DISTRIBUTIONAL PATTERNS OF LATE LARVAL GROUNDFISH OFF CENTRAL CALIFORNIA IN RELATION TO HYDROGRAPHIC FEATURES DURING 1992 AND 1993

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ABSTRACT

Late larval groundfish were collected off central California during late February and early March of 1992 and 1993. Hydrographic data obtained during these surveys showed that in both years ocean temperatures were relatively warm as a result of El Niño conditions. Contour plots of dynamic height topography at the surface indicated poleward flow in 1992, but equatorward flow in 1993. During 1992 large catches of shortbelly rockfish (*Sebastes jordani*), bocaccio (*S. paucispinis*), and other rockfishes (*Sebastes* spp.) were made on the shoreward side of a temperature front located 100–150 km off the continental shelf. Higher catches of Pacific and speckled sanddabs (*Citharichthys sordidus* and *C. stigmaeus*) were also associated with the front, but these species were found on both sides of the gradient. In contrast, Pacific whiting (*Merluccius productus*) were most abundant in the warm, nearshore waters of the southeastern portion of the survey area, which suggests that these fish had been advected northward by poleward flow during El Niño. Catches of all species were lower in 1993 than in 1992, and there were markedly fewer large (>20 mm SL) individuals. High catches of shortbelly rockfish and other rockfishes, and moderate abundances of bocaccio, Pacific and speckled sanddabs, and Pacific whiting were associated with an eddy feature detected in the salinity field off Monterey Bay; catches were also generally higher in nearshore waters, which were more saline. As in 1992, the largest catches of Pacific whiting in 1993 came from the warm nearshore waters of the southeastern portion of the survey area.

INTRODUCTION

Successful recruitment of marine organisms with planktonic eggs and larvae is often strongly affected by the hydrographic conditions prevailing during the early life history (Bailey and Francis 1985; Cowen 1985; Ebert and Russell 1988; Roughgarden et al. 1988; Sinclair 1988; Cury and Roy 1989; Hollowed 1992). The hydrographic regime off central California is driven by a complex mixture of geostrophic and wind-driven flow patterns (Parrish et al. 1981; Simpson 1987; Strub et al. 1987; Schwing et al. 1991). Geostrophic flow patterns are dominated by equatorward transport in the California Current (surface to 200 m) throughout the year, with a nearshore reversal to poleward flow during the winter months in association with the shoaling of the California Undercurrent (core at approximately 300 m; Parrish et al. 1981; Simpson 1987). Wind-driven flow patterns show strong high-frequency and seasonal variability (Largier et al. 1993). Southerly (i.e., northward-progressing) winds during winter storms typically lead to turbulent mixing, onshore transport, and downwelling. Following the spring transition to upwelling-favorable northwesterly winds, however, wind forcing leads to offshore transport in the upper mixed layer, nutrient enrichment, and increased primary productivity (Parrish et al. 1981; Simpson 1987; Strub et al. 1987).

Although the increased productivity during upwelling is generally viewed as beneficial, the offshore advection of planktonic larvae could adversely affect recruitment to nearshore settlement areas (Roughgarden et al. 1988). It has been hypothesized that, for many species off central California, spawning in the winter season, before spring transition, is a strategy for avoiding such advection offshore (Parrish et al. 1981).

The purpose of this study is to examine the distributional patterns of larval and late larval groundfish—in particular, rockfishes (*Sebastes* spp.), sanddabs (*Citharichthys* spp.), and Pacific whiting (*Merluccius productus*)—off central California during the period just before spring transition, and to relate observed patterns to the prevailing hydrography. Previous studies of distributional patterns have either used bongo nets to examine early larvae (Loeb et al. 1983; Moser et al. 1993) or midwater trawls to examine pelagic juveniles (Wyllie Echeverria et al. 1990; Larson et al. 1994). But there have been few studies on the distributional patterns of late larvae within the 10 to 20 mm size range, a stage during ontogeny that has been implicated as important in establishing year-class strength (Smith 1985).

MATERIALS AND METHODS

Late larval groundfish were collected with a 5 m^2 frame trawl fitted with a 2 mm mesh net and a 505 μm mesh codend (Methot 1986). A large Isaacs-Kidd depressor was used to stabilize the net at its targeted depth. Trawling was conducted in midwater aboard the National

[Manuscript received January 30, 1995.]

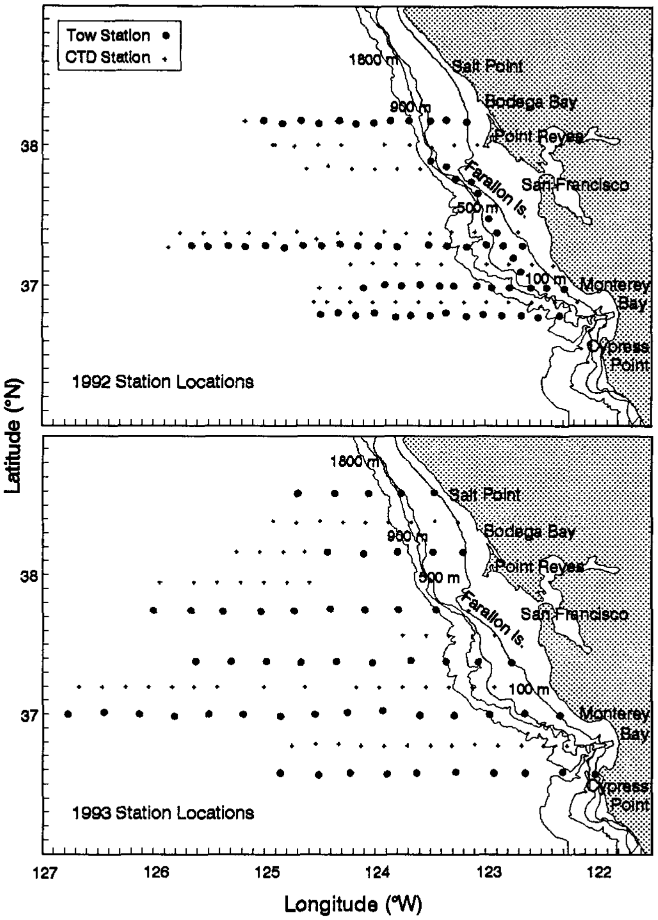

Figure 1. Map of the study area, showing the locations of trawl and CTD stations conducted during 1992 and 1993.

Oceanic and Atmospheric Administration (NOAA) R/V *David Starr Jordan* during the winters of 1992 (February 23–March 6) and 1993 (March 2–13). The survey area ranged from Bodega Bay to Monterey Bay in 1992 and from Salt Point to Cypress Point in 1993 (figure 1). Oblique tows were conducted at night for a duration of 20–30 minutes. The maximum depth fished by the net, determined from an attached time-depth recorder (TDR), was 70 m in 1992 and 80 m in 1993. At one station per night, an additional deep tow was conducted to a maximum depth of 135 m in 1992 and 149 m in 1993. Average tow speed was 1.2 m/second. A flowmeter affixed to the mouth of the net was used to determine the volume sampled.

In 1992 a conductivity-temperature-depth (CTD) cast was performed at each trawl station, with additional CTD stations sampled during the day (figure 1). In 1993 CTD casts were conducted at every other trawl station and at additional daytime stations (figure 1). Horizontal contour maps of temperature, salinity, and density (σ_t) at depths of 2, 10, 30, 100, 200, 300, and 500 m were created to chart the hydrography of the survey region. Contouring methods and plots are described and presented in Sakuma et al. (1994a, b). In addition, temperature and salinity at 60 m were contoured specifically for this study to characterize the hydrography within the lower depth range of the oblique tows. Likewise, dynamic height topography at the surface (0/500 m) and at depth (200/500 m) was contoured with the methods described in Sakuma et al. (1994a, b). To compare sea-surface temperature (SST) during the two survey years with data from previous years, we examined March SST data from 1973 to 1993 for the Farallon Islands shore station (37°41.8' N, 122°59.9' W) monitored by the Point Reyes Bird Observatory (PRBO; data obtained from Scripps Institution of Oceanography Marine Life Research Group). We also examined anomalous March sea levels from 1975 to 1993 obtained at the NOAA, National Ocean Service (NOS) San Francisco tide gauge station at Fort Point (37°48' N, 122°28' W; data obtained from the Joint Archive for Sea Level Data, University of Hawaii).

In 1992, larval fish were sorted at sea and placed in 95% EtOH. Two subsamples of the sorted remainder were saved from each tow to check the accuracy of the sorting conducted at sea. In the laboratory, larval shortbelly rockfish (*Sebastes jordani*), bocaccio (*S. paucispinis*), other rockfishes (*Sebastes* spp.), Pacific and speckled sanddabs (*Citharichthys sordidus* and *C. stigmaeus*), Pacific whiting (*Merluccius productus*), and "other" fish larvae were sorted and enumerated. In addition, standard length (SL) measurements were recorded for shortbelly rockfish, Pacific sanddab, and Pacific whiting, with large catches randomly subsampled and length measurements expanded to the whole catch.

