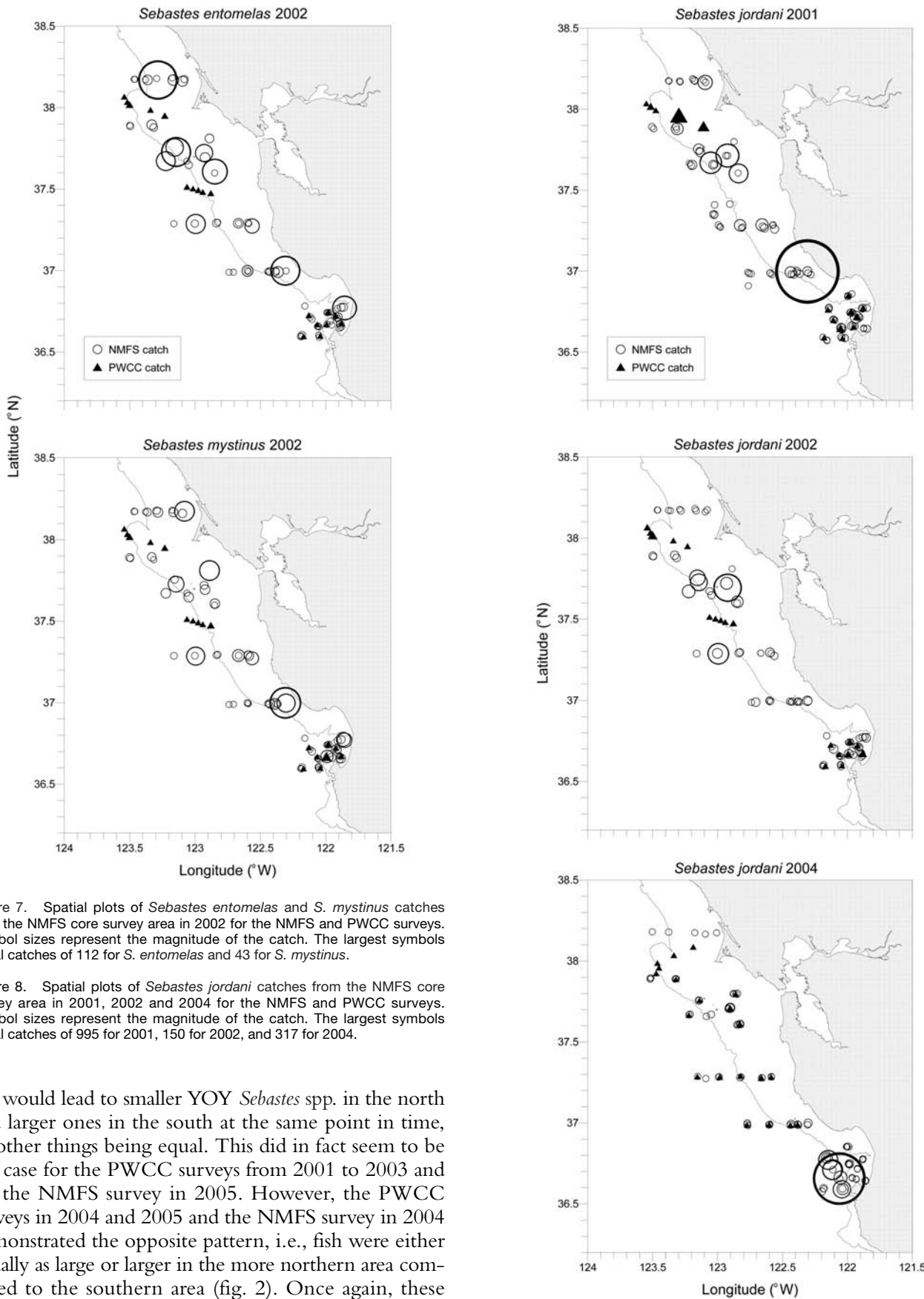


Figure 7. Spatial plots of *Sebastes entomelas* and *S. mystinus* catches from the NMFS core survey area in 2002 for the NMFS and PWCC surveys. Symbol sizes represent the magnitude of the catch. The largest symbols equal catches of 112 for *S. entomelas* and 43 for *S. mystinus*.

