DEPTH DISTRIBUTIONS OF LATE LARVAE AND PELAGIC JUVENILES OF SOME FISHES OF THE CALIFORNIA CURRENT

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ABSTRACT

The vertical distribution of pelagic young-of-the-year larval and juvenile fishes in the California Current is reviewed. New data from synoptic midwater trawls conducted at depths of 13, 37, and 117 m along the central California coast are presented. Data for 15 species of rockfish, Dover and rex soles, northern anchovy, and Pacific whiting show that most species tend toward a uniform distribution among the three sampled depths. Notable exceptions include bocaccio (most abundant at 13 m) and blue, yellowtail, and pygmy rockfishes (most abundant at 117 m). With the advent of persistent upwelling during May and June, pelagic juvenile rockfish tend to occur deeper in the water column than in March–April. Data about shortbelly rockfish support the view that during periods of intense upwelling (May–June) relatively small fish stay deep, presumably to avoid advection offshore. There was not a clear relationship between depth distribution of fish and depth of the thermocline.

RESUMEN

Se revee la distribución vertical de larvas y juveniles de peces nacidos en el año en la Corriente de California. Se presentan datos nuevos de estudios sinópticos con redes de arrastre conducidos a profundidades de 13, 37, y 117 m a lo largo de la costa de California central. Datos de 15 especies de rocotes (*Sebastes* spp.), lenguados como *Microstomus pacificus* y *Glyptocephalus zachirus*, anchoveta norteña (*Engraulis mordax*), y merluza del Pacífico (*Merluccius productus*) demuestran que la mayoría de las especies tienen distribución uniforme entre las tres profundidades muestreadas. Excepciones notables incluyen *Sebastes paucispinis* (más abundante a 13 m) y *S. mystinus*, *S. flavidus*, y *S. wilsoni* (más abundantes a 117 m). Debido a la persistente surgencia de aguas, los juveniles pelágicos de rocotes tienden a ocurrir a mayores profundidades en la columna de agua durante mayo y junio que en marzo y abril. Datos sobre *S. jordani* apoya la noción que los peces pequeños se mantienen a profundidad durante períodos de intensa surgencia, presumiblemente tratando de evitar transporte hacia mar abierto. No se encontró una clara relación entre la distribución por profundidad de los peces y la profundidad de la termoclina.

INTRODUCTION

Knowledge of the vertical distribution of pelagic early life stages of fish is needed to understand transport and biological processes. Fish may adapt their behavior to take advantage of vertical shears in currents that might either retain the fish in or transport them to favorable areas (Bakun 1986; Sinclair 1988). After reviewing pertinent literature, we present results on the vertical distribution of rockfish (*Sebastes* spp.) and other species from our surveys of pelagic young-of-the-year rockfish off the coast of California from Monterey to Point Reyes.

Small rockfish larvae, which are only identified to genus because diagnostic characteristics are not known for most species, have generally been found at relatively shallow depths. Ahlstrom (1959) published the most detailed study on rockfish larvae off the coast of southern and Baja California. The larvae were found mostly in the upper mixed layer and thermocline. All but 3% of the rockfish larvae were collected in strata shallower than 80 m. Moser and Boehlert (1991) obtained similar results at two stations off southern California. Both studies indicated that the depth distribution of rockfish larvae is directly related to the depth of the thermocline. Rockfish larvae were found even shallower off Oregon (Richardson and Pearcy 1977; Boehlert et al. 1985). Barnett et al. (1984) found rockfish larvae in the neuston layer off southern California; Shenker (1988) found them in the neuston layer off Oregon. The data collected off southern California indicated that larvae were more abundant in the water column than in the neuston and epibenthic layers.

Ahlstrom (1959) found Pacific whiting (*Merluccius productus*) larvae deeper than rockfish and usually within or below the thermocline. Only 5% of the whiting were caught above 43 m, whereas 56% of the rockfish larvae were taken there.

