DISTRIBUTIONS OF LATE-LARVAL AND PELAGIC JUVENILE ROCKFISHES IN RELATION TO WATER MASSES AROUND THE SANTA BARBARA CHANNEL ISLANDS IN EARLY SUMMER, 1996

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ABSTRACT

I describe the distributions of late-larval and pelagic juvenile rockfishes in relation to water masses around the Santa Barbara Channel Islands in early summer 1996 from samples collected during a midwater trawling and oceanographic survey. Overall low abundance of pelagic juvenile rockfishes around the islands reflects a large-scale, long-term decline in productivity along California. Rockfish abundance and diversity were higher in the 30 to 54 m trawling stratum than in the deeper stratum (60 to 100 m). I identified four distinct water masses in the 30 to 54 m stratum. Upwelled water occupied the western portion of the island chain. Water in the eastern portion was warmer and fresher and likely originated from the Southern California Bight. Rockfishes, dominated by *Sebastes jordani*, were rare on the north side of the islands and in upwelled water; they were most abundant and diversity was high in the vicinity of a thermohaline frontal zone on the south side of the island chain. Large specimens of *S. jordani* (>30 mm SL) were under-represented in the cooler water masses associated with upwelled water and in the deeper trawling stratum. Episodic contact of reefs with concentrations of recruits in dynamic mesoscale frontal features may control local recruitment (i.e., arrival of recruits to reefs) along the islands.

Keywords: Front, pelagic juvenile fishes, recruitment, Santa Barbara Channel Islands, *Sebastes*, upwelling, water masses.

INTRODUCTION

Many nearshore fish species, including economically important rockfishes, are adrift in the plankton for weeks to months through the juvenile stage before they develop adult behaviors or recruit to nursery or adult habitats (Love et al. 1991; Moser and Boehlert 1991). Along-shore and cross-shore flowing currents can carry the eggs, larvae and juveniles hundreds of kilometers from where spawning occurred. Thus, recruitment success and patterns of recruitment are critically linked to physical transport processes that potentially affect the distribution of not only larvae and juveniles, but also their food, competitors and predators. It is important to understand whether larvae and pelagic juveniles move among water masses, or stay in the same water in which they were spawned. Results from studies addressing this and related questions have important implications in pure and applied research. If pelagic early life stages are for the most part retained in distinct water masses, then patterns of nearshore settlement—critical knowledge for population biology and for assessing potential marine reserve locations—potentially could be predicted from models of transport processes and the distribution of prerecruits in the pelagic environment.

We know little of the distributions of pre-recruiting juvenile fishes before they settle in nursery and adult habitats and how the distributions are affected by changes in oceanographic conditions at various temporal and spatial scales. The extent to which larvae or juveniles traverse frontal features from one water mass into another during the pelagic phase is probably related to species-specific development and behavior. Very few surveys have targeted pelagic juvenile fishes primarily because of gear limitations and costs (Larson et al. 1994; Sakuma and Ralston 1995). The need for these surveys to examine the distributional patterns of various species is emphasized in recent studies that show that year-class strength for many coastal fishes, including rockfishes, likely is determined by the late pelagic juvenile stage (Bradford 1992; Ralston and Howard 1995).

The hypothesis of this paper is that spatial distributional patterns of pelagic juvenile fishes reflect the hydrography and circulation in the Santa Barbara Channel. I focus on a commercially and recreationally important group of fishes, rockfishes, and show how patterns in abundance and composition of the pre-recruits relate to water masses found around the Santa Barbara Channel Islands during a midwater trawl survey in June 1996. In addition, I show how hydrographic changes in sampling areas were accompanied by changes in rockfish abundance and composition. Rockfish size distributions in relation to trawling depth and water masses are also examined. The 1996 midwater trawl survey is one in an annual series that began in 1995, the first of its kind in Southern California, to examine distributional patterns of pelagic juvenile pre-recruits of nearshore fishes in relation to oceanography and physical processes.

Study Area

The Santa Barbara Channel (SBC) is a semi-enclosed, elongated basin about 100 km long by about 40 km wide in the northern region of the Southern California Bight. Our study area encompassed the SBC Islands: Tuqan (Native American Chumash name for San Miguel); Wi'ma (Santa Rosa); Limuw (Santa Cruz); and Anyapax (Anacapa) (J. Timbrook, pers. comm.). The west-east trending chain of islands forms the southern boundary of the SBC. At the western entrance of the SBC is the massive headland of Point Conception and Point Arguello where the California coastline makes nearly a right-angle bend and trends eastward forming the northern boundary of the channel. This abrupt change in the coastline orientation contributes to the unique and complex atmospheric and ocean circulation in the SBC and around its islands.