In 1993, because of reduced catch rates, the seven taxa were sorted, identified, enumerated, and placed in 95% EtOH at sea. Subsamples of the sorted remainder were saved again and returned to the laboratory to check the accuracy of the shipboard sorts. Identifications of all taxa were reconfirmed in the laboratory. As in 1992, length measurements were recorded for shortbelly rockfish, Pacific sanddab, and Pacific whiting; large catches were subsampled; and the total length composition was estimated through expansion. Catch statistics for both years were adjusted with the flowmeter readings to numbers per 10,000 m^3 of water filtered.

We could not characterize the depth distributions of these species because of the vertical integration of abundance that occurs during an oblique tow. Therefore we excluded all deep trawls to standardize sampling to a specific depth range. We then calculated Spearman rank correlation coefficients to compare log-transformed abundance statistics ($\log_e[x+1]$) with hydrographic variables (i.e., temperature, salinity, and density) measured in situ (30 m depth). We selected this depth because prior

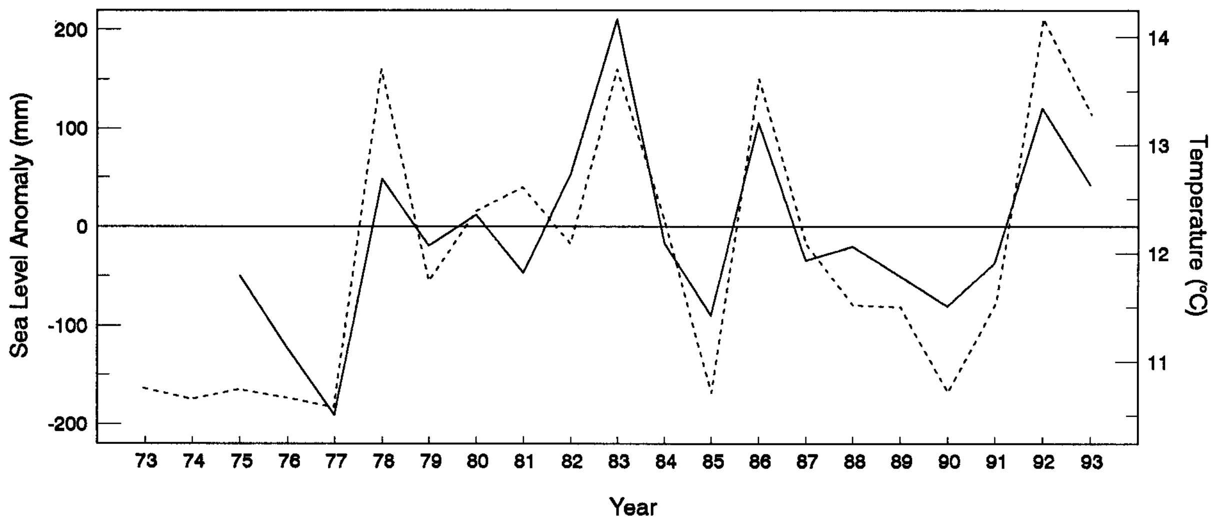

Figure 2. March sea-level anomaly at the NOAA, NOS San Francisco tide gauge station (*solid line*) from 1975 to 1993, and March sea-surface temperature at the Farallon Islands shore station (*dotted line*) from 1973 to 1993.

studies by Ahlstrom (1959) and Lenarz et al. (1991) indicated that larval and pelagic juvenile rockfish, sanddabs, and Pacific whiting are generally most abundant below 20 m. Likewise, additional data obtained during a 10 m^2 MOCNESS cruise conducted in March 1994 indicated that the vertical distribution of most of these fishes is broadly centered between 20 and 60 m (unpubl. data, National Marine Fisheries Service, Tiburon Laboratory, 3150 Paradise Drive, Tiburon, CA 94920). To increase sample sizes in 1993, we used gridded interpolations of the hydrographic variables when actual data were not available.

We superimposed total catches of shortbelly rockfish, bocaccio, other rockfishes, Pacific and speckled sanddabs, and Pacific whiting onto horizontal contour maps of temperature and salinity to examine spatial patterns of abundance in relation to the hydrographic regime. We then stratified catches of shortbelly rockfish, Pacific sanddab, and Pacific whiting into small (<10 mm SL), medium (10–19 mm SL), and large (>19 mm SL) size classes, and overlaid the data on hydrographic contours to examine differences in spatial distribution with size.

RESULTS

Increased sea levels were observed during March of 1992 and 1993 at the NOAA, NOS San Francisco tide gauge station (figure 2). In addition, data from the Farallon Islands shore station indicated that SSTs in March of 1992 and 1993 were anomalously warm (figure 2). Both the Farallon Islands shore station data and contours of CTD temperature at the surface indicated that SSTs were generally warmer in 1992 than in 1993 (figure 2). Sakuma et al. (1994a, b) reported that in both years the warmest SSTs were observed in the southern portion of the survey area off Monterey Bay. In addition, contours of temperature and salinity at the surface and at 30 m indicated that nearshore waters were generally warmer and more saline than offshore waters. A notable exception in 1993 was a high-salinity eddy feature offshore of Monterey Bay. This feature was most prominent at 30 m, but was present at the surface and down to 100 m (figure 3b; Sakuma et al. 1994b). A conspicuous hydrographic feature observed in 1992 was a strong alongshelf temperature gradient about 150 km from the coast; this feature was most prominent at 30 and 60 m (figure 3a; Sakuma et al. 1994a).

In 1992, plots of dynamic height topography, both at the surface and at 200 m, showed elevated values nearshore and progressively decreasing values offshore, indicating an overall pattern of poleward flow at distances up to ~140 km offshore (figure 4a). In contrast, the plot of 0/500 m dynamic height in 1993 showed elevated values well offshore and, to a lesser degree, over the continental slope, indicating a general pattern of equatorward flow, whereas the nearshore flow pattern was not readily discernable (figure 4b). At 200 m, dynamic heights were elevated both nearshore and well offshore, suggesting a general pattern of weak poleward flow nearshore and relatively strong equatorward flow offshore (figure 4b).

A total of 81 tows (including 14 deep tows) were made in 1992, and 65 tows (including 10 deep tows) in 1993. The preserved subsamples of the sorted remainders revealed substantial numbers of fish (i.e., more than 15% of the number originally sorted at sea) in 11 of the 81 tows in 1992, and 10 of the 65 tows in 1993. In these cases larval fish were enumerated from the subsamples, and their numbers were expanded to the total volume