Northern anchovy (*Engraulis mordax*) larvae are found at very shallow depths. For a 1959 study, Ahlstrom caught about 48% of anchovy between the surface and 48 m; less than 1% came from deeper than 88 m. Boehlert et al. (1985) did not catch any anchovy larvae deeper than 10 m. Shenker (1988) caught anchovy larvae in the neuston layer off Oregon. Barnett et al. (1984) tended to catch more anchovy larvae in the water column than in the neuston and epibenthic layers off southern California.

Larvae of the two species of flatfish in our study differ in their depth distribution. Pearcy et al. (1977) found that almost all Dover sole (*Microstomus pacificus*) larvae occurred in the upper 600 m of water off Oregon. Best catch rates were made in the 0–50-m depth stratum, but high rates also occurred in the 100–150-m stratum. Boehlert et al. (1985) caught rex sole (*Glyptocephalus zachirus*) larvae between the surface and 30 m; the highest catches occurred between 10 and 20 m. Shenker (1988) caught rex sole larvae in the neuston layer off Oregon.

Juveniles of several species of rockfish, including splitnose (*S. diploproa*) and bocaccio (*S. paucispinis*), have been captured at the surface associated with drifting kelp (Mitchell and Hunter 1970; Boehlert 1977). Shenker (1988) captured unidentified juvenile rockfish and juvenile black (*S. melanops*), blue (*S. mystinus*), and canary (*S. pinniger*) rockfish in the neuston layer. Juveniles of many species of rockfish have been captured with midwater trawls and purse seines in the upper 100 m (Brodeur and Pearcy 1986; Kendall and Lenarz 1987, and papers reviewed by them), but the vertical distribution of these species in the upper water column has not been published. Moser and Ahlstrom (1978) found juvenile blackgill rockfish (*S. melanostomus*), and a few other species that we rarely capture in our surveys, between 200 and 250 m.

METHODS

We collected juvenile fish at night with a modified Cobb midwater trawl off the coast between Monterey (36°35′N) and Point Reyes (38°10′N). The net, which is described by Wyllie Echeverria et al. (1990), nominally has a square mouth, but acoustic measurements showed that although the height of the mouth was 14 m, the width varied from 8 m (when the center of the net was at 13-m depth) to 13.5 m (at 117-m depth).

Acoustic measurements also showed that the net was not always at targeted depths, but precision was sufficient to separate tows taken at different targeted depths. We assume here that all tows were at their targeted depths. During the survey the targeted depth was usually 37 m but was set at 13 m for shallow stations. When time and depth allowed we towed at 13 m, 37 m, and 117 m to obtain data on the vertical distribution of fish. Since we did not use an opening-closing net, some contamination by specimens from nontargeted depths was possible. The net was dropped to the targeted depth as rapidly as possible while the vessel maintained steerage, was towed for 15 minutes at about 5 km per hour, and was then retrieved as rapidly as possible while the vessel maintained steerage. We do not believe that contamination is a serious problem. We used a cod end with 9.5-mm stretched mesh width that retained only some of the largest larvae and did not retain all of the smaller juveniles encountered. We did most of the work from mid-May through June, and from late March through mid-April, between 1983 and 1990.

We standardized catches for net mouth width by dividing by the width. For each station with tows at 13, 37, and 117 m, we calculated average depth for each captured species. We calculated average depths both as simple averages of individual station averages (unweighted) and from the sums of catches made at each depth over all stations (weighted). If the fish were equally abundant at the three sampled depths, the average depth would be 55.7 m. If the fish and samples were evenly distributed between 0 and 117 m, the average depth would be 58.5 m. Thus under the even-fish-distribution assumption, the uneven depth distribution of our samples had little effect on our estimates of average depth between the surface and 117 m. However, if there were relatively high densities of fish in unsampled strata, our estimates of average depth could be biased. We tested null hypotheses that catch rates for two depths were equal by using the paired t test and the sign test (Dixon and Massey 1957).