The Channel region is embedded within the much larger California-Baja California coastal current regime (Brink and Muench 1986; Harms and Winant 1998; Hickey 1992). In general, coastal surface waters west of the SBC and off the central California coast are cooler than waters south of the channel due to coastal upwelling and input of the California Current that carries subarctic water from high latitudes year-round. Waters in the Southern California Bight originate from the California Current and water of subtropical origin. Seasonal warming of water in the Bight is from atmospheric heating. The warm, poleward-flowing current along the coast is called the Southern California Countercurrent. On seasonal time scales, the larger-than-SBC scale flow near the surface is equatorward in spring and poleward from summer through winter (Harms and Winant 1998). The increase in equatorward flow along the coast in spring occurs concurrently with increases in equatorward wind stress and coastal upwelling.

Circulation within the SBC is highly variable in time and space and is determined by the relative strengths of wind stress and a deep-water pressure gradient through the channel (Harms and Winant 1998; see Washburn et al. 1999, this volume). Harms and Winant (1998) describe six circulation patterns in the channel. Generally, warm water from the Southern California Bight enters the SBC's east entrance and flows westward along the channel's northern boundary, and cool water flows through the southern portion of the west entrance then eastward along the islands. A cyclonic gyre associated with these opposing flows persists through much of the year in the Santa Barbara Channel, but its position and intensity varies seasonally (Lagerloef and Bernstein 1988; see Washburn et al. 1999, this volume). Water upwelled at Points Conception and Arguello is advected offshore then often turns into the channel. Upwelling at Points Conception and Arguello and at discrete centers along the Central California coast occurs year-round, but is most intense during the spring and summer when winds blow most persistently from the northwest. The upwelling plume at the west entrance frequently extends southward and into the channel impinging on the westernmost island, Tuqan.

Compared to the amount of information now available on the circulation patterns in the Santa Barbara Channel (see Harms and Winant 1998), little has been published on the mesoscale (1 to 10 km resolution) circulation outside of the channel around the islands.

METHODS

A midwater trawl survey on the F/V *Gus-D* (73 ft) was conducted in summer 1996 around the Santa Barbara Channel Islands (Figure 1). Our primary goal was to collect samples from distinct water masses in different geographic areas around the islands. The sampling plan remained flexible throughout the study to provide opportunities to sample across sea surface thermal fronts located on AVHRR imagery or by monitoring sea surface temperature (SST) using a through-the-hull sensor positioned about 2 meters below the vessel's water line. Images could not be viewed on the vessel, but daily communication with personnel on shore provided information about sea surface temperature patterns and the location of frontal features. I assumed that SST frontal features demarcated boundaries between different water masses at trawling depth. Smith et al. (1987) showed that the position of a SST front south of the Santa Barbara Channel Islands corresponded with the horizontal variability of water-column properties (e.g., light transmittance, mixed layer depth, chlorophyll a) down to at least 30 m.

We used a 24.4 m midwater trawl which has a spread of approximately 15 m horizontally and 12 m vertically (D. Woodbury, pers. comm.). The codend was made of 8 mm stretch mesh. All trawls were conducted at night by

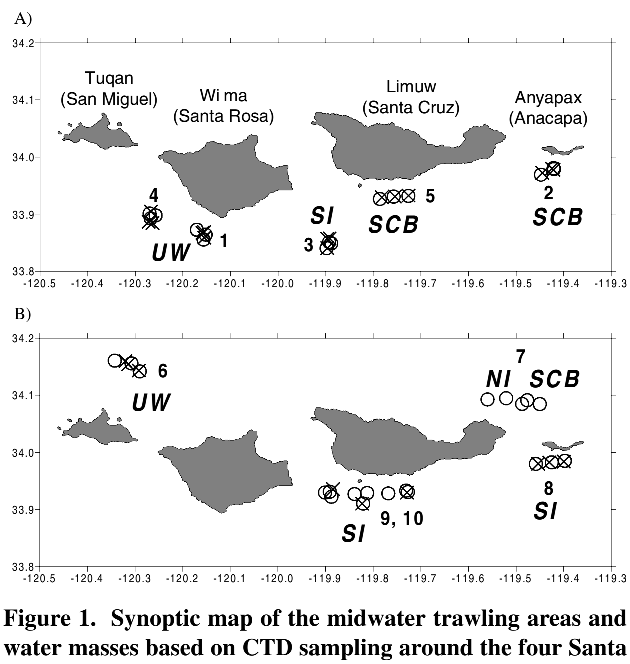

Figure 1. Synoptic map of the midwater trawling areas and water masses based on CTD sampling around the four Santa Barbara Channel Islands in 1996. The survey was divided into two legs: (A) Leg 1 (5-10 June) and (B) Leg 2 (26-28 June, two nights; and 30 June-2 July, three nights). Numbers indicate the areas sampled during the 10 cruise nights. Open circles mark locations of shallow tows (Mean = 37 m, SD = 2 m) and Xs mark locations of deeper tows (Mean = 67, SD = 6 m). The four mass water types are upwelled water, *UW*; southside island water *SI*; Southern California Bight water, *SCB*; and northside island water, *NI*.