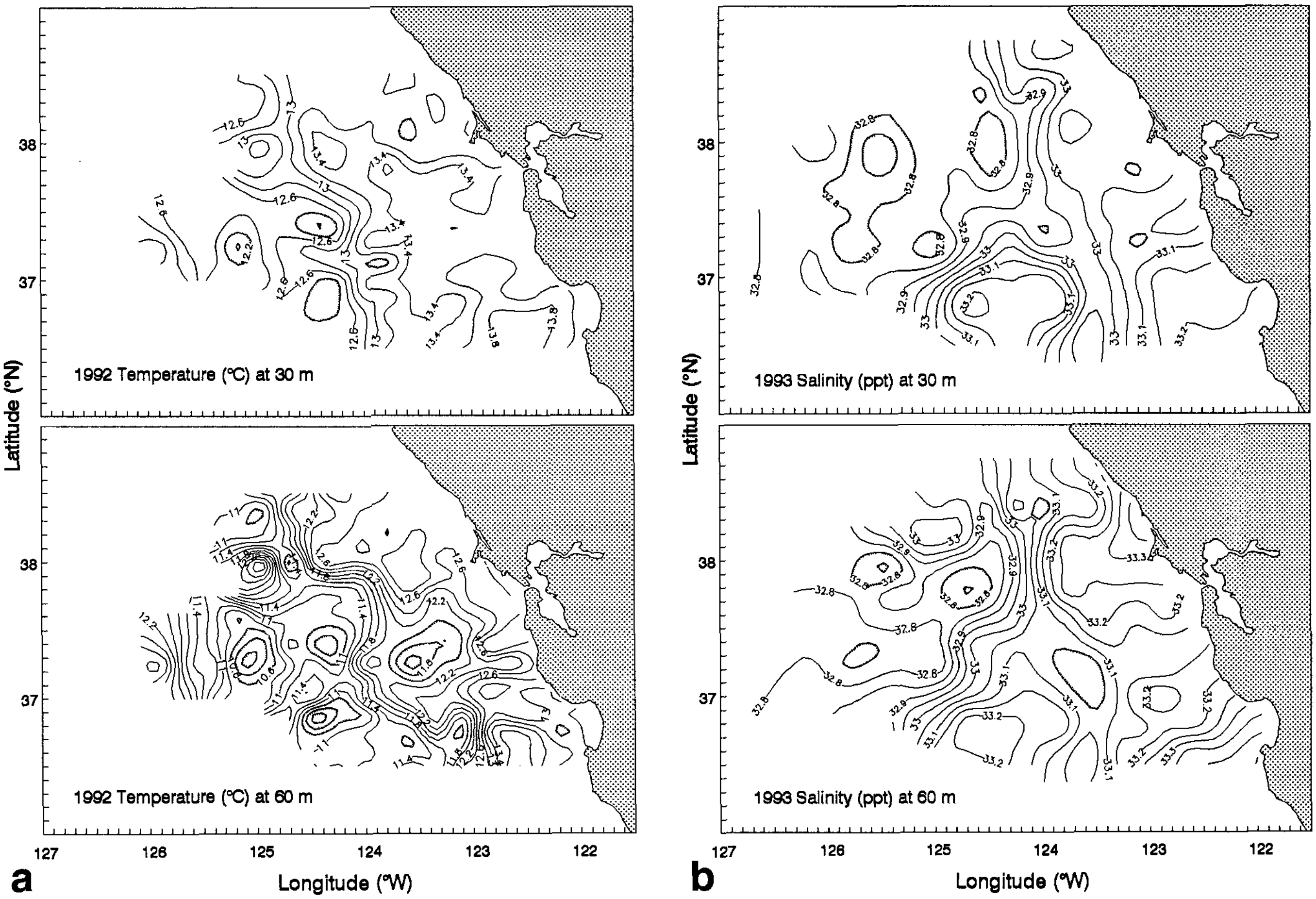

Figure 3. Contours of (*a*) temperature at 30 and 60 m in 1992 and (*b*) salinity at 30 and 60 m in 1993.

and added to the preliminary total. Catch rates of all taxa were higher in 1992 than in 1993 (figure 5). In addition, the length-frequency data revealed that fish collected in 1992 represented a wider size range than in 1993 (figure 6).

Catches of shortbelly rockfish, other rockfishes, and Pacific whiting were positively correlated with temperature in 1992 (table 1). Moreover, temperature correlations between other rockfishes and Pacific whiting were among the highest observed, indicating that temperature may have been an important influence on the distributions of these fishes in 1992 (table 1). In contrast, catches of Pacific and speckled sanddabs were negatively correlated with density and were uncorrelated with temperature (table 1). Catches of bocaccio were not significantly correlated with any variable, although there appeared to be a slight negative relationship with density (table 1).

In 1993, unlike the preceding year, only catches of shortbelly rockfish were correlated with temperature (table 2). Instead, all species showed strong positive correlations with salinity, indicating that this hydrographic variable most strongly affected the distributions of these fishes in 1993. In a reversal of trend, catches of Pacific and speckled sanddabs were positively correlated with density in 1993 (table 2). Likewise, catches of shortbelly rockfish, other rockfishes, and Pacific whiting were positively correlated with density (table 2).

Although symbols proportional in size to catch rate were superimposed onto contour maps of temperature and salinity, only temperature maps are presented for 1992, because the distributional patterns correlated best with temperature (table 1). Similarly, because salinity had the highest correlations in 1993 (table 2), we present only overlays of abundance on the salinity field for that year.

The overlays for 1992 showed that shortbelly rockfish, bocaccio, other rockfishes, Pacific and speckled sanddabs, and Pacific whiting were found offshore as well as nearshore (figure 7). However, large offshore catches of shortbelly rockfish and other rockfishes were made only on the warmer, nearshore side of the temperature front (figure 7a). Similarly, the largest catches of bocaccio came from the nearshore side of the gradient (figure 7a). In contrast, Pacific and speckled sanddabs were

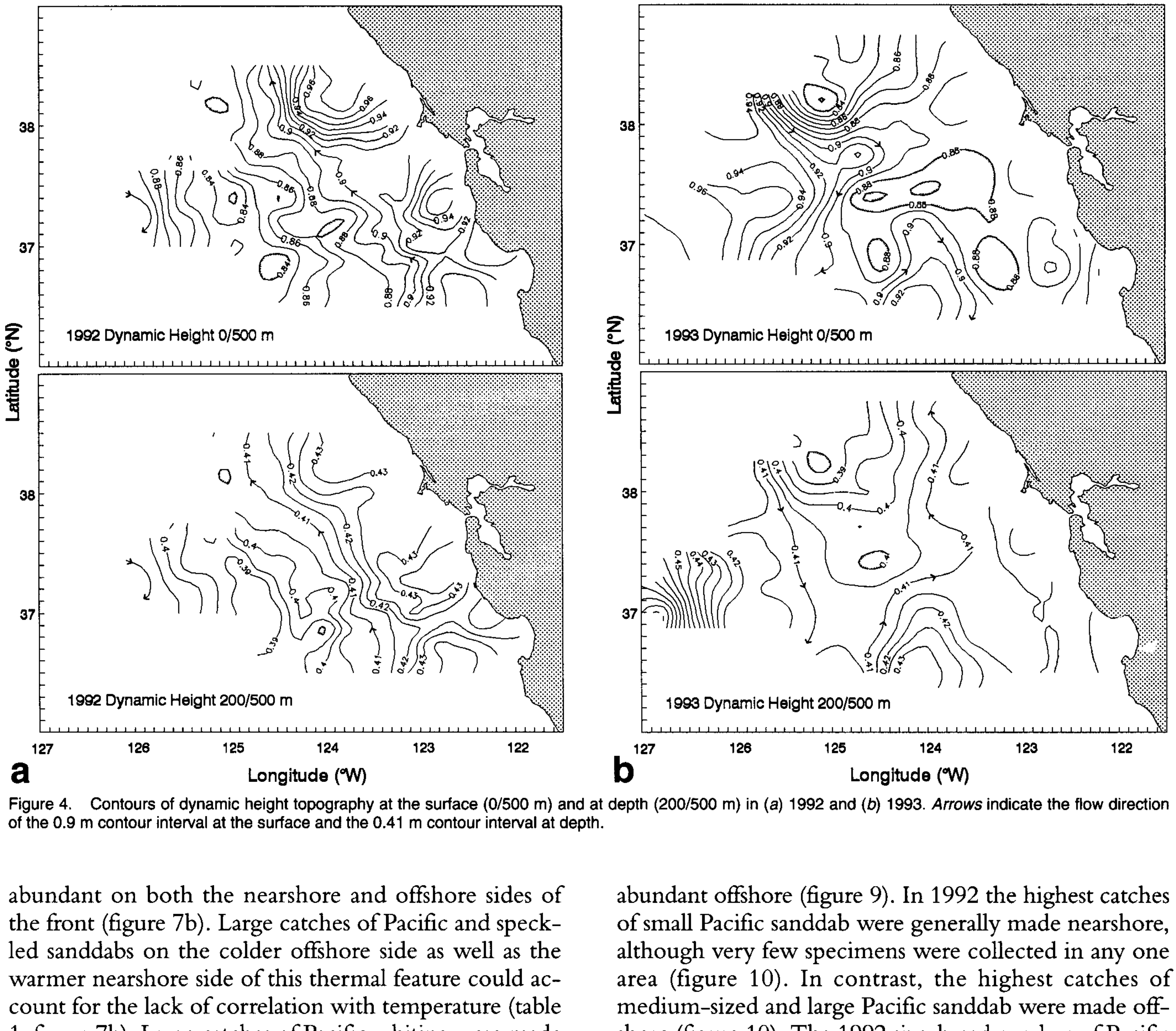

Figure 4. Contours of dynamic height topography at the surface (0/500 m) and at depth (200/500 m) in (*a*) 1992 and (*b*) 1993. *Arrows* indicate the flow direction of the 0.9 m contour interval at the surface and the 0.41 m contour interval at depth.

abundant on both the nearshore and offshore sides of the front (figure 7b). Large catches of Pacific and speckled sanddabs on the colder offshore side as well as the warmer nearshore side of this thermal feature could account for the lack of correlation with temperature (table 1, figure 7b). Large catches of Pacific whiting were made primarily in the southern portion of the survey area on the nearshore side of the frontal gradient in association with the warmest water temperatures, which accounts for the high correlation between temperature and whiting abundance (table 1, figure 7b).

In 1993 the largest catches of shortbelly rockfish, bocaccio, other rockfishes, Pacific and speckled sanddabs, and Pacific whiting were made in relatively saline nearshore waters or in association with the offshore eddy feature (figure 8). These results account for the significant correlations with salinity observed in 1993 (table 2).

The size-based overlays of shortbelly rockfish in 1992 indicated that small individuals were most abundant nearshore (figure 9). Medium-sized shortbelly rockfish were also relatively abundant nearshore, but the highest catches were made offshore. Large individuals were most abundant offshore (figure 9). In 1992 the highest catches of small Pacific sanddab were generally made nearshore, although very few specimens were collected in any one area (figure 10). In contrast, the highest catches of medium-sized and large Pacific sanddab were made offshore (figure 10). The 1992 size-based overlays of Pacific whiting showed no distinct differences in the distributions of small, medium, and large individuals (figure 11).