RESULTS

Results are presented for 15 species of rockfish — bocaccio, darkblotched rockfish (*S. crameri*), bank rockfish (*S. rufus*), black rockfish, shortbelly rockfish (*S. jordani*), squarespot rockfish (*S. hopkinsi*), canary rockfish, stripetail rockfish (*S. saxicola*), chilipepper (*S. goodei*), halfbanded rockfish (*S. semicinctus*), yellowtail rockfish (*S. flavidus*), brown rockfish (*S. auriculatus*), widow rockfish (*S. entomelas*), blue rockfish, and pygmy rockfish (*S. wilsoni*); 2 species of flatfish — Dover and rex sole; Pacific whiting; and northern anchovy (table 1). We also caught Pacific and speckled sanddabs (*Citharichthys sordidus* and *C. stigmaeus*), but the depth distribution data on these two species are being used for a thesis by graduate student Keith Sakuma at San Francisco State University and are not included in this paper. We collected at least one specimen at 61 stations with tows at 13, 37, and 117 m; 83 stations with tows at 13

TABLE 1
Number of Positive Stations, Average Depth (m) and Standard Error of the Average Depth for Pelagic Young-of-the-Year Fish off Central California during May–June

		Unweighted		Weighted	
Species	Number of stations	Average depth	Standard error	Average depth	Standard error
Bocaccio	29	30.4	3.0	26.2	3.6
Darkblotched rockfish	9	33.7	11.7	24.7	5.3
Dover sole	10	39.0	11.8	28.8	9.1
Northern anchovy	9	41.8	12.2	25.0	17.8
Bank rockfish	4	52.3	26.5	15.4	12.1
Black rockfish	7	53.0	18.4	43.9	21.7
Shortbelly rockfish	43	53.6	5.0	36.2	8.2
Squarespot rockfish	27	54.7	7.6	39.4	27.6
Pacific whiting	59	54.8	3.3	27.8	9.1
Canary rockfish	20	55.2	6.2	80.3	38.3
Stripetail rockfish	11	56.9	6.5	51.1	17.6
Chilipepper	22	58.5	8.6	39.1	10.9
Halfbanded rockfish	5	60.5	17.6	40.7	32.3
Rex sole	24	63.5	7.4	42.5	6.7
Yellowtail rockfish	21	64.8	9.1	66.2	18.4
Brown rockfish	5	69.0	21.9	60.2	28.4
Widow rockfish	31	70.2	7.0	45.6	14.1
Blue rockfish	30	82.0	7.3	57.8	20.9
Pygmy rockfish	13	83.0	13.4	75.9	23.5
Average		56.7	10.8	43.5	17.1

Weighted averages are weighted by catches. Species are arranged by unweighted average depth.

and 37 m; 77 stations with tows at 37 and 117 m; and 64 stations with tows at 13 and 117 m. We captured more than 150,000 rockfish, 125,000 Pacific whiting, 1,250 northern anchovy, and 500 flatfish.

The unweighted average depth of most species was close to the average expected (55.7 m) when densities are equally distributed at the three sampled depths (table 1 and figure 1). The unweighted average over all species was 56.7 m. Weighted average depths were shallower than the unweighted averages for 17 of the 19 species. The average over species of weighted average depths was 13 m less than the unweighted average. Very large catches tended to occur at shallow depths. Weighted standard errors were about 50% greater than unweighted.

The results indicate that bocaccio were more common at shallow than at deep depths; densities of canary and halfbanded rockfish were lower at 13 m than at 37 m; and yellowtail, blue, and pygmy rockfish were most abundant at 117 m (table 2 and figure 2). Weighted 13-m densities of Pacific whiting were greater than 37-m densities, but the converse was true for unweighted densities. Catch rates of Pacific whiting appeared to be lowest at 117 m. Weighted and unweighted depth comparisons differed for widow rockfish.