standard convention to minimize net avoidance. Trawling time was 15 min at depth. A time-depth recorder attached to the headrope provided trawling depth data. Generally, three shallow hauls and three deep hauls targeting 30 and 60 m, respectively, were conducted per night near the 200 m isobath in a sampling area. Each shallow haul overlaid a deep haul.

Oceanographic sampling included vertical conductivity-temperature-depth (CTD) casts (Seabird Electronics profiler, model SBE 19 with pump) at all trawl stations to 200 m or 5 to 10 m above the bottom at shallower bottom depths. Occasionally, additional CTD cast stations were added on route from one sampling area to another (e.g., Cruises 7, 8, and 9). After the survey, water mass types were identified by visually grouping temperature-salinity (TS) plots of CTD cast data from 30 to 54 m (corresponding with the trawling stratum through which all shallow tows fished).

All fishes were sorted and identified to species if possible, then frozen. In the laboratory, rockfishes were identified to species and the thawed specimens were measured to the nearest 0.1 mm. Nonparametric analyses were used to compare catch data (number of fish per haul) from the shallow and deep trawls and among water masses. To compare rockfish abundances from the two depth strata, the Wilcoxon Signed Rank Test was used on a pool of paired hauls (i.e., shallow and deep) from eight cruise nights. Data from Cruises 7 (north side of Limuw (Santa Cruz)) and 10 (south side of Limuw) were excluded, because only shallow hauls were conducted. Rockfish catches from the different water masses were compared using the Kruskal-Wallis test and *post hoc* Tukey test on ranked data of abundance from shallow hauls grouped by water mass type. Size frequency distributions of rockfishes in the different water masses were compared using the Kolmogorov-Smirnov two-sample test on data classed into 2.5 mm bins.

RESULTS

The 10-night survey around the SBC Islands was divided into two legs; Leg 1 was comprised of five cruise nights (5 to 10 June) and was separated by 17 days from Leg 2 also comprised of five cruises (26 to 28 June, two nights; and 30 June to 2 July, three nights) (Figures 1A and 1B). The second leg was broken into two segments because of inclement wind conditions. We completed 59 midwater tows. Of these, 35 tows were conducted at shallow head rope depths ranging from 32 to 41 m (mean = 37 m, SD= 2 m) and 24 tows at a deep depth ranging from 60 to 89 m (mean = 67, S.D. = 6 m). Trawling was conducted only at the shallow stratum during Cruises (i.e., nights) 7 and 10.

Hydrography of the Survey Region

Four water mass types were discernable and are mapped for a synoptic perspective of the hydrography around the SBC Islands during the trawl survey (Figure 1). The sampling pattern of CTD casts was clustered, therefore the characteristics and positioning of the convergences between water mass types could not be determined. Cold, saline *upwelled water* (*UW*) occupied the western portion of the islands region throughout the survey, and warmer, fresher *Southern California Bight water* (*SCB*) occupied the east. On the channel side of the island chain, a thermohaline front was detected along eastern Limuw (Santa Cruz) with *UW* to the west and *SCB* to the east. Situated in the frontal zone between these water masses was an intermediate type that I call *northside island water* (*NI*). We surveyed this area only during Leg 2 (Cruise 7); however, SST images indicate this feature persists on the scale of days to weeks. Outside of the channel, another intermediate type that I call *southside island water* (*SI*) was found offshore of the Wi'ma-Limuw (Santa Rosa-Santa Cruz) gap during Leg 1 (Cruise 3). A significant change in hydrography occurred during the survey: sampling during Leg 2 (Cruises 9 and 10) indicated that *SI* expanded eastward and replaced *SCB* (Cruises 2 and 5) off the south side of Limuw and Anyapax (Anacapa).

