

ROCKFISH (*SEBASTES SPP.*) RECRUITMENT
TO SOFT BOTTOM HABITATS IN MONTEREY BAY, CA

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ABSTRACT

A major problem in managing rockfish resources is the difficulty in predicting year class strength of adult populations because of high variability in recruitment. Understanding the processes that affect rockfish recruitment, and thus subsequent year class strength, would greatly benefit management of this group of fishes. The purpose of this study was to describe recruitment of juvenile rockfish to soft bottom habitats in Monterey Bay during 1995.

A number of ecologically and economically important species recruited to the sampling area. This juvenile assemblage was dominated by *Sebastes elongatus*, *S. saxicola* and *S. levis*. All three of these species showed increasing densities and sizes with depth. Recruitment processes were closely associated with oceanic conditions, specifically upwelling and sea surface temperature. Peak settlement occurred subsequent to upwelling. Once settled, YOY rockfish exhibited ontogenetic movements towards adult depths. Timing of back-calculated birthdates corresponded with periods of increased upwelling. Growth rates ranged from 0.17 to 0.35 mm/d, with growth declining during months of highest sea surface temperature. Significant emigration out of the sampling area occurred during the onset of winter storms.

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INTRODUCTION

At least sixty-two species of rockfishes (*Sebastes spp.*) inhabit waters off the Pacific Coast of North America (Eschmeyer and Herald 1983). Rockfishes range from intertidal depths to over 850 m. Individual species often are associated with specific substrata that are remarkably diverse (Pearcy et al. 1989). A few are midwater species, whereas most are more closely associated with benthic habitats. Rockfishes are found within nearshore kelp communities, on rocky outcrops in deep water submarine canyons and along the continental slope, on low relief cobble beds and on sand and mud bottoms (Miller and Lea 1972, Mearns et al. 1980, Eschmeyer and Herald 1983, Love 1991).

The reproductive characteristics and early life history of rockfishes have strong implications for population dynamics of adults. Fertilization occurs internally, embryos develop within paired ovaries, and larvae are released into the water column 1-2 months after fertilization (Moser 1967, Boehlert and Yoklavich 1983, Echeverria 1987, Eldridge et al. 1991). Larval rockfishes are released in almost every month of the year, but the timing and duration of parturition differs among species (Echeverria 1987, Kendall and Lenarz 1987, Love et al. 1990, Moser and Boehlert 1991).

Rockfish larvae develop into pelagic juveniles that occur in the upper 100 m of the water column for the first several months following parturition (Larson et al. 1994, Lenarz et al 1991). Pelagic juveniles settle out of the water column and recruit to benthic habitats (Moser and Ahlstrom 1978, Echeverria et al. 1990, Moser and Boehlert 1991, Reilly et. al. 1992, Larson et al. 1994). In this study the term recruitment is defined as settlement of pelagic juvenile rockfish to benthic habitats.

Juvenile rockfish might gain competitive advantage and avoid predation by settling in areas with algae, sea grasses or rocky outcroppings that provide shelter and

protection (Carr 1983, Haldorson and Richards 1987, Carr 1991, Matthews 1990).

However, recruitment of rockfish to open, soft bottom areas has been cited in a number of studies. Mearns et al. (1980) recorded large numbers of juvenile rockfish, dominated by *S. saxicola*, *S. dalli* and *S. semicinctus*, settling onto soft, sandy bottoms in southern California. Boehlert (1977) reported migration of juvenile *S. diploproa* from offshore surface waters to nearshore soft bottom areas within southern California. *S. alutus* recruits to sand and cobble substrata in the coastal fjords of southeastern Alaska (Carlson and Haight 1976). In addition, large numbers of young-of-the-year rockfish dominated by *S. saxicola* and *S. semicinctus* have been caught in otter trawls on soft bottom areas in southern Monterey Bay (G.M. Cailliet, Moss Landing Marine Labs, unpublished data). Spatial patterns of juvenile rockfish over soft bottom habitats in Monterey Bay have not been documented. Approximately 80% of Monterey Bay is shallower than 100 m and most of this area is soft bottom habitat (Breaker and Broenkow 1994). This habitat may be important for the recruitment of selected rockfish species.

Once recruited, juvenile rockfish gradually move to adult habitats, joining adult populations (Love et al. 1991). As adults, many rockfish species are important in both commercial and sport fisheries, but their life histories make management difficult. Rockfish species are highly sensitive to fishing pressure because they mature relatively late (e.g. 4-10 yr), have reduced growth rates, large body size and long life span (Adams 1980). Because different rockfish species may co-exist in a single habitat, many species that are not exploited directly are nonetheless vulnerable to harvest because of their association with more valuable species (Matthews and Richards 1991). Current management strategies based on short-lived fishes or single-species fisheries may not be adequate to manage multi-species fisheries or sustain populations of longer-lived species (Richardson and Laroche 1979, Gunderson 1984, Leaman and Nagtegaal 1987, Leaman

1991.) Research on the life history of individual species is needed to more effectively manage the rockfish fishery as a whole.

A major problem in managing rockfish resources is the difficulty in predicting year class strength of adult populations (Mearns et al. 1980). Studying the magnitude and timing of recruitment of benthic young-of-the-year (YOY) fishes, and the processes that affect their survival, is useful for understanding and predicting the relative size of the year class when it enters the fishery. For many fish species, egg and larval abundances have little predictive capability for the magnitude of recruitment to fisheries (Bradford 1992). Differences in annual spawning rates were too small to account for variation in larval survival of yellowtail rockfish, *S. flavidus* (Eldridge and Jarvis 1995). Furthermore, the abundance of pelagic juvenile rockfishes varies tremendously from year to year despite the dominance of *Sebastes spp.* larvae in plankton samples off central California (Hobson et al. 1986, Echeverria et al. 1990, Moser and Boehlert 1991, Larson et al. 1994, Eldridge 1994). The abundance of older, pelagic juveniles, however, have been significantly correlated with abundances of settled juveniles indicating decreased mortality during these stages (Ralston and Howard 1995, Adams and Howard 1996). Thus, although larval abundances do not correlate well with adult populations, a closer relationship may exist with juveniles that have survived through the pelagic stages.

Because rockfish are pelagic as larvae and early juveniles, ocean conditions, such as upwelling, directly affect growth, survival, and distribution. Seasonal and yearly changes in these environmental conditions are thought to influence variations in yearly survival of young rockfishes (Mearns et al. 1980, Hobson et al. 1986, Larson et al. 1994, Ralston and Howard 1995). Upwelling centers are located just north of Monterey Bay at Point Año Nuevo and south of Monterey Bay at Point Sur (Tracy 1990, Rosenfeld et al. 1994). Upwelling is generally characterized by high nutrient concentrations, low

temperatures, and offshore transport, and has been suggested to benefit larval and juvenile rockfish in a number of ways (Ainley et al. 1993, Larson et al. 1994, Yoklavich et al. 1996).