There is evidence that average depth changes as the season progresses. We compared average depth in March and April with May and June for bocaccio, chilipepper, and blue, shortbelly, and widow rockfish in 1987, 1988, and 1990. Our data were insufficient to make such comparisons for other species. Unweighted average depth between the two time periods increased in all cases except for bocaccio in

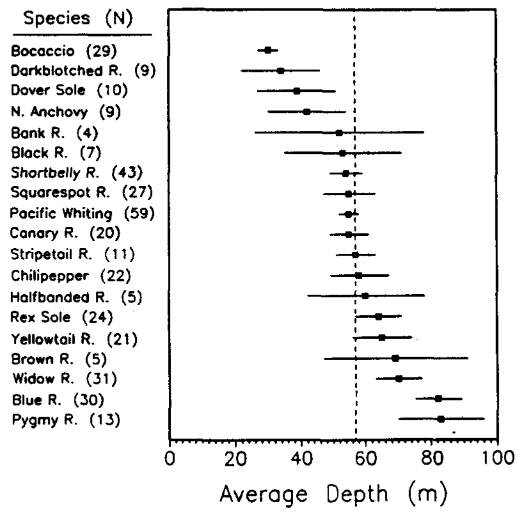

Figure 1. Unweighted average depths (*solid squares*), standard errors (*horizontal lines*), and number of stations with at least one positive tow at 13, 37, or 117 m (N) for pelagic young-of-the-year off central California during May–June. The overall average is shown as a *dashed vertical line*. (R. = rockfish)

TABLE 2
Results of Sign and Paired *t*-Tests That Catch Rates of Young-of-the-Year Fish Are Independent of Depth of Tow off Central California during May–June

	Probability of greater difference due to chance alone								
	13 and 37 m			37 and 117 m			13 and 117 m		
Species	*n*	Sign	*t*	*n*	Sign	*t*	*n*	Sign	*t*
Bocaccio	31	<0.10	>0.10	22	<0.01	<0.01	12	<0.05	<0.01
Darkblotched rockfish	12	>0.10	>0.10	5	>0.10	>0.10	6	>0.10	<0.05
Dover sole	11	>0.10	>0.10	9	>0.10	>0.10	8	>0.10	>0.10
Northern anchovy	14	>0.10	>0.10	12	>0.10	>0.10	3	>0.10	>0.10
Bank rockfish	6	>0.10	>0.10	4	>0.10	>0.10	4	>0.10	>0.10
Black rockfish	12	>0.10	<0.10	7	>0.10	>0.10	4	>0.10	>0.10
Shortbelly rockfish	63	>0.10	>0.10	53	>0.10	<0.10	40	>0.10	>0.10
Squarespot rockfish	26	>0.10	>0.10	30	>0.10	>0.10	24	>0.10	>0.10
Pacific whiting	73	<0.10	<0.01	68	<0.05	>0.10	58	>0.10	<0.05
Canary rockfish	19	<0.05	<0.05	16	<0.10	>0.10	6	>0.10	>0.10
Stripetail rockfish	14	>0.10	>0.10	11	>0.10	>0.10	6	>0.10	>0.10
Chilipepper	27	>0.10	>0.10	29	>0.10	>0.10	14	>0.10	>0.10
Halfbanded rockfish	9	<0.05	<0.10	6	>0.10	>0.10	3	>0.10	>0.10
Rex sole	26	>0.10	>0.10	30	>0.10	>0.10	24	>0.10	>0.10
Yellowtail rockfish	29	>0.10	>0.10	23	<0.10	<0.10	15	>0.10	>0.10
Brown rockfish	5	>0.10	>0.10	11	>0.10	>0.10	—	—	—
Widow rockfish	35	>0.10	>0.10	32	<0.10	<0.05	31	<0.10	<0.10
Blue rockfish	33	>0.10	>0.10	36	>0.10	<0.10	32	<0.05	<0.10
Pygmy rockfish	6	>0.10	>0.10	13	<0.10	<0.05	12	>0.10	>0.10

Results with probabilities less than 0.10 are underlined. *n* is the number of positive stations. Cases with fewer than three positive stations are not included.