Figure 2 shows temperature-salinity (TS) plots divided into four groups defining the water mass types mapped in Figure 1. Two water mass types, *UW* and *SCB* were very distinct from one another. *UW* was the coolest and most saline water type; TS characteristics were similar to that of recently upwelled water described by Bray et al. (1996) and Morawitz et al. (1996). *SCB* was the warmest and least saline water. Its salinity range, 33.4 to 33.7 ppt, corresponded with salinity variations in the Southern California Bight which average about 33.3 to 33.6 ppt (Jones 1971) indicating that this water mass originated from the Bight. Two remaining water mass types, *NI* and *SI*, had intermediate characteristics and occupied frontal regions between *UW* and *SCB*. Salinity and temperature characteristics of *NI* were characteristically higher than that of *SI*. Although *NI* density was similar to *SCB* due to temperature, *NI* salinity was more closely aligned with *UW*. In contrast, *SI* was relatively cool like *UW*, and its salinity varied with increasing depth from low values characterizing *SCB* to high values of *UW*.

Species Composition and Abundance

Pelagic juvenile rockfishes were not common in midwater trawl catches and were patchily distributed. (Herein, my reference to pelagic juveniles includes postflexion larvae that were also collected). Rockfishes occurred in 21 of the 59 hauls (36%) and the catch ranged from 0 to 57 rockfish/haul.

Considering only the paired shallow and deep hauls (n=48 hauls), the rockfish catch from the shallow trawling stratum was significantly greater than that from the deep stratum (p=0.011); mean abundances from the shallow and deep tows were 3.8 and 0.8 per haul, respectively (Table 1A). Rockfish were present in 50% of the shallow hauls (12/24 hauls) and 38% of deep hauls (9/24). The vertical distribution of total rockfishes reflects that of *Sebastes jordani* (shortbelly rockfish), the dominant species.

Rockfish diversity was greater in the shallow stratum than in the deep stratum. Five species, one complex of the strata were *S. hopkinsi* (squarespot rockfish) and *Sebastomus*. *Sebastes paucispinis* (bocaccio), *S. semicinctus* (halfbanded

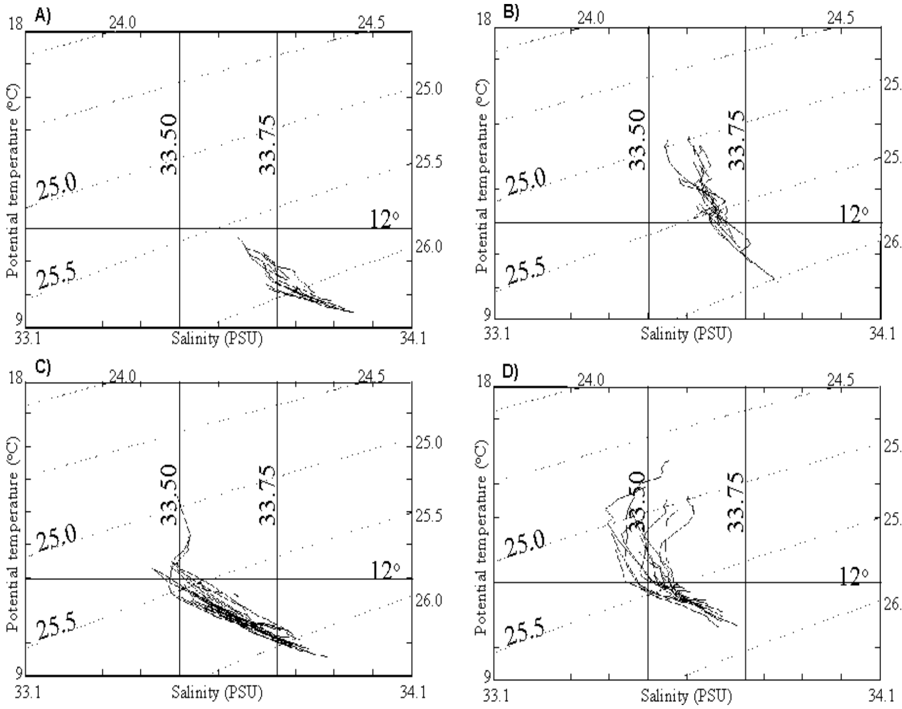

Figure 2. Temperature-salinity (TS) plots visually grouped into four water mass types: (A) upwelled water, *UW*; (B) northside island water, *NI*; (C) southside island water, *SI*; and (D) Southern California Bight water, *SCB*. Data from the 30-54 m section of vertical CTD cast profiles (corresponding with the trawling stratum through which all shallow tows fished) are plotted.

rockfish) and *S. diploproa* (splitnose rockfish) were collected only in the shallow stratum.

Hydrography, Rockfish Abundance and Composition

Mean abundance of pelagic juvenile rockfishes differed among water masses ($p<0.05$)(Table 1B). Pelagic juvenile rockfishes were rare in *upwelled water* (*UW*) and absent in *northside island water* (*NI*) Only one specimen, *Sebastes jordani*, was collected in *UW*. In contrast, pelagic juvenile rockfishes occurred frequently (6 of 9 hauls) and were most abundant in *SCB*.