Larson et al. (1994) described high abundances of young juvenile rockfish offshore, within and just beyond upwelling fronts, with abundances decreasing farther offshore and further inshore. When offshore advection due to upwelling is strong, abundances of juvenile rockfish are lower in the stomachs of nearshore predators (Ainley et al. 1993). During El Niño years when upwelling and offshore advection are low, juvenile rockfish abundances decrease, perhaps due to increased mortality on the larval stage (Yoklavich et al. 1996). These findings all indicate that upwelling acts to transport larval and early pelagic juveniles offshore.

The influence of environmental conditions on interannual variation in juvenile rockfish abundance can be evaluated by comparing ocean conditions with the distribution of birthdates for juveniles that have survived through the pelagic stages. Birthdate distributions have been estimated by subtracting age, as determined by daily growth increments in otoliths, from the known date of collection (Boehlert and Yoklavich 1985, Campana and Neilson 1985, Yoklavich and Boehlert 1987, Yoklavich and Bailey 1990, Woodbury and Ralston 1991). These birthdate distributions for surviving juveniles can then be compared with the full range of spawning as predicted from the literature to determine periods of increased or decreased survival. Corresponding environmental conditions can be reviewed for possible influence on survival and growth of early stage rockfishes.

The purpose of this study was to monitor recruitment of rockfishes to soft bottom habitats within Monterey Bay. The first goal was to describe spatial and temporal patterns of recruitment. Specifically, I : (1) determined species composition of juvenile

rockfish in soft bottom areas; (2) determined if there was a difference in juvenile rockfish density and size among depths and between the north and south part of Monterey Bay; (3) evaluated the association of the three dominant species with sediment types from historic maps; and (4) assessed the timing and magnitude of rockfish recruitment to soft bottom habitats during 1995. The second goal of the study was to examine growth and survival of dominant species. Specifically, I: (5) determined age and growth of dominant species during the benthic juvenile stage; and (6) interpreted birthdate distributions of juvenile rockfish using corresponding oceanographic conditions during the parturition period.

MATERIALS AND METHODS

Sampling Area

Monterey Bay is located along the central California coast between 36.5° N and 37° N (Fig. 1). The bay is symmetrical in shape measuring 37 km long, from north to south, and covering approximately 550 km². The Monterey submarine canyon divides Monterey Bay more or less evenly into northern and southern sectors. The northern half of the bay is shallower and has a gentler slope than the southern half. Approximately 80% of the bay is shallower than 100 m and most of this area is soft bottom habitat (Breaker and Broenkow 1994). Within the soft bottom areas, sediments in less than 10 m depths are characterized as coarse to fine sand with grain size becoming finer with depth. At 100 m, sediments are mostly silt and clay (Galliher 1932).

Collections

The R/V Ed Ricketts was used to sample fishes on soft bottoms within Monterey Bay. The primary gear was an otter trawl with a bridle length of 22.9 m, a mouth width of 8.3 m, a body mesh size of 3.8 cm, and a cod-end mesh size of 1.0 cm. A 4:1 wire ratio was used for all tows to ensure that the trawl was consistently fishing on the bottom. The duration of each tow was approximately 20 minutes. Boat speed was kept between 1-2 knots. Sampling sites were located within three depth ranges in Monterey Bay: 40-60 m, 60-80 m, and 80-100 m. To maximize trawling time, all of one day's sampling was conducted in either the north or the south bay, relative to the submarine canyon. A combination of random and fixed sites was used to distinguish both spatial and temporal variations (Fig. 1). On each sampling day I attempted to complete a total of six tows, at one fixed and one random station in each of the depth ranges. When it was not possible

to complete all six tows, priority was given to fixed stations. Sampling began in March 1995 and continued weekly, as weather permitted, through February 1996.

All *Sebastes spp.* specimens were separated from the catch, brought ashore and frozen. In the laboratory, standard length (SL) was measured to the nearest millimeter, and all specimens were identified to species. Identifications were determined using color patterns and meristic counts (Laidig and Adams, 1991). Individuals were kept frozen for otolith removal.

Spatial Distribution

Catch data from random stations were used to describe spatial distribution of YOY rockfishes in Monterey Bay. A detailed analysis was carried out for each of the three dominant species, *S. saxicola*, *S. elongatus* and *S. levis*. Catch from each tow was considered one sample. Catch per unit effort (cpue; fish/ha) at each station was plotted using a geographic information system (GIS) software program, MapGrafix (ComGraphix Inc, © 1994). Size data is reported as mean standard length \pm one standard error.

All tows were standardized by area swept (distance traveled x net width) to provide comparable density estimates. Densities are reported as mean \pm standard error. Because of the large wire to depth ratio, it is possible that the trawl was fishing on the bottom before all of the wire was out, and that it continued to fish for a small distance after beginning to bring the wire back in. I had no method of determining either the exact time that the net reached the bottom or the exact time it stopped fishing. Therefore, in order to keep distance estimates consistent between tows, the latitude and longitude coordinates, taken just as the appropriate amount of wire had been let out, and just before bringing the wire back in, were used as estimates of the beginning and ending of each

tow. All efforts were made to keep the boat traveling in a straight line during tows. The distance between the start and end coordinates was then used as an estimate of distance traveled. A net width of 8.3 m was multiplied by the distance traveled to determine the area swept of each individual tow.

Net width was measured with the net lying flat on land. In reality, the net opening is probably narrower when fishing, due to the vertical separation by the otter boards and water pressure, as it is towed through the water (Sissenwine and Bowman 1978, Byrne et al. 1981). This would lead to an over-estimate of net width. However, over-estimating width leads to a larger estimate of area swept, and thus a more conservative measure of fish density. I was unable to account for differences in the way the net fished due to currents or swell. These parameters factor into the inherent variability in trawl sampling and fish distribution.

Resampling Stats™ (J. Simon, © 1992), a computer program based on randomization and "bootstrapping", was used as a nonparametric two-way analysis of variance to determine if there were significant differences in densities with depth and between the north and south bay. A nonparametric analysis was necessary because sample sizes were unequal and data were not normal. Post hoc tests of differences in means between sampling strata were done using the Games and Howell modification of Tukey's pairwise comparison (Day and Quinn 1989). This method accounts for unequal variances and unequal sample sizes. Standard lengths of fishes from the random stations were compared among depth strata using Kolmogorov-Smirnov tests (Zar 1984).

Additional analyses were used to describe patterns of rockfish distribution. A standardized Morisita's Index (Krebs 1989) was used to describe dispersion patterns. This index ranks the distribution of a given species from -1 to 1, with 0 indicating random dispersion, positive numbers indicating clumped dispersion, and negative numbers

indicating uniform dispersion. The statistical significance of the Morisita's Index was determined using methods described in Elliott (1971). Each of the three dominant species was analyzed separately.

A historical chart of general sediment types in Monterey Bay was obtained from Galliher (1932). This chart was digitized into MapGrafix and visually compared with densities of juvenile rockfishes caught during the present study.