In contrast to the pattern observed in 1992 (figure 9), there were no distinct differences in distribution between small and medium-sized shortbelly rockfish in 1993 (figure 12). Small and medium-sized shortbelly rockfish were abundant nearshore and in association with the offshore eddy (figure 12). The spatial distribution of large shortbelly rockfish could not be discerned because only one specimen was collected (figures 6 and 12). Similarly, no size-based differences in distribution were observed for Pacific sanddab in 1993, because catches of small and large specimens were much reduced (figure 13). Although catches of Pacific whiting were much lower in 1993 compared with 1992, moderate numbers of small and medium-sized specimens were collected at several stations

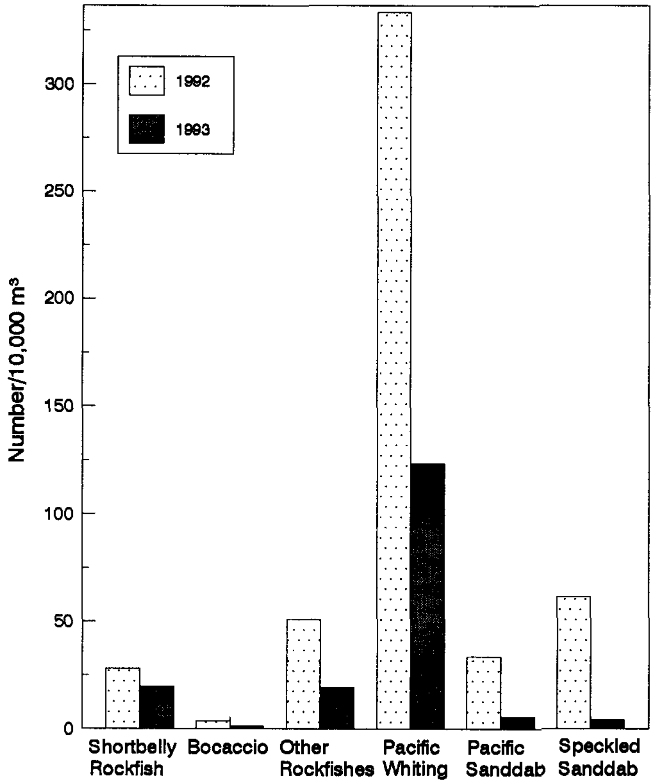

Figure 5. Abundances of larval groundfish (mean number/tow) collected in 1992 and 1993.

(figure 14). Small Pacific whiting were generally most abundant nearshore, whereas medium-sized individuals were abundant nearshore as well as offshore in association with the eddy (figure 14). Unfortunately, the largest single catch of Pacific whiting taken in 1993 (second station off Cypress Pt.; figure 8b) was discarded at sea, and no size data were recorded. However, the lack of size information for this nearshore station was not critical to describing differences in distribution with size, because all three size categories of Pacific whiting generally increased in abundance near shore (figure 14).

DISCUSSION

The relatively warm conditions in 1992 and 1993 were associated with a major El Niño event (see Symposium section; figure 2; Hayward 1993; Sakuma et al. 1994a, b). Along with increased temperature, other characteristics of El Niño along the California coast include a nearshore rise in sea level, enhanced poleward transport, increased onshore transport, reduced upwelling, and a depressed thermocline (Brodeur et al. 1985; Mysak 1986; Pearcy and Schoener 1987; Clarke and Van Gorder 1994). Anomalously high sea levels were observed in both survey years (figure 2). Enhanced poleward transport was clearly evident in our dynamic height data for 1992, but geostrophic flows at the surface apparently had

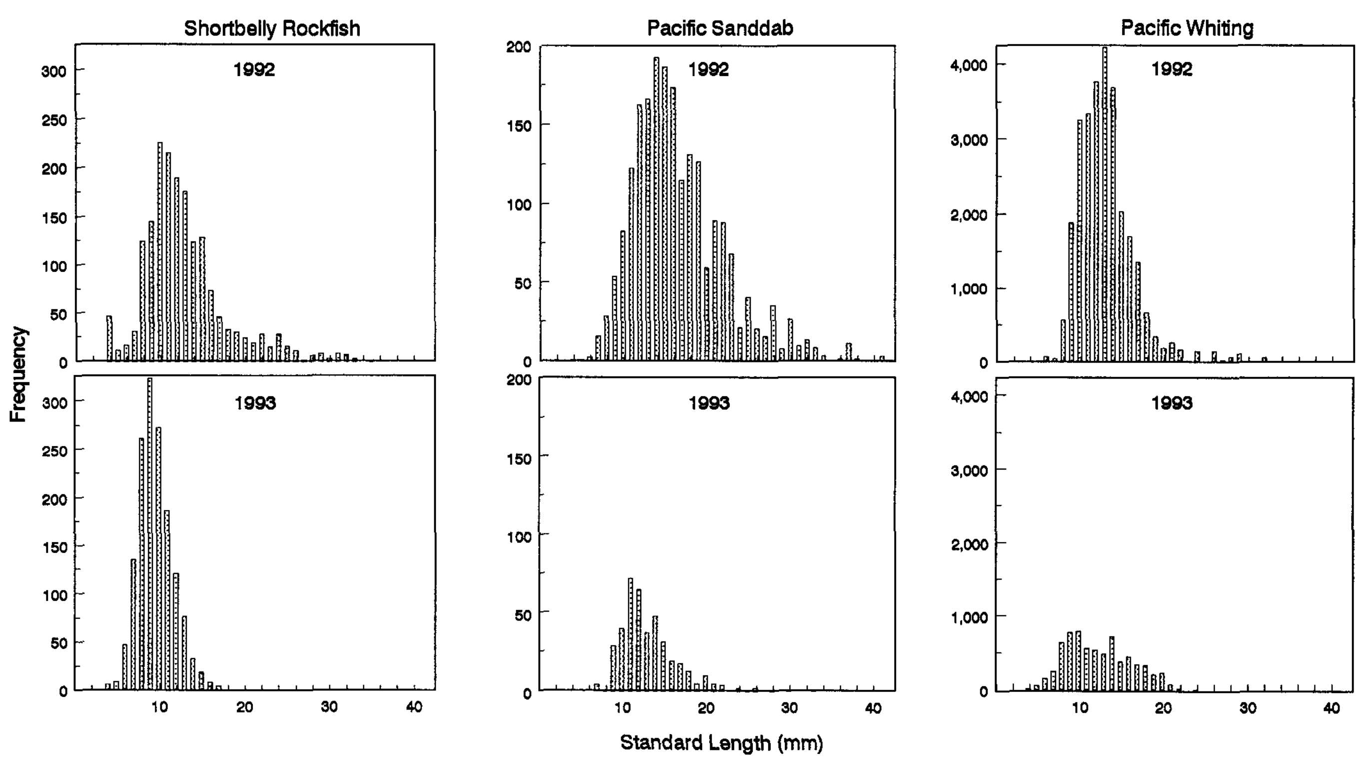

Figure 6. Length-frequency distributions of larval groundfish collected in 1992 and 1993.

TABLE 1
Spearman Rank Correlation Coefficients for 1992 (n = 66)

	Temperature (°C)	Salinity (ppt)	Density (kg/m^3)
Shortbelly rockfish	0.30 **0.0134**	0.35 **0.0044**	0.20 **0.1020**
Bocaccio	0.03 **0.8082**	−0.16 **0.2012**	−0.21 **0.0887**
Other rockfishes	0.42 **0.0005**	0.32 **0.0087**	0.11 **0.3815**
Pacific whiting	0.33 **0.0066**	0.09 **0.4565**	−0.11 **0.3942**
Pacific sanddab	0.05 **0.6777**	−0.23 **0.0655**	−0.30 **0.0145**
Speckled sanddab	0.12 **0.3463**	−0.13 **0.2890**	−0.28 **0.0234**

Significance probabilities for each correlation are given in boldface under the coefficients.

TABLE 2
Spearman Rank Correlation Coefficients for 1993 (n = 53)

	Temperature (°C)	Salinity (ppt)	Density (kg/m^3)
Shortbelly rockfish	0.30 **0.0292**	0.73 **0.0001**	0.58 **0.0001**
Bocaccio	0.24 **0.0851**	0.22 **0.1227**	0.10 **0.4863**
Other rockfishes	0.24 **0.0892**	0.49 **0.0002**	0.40 **0.0030**
Pacific whiting	0.20 **0.1338**	0.73 **0.0001**	0.61 **0.0001**
Pacific sanddab	0.05 **0.7246**	0.46 **0.0006**	0.49 **0.0003**
Speckled sanddab	−0.14 **0.3084**	0.27 **0.0530**	0.44 **0.0010**

Significance probabilities for each correlation are given in boldface under the coefficients.

reverted to the more typical condition of offshore equatorward transport in 1993 (figure 4). However, nearshore flow patterns at the surface in 1993 were not readily discernable (figure 4b). Therefore, because increased sea levels generally coincide with enhanced poleward transport (Mysak 1986), the timing of the 1993 survey may have coincided with a waning period in poleward transport rather than a total reversal of flow to equatorward transport (figures 2 and 4b). Because of unusual El Niño conditions, the distributional relationships we observed may not be indicative of spatial patterns prior to spring transition in other non–El Niño years.