Off the southside of Limuw (Santa Cruz), the highest abundance of rockfishes (Cruise 5, Figure 3A) was in *Southern California Bight water (SCB)* and associated with a front visible on SST images. The largest rockfish catch of the survey (57 fish) was collected at the cool end of the Cruise 5 transect (n=3 hauls) near *southside island water* (*SI*), a frontal water mass between *UW* and *SCB*. The two remaining shallow hauls from Cruise 5 were comprised of 3 and 6 fish which were comparable to the mean catch size on the southside of the island chain outside of the upwelled area—in *SCB* off Anyapax (Anacapa) during Cruise 2 and in *SI* off the Wi'ma-Limuw (Santa Rosa-Santa Cruz) gap during Cruise 3. *Sebastes jordani* and *S. hopkinsi* showed similar patterns.

In comparison, rockfishes were absent in a frontal zone that was located off the northside of Limuw and visible in SST images. TS characteristics indicated that *SCB* converged with *NI* in the area sampled during Cruise 7. The abundance patterns on the south side of the island chain contrasts with that on the north side; no rockfishes were collected in any water mass on the north side of the island chain (Cruise 6, *UW*, n=3 hauls; Cruise 7, *SCB*, n=3; Cruise 7, *NI*, n=2) (Figure 3A).

Rockfish diversity was influenced by the distribution of water masses and was attributed in part to the size of the catch. The number of taxa in the shallow stratum was highest in the region of a frontal zone on the south side of the island chain. Eight taxa were collected in *SI* during Cruise 3 (n=3 hauls) (Figure 3B) when this water mass occupied a relatively narrow frontal zone between *UW* and *SCB* (Figure 1). Also, five taxa were collected in *SCB* during Cruise 5 close to the frontal zone. Diversity was low during the other cruises because rockfishes were rare; with exception of Cruise 2 (n=3 hauls, X=2.7 rockfish/haul), no more than one rockfish was collected in the shallow hauls.

Temporal Changes in Hydrography, Rockfish Abundance and Composition

Significant movement of water masses occurred on the south side of the island chain during the survey and coincided with a change in the distribution of rockfishes. Anyapax (Anacapa), the Wi'ma-Limuw (Santa Rosa-Santa Cruz) gap, and western Limuw initially were sampled during Cruises 2, 3, and 5, respectively (Leg 1, Figure 1A). About three weeks later, we revisited Anyapax during Cruise

Table 1A. Mean, standard deviation, minimum and maximum abundance (number of fish per haul) of pelagic juvenile rockfishes, and their percent occurrence in paired shallow and deep hauls and in these hauls combined.

	Shallow hauls (n=24)					Deep hauls (n=24)					All paired hauls (n=48)	
Taxon	**Mean**	**SD**	**Min**	**Max**	**% occ**	**Mean**	**SD**	**Min**	**Max**	**% occ**	**Mean**	**SD**
Sebastes jordani	3.0	(10.2)	0	50	33.3	0.5	(1.0)	0	4	33.3	1.8	(7.3)
Sebastes hopkinsi	0.3	(1.0)	0	5	8.3	0.1	(0.3)	0	1	8.3	0.2	(0.8)
Sebastomus	0.3	(0.4)	0	1	25.0	0.1	(0.3)	0	1	8.3	0.2	(0.4)
Sebastes paucispinis	0.1	(0.3)	0	1	8.3	0				0	<0.05	(0.2)
Sebastes semicinctus	<0.05	(0.2)	0	1	4.2	0				0	<0.05	(0.1)
Sebastes diploproa	<0.05	(0.2)	0	1	4.2	0				0	<0.05	(0.1)
Unknown	0.1	(0.4)	0	2	8.3	0				0	0.1	(0.3)
Damaged	0	(0.0)	0	0	0	<0.05	(0.2)	0	1	4.2	<0.05	(0.1)
Total	3.8	(11.6)	0	57	50.0	0.8	(1.3)	0	5	37.5	2.3	(8.3)

Table 1B. Mean, standard deviation, minimum and maximum abundance (number of fish per haul) of pelagic juvenile rockfishes, and their percent occurrence in the four water mass types.