Oceanographic Conditions

Wind data can be used to compute offshore Ekman transport due to wind stress (Bakun et al. 1974). The Pacific Fisheries Environmental Group of NOAA/NMFS provided upwelling indices based on wind velocity recorded at 36° N, off central California. Sea surface temperature (SST) data were collected at a buoy station near Monterey Bay (M1: 36° 45.25' N, 122° 01.10' W) and obtained from the Monterey Bay Aquarium Research Institute

Sea surface temperature and offshore Ekman transport were graphically compared with timing and magnitude of recruitment to identify possible influences of transport on recruitment. Specifically, I wanted to determine whether offshore transport during upwelling and onshore transport during periods of relaxed upwelling might be related to rockfish recruitment in nearshore habitats. Oceanographic data were graphically compared to birthdate distributions to identify possible influences of ocean condition on survival of recruits.

Temporal Distribution

Catch data from fixed stations were used to describe timing of recruitment and changes in abundance for juvenile rockfish over time. Frequencies of cpue grouped by

month for each depth range, and standard length grouped by 10 mm increments, were compared graphically versus time for *S. saxicola*, *S. elongatus* and *S. levis*. Size distributions were graphed by month to describe changes over time. Size ranges of benthic juvenile rockfishes also were compared with size ranges of conspecific pelagic juvenile rockfishes collected during previous years by R. Larson (California State University at San Francisco, pers. comm.) and the Tiburon Lab of NMFS.

Ageing

Ages were determined for subsamples of the three most abundant species, *S. elongatus*, *S. saxicola* and *S. levis*, using techniques described by Stevenson and Campana (1992). Subsamples represented fishes from all months of sampling and the entire size range. Sagittal otoliths were removed and stored in 80 percent ethanol buffered with marble chips.

The frontal plane of each otolith, mounted in resin, was ground to the nucleus using 320, 800 and 1200 grit aluminum carbide wet-dry grinding paper on an Ecomet III grinding wheel. The otolith was then mounted, exposed side down, onto a microscope slide using Cytoseal adhesive medium, and ground again until a thin frontal section of otolith remained on the slide (Stevenson and Campana 1992). Further polishing using 1200 grit aluminum carbide wet-dry paper was used to remove abrasions.

Daily growth rings were enumerated under oil immersion at 1000x magnification with a compound microscope. Counts were made along the longest and clearest path from the nucleus to the otolith edge. The otoliths were read twice, with results from the first read unknown during the second read. Each section was ranked from 0-4 for discernability of rings. A section with distinct increments from the edge of the otolith to the very core was ranked as a 4. Only otoliths with ranks of 3 or better were used for

growth analysis. Additional age data for larval *S. saxicola* were provided by the Tiburon Lab of the National Marine Fisheries Service (Laidig et al. 1996).

Ageing precision was determined using Average Percent Error (APE; Beamish and Fournier 1981), Coefficient of Variation (CV) and Index of Precision (D; Chang 1982). APE is the average absolute deviation from the mean age estimate per fish. CV uses standard deviation as a statistical test of reproducibility of age estimates between reads. D uses CV to determine the percent error contributed by each observation.

Fish length and age data were fit to linear regression, Gompertz, von Bertalanffy and logistic growth models using a statistical computer software program, Systat (Systat, Inc. copyright © 1992). The linear regression was used to calculate a growth rate in mm/d for each species. The remaining models were forced through a given size at parturition (4.5 mm for *S. elongatus*, 5 mm for *S. saxicola* and *S. levis*) as reported by Laidig et al. 1991. The most appropriate growth model, as defined by the lowest mean square error, was used to determine ages for all individuals sampled within the size range of aged fishes, for each of the three species. This age was subtracted from the date of capture for each individual specimen to provide a distribution of birthdates for the surviving juveniles. The software program Jandel TableCurve (AISN Software © 1989), was used to estimate the best fit curve given unlimited parameters for *S. saxicola*. This curve was then used to back-calculate birthdates for *S. saxicola* to determine if the birthdate distributions differed when using the TableCurve and Gompertz curves.

RESULTS

General

A total of 4,193 fishes from fifteen species of rockfish was caught in 197 tows completed during 42 cruises (Figure 1). From the 26 cruises in the north half of Monterey Bay, 2,160 rockfishes were caught in 117 tows. In the southern Bay, 2,013 rockfishes were caught in 80 tows completed during 16 cruises.

Combined total catch and catch/tow of rockfishes for random stations was similar between the north and south stations (Table 1). Catch/tow at fixed stations was much higher at the south stations than at north stations, equaling 27.1 and 9.9, respectively. Total catches and catch/tow increased with depth at fixed and random stations in the south and at the fixed stations in the north. This trend was not seen in the random north stations because of the high catches from the intermediate depth range.

Three species, *Sebastes elongatus*, *S. saxicola* and *S. levis* dominated the samples, accounting for over 90% of the total rockfish catch (Table 2). *S. elongatus* was the most abundant species with a total catch of 1,810 individuals. Total catches from combined fixed and random stations for *S. elongatus* were nearly three times higher north of the submarine canyon. Standard length of *S. elongatus* ranged from 30 - 80 mm with a mean length of 41.2 ± 1.0 . *S. saxicola* was the next most abundant species with a total catch of 1,736 individuals. Total catches were more than twice as high south of the submarine canyon. The size range for *S. saxicola* was broader than that for *S. elongatus*, and ranged from 32-116 mm with a mean standard length of 65.8 ± 1.6 mm. *S. levis*, the third most abundant species, accounted for 7% (289 individuals) of the total catch. Total catch for *S. levis* was evenly distributed between the northern and southern Monterey Bay samples.

The mean standard length of *S. levis* was comparable to that of *S. saxicola*, with lengths from 49-104 mm, and mean size of 66.3 ± 3.9 mm.

Each remaining rockfish species accounted for less than 5% of the total catch of rockfish. *S. goodei* and *S. semicinctus* were the next most abundant species, with catches of 182 and 83 individuals, respectively. Mean size was 92.5 ± 6.9 mm for *S. goodei* and 85.1 ± 9.3 mm for *S. semicinctus*. Thirty-seven and thirty-one individuals were caught of *S. crameri* and *S. diploproa*, respectively. Less than ten individuals were caught of *S. wilsoni*, *S. paucispinis*, *S. miniatus*, *S. hopkinsi*, *S. pinniger*, *S. jordani*, *S. eos* and *S. entomelas*.

Spatial Distribution

S. elongatus

Density of *S. elongatus* ranged from 0-40 fish/ha, with the exception of a single sample of 144 fish/ha, and increased significantly with increasing depth ($p = 0.04$; Fig. 2). Highest densities were found in the south half of Monterey Bay from 80-100 m and in the north half from 60-80 m. Catches within the southern deep stratum, with a mean of 38.8 ± 17.9 fish/ha, were higher than densities of all other strata except the northern, intermediate depth stratum that had a mean of 25.1 ± 5.59 fish/ha. Catches were lower in the 40-60 m stratum which had mean densities of 4.78 ± 3.86 and 2.19 ± 2.19 fish/ha. No significant difference ($p > 0.05$) was found between the north and south parts of the Bay, and no significant differences were found in posthoc pairwise comparisons of individual sampling strata. The standardized Morisita's Index (I_d) indicated a clumped distribution ($I_d = 0.54$, $n = 40$, $p < 0.05$).