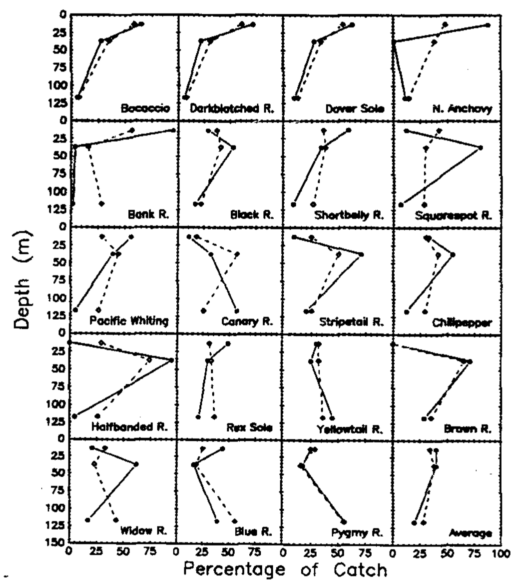

Figure 2. Weighted (*solid circles and lines*) and unweighted (*open diamonds and dashed lines*) depth distributions for pelagic young-of-the-year fish off central California during May–June. (R. = rockfish)

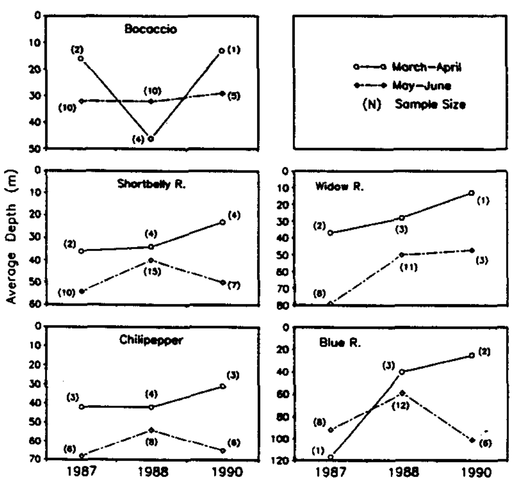

Figure 3. Unweighted average depths for pelagic young-of-the-year bocaccio, chilipepper, and shortbelly, widow, and blue rockfish off central California during March–April and May–June. Sample size is the number of stations with at least one positive tow at 13, 37, or 117 m. (R. = rockfish)

1988 and blue rockfish in 1987 (figure 3). Catches of these five species at 117 m were typically quite low in March–April. Similar results were obtained for weighted average depths. The unweighted overall average depth increased 19 m between the two periods, and weighted average increased 9 m.

Data were also available to compare size compositions of shortbelly rockfish in paired 13- and 37-m tows from 1987–90, and from unpaired 13- and 37-

m tows in 1987 and 1988. During May–June, small shortbelly rockfish (<50 mm) tended to be deeper than larger fish (figure 4). This was true both when the data were unweighted, as in the figure, or weighted by catch.

DISCUSSION

The vertical distribution of late larval and juvenile rockfish that we found in March–April is similar to that of rockfish larvae (Ahlstrom 1959; Richardson and Pearcy 1977; Boehlert et al. 1985; Moser and Boehlert 1991). Our catches were relatively low in tows deeper than 37 m. By May–June the average depth of capture increased by 9–19 m, and catch rates for 117-m tows were seldom significantly less than rates for shallow tows (table 2 and figure 2). Also, reported distributions of larval northern anchovy (Ahlstrom 1959; Boehlert et al. 1985) and rex sole (Boehlert et al. 1985) were shallower than we found for young-of-the-year of the same species in May–June. In contrast, our May–June catch rates for juvenile Pacific whiting indicated greater relative abundance at shallow depths than was reported for larvae by Ahlstrom (1959).