	Upwelled (UW) n=9			Northside Island (NI) n=2			Southside Island (SI) n=15			Southern California Bight (SCB) n=9		
Taxon	**Mean**	**SD**	**% occ**	**Mean**	**SD**	**% occ**	**Mean**	**SD**	**% occ**	**Mean**	**SD**	**% occ**
Sebastes jordani	0.1	(0.3)	11.1	0		0	0.3	(1.3)	6.7	7.2	(16.2)	66.7
Sebastes hopkinsi	0		0	0		0	0.1	(0.3)	6.7	0.6	(1.7)	11.1
Sebastomus	0		0	0		0	0.3	(0.5)	26.7	0.2	(0.4)	22.2
Sebastes paucispinis	0		0	0		0	0.1	(0.3)	6.7	0.1	(0.3)	11.1
Sebastes semicinctus	0		0	0		0	0		0	0.1	(0.3)	11.1
Sebastes diploproa	0		0	0		0	0.1	(0.3)	6.7	0		0
Unknown	0		0	0		0	0.2	(0.6)	13.3	0		0
Damaged	0		0	0		0	0		0	0		0
Total	0.1	(0.3)	11.1	0		0	1.0	(2.4)	33.3	8.2	(18.4)	66.7

8 and Limuw during Cruises 9 and 10 (Leg 2, Figure 1B). The proximity of *southside island water* (*SI*) and *Southern California Bight water* (*SCB*) during Leg 1 indicates a frontal zone in the vicinity of Limuw. Leg 2 TS characteristics off Limuw and Anyapax indicated that *SI* expanded eastward and replaced *SCB* off Limuw and Anyapax.

I compared catches from these cruises and found that rockfishes all but disappeared from these two areas after the water mass transition. During Leg 1, rockfish abundance and species richness were highest in the Wi'ma-Limuw gap (Cruise 3) and off Limuw (Cruise 5) (Figure 3A). Eight taxa were collected in the gap, five off Limuw (Cruise 5), and two off Anyapax (Cruise 2) (Figure 3B). In contrast during Leg 2, only one specimen, subgenus *Sebastomus*, was collected off Anyapax (Cruise 8). Similarly, only one fish, also *Sebastomus*, off Limuw (Cruise 9, Cruise 10) (Figure 3A and 3B).

Rockfish Size Distribution

Rockfishes were represented by postflexion larvae and pelagic juveniles. Mean size for the various taxa ranged from 14.1 to 39.1 mm SL (Table 2). The largest rockfishes were *Sebastes jordani*, *S. hopkinsi* and *S. semicinctus*. Their mean sizes ranged from 26.1 to 39.1 mm SL corresponding with the pelagic juvenile stage, and were nearly two times that of the other rockfish taxa (14.1 to 17.1 mm SL) represented by postflexion larvae.

Only *S. jordani* was sufficiently abundant to examine size distribution in relation to depth and water masses (Figure 4). The size distribution of *S. jordani* was depth-related ($p<0.05$). Its size distribution in the shallow stratum was bimodal with a substantial proportion of the sample centered around 32.5 mm (pelagic juvenile stage) and a lesser mode centered around 17.5 mm (postflexion larvae). In contrast, larger juveniles (>30 mm) were rare in the cooler, deeper trawling stratum. Smaller juveniles (<30 mm SL) made up 39% (27/70 fish) of the *S. jordani* catch in the