Although ocean temperatures were warm in both 1992 and 1993 (figure 2; Sakuma et al. 1994a, b), there were distinct differences between these two years in the abundance patterns of the late larval fish we surveyed. In 1992 the best correlations of physical and biological data were between the various larval abundances and temperature (table 1). In contrast, salinity was more strongly correlated with abundance in 1993 (table 2). These interannual differences were probably representative of a more complex underlying relationship between the hydrographic regime and the distributional patterns of larval fish.

Between-year differences were also evident in our size-based analysis of shortbelly rockfish and Pacific sanddab. In 1992, these species were distributed progressively offshore with increasing size (figures 9 and 10); in 1993 all size categories of these species were found primarily in nearshore waters, or in association with the offshore eddy feature evident in the salinity field (figures 12–14). Whereas small shortbelly rockfish were found primarily nearshore in 1992, elevated numbers of small individuals occurred well offshore in association with the eddy feature in 1993, suggesting that in 1993 these early larvae were advected offshore (figure 12).

Larval catch rates during the winter of 1992 were high relative to 1993 (figure 5). However, this did not translate into greater year-class strength in 1992 than in 1993. To the contrary, midwater trawl surveys conducted in May and June indicated that catch rates of all pelagic juvenile rockfish species were very low in 1992, whereas abundances in May and June of 1993 were moderate (Eldridge 1994). This suggests that annual reproductive success, at least among the rockfishes, had not been established at the time our 1992 larval survey was conducted (early March), although the effect of advection or emigration of individuals out of the survey area cannot be discounted. Ralston and Howard (in press) have shown that rockfish year-class strength is set by May–June, even though cohort variability may increase later, upon settlement.

It is important to note that high catches of several species were made well offshore in both years (figures 7 and 8). One might presume that offshore-distributed late larvae of species like shortbelly rockfish, bocaccio, and Pacific and speckled sanddabs are effectively lost to adult populations, which inhabit the nearshore continental shelf and slope regions. Indeed, offshore Ekman transport due to equatorward wind stress has often been implicated as a contributing factor leading to poor recruitment in nearshore benthic species (Parrish et al. 1981; Bakun and Parrish 1982; Wild et al. 1983; Roughgarden et al. 1988; Ebert and Russell 1988).

It should be emphasized that even though both our surveys were conducted before the spring transition to

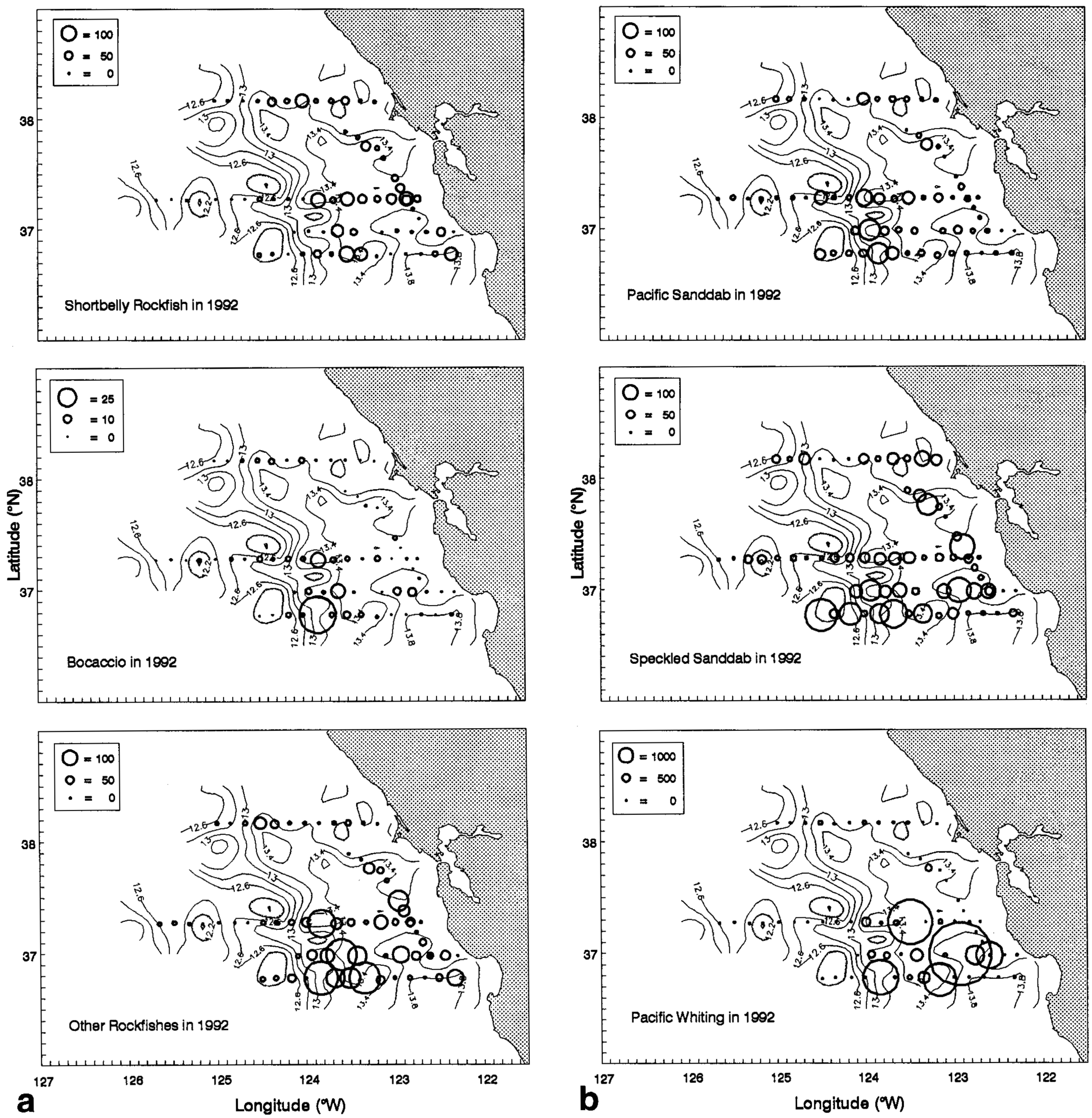

Figure 7. Temperature at 30 m in 1992 overlaid with total catches of (*a*) shortbelly rockfish, bocaccio, and other rockfishes; (*b*) Pacific and speckled sanddabs, and Pacific whiting.

the upwelling season, when offshore Ekman transport is greatest (Parrish et al. 1981; Strub et al. 1987; Largier et al. 1993), episodic cross-shelf transport to offshore waters does occur in winter. Results presented in Sakuma et al. (1994a, b) showed upwelling-favorable wind events during January of both years. We believe the offshore distribution of larvae may have been due to offshore Ekman transport stemming from episodic events of equatorward wind stress. In 1992 the offshore distribution of larvae may have been maintained by the poleward propagation of the warm-saline coastal water mass in association with the El Niño event (figure 4a; Clarke and Van Gorder 1994; Norton and McLain 1994). In 1993 the offshore distribution of larvae was probably maintained by the eddy feature evident in the salinity field (figure 3a).