Perhaps the different pattern for Pacific whiting is related to their habit of spawning at depths of 130–500 m in midwater, up to 400 km off the coast (Bailey et al. 1982). Except for northern anchovy, the other species spawn relatively close to shore. Northern anchovy spawn at midwater (sometimes far offshore) in fairly shallow depths. Bailey et al. (1982) present data showing that large catches of Pacific whiting eggs and larvae often occur in areas where northward geostrophic flow at 200 m would tend to advect the fish onshore.

The young-of-the-year fish in our study inhabit a greater depth range in the water column than other investigators found for earlier life stages. The larger fish that characterize our samples may be adapted to searching the water column for optimal feeding conditions, low predation rates, or favorable currents, while the smaller fish tend to occupy depths that, on the average, are favorable. We found that, even though shortbelly rockfish tend to be closer to the surface in March–April than in May–June, the smaller fish were often deeper than the larger fish in May–June. Offshore transport of surface waters due to upwelling is more prevalent in May–June than in March–April. Perhaps the smaller fish are adapted to avoid the surface waters, and thus reduce the risk of offshore advection, during May–June.

We often found bocaccio at very shallow depths in May–June. Bocaccio grow very rapidly compared to other rockfish and can reach 20 cm in their first year (Phillips 1964). In order to realize their rapid growth, very young bocaccio may need to remain in the upper water column to encounter higher temperatures and food densities. The time spent in the upper water column may subject them to increased offshore advection. Other studies indicate that such advection may occur, because larvae of bocaccio are found farther offshore than the more abundant larvae of shortbelly rockfish (MacGregor 1986; Moser and Boehlert 1991).

Depth distributions were often shallower when observations were weighted by catches than when not weighted (tables 1 and 2 and figure 2). This was because very large catches tended to occur at shallow depths. It is possible that the fish school when at shallow depths, or avoid shallow depths unless con-

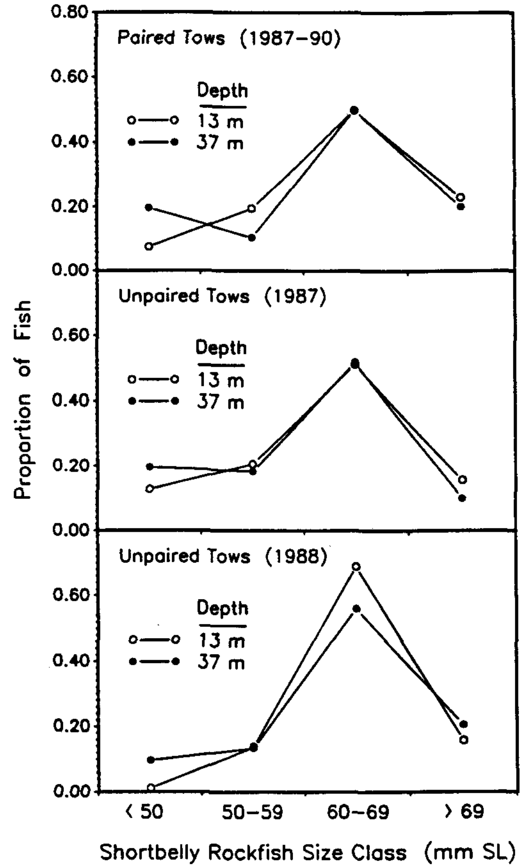

Figure 4. Size class compositions unweighted by catch for pelagic young-of-the-year shortbelly rockfish off central California during May–June.

ditions are particularly advantageous. Attempts to relate depth distributions at individual stations to oceanographic conditions have not produced convincing results. We did not find a clear relationship between depth distribution and the depth of the thermocline, as Ahlstrom (1959) and Moser and Boehlert (1991) found for rockfish larvae. However, large catches of juveniles often occur near to and offshore of upwelling fronts. We will continue to explore these relationships.

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