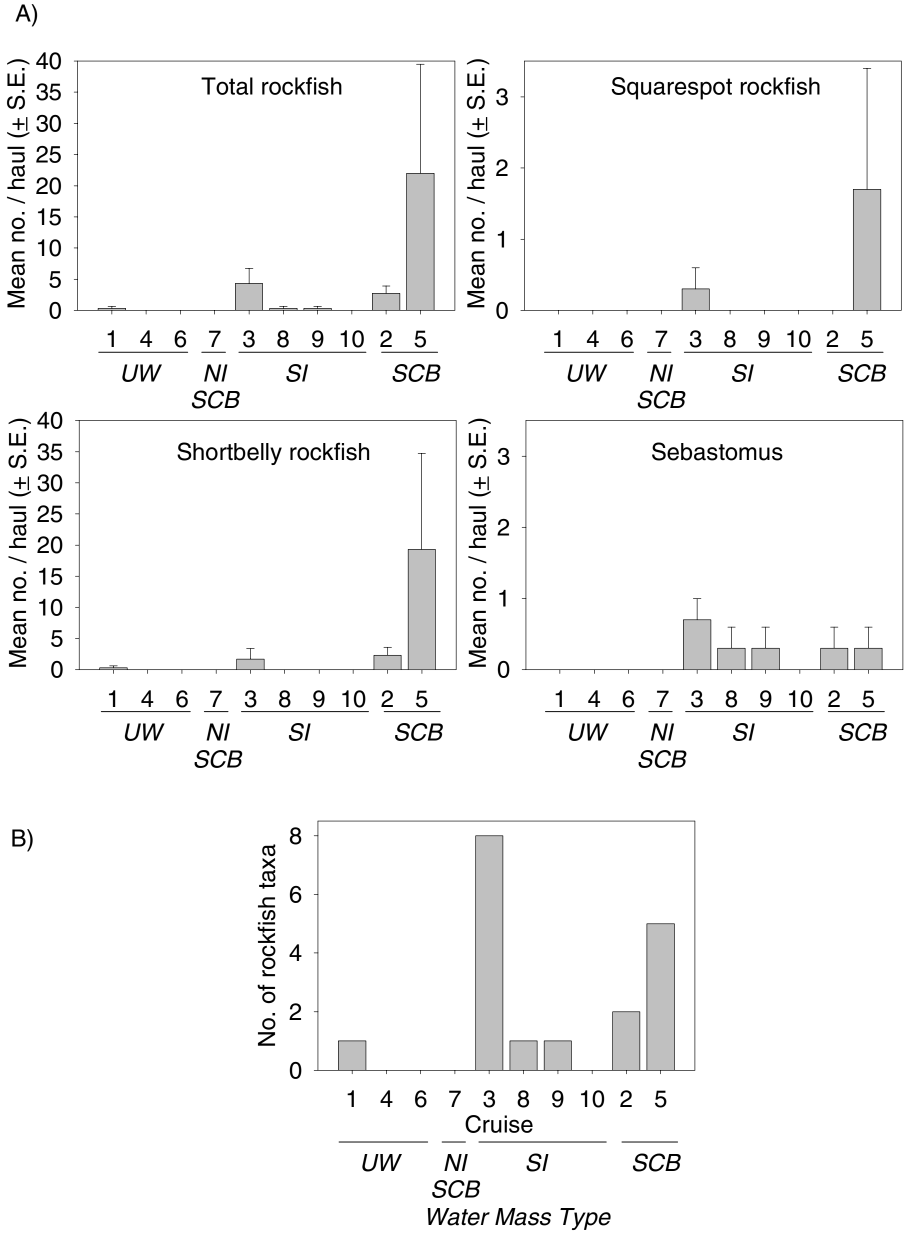

Figure 3. (A) Abundance (mean number of fish per haul, SE) in shallow hauls from cruises (i.e. nights) 1-10 of total rockfish and the most abundant rockfish taxa: Squarespot rockfish (*Sebastes hopkinsi*), Shortbelly rockfish (*S. jordani*), and subgenus *Sebastomus*. (B) Number of rockfish taxa collected in pooled hauls from each cruise. Three shallow tows (n=3) were conducted during each cruise with exception of Cruises 7 and 10 (n=5 for each). Cruises were grouped by water mass type: upwelled water, *UW*; northside island water, *NI*; southside island water, *SI*; and Southern California Bight water, *SCB*.

upper stratum compared to 85% (11/13) in the lower stratum. Size distributions in two water masses, *Southern California Bight water* (*SCB)* and *southside island water* (*SI*), differed (p<0.05) and contrasted similarly. The bimodal distribution of *S. jordani* in *SCB* was similar to that for all shallow hauls, because 64 of 70 fish collected in the shallow hauls were from *SBC*. Five of the remaining specimens were collected in cooler *SI*, and all were postflexion larvae. Only one rockfish, *S. jordani*, the largest juvenile specimen, was collected in *upwelled water* (*UW*).

DISCUSSION

There are several lines of evidence that indicate mesoscale hydrography influences the distributional patterns of pelagic juvenile rockfishes. My results show that few juvenile fishes reside in upwelled water. Furthermore, pelagic juvenile rockfishes were concentrated near a front; juveniles were most abundant in the vicinity of a frontal boundary off the south side of Limuw (Santa Cruz). When the frontal boundary was replaced by cool water, rockfish abundances decreased significantly in the area. Water upwells from

Table 2. Number of specimens (N), and the mean, standard deviation, minimum and maximum sizes (mm SL) of pelagic juvenile rockfishes collected in shallow and deep hauls, and all hauls combined.