The hypothesis that offshore larvae are vagrants gone

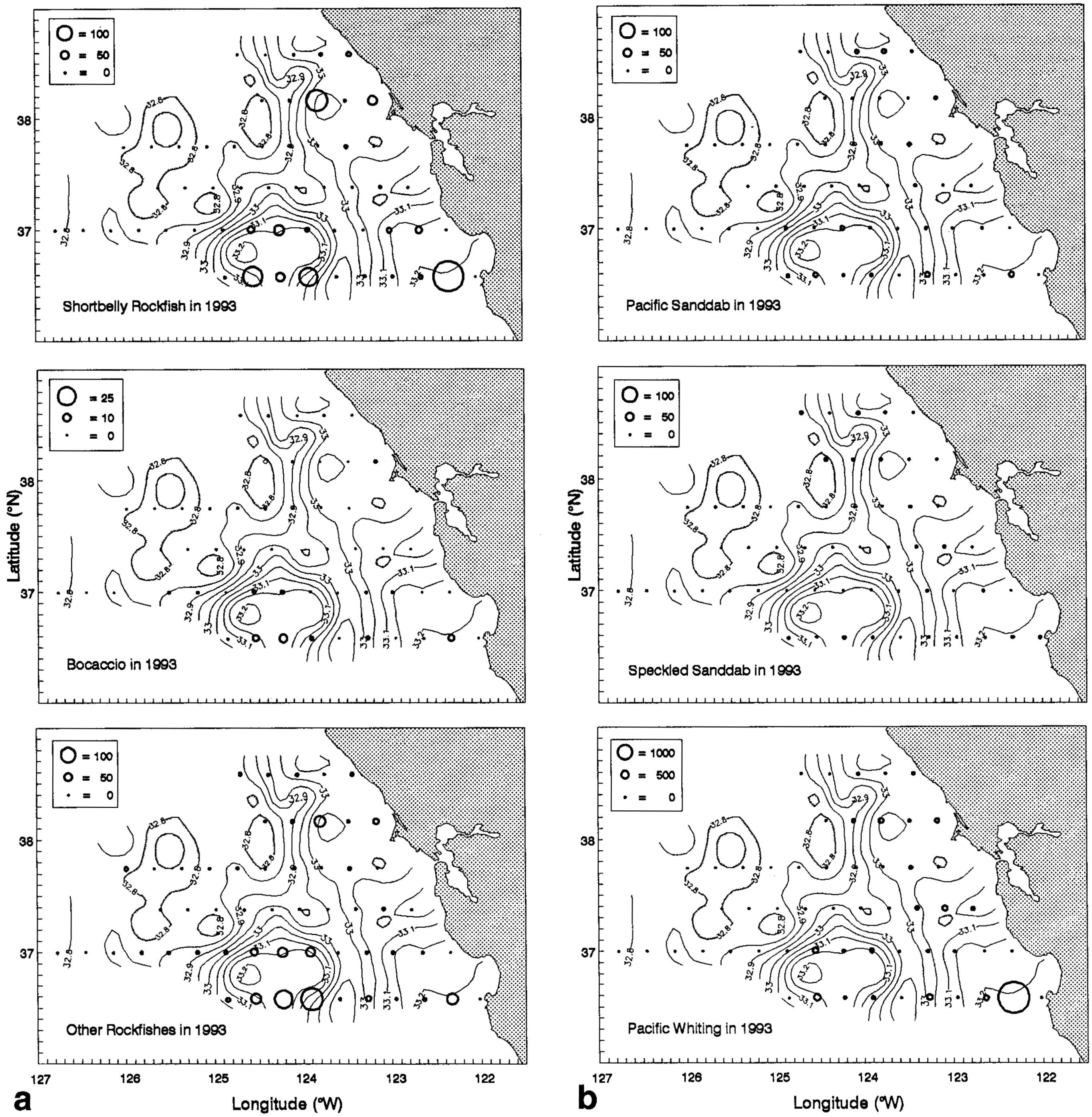

Figure 8. Salinity at 30 m in 1993 overlaid with total catches of (*a*) shortbelly rockfish, bocaccio, other rockfishes; (*b*) Pacific and speckled sanddabs, and Pacific whiting.

astray from retention areas (*sensu* Sinclair 1988) is consistent with additional data for young-of-the-year shortbelly rockfish and other rockfishes gathered in 1992. Midwater trawls conducted later in that year revealed that survival to the pelagic juvenile stage was very low (Eldridge 1994). It is not implausible to speculate that larvae distributed far offshore have little chance of reaching nearshore settlement areas. However, larvae within reasonable range of the continental shelf may reach nearshore settlement areas under the right set of conditions. Bakun and Parrish (1982) concluded that upwelling and offshore transport could be beneficial, depending on the timing and duration of the upwelling events relative to the life stage of the species being considered. In 1993 the survival of shortbelly rockfish and other rockfishes was moderate (Eldridge 1994), despite an

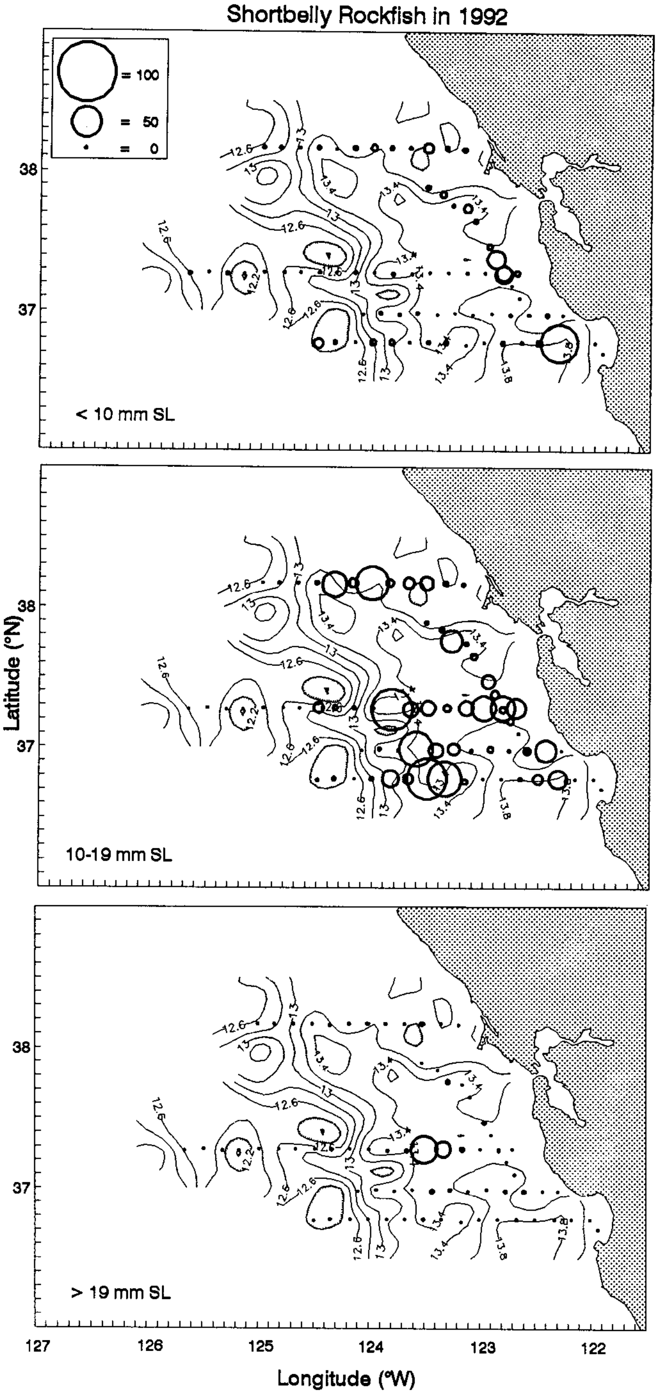

Figure 9. Temperature at 30 m in 1992 overlaid with total catches of small (<10 mm SL), medium-sized (10–19 mm SL), and large (>19 mm SL) shortbelly rockfish.

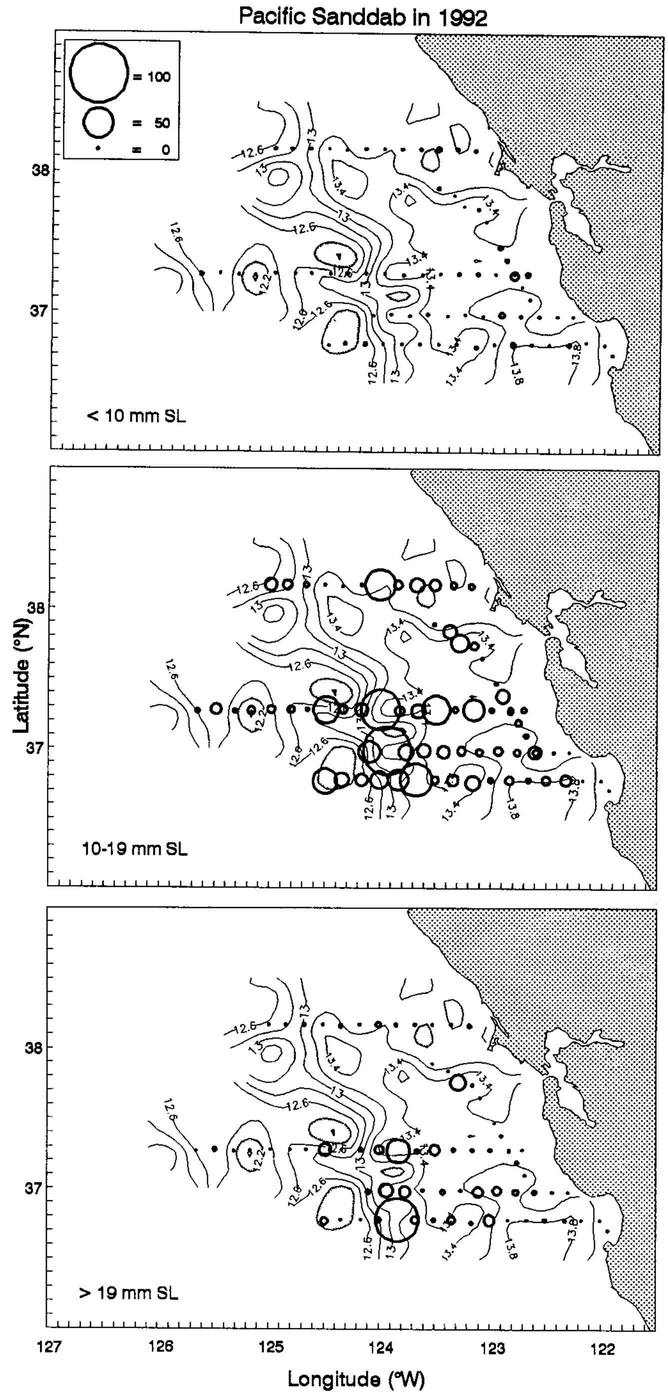

Figure 10. Temperature at 30 m in 1992 overlaid with total catches of small (<10 mm SL), medium-sized (10–19 mm SL), and large (>19 mm SL) Pacific sanddab.