Standard lengths distributions of *S. elongatus* were significantly different between depth strata ($p < 0.05$) and mean standard length increased with depth (Fig. 3, Table 3). In

the shallow strata, fish lengths ranged from 32-51 mm with a mean of 40 ± 0.21 mm. In the intermediate depth range, the majority of fish ranged from 31-54 mm, with small numbers of fish as large as 55 mm, and an overall mean of 42 ± 0.11 mm. In the 80-100 m depth range, the range of lengths extended from 30-85 mm, but the mean standard length remained at 42 ± 0.45 mm. Only one sample had a mean length greater than 50 mm. This sample was collected in December at 100 m water depth. Overall, the size range of *S. elongatus* was narrower than either *S. saxicola* or *S. levis*.

Mapping densities of *S. elongatus* with historic bottom typing suggests highest densities of *S. elongatus* were present along the interface between fine sand (grain size 0.0625-0.125 mm) and clay sediments (grain size 0.005-0.0625 mm; Fig. 2). High densities were also associated with two specific sites in southern Monterey Bay.

S. saxicola

Although total catch of *S. saxicola* was slightly lower than *S. elongatus*, density was highest for this species. *S. saxicola* densities ranged from 0 to 90 fish/ha, with the peak densities over twice the magnitude of *S. elongatus* (Fig. 4). A significant increase in density occurred both with increasing depth ($p = 0.008$) and in the south half of Monterey Bay ($p = 0.001$). Mean densities at 60-80 m and 80-100 m in the south half of the bay, at 21.4 ± 8.57 fish/ha and 28.5 ± 7.08 fish/ha respectively, were higher than all other strata. All samples with densities higher than 40 fish/ha in the north bay fell close to the 100 m isobath. Again, catches were lowest between 40-60 m, with mean densities of 3.51 ± 2.68 and 1.38 ± 0.71 fish/ha, respectively. The only significant difference occurred between the south 60-80 m stratum and the north 40-60 m stratum. The Standardized Morisita's Index indicated a clumped distribution ($I_d = 0.51$, $n = 81$, $p < 0.05$).

Standard lengths of *S. saxicola* individuals increased significantly with depth

($p < 0.05$; Fig. 5, Table 3). All specimens of *S. saxicola* within the shallow depth strata were measured between 32 and 88 mm in length with a mean of 50 ± 1.14 mm. Maximum length increased to 90 mm and the mean length increased to 62 ± 0.50 mm within the intermediate depth range. The broadest size range, 36 to 116 mm standard length, and the greatest mean standard length, 74 ± 0.71 mm, occurred within the deepest depth strata. In both the north and south halves of the bay, all samples of fish with mean standard length greater than 70 mm were collected along the 100 m isobath.

Similar to *S. elongatus*, higher densities of *S. saxicola* occurred at the interface between fine sand and silty clay sediments (Fig. 4). High densities also were associated with two specific sites in southern Monterey Bay.

S. levis.

Generally, densities of *S. levis* were lower than those for either *S. saxicola* or *S. elongatus* (Fig. 6). Densities ranged from 0-24 fish/ha, with mean densities for each sampling strata ranging from 0.16 ± 0.02 to 6.07 ± 3.41 fish/ha. There was a significant difference in density between depths ($p=0.008$), with higher mean densities at the 60-80 m strata within each direction. No significant differences were found with posthoc pairwise comparisons of strata means. Standardized Morisita's Index for *S. levis* indicated a clumped distribution ($I_D = 0.54$, $n = 77$, $p < 0.05$), similar to that of *S. elongatus* and *S. saxicola*.

In order to increase the sample size, standard lengths of *S. levis* from both the fixed stations and random stations were used to evaluate size by depth strata. Standard length was significantly greater at 80-100 m than at either 40-60 m ($p = 0.002$) or 60-80 m ($p = 0.03$; Table 3). No differences in standard length were evident between depth strata when only the fish from the random stations were used, possibly due to the smaller

sample size. Fish ranged from 52 to 76 mm in length at the shallow strata, with a mean of 64 ± 1.34 mm (Fig. 7). At intermediate depths, standard lengths ranged from 49-85 mm, with a mean size of 65 ± 0.59 mm. In deep waters the proportion of fish 50-70 mm long decreased, while the proportion over 80 mm increased. Lengths ranged from 53-104 mm with a mean of 70 ± 1.20 mm. All samples with mean standard lengths greater than 80 mm were located in water depths of 100 m.

High densities of *S. levis* occurred at the interface between fine sand and silty clay or close to 100 m water depths (Fig. 6).

Oceanographic Conditions

High offshore transport and low SST corroborate the occurrence of upwelling during 1995 (Fig. 8). Upwelling occurred at intervals between April and July 1995 off central California. SST dropped from approximately 13 °C in March to 10 °C at the end of April, indicating the onset of upwelling. At the end of May, into the beginning of June SST dropped again, remaining below 11° C from June 5-17. SST generally increased through July as summer progressed, but a sudden drop to a low of 11.78 °C occurred in mid-July. For a period of seven days, from August 30 - September 6, temperatures dropped to approximately 12 °C. These periods of lowered SST were associated with increased offshore transport, and can thus be characterized as upwelling.

SST generally remained above 13 °C from August through November. During this period, offshore transport declined. Temperatures peaked in September, reaching as high as 15.5 °C. At the same time offshore transport ceased, and periods of onshore transport were evident. This time period can be described as the conclusion of the upwelling season.

Temporal Distribution

S. elongatus

A total of 634 individuals of *S. elongatus* was caught at fixed sampling stations and mean densities per stratum ranged from 0 to 67 fish/ha. *S. elongatus* appeared in samples beginning in late August (Fig. 9). *S. elongatus* recruited to all strata at the same time, except at the shallow station in the south. No individuals of *S. elongatus* were caught at the shallow south station and catches were always less than 10 fish/ha at the shallow north station. First appearance of *S. elongatus* occurred following a long period of high SST, corresponding with a period of relaxation of upwelling (Fig. 9).

Densities of *S. elongatus* peaked in September and October. From August through October, densities ranged from 9.2 to 66.8 fish/ha at the 60-80 m stations, peaking in September. In November and December all catches were less than 2.7 fish/ha and no individuals of *S. elongatus* were caught at these stations in January or February. Mean densities were higher at the 80-100 m stations, with catches ranging from 7.0 to 66.9 fish/ha, and remained high through the first half of November. Catches at the 80-100 m stations peaked in October, one month later than at the 60-80 m stations. *S. elongatus* were still caught at the deep stations during December and January, but densities were below 10.0 fish/ha. No individuals of *S. elongatus* were caught in February.