	Shallow hauls					Deep hauls					All hauls				
Taxon	**N**	**Mean**	**SD**	**Min**	**Max**	**N**	**Mean**	**SD**	**Min**	**Max**	**N**	**Mean**	**SD**	**Min**	**Max**
Sebastes jordani	70	30.3	(8.2)	13.8	53.2	13	23.2	(7.8)	10.0	38.7	83	29.2	(8.5)	10.0	53.2
Sebastes hopkinsi	6	26.7	(7.0)	16.7	34.2	2	24.3	(8.6)	18.2	30.3	8	26.1	(6.8)	16.7	34.2
Sebastomus	6	15.7	(1.2)	14.4	17.6	2	16.2	(7.4)	10.9	21.4	8	15.8	(3.0)	10.9	21.4
Sebastes paucispinis	2	17.1	(3.3)	14.8	19.4						2	17.1	(3.3)	14.8	19.4
Sebastes semicinctus	1	39.1									1	39.1			
Sebastes diploproa	1	16.7									1	16.7			
Unknown	3	14.1	(1.3)	13.1	15.6						3	14.1	(1.3)	13.1	15.6

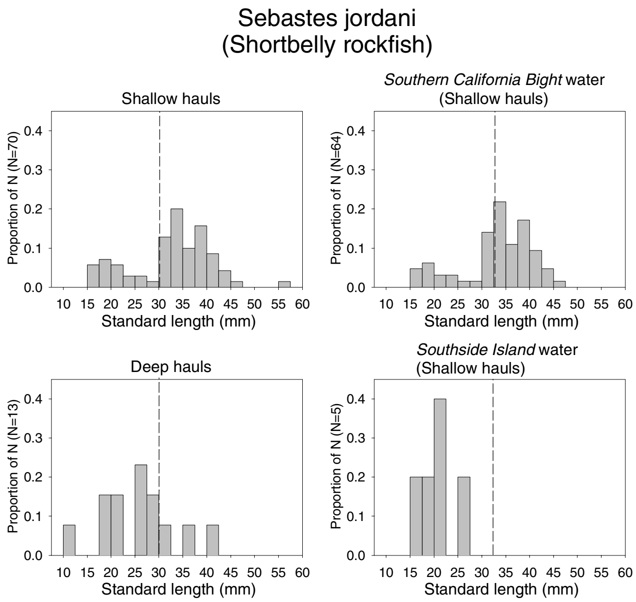

Figure 4. Size distribution of *Sebastes jordani* in shallow hauls, deep hauls, and in the two water mass types where specimens were collected in shallow hauls. Dashed vertical line marks the mean size (30 mm SL) of *S. jordani* collected in shallow hauls.

depths that correspond with the deep trawling stratum. I found that juveniles were four times less abundant in the cooler, deep stratum (60 to 100 m) than in the warmer, shallow stratum (30 to 55 m). Concentrations of pelagic juvenile fishes along the frontal boundary may have been displaced by water that shoaled from depth and expanded eastward during upwelling.

Interactions of wind and hydrography in the Santa Barbara Channel Islands region strongly influence alongshore recruitment patterns (D. M. Schroeder, unpublished 1998). I found that rockfishes in the cool, western water mass (*southside island water*) were smaller than those in the warm, eastern water mass (*Southern California Bight water*), indicating that the two cohorts have been separated by frontal boundaries and may have originated from different water masses. If there is little exchange across frontal boundaries throughout the pelagic life history, then variable survival of fishes in different water masses can be hedged over the season. Movement of water masses and frontal boundaries and their episodic collision with suitable settlement habitat may underly variability in population structure of young-of-year fishes at a reef.

Episodes of contact with concentrations of young fishes in dynamic mesoscale frontal features associated with upwelling may control the arrival of recruits to reefs along the Santa Barbara Channel Islands. Recruitment of many nearshore fish and invertebrate species with planktonic early life histories coincides in space and time with strong wind-induced upwelling and offshore advection. An important recruitment mechanism off central California is the onshore transport of upwelling fronts during episodic relaxation of wind and the cessation of upwelling (Graham 1993; Roughgarden et al. 1991). As a result, recruits concentrated in the frontal convergence separating upwelled water and offshore water are transported inshore to settlement habitat.

A striking finding is that pelagic juvenile rockfish abundance was extremely low. These values were comparable to catch densities in the June 1995 midwater survey in the channel in the vicinity of oil/gas platforms and in June 1997 when sampling was repeated around the islands (M. Nishimoto, unpublished 1998). Corroborating these findings are the observations of National Marine Fisheries Service, Tiburon Laboratory, that show declining pelagic juvenile rockfish abundances in midwater trawl surveys off central California during the last 10 years (D. Woodbury, pers. comm.). The overall low abundance of rockfish pelagic juveniles might be one of many biological responses to large-scale ocean warming observed in the Channel Islands region and in other areas along the Pacific coast (Engle 1994; McGowan et al. 1998).

An important practical implication of this research is that oceanography and the potential levels of recruitment relative to all sites should be a consideration when designating marine reserve areas. Moreover, during large-scale reductions in productivity exemplified by present conditions, the importance of mesoscale dynamics of oceanographic convergences (e.g., fronts) in recruitment processes may be heightened.

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