Figure 8. Spatial plots of *Sebastes jordani* catches from the NMFS core survey area in 2001, 2002 and 2004 for the NMFS and PWCC surveys. Symbol sizes represent the magnitude of the catch. The largest symbols equal catches of 995 for 2001, 150 for 2002, and 317 for 2004.

ing would lead to smaller YOY *Sebastes* spp. in the north and larger ones in the south at the same point in time, all other things being equal. This did in fact seem to be the case for the PWCC surveys from 2001 to 2003 and for the NMFS survey in 2005. However, the PWCC surveys in 2004 and 2005 and the NMFS survey in 2004 demonstrated the opposite pattern, i.e., fish were either equally as large or larger in the more northern area compared to the southern area (fig. 2). Once again, these

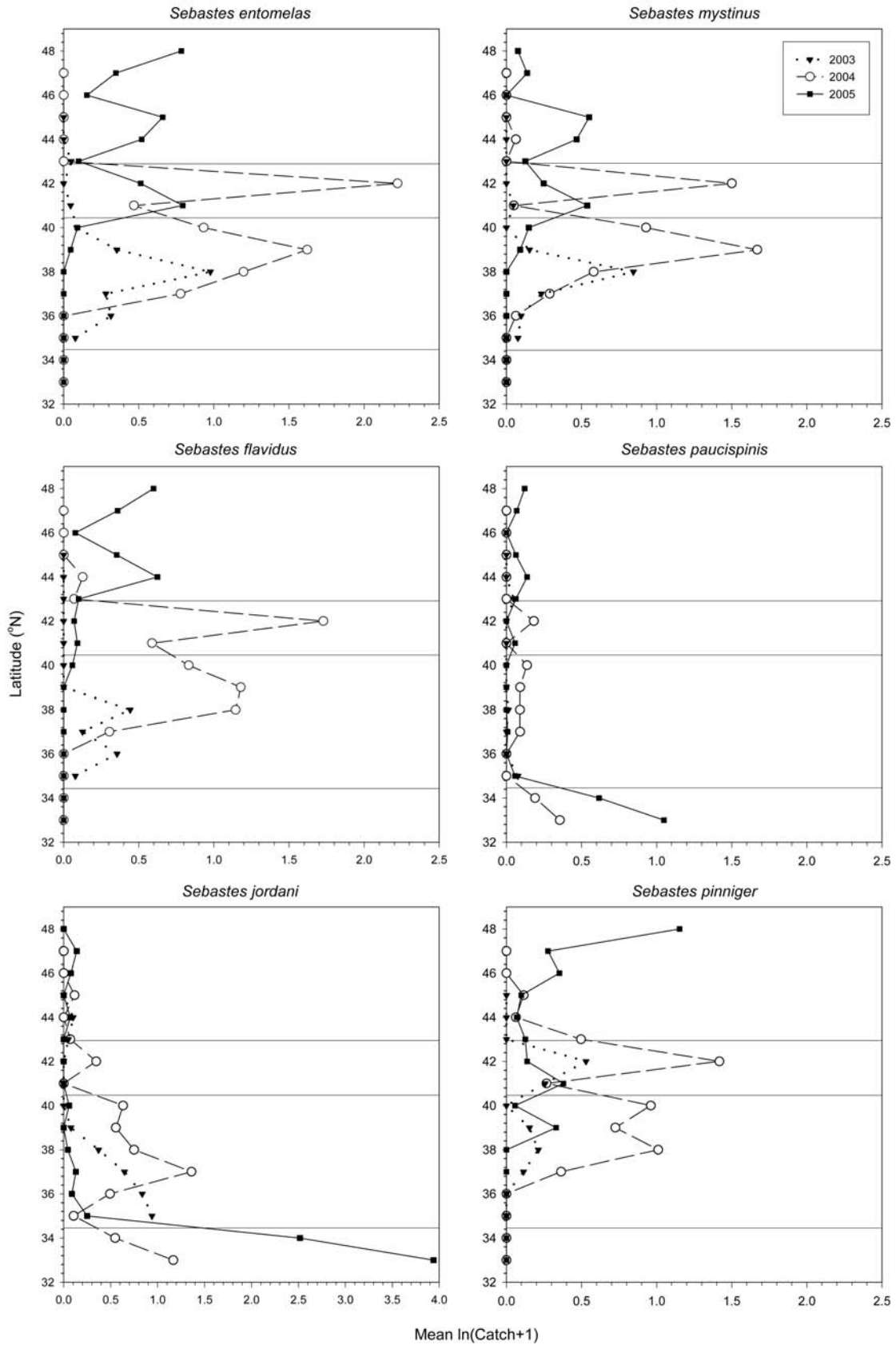


Figure 9. Mean log-transformed catches by degree latitude for individual *Sebastes* spp. from the 2003 to 2005 NMFS and PWCC surveys combined. The solid horizontal lines designate the biogeographic boundaries of Point Conception, Cape Mendocino, and Cape Blanco.

differences could potentially be accounted for by geographic variability in species composition.

The catch and species diversity findings from the paired trawling portion of this study showed good agreement between the two surveys over the last three years (2003 to 2005) (fig. 3). However, there was a tendency for the NMFS surveys to have somewhat higher catches than the PWCC surveys. Between-trawl variability has been shown to exist for replicate midwater trawls (Atsatt and Seapy 1974), but at this time it is not discernable whether the inter-vessel variability observed was substantially greater than the intra-vessel between-trawl variability. Perhaps fine scale differences in bathymetry and localized hydrography were contributing factors to the observed discrepancy. For example, greater differences in bottom depth at the start of trawling were observed in 2001 to 2003 (years where all the trawls were done within the Monterey Bay area) than in 2004 