The modal, minimum and maximum standard lengths for *S. elongatus* increased steadily from August to January (Fig. 10). In August *S. elongatus* ranged from 30 to 50 mm with a mean standard length of 38 ± 0.22 mm. By November the range shifted to 35-55 mm with a mean of 44 ± 0.32 mm. In December and January all *S. elongatus* were between 40 and 55 mm and the mean standard length had increased to 48 ± 0.61 mm.

S. saxicola

The total number of *S. saxicola* caught at fixed stations was 897, with individual catches ranging from 0 to 140 fish/ha. *S. saxicola* was first caught in March, but did not appear at the 40-60 m stations until June (Fig. 11). Standard lengths of fish caught at these stations during June ranged between 30 and 40 mm. Modal standard lengths at this depth increased somewhat through October, but densities remained low with only two samples containing densities higher than 10 fish/ha. No *S. saxicola* were caught at the shallow stations after October. *S. saxicola* was caught at the 60-80 m and 80-100 m stations beginning in March with smaller fish appearing in June. Densities at the 60-80 m stations peaked in August and then gradually declined through January. Density at the 80-100 m stations peaked in October, two months later than at the shallower stations. Another peak was evident in January, but was associated with high error.

From April through May, all fish were between 50 and 80 mm standard length (Fig. 12). In mid-June, during a period of intense upwelling, a group of *S. saxicola* ranging from 30 to 40 mm standard length appeared in the catches. This group of fish will be referred to as a second cohort. Catches of the first cohort continued to increase in July and August, declining in September and October, and not occurring in November. Fish in the second cohort were caught in low numbers through July, but increased in abundance beginning in August and September. Densities peaked in October, but started to decline in November. *S. saxicola* individuals were still present in samples through January and February.

S. levis

A total of 148 *S. levis*, approximately half of the combined total catch for *S. levis*, was caught at fixed stations in Monterey Bay, with densities ranging from 0-19.7 fish/ha.

One individual of *S. levis* was caught in June, and two were caught in July. Large numbers of *S. levis* did not appear in catches until early August, but they remained through February (Fig. 13). Only one *S. levis* was caught at the shallow fixed stations (caught in October). At the 60-80 m stations, the majority of *S. levis* individuals were caught between August and November, with only 6 individuals caught after November. Densities in this depth stratum peaked in September, remained high through October and then declined considerably in November. *S. levis* did not appear in the catches at the deep stations until September, but peaked in December and was still present through February. Highest density switched from the 60-80 m stations between August and October to the 80-100 m stations from November through February.

In August all individuals of *S. levis* ranged between 40 and 60 mm standard length with a mean of 56 ± 0.64 mm (Fig. 14). Catches increased in September and October with standard lengths increasing to 50-70 mm and the mean increased to 64 ± 0.58 mm. Densities dropped beginning in November. Only 12 fish were caught at fixed stations after December, all of which were larger than 70 mm.

All three species, *S. elongatus*, *S. saxicola*, and *S. levis*, increased in abundance simultaneously, with peak densities in September and October. This time period corresponded to a period of relaxed upwelling (Fig. 8).

Ageing

S. elongatus

Otoliths were removed from 181 individuals of *S. elongatus*. A subsample of eighty-four otoliths was sectioned and aged. This subsample included some of the smallest and largest individuals of *S. elongatus*. Thirty-nine sections were ranked as 3+ or better, and used to describe the growth of YOY *S. elongatus*. This sample represents

fish between 33-51 mm in length, with ages ranging from 67 to 169 days. Average percent error (APE) between age estimates for *S. elongatus* was 3.55. The coefficient of variation (CV) and index of precision (D) between replicate ages of *S. elongatus* were 5.02 and 3.55 days, respectively, indicating high precision and reproducibility of age estimates.

Growth of *S. elongatus* after recruitment, as determined by the linear regression, was estimated at 0.17 mm/day (Table 4; Fig. 15). A Gompertz growth function best described the growth curve. The resulting growth curve predicts an age of approximately -30 days at a size of 0 mm, therefore estimating parturition at approximately 30 days following fertilization. Using the smallest *S. elongatus* individuals caught, the initial age at recruitment was approximately 60 days following parturition. From the Gompertz model, the initial age at recruitment was at 75 days following parturition. The growth curve begins to slow at approximately 125 days.

S. saxicola

Otoliths were removed from 169 individuals of *S. saxicola*. Out of 104 prepared sections, 35 were ranked as "3" or higher and used to determine growth of YOY *S. saxicola*. Fish used for ageing ranged from 35 - 93 mm in length and 100 - 213 days in age (Fig. 16). The APE for replicate *S. saxicola* ages was 2.52 %. The CV and D were 3.56 and 2.52 days, respectively, indicating high precision and reproducibility of age estimates.

The growth rate of YOY benthic *S. saxicola* was estimated at 0.32 mm/d by the linear regression (Table 4; Fig. 16). The Gompertz growth curve predicts an age of approximately -30 to -40 days at a size of 0 mm, therefore estimating parturition at approximately 30-40 days following fertilization. Using the smallest *S. saxicola*

individuals caught, the initial age at recruitment was approximately 80 days following parturition. The Gompertz model predicts an age at recruitment of approximately 75 days. The curve fitting software estimated the best fitting curve for *S. saxicola* with the following equation: $SL = e^{(1.57 + (0.012 \times \text{Age}) + (2.5 \times 10^{-4} \times \text{Age}^2) + (-2.05 \times 10^{-6} \times \text{Age}^3) + (4.29 \times 10^{-9} \times \text{Age}^4))}$; $r^2 = 0.97$. The resulting curve increases exponentially through the larval and early juvenile stages, slows considerably at an age of approximately 150 days and then increases again at approximately 220 days.

S. levis

Otoliths were dissected from 58 *S. levis* individuals, all of which were sectioned and aged. Thirty-three sections were ranked as "3+" or better and used to describe growth of YOY, benthic *S. levis*. The sample of aged individuals represents fish from 49-84 mm and 94-214 days in age. The APE or replicate *S. levis* ages was 1.61 %. CV and D were 2.28 and 1.61 days, respectively, indicating high precision and reproducibility of age estimates.

The linear regression estimated the growth rate of benthic, YOY *S. levis* at 0.25 mm/day (Table 4; Fig. 17). The Gompertz growth curve predicts an age of approximately -30 days at a size of 0 mm, therefore estimating parturition at approximately 30 days following fertilization. Using the smallest *S. levis* caught, the initial age at recruitment was approximately 100 days following parturition. The growth curve slows at approximately 160 days.

Differences in growth rates were evident between each of the three species (Table 4; Fig. 18). Growth curves for *S. saxicola* and *S. levis* were similar in shape, but *S. levis* growth has higher than *S. saxicola*. Growth of *S. elongatus* was slower than the other two species.