extensive offshore distribution of late larvae (figure 8a). Even so, these offshore larvae were primarily distributed around an eddy feature (figure 8), which may have acted as a larval retention mechanism (Sinclair 1988). Schwing et al. (1991) have proposed that such mesoscale features can aggregate and maintain larvae near potential settlement areas (see also Lobel and Robinson 1986), despite the predominant equatorward flow of the California Current and offshore Ekman transport associated with upwelling. In addition, Hayward and Mantyla (1990) have reported that certain types of eddies can raise the nutricline into the photic zone, leading to increased primary production at the perimeter. The increased production in such areas would allow for better larval survival than

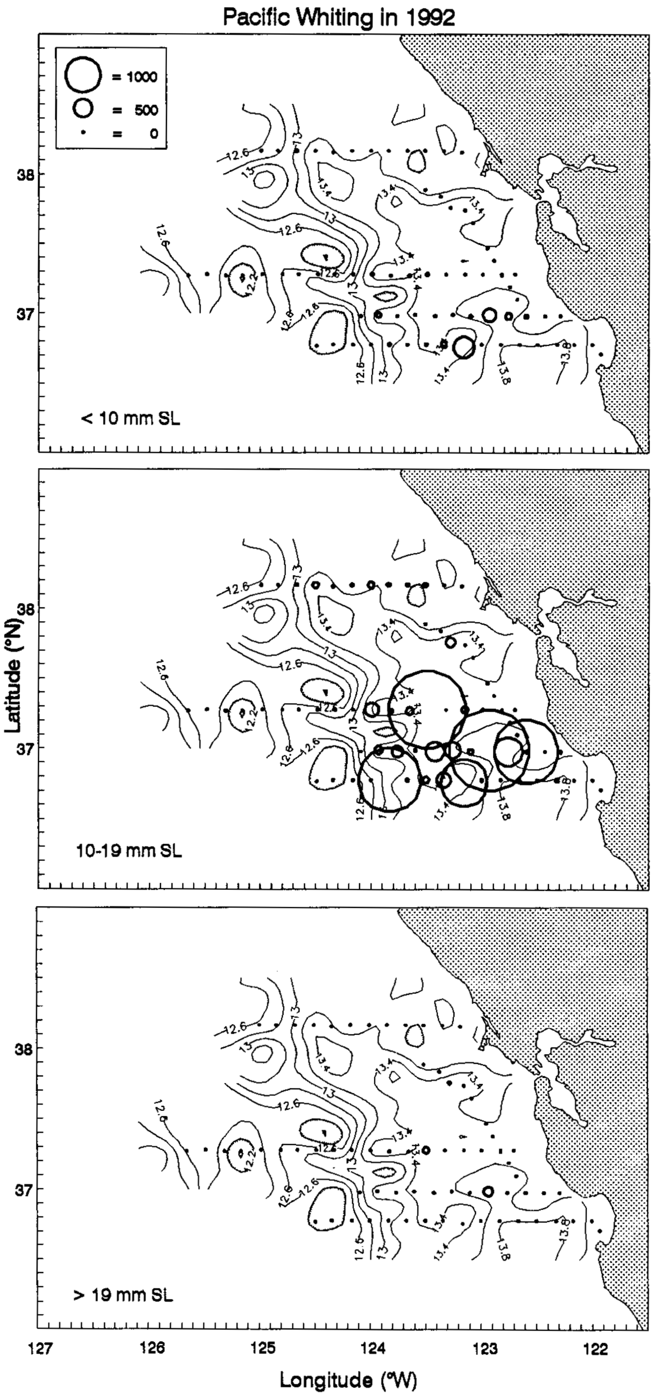

Figure 11. Temperature at 30 m in 1992 overlaid with total catches of small (<10 mm SL), medium-sized (10–19 mm SL), and large (>19 mm SL) Pacific whiting.

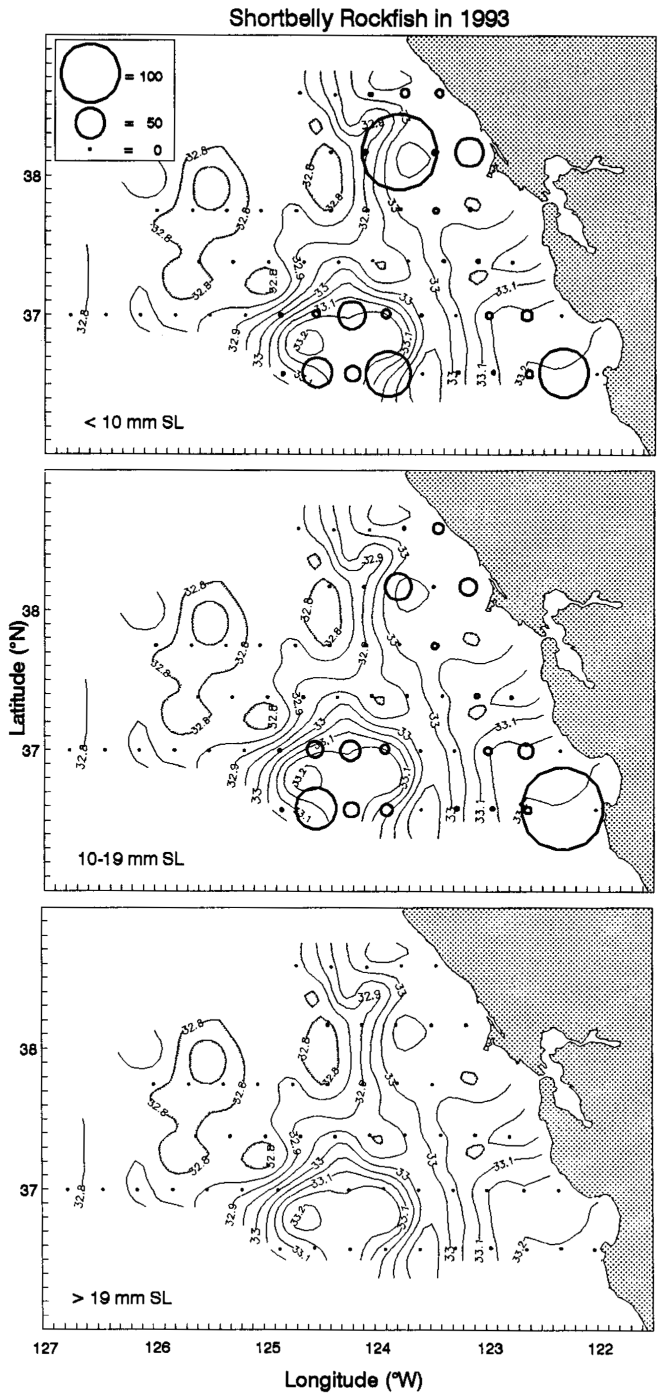

Figure 12. Salinity at 30 m in 1993 overlaid with total catches of small (<10 mm SL), medium-sized (10–19 mm SL), and large (>19 mm SL) shortbelly rockfish.

in the surrounding oligotrophic offshore waters. Therefore, within limits, an offshore distribution of larvae, in and of itself, may not be detrimental to survival.