and 2005 (tab. 1). The topographic complexity created by the existence of Monterey Canyon within Monterey Bay could have led to dramatic changes in bottom depth over very short distances, which may have led to greater hydrographic complexity as well. While no studies have examined the spatial distribution of YOY *Sebastes* spp. on a scale less than 1.0 km, Yoklavich et al. (1996) did report noticeable differences in larval *Sebastes* spp. catches in the vicinity of Monterey Bay from stations only 2.0 km apart. In addition, Graham et al. (1992) reported that persistent “upwelling shadows” in northern Monterey Bay significantly affected the zooplankton assemblages in that region. Therefore, due to the bathymetric complexity associated with sampling in Monterey Bay, even if the two surveys were within 0.46 km of each other, the bottom depths and the associated hydrographical and biological conditions potentially could have been different.

The significant differences in mean log-transformed abundance between the two surveys for 2001 and 2002 in the NMFS core survey area (fig. 5) could be accounted for by temporal factors, such as the PWCC survey starting day offset (tab. 2), and spatial factors, such as where individual species were collected by each survey (fig. 7 and fig. 8). It should be noted that in 2002, although the PWCC survey caught very few *S. entomelas* and *S. mystinus* within the core survey area, high catches of both of those species were recorded at the next set of stations immediately to the north. Therefore, if the geographic area of comparison had been expanded only slightly, the mean log-transformed catches of the two surveys in 2002 would have been much more similar. Perhaps another factor contributing to the observed differences between the two surveys in 2001 was the smaller size of the *Sebastes* spp. recorded in that year compared with subsequent years (fig. 2). Smaller sized fish would have been subject to greater advective dispersal due to hydrographic conditions (Larson et al.