Birthdate Distributions

S. elongatus

Because the linear regression was similar to the upper part of the Gompertz curve for *S. elongatus*, the birthdate distribution was the same when using either equation. In order to compare birthdate distributions between the three species, further analyses were conducted using the Gompertz equation. *S. elongatus* birthdates ranged from March through September (Fig. 19). However 98% of the birthdates fell between May and August, peaking in late June and early July with frequencies of 794 and 784 individuals, respectively. Peaks in birthdates corresponded to periods of low sea surface temperature.

S. saxicola

Visually, the growth curve estimated by the software program, TableCurve, provided the best fit to the *S. saxicola* data. However, the resulting birthdate distributions were similar when using either the TableCurve curve or the Gompertz growth curve. Because the Gompertz curve provided for interspecific comparisons, further analyses were conducted using the Gompertz equation. *S. saxicola* birthdates ranged from September 1994 to October 1995 with two peaks in frequency (Fig. 19). The first peak occurred in December through February 1994 with a frequency of 192 individuals, and the second peak occurred in June 1995 with a frequency of 489 individuals. Again, peaks in birthdates corresponded to periods of low sea surface temperature.

S. levis

The linear regression and Gompertz growth curves were similar for *S. levis*. Again, the Gompertz curve was used to back-calculate the birthdate distribution for *S. levis*. Back-calculated birthdates for *S. levis* ranged from February 1995 to August 1995

(Fig. 19). The peak in abundance occurred in May, corresponding to a period of low sea surface temperature.

DISCUSSION

Species Composition

A number of studies have examined the recruitment of juvenile rockfish into specific habitats along central California. Nearshore kelp communities and shallow, rocky outcroppings were the focus of extensive surveys by California Department of Fish and Game (CDFG) along the central California coast from 1987 to 1992 (VenTresca et al. 1994). Other studies have investigated the recruitment, identification, development and food habits of juvenile rockfish recruiting to central California kelp beds (Singer 1982, Anderson 1983, Carr 1983, Hobson et al. 1986, Hoelzer 1988). Soft bottoms have not traditionally been sampled for rockfish recruitment in Monterey Bay. In this study, however, fifteen species of YOY rockfish were collected on soft bottom habitats, indicating that these could be significant areas of recruitment, especially for *Sebastes elongatus*, *S. saxicola*, and *S. levis*.

These three dominant species are deep dwelling as adults and have important ecological and economic roles in Monterey Bay. *S. elongatus*, for example, accounted for approximately 4% of the recreational rockfish fishery in 1994 (Wilson-Vandenberg et al. 1996). *S. saxicola* accounts for a substantial amount of rockfish biomass in Monterey Bay and constitutes a large proportion of commercial rockfish bycatch (Gunderson and Sample 1980, Adams et al. 1995). Specimens are usually discarded because of their small size. *S. levis* is taken in small numbers, but are often targeted by private and commercial passenger vessels because of their large size (Love 1991). Some are also caught commercially in trawl nets and on set lines (Eschmeyer and Herald 1983).

This study only extended through one year of sampling, examining the affects of depth and habitat on recruitment of rockfishes. Rockfish recruitment exhibits huge

interannual variability in species composition and spatial distribution (Mearns et al. 1980, Carr 1991, Larson et al. 1994, VenTresca et al. 1994). A combination of biotic and physical parameters, including SST, turbidity, adult condition and predation pressure, influence the survival of rockfish larvae, and thus subsequent recruitment (Boehlert 1977, Larson et al. 1994, Ralston and Howard 1995, Yoklavich et al. 1996). Differences in latitude affect the depth ranges of adult rockfishes and may also affect the recruitment of juveniles. Mearns et al. (1980) sampled juveniles of additional rockfish species, including *S. semicinctus* and *S. jordani*, over soft bottom habitats in southern California. These species were not collected in large numbers during this study. Because so many different factors can affect rockfish recruitment, further studies, spanning several years, may be necessary to understand the huge variability in species composition and magnitude of recruitment. In Monterey Bay during 1995, however, three species of deeper dwelling rockfishes recruited to soft bottom habitats.

Spatial Distribution

Rockfishes develop strong associations with specific substrata through different stages of their life (Larson 1980, Carlson and Straty 1981, Richards 1987, Matthews 1990, Carr 1991, Love et al. 1991, Matthews and Richards 1991, VenTresca et al. 1994). The type of habitat varies greatly among species. All three of the most abundant species in this survey are deep dwelling, but not strictly associated with soft sediment habitats as adults.

S. saxicola is found from 46-421 m, but juveniles and adults are most abundant from 120-180 m (Love 1991). It is the one dominant species from this study that occurs over soft bottom habitats once it has settled to the bottom. Because *S. saxicola* is one of the smaller rockfishes as adults (maximum recorded length 38 cm) it might not require

the shelter and protection provided by high relief, rocky habitats. *S. elongatus* occurs from 60-400 m (Eschmeyer and Herald 1983). *S. elongatus* observed from submersibles is commonly seen over mud-cobble substrata near the edges of rocky areas (Pearcy et al. 1989, Stein et al. 1992). *S. levis* occur between 152-244 m over high relief rocky areas, often intermixed with soft, mud bottoms (Love 1991). Individuals of *S. levis*, are commonly seen associated with rock crevices or overhangs. Because *S. levis* is one of the largest rockfishes species, it may require the increased protection and shelter of these high relief areas.

Densities differed between the three dominant species. Densities of *S. saxicola* were twice as high as those of *S. elongatus* and over nine times greater than those of *S. levis*. These differences reflect adult densities and habitats. Adult densities have been estimated from submersible surveys conducted over mud, cobble and rock habitats (M. Yoklavich, NMFS, unpublished data). From these surveys, average densities of adult *S. saxicola* ranged from 2.7 ± 0.7 to 3.6 ± 0.6 fish per 100 m^2 . Adult densities of *S. elongatus* were about half that of *S. saxicola*, ranging from 0.9 ± 0.3 to 1.9 ± 0.5 fish per 100 m^2 . Densities of both of these species dropped considerably as the amount of rock habitat increased in the survey area. Adult *S. levis* densities were the lowest, ranging from 0.1 ± 0.1 to 0.6 ± 0.4 fish per 100 m^2 , and differed from the other two species by increasing as the amount of rock habitat increased in the survey area.

The distribution of YOY rockfish on soft bottoms in Monterey Bay may also be affected by specific sediment type. The soft bottom habitat in Monterey Bay is characterized by fine sand sediments at the shallow depth stratum (40-60 m) grading to silt and clay at depths nearing 100m. Within the 60-100 m depth range, high densities of *S. elongatus* and *S. saxicola* were found at the interface between fine sand and silt and

clay. The present study, however, was not designed to test differences in substrate type within the soft bottom areas.