Sakuma (1992) observed that early-stage metamorphic Pacific and speckled sanddabs were predominantly distributed farther offshore than late-stage individuals, which were distributed closer to shore. In this study, high catches of medium-sized and large Pacific sanddab, which correspond to the early-stage individuals in Sakuma 1992, were predominantly distributed offshore (figures 10 and 13). Larson et al. (1994) observed a similar trend in the pelagic juveniles of several species of rockfish, in which smaller individuals had a more offshore distribution, while larger ones were more often found nearshore. In this

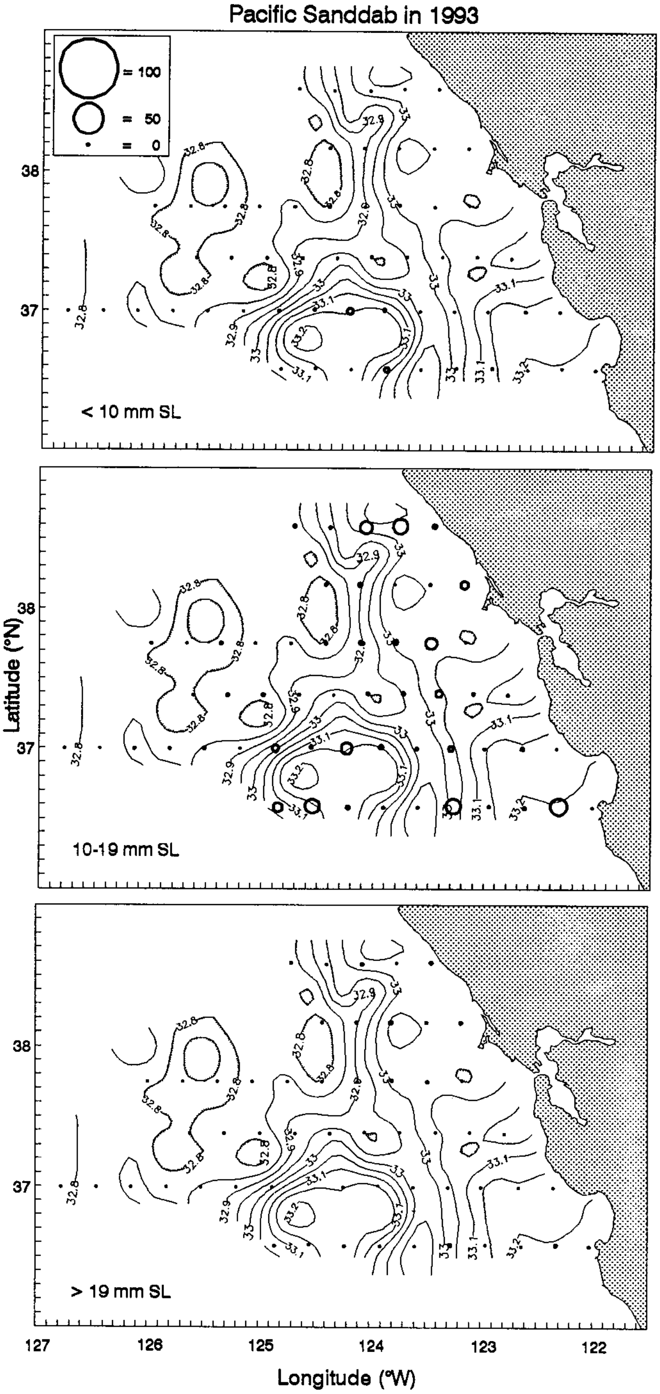

Figure 13. Salinity at 30 m in 1993 overlaid with total catches of small (<10 mm SL), medium-sized (10–19 mm SL), and large (>19 mm SL) Pacific sanddab.

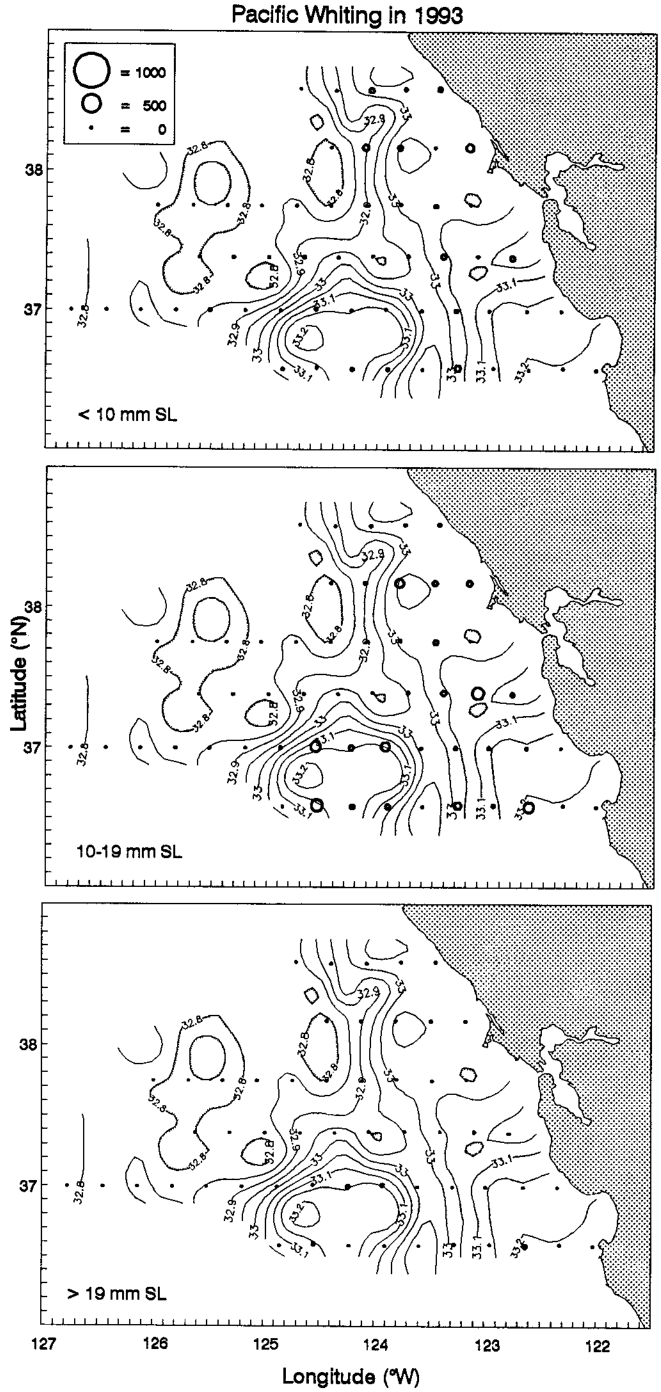

Figure 14. Salinity at 30 m in 1993 overlaid with total catches of small (<10 mm SL), medium-sized (10–19 mm SL), and large (>19 mm SL) Pacific whiting.

study, we observed high offshore catches of medium-sized and large shortbelly rockfish (figures 9 and 12), which corresponded to the small pelagic juveniles in Larson et al. (1994). Larson et al. (1994) and Sakuma (1992) both indicated that earlier larval stages were subject to transport offshore by prevailing current patterns, whereas later juvenile stages were able to reach nearshore settlement areas through some still-unknown set of mechanisms (Sakuma 1992; Larson et al. 1994). Given that juvenile rockfishes can remain pelagic for over 150 days (Woodbury and Ralston 1991), and that Pacific and speckled sanddabs can remain pelagic for over 270 days (E. B. Brothers, unpubl. data. EFS Consultants, 3 Sunset West, Ithaca, NY 14850; Kendall 1992), it is reasonable to postulate that larvae distributed offshore may be transported toward shore at some later period.

In contrast to the distributional patterns of sanddabs and rockfishes, the largest catches of Pacific whiting were made closer to shore in the southernmost portion of the survey area (figures 7b and 8b). This may have been due to northward transport of larvae spawned to the south, or a northward shift in spawning location during El Niño conditions (Bailey and Francis 1985; Hollowed 1992).

The difference in the horizontal distribution of Pacific whiting with respect to sanddabs and rockfishes could also be attributed to differences in their vertical distributions. Larval sanddabs and rockfishes are generally abundant between 20 and 60 m within the mixed layer (Ahlstrom 1959; unpubl. MOCNESS data), whereas Pacific whiting are generally most abundant below the mixed layer at depths greater than 50 m (Ahlstrom 1959; Bailey and Francis 1985). The deeper distribution of Pacific whiting larvae below the mixed layer would subject them to different current patterns and transport mechanisms than fish found within the mixed layer. Figure 3 indicates that, although the overall flow patterns observed at 30 m were similar to those at 60 m, there were smaller-scale differences in hydrography between the two depths. These smaller-scale differences over a period of time could account for the difference in the distribution of Pacific whiting compared with rockfishes and sanddabs in 1992 (figure 7).

In summary, the distributional patterns of these late larval groundfish prior to spring transition appear to depend on the prevailing hydrography. The hydrographic regime is subject to interannual variations in flow, and the various species groups are affected differently by these variations. Larvae appear to be subject to transport offshore away from the shelf and slope areas, but this does not preclude future recruitment to nearshore areas. In addition, at least for the rockfish species, reproductive success in 1992 had not been determined by early March, indicating that prevailing and future environmental conditions could dramatically affect recruitment.

ACKNOWLEDGMENTS

We wish to thank Tom Laidig, Bill Lenarz, Beth Norton, Don Pearson, Gareth Penn, Dale Roberts, and Dave Woodbury, who all participated as members of the scientific field party. We also thank the officers and crew of R/V *David Starr Jordan* for their able assistance. In addition, Glenn Almany, Tracy Hannigan, and Jennifer McCarthy helped process samples ashore. Special thanks to Ed Armstrong for providing the dynamic height calculations from the CTD data. The ideas we present evolved as a result of many discussions and careful manuscript critiques by Ralph Larson, Bill Lenarz, Dale Roberts, Frank Schwing, and Dave Woodbury.

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