1994), further confounding differences in the spatial coverage of the two surveys. Despite the existence of potentially confounding temporal and spatial factors, the results from the NMFS core survey area for the two surveys still matched up very well for 2003, 2004, and 2005.

Geographic variability in YOY *Sebastes* spp. survival, based upon the prevailing environmental and biological conditions, seems to have led to interannual latitudinal shifts in distribution (fig. 9). Given interannual variability in survivorship (Woodbury and Ralston 1991; Ralston and Howard 1995) and geographic variability in parturition (Wyllie-Echeverria 1987), the conditions in 2004 and 2005 could have been more conducive to survival in areas progressively northward for northerly distributed species, such as *S. entomelas*, *S. flavidus*, *S. mystinus*, and *S. pinniger*. Perhaps in localities north of Cape Mendocino the survival of YOY *Sebastes* spp. depended upon a different set of environmental variables than those occurring south of Cape Mendocino. Interestingly, it appears that the area between Point Conception and Cape Mendocino suffered a total failure in reproductive success in 2005 (figs. 5, 6, and 9). Examining sea surface temperatures (SST) from NOAA CoastWatch advanced very high resolution radiometer (AVHRR) satellite images showed an anomalous absence of upwelling during May (see Schwing et al. 1991), as evidenced by the lack of cold-water plumes/filaments at typical sites—such as Point Reyes and Point Arena—and the lack of a pronounced gradient between the nearshore and offshore SSTs (fig. 10). SST patterns in 2005 were similar for AVHRR images from 5 to 21 May. Normal upwelling conditions did not fully return until early June, when cold-water plumes/filaments developed off Point Reyes and Point Arena leading to a pronounced gradient between the nearshore and offshore SSTs (fig. 11). The lack of upwelling and the associated reduction in primary productivity, similar to conditions in El Niño years, could have led to poor conditions for survivorship of YOY *Sebastes* spp. (Lenarz et al. 1995; Ralston and Howard 1995; Yoklavich et al. 1996).

The northward shift in latitudinal distribution also could have been due to transport and active movement of YOY *Sebastes* spp. Many studies have shown that the distribution of YOY *Sebastes* spp. was subject to the effects of hydrographic conditions, e.g., coastal upwelling (Larson et al. 1994; Sakuma and Ralston 1995; Yoklavich et al. 1996; Bjorkstedt et al. 2002). The northward movement of many species during El Niño events also has been well documented (Hubbs 1948; Radovich 1960; Brodeur et al. 1985; Pearcy and Schoener 1987; Dorn 1995; Lenarz et al. 1995). In addition, laboratory experiments have shown that YOY *Sebastes* spp. at ~40 mm SL can sustain swimming speeds of ~25 cm/second¹, which could result in a theoretical (albeit unlikely) 648

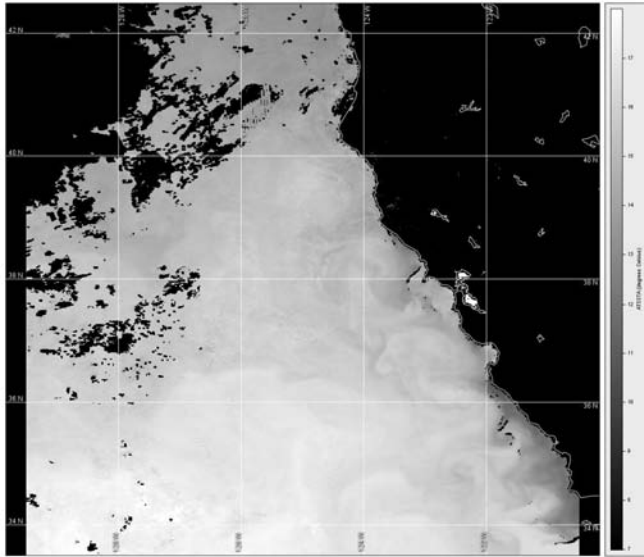


Figure 10. NOAA CoastWatch AVHRR satellite image of SST off northern/central CA for 21 May 2005.