Habitat information was obtained from a historic map. Sediment types at specific sites were determined by using sediment grabs. Results from these sites were used to contour sediment type for the entire bay. There are a number of possible biases in this method; grabs can not be used over hard bottoms, habitat patches are possibly missed, and boundary lines are based on estimates. The otter trawl is capable of sampling over any flat, non-relief substrata. The soft bottom habitats sampled during this study could also include pebble and cobble areas in addition areas with sand, mud, silt and clay. Discrepancies in navigation and positioning can also cause problems in comparing densities collected recently with habitat types from historic studies. A more in-depth sampling design is needed to separate possible effects of depth and fine scale sediment types on distribution of YOY rockfish.

Side scan sonar, conducted over parts of southern Monterey Bay, indicate areas of low relief granite basement rocks and sedimentary outcrops, bounded by flat mud-sand seafloor (M. Yoklavich, NMFS, pers. comm.). Within and around this rocky habitat are linear scarps of cobble and sand patches. Some of the highest densities of all three species occurred at two distinct locations in the southern half of Monterey Bay. The location of my samples does not overlap with the exact areas surveyed by side scan sonar, and could not have been taken over rocky habitats without snagging the trawl on the bottom. It is possible, however, that the trawl sampled within the sand-cobble patches or along the sand-mud bottoms that surround the rock outcrops. YOY *S. elongatus* and *S. saxicola* have been associated with these cobble and sand patches as observed from submersibles (M. Yoklavich pers. comm.) and scuba diving (R. Larson, San Francisco State University, pers. comm.). It is possible that juveniles are attracted to areas near

these rocky habitats by higher food resources or adult aggregations. Before or during ontogenetic shifts to deeper waters, juveniles may find these areas to be suitable adult habitats and remain there instead of moving on to greater depths.

Temporal Distribution

The timing, duration and magnitude of rockfish recruitment is directly related to timing of parturition, survival and transport during pelagic stages (Love et al. 1991, Carr 1991). These processes are highly dynamic and result in high interannual and interspecific variation in recruitment (Andersen 1983, Kendall and Lenarz 1987, Carr 1991, Moser and Boehlert 1991, Ainley et al. 1993). A number of deep-dwelling rockfish species, including *S. melanostomus*, *S. aurora*, *S. paucispinis*, *S. pinniger* and *S. miniatus*, settle nearshore and then gradually move into deeper waters where they join the adult conspecifics (Moser et al. 1985, Moser and Ahlstrom 1978, Matthews 1990). Many kelp bed species recruit to kelp canopies and migrate down to the substratum as they grow (Anderson 1983, Matthews 1990, Carr 1991). Benthic recruitment of rockfish to nearshore habitats in central California typically occurs between April and August with peak abundances in summer (Carlson and Haight 1976, Boehlert 1977, Anderson 1983, Matthews 1990, VenTresca 1994).

Recruitment for rockfishes to soft bottoms in Monterey Bay in 1995 began during June with abundances peaking in late summer and early fall. Strong upwelling conditions were still evident during this time period, as in earlier months, but there were also periods of relaxed upwelling, with warmer sea surface temperatures and onshore transport. The question still exists whether passive ocean transport or active transport related to an ontogenetic stage is most responsible for the timing and size at recruitment. It is possible that juvenile rockfish reach an ontogenetic stage during which they undergo biological or

behavioral changes that allow them to move towards shore. Juveniles may change their position in the water column to minimize the effects of offshore transport and maximize any onshore transport (Lenarz et al. 1991). And, assuming that they are capable of determining the correct direction, pelagic juveniles are large enough to start actively swimming towards nearshore environments (Moser and Ahlstrom 1978, Larson et al. 1994).

Several species of rockfish first appear as benthic juveniles at standard lengths between 40-60 mm (Boehlert 1977, Moser and Ahlstrom 1978, Richardson and Laroche 1979, Andersen 1983, Moser et al. 1985). However, size of new recruits can range from 30 to over 100 mm, and the size at settlement for a given species can vary among years (Hobson et al. 1986). If size alone were a trigger for recruitment, then a more coherent size range would be expected from year to year.

The time and size at first appearance in this study differed between species, but peak abundance for all species occurred simultaneously during September and October. At this time *S. levis* individuals were up to 20 mm larger and 1 month older than those of *S. elongatus*. It is possible that the minimum size for recruitment is simply larger for *S. levis* than for the other species. However, the fact that recruitment for both of these species occurred during exactly the same time period for these species, despite interspecific differences in size, suggests that onshore advection, or at least a relaxation of offshore advection, is important for juvenile recruitment to nearshore habitats.

The dependence of recruitment to onshore transport was not clear cut for all dominant species. Although the highest recruitment of *S. saxicola* occurred during relaxed upwelling, smaller individuals of *S. saxicola* did appear in mid-June during periods of heavy upwelling. Similar occurrences of larger pelagic *S. saxicola* in nearshore waters of Monterey Bay during heavy upwelling were reported by Larson et al.

(1994). This suggests that larger pelagic juveniles may be capable of actively moving towards nearshore habitats even in the presence of offshore advection during upwelling. Passive transport by onshore currents would work in concert with these active efforts. Therefore, some recruitment based on size/age despite ocean currents could be expected, with much higher recruitment during periods when both passive and active transport are occurring (VenTresca 1994, Carr 1991, Anderson 1983).

There also is question whether YOY rockfish move directly from pelagic habitats to the benthic habitats. Some species, such as *S. diploproa* and *S. melanostomus*, are thought to have an extended midwater transitional stage before settlement (Ahlstrom 1961, Boehlert 1977). Juveniles may take several weeks to reach benthic habitats, or may remain in midwater before settling even after they have reached nearshore habitats. It is possible that juveniles in this study settled elsewhere prior to their capture within the study area. One way to answer this question is to look at the maximum sizes of pelagic juveniles versus the minimum sizes of benthic juveniles. A substantial gap between sizes of pelagic and benthic juveniles could support the occurrence of a transitional habitat for these YOY rockfish.

A gap between sizes of pelagic and benthic fishes could also be explained by sampling gear. Certain sized fishes may not be effectively sampled by either midwater or benthic trawls. However, the mesh size of the otter trawl used in this study is efficient at sampling fishes as small as 19 mm (NMFS unpublished data). The lower size limit of all three species was approximately 30 mm, so I assume that the smallest settled fishes present were being sampled. In addition, midwater trawls used by NMFS have caught pelagic juveniles over 80-90 mm. This is well beyond the size of the fishes recruiting to benthic habitats in this study. Therefore, a discrepancy in size between pelagic and benthic juveniles would most likely be a result of fish distribution rather than sampling.

The size threshold for *S. saxicola* caught was 32 mm, with the majority falling between 45-60 mm. Anderson (1983) observed benthic juveniles between 27 and 53 mm recruiting to the soft bottoms on the outer edges of kelp beds in Monterey Bay. Pelagic juveniles of *S. saxicola* caught off central California in midwater trawls during 1984-95 were mostly between 20 and 40 mm, but a few were as large as 52 mm (Larson, San Francisco State University, pers.comm.). These pelagic juveniles may take some time to reach benthic habitats, but the overlap in size between pelagic and benthic juveniles suggests that they do not settle into intermediate habitats before recruiting to the area sampled in this study.