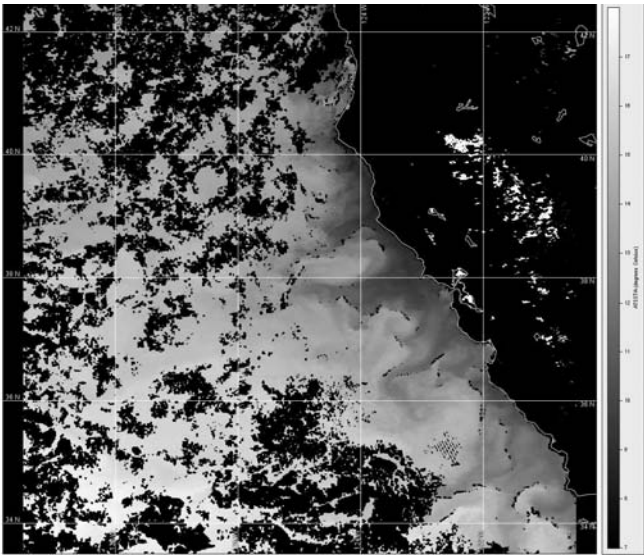


Figure 11. NOAA CoastWatch AVHRR satellite image of SST off northern/central CA for 5 June 2005.

km distance traveled over a one-month period. However, examination of otolith microchemistry in black rockfish, *S. melanops*, by Miller and Shanks (2004) indicated that dispersal distances were quite restricted, i.e., largely less than 120 km. In contrast, Field and Ralston (2005) observed substantial spatial synchrony in year-class strength on the order of 500 to 1000 km for *S. entomelas*, *S. flavidus*, and *S. goodei* suggesting a much broader dispersal range for these species. Whether the interannual shifts in distribution were related to geographic differences in survivorship, advection and active movement of

YOY *Sebastes* spp., or a combination of these two factors, it was interesting to note that dramatic changes in survey catches were almost always associated with the known biogeographic boundaries of Point Conception, Cape Mendocino, and Cape Blanco, all areas which have been shown to affect the distribution of many marine species (Horn and Allen 1978; Parrish et al. 1981; Barth et al. 2000; Wares et al. 2001; Blanchette et al. 2002; Williams and Ralston 2002; Cope 2004; Field and Ralston 2005).

In summary, the combined results from the NMFS and PWCC surveys allowed *Sebastes* spp. abundance to be examined on a much broader spatial scale than would otherwise be possible by each survey individually. For example, for the NMFS survey to obtain the full spatial coverage in 2005 (see fig. 1), a minimum of 32 sample days would have been required to sample each station once (estimating that each line of stations requires one night of sampling). This would have led to over a one-month disparity in the temporal sampling between the southernmost and northernmost stations, a period of time during which settlement of YOY *Sebastes* spp. could have occurred, resulting in these fish becoming unavailable to the survey. With both surveys operating simultaneously, a more synoptic picture of YOY *Sebastes* spp. annual abundance can be obtained. In addition, the NMFS survey's replicate station sampling allows for within-year variability in YOY *Sebastes* spp. at various geographic areas to be examined. In the future, after more in-depth comparisons between the NMFS and PWCC surveys are conducted, perhaps the two surveys can reduce the geographic area of sampling overlap, thereby reducing the logistical and financial requirements of each survey. The increased spatial coverage offered by combining the two surveys should be of great benefit in better predicting year-class strength for commercially and recreationally important *Sebastes* spp., which, as adults, may cover a broad geographic range. In addition, it is beneficial for the federal regulatory agencies and the commercial industries to cooperate in the process of obtaining such fisheries independent data, which can then be used in the management process.

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¹R. Fisher, Dept. of Marine Biology, James Cook University, Townsville, Australia, unpublished data.

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