YOY of *S. levis* are not abundant in samples collected by midwater trawls off central California (NMFS). From 1988-96 only 30 YOY of *S. levis* were caught, but the sizes of these individuals ranged from 15-58 mm. *S. levis* began recruiting to soft bottoms at approximately 50-60 mm. This large size range for pelagic YOY further suggests that *S. levis* may be dependent on some parameter other than size to initiate recruitment. The overlap in pelagic to benthic YOY sizes, suggests that *S. levis* does not settle out to an intermediate habitat before recruiting to the soft bottom habitats sampled in this study.

Once juveniles of *S. elongatus*, *S. saxicola* and *S. levis* recruited to the soft bottom habitats, there was variation in the time they were present in the area. *S. elongatus* individuals recruited at a small size, remained in the area for approximately three months, with abundances declining sharply over 50 mm. The few specimens that were over 50 mm were caught right along the edge of the canyon. *S. saxicola* and *S. levis* recruited at larger sizes, and used the area until a much larger size and for a longer duration.

Juveniles of *S. saxicola*, *S. elongatus* and *S. levis* all underwent ontogenetic movements to deeper waters during the course of this study. Catches at the deep stations

were usually higher and peaked at least one month later than at the shallower stations. This indicates that fishes recruited to all of the depths sampled, but moved from the shallower to deeper depth ranges as the study progressed. This phenomenon is further supported by the increase of size with depth. Because juvenile rockfishes generally recruit to shallower habitats than adults, ontogenetic movements are common for many species (Love et al. 1991, Boehlert 1977).

In addition to the gradual movements to adult depths, large-scale emigration was evident in December and January. Movement to deeper waters could be triggered by a number of physical or biological factors. Parameters previously cited for initiation of movement include temperature, size/age, food conditions and photoperiod (Boehlert 1977, Boehlert and Yoklavich 1983, Haldorson and Richards 1987) In this study the decrease in densities corresponded to a period of increased winter storms.

Lower catches during storms are probably a result of fish behavior and fishing efficiency of the otter trawl. When wind and swell were high, fewer numbers of all fishes, not just rockfishes, were caught in the trawl suggesting a lower fishing efficiency of sampling gear. Also, juvenile rockfishes could have moved up into the water column or to greater depths to avoid high water motion or turbidity near the bottom caused by the storms. The fact that densities increased again, but only at the greater depths, after storm conditions had passed, suggests that movement to greater depths was initiated by storms. Carr (1983) saw a similar pattern of juvenile rockfish abundance in Monterey Bay for 1981-82. During his study, significant numbers of YOY rockfish left the kelp forests or shifted habitats after the onset of fall storms.

Growth

Daily growth increments in sagittal otoliths of *S. elongatus*, *S. saxicola* and *S. levis* were not directly validated in this study. However, previous studies have validated daily growth rings in otoliths of a number of fishes (Brothers et al. 1976, Butler 1989, Stevenson and Campana 1992). Yoklavich and Boehlert (1987) used radioisotopes (Ca_{45}) and tetracycline fluorescent markers to validate the deposition of daily growth increments in otoliths of juvenile black rockfish, *S. melanops* held in the laboratory. From additional studies on juvenile rockfish, growth increments begin forming at extrusion (Penney and Evans 1985, Laidig et al. 1991, Ralston et al. 1996). For all analyses of growth and birthdate distributions, growth increments counted in this study for *S. elongatus*, *S. saxicola* and *S. levis* are assumed to be daily.

Growth rates are highly variable within and among species of young fishes (Houde 1990, Woodbury and Ralston 1991). Temperature, food availability and energy requirements are a few of the factors known to affect growth rates of young fishes (Brett 1979, Boehlert 1981a, Boehlert and Yoklavich 1983, Freeburg et al. 1990). Woodbury and Ralston (1991) attributed coherent interannual variation in growth of five species of pelagic rockfish to temperature. Species reared in laboratory studies exhibited highest growth rates within a range of optimal temperatures (Boehlert 1981a, Boehlert and Yoklavich 1983, Boehlert 1991). This range of optimal temperatures will typically decrease as fishes age, presumably coinciding with the ontogenetic shift of fishes to deeper, colder habitats (Boehlert and Yoklavich 1983). This relationship between temperature and growth, however, is confounded by energy requirements. Metabolic rates increase as temperature increases, requiring a higher food intake. If a decrease in food availability coincides with an increase in temperature, fishes are faced with a higher possibility of starvation (Houde 1990).

Larval rockfish typically grow slowly until flexion, with growth increasing during late larval stages (Sakuma and Laidig 1995). Growth rates of larval *S. saxicola* collected from 1992-94 were 0.125 mm/d from 0-40 d and 0.367 mm/d from 40-80 d (Laidig et al. 1995). Individuals of *S. jordani* collected during 1989 grew 0.165 mm/d from 0-20 d and 0.53 mm/d from 40 and 160 d (Laidig et al. 1991). This increased growth during the late larval stage continues through the pelagic juvenile stage for rockfish, with rates between 0.3-0.6 mm/d (Woodbury and Ralston 1995). High growth is possible during these stages because maintenance energy requirements for metabolism are low, allowing a higher ration of energy available for growth (Houde 1990). This relatively fast growth during early stages leads to shorter stage durations, which potentially results in lower age-specific mortality and increased survival rates (Houde 1989). As fishes increase in size growth rates decline (Boehlert 1981b, Love et al. 1991). This decrease in growth may be attributed to an increase in maintenance energy requirements and a subsequent decrease in energy available for growth (Houde 1989). Alternatively, it may reflect an increase in biomass rather than just an increase in length.

Growth rates estimated for demersal rockfish juveniles range from 0.20 - 0.30 mm/d with slightly higher growth rates for *S. jordani* (0.59 mm/d) and *S. paucispinis* (0.72 mm/d; Carlson and Haight 1976, Love et al. 1991, Matthews 1990). During this study, mean growth rates of demersal juveniles ranged from 0.17 mm/d for *S. elongatus* to 0.32 mm/d for *S. saxicola*. Because *S. elongatus* individuals were born slightly later than those of *S. saxicola* and *S. levis*, they were subjected to warmer ocean temperatures at earlier stages. This could explain the lower growth rates for *S. elongatus*.

An inflection point leading to slower growth was evident in the growth curves for *S. elongatus*, *S. saxicola* and *S. levis*. This decrease in growth may be the natural decline in growth during the benthic juvenile stage. However, the decrease in growth occurred

up to a month after juveniles recruited and occurred simultaneously for all three species in late September and early October. These two months had the highest mean temperature in 1995. Also, fishes were different ages when the decline began; *S. elongatus* was approximately 120 days and *S. saxicola* and *S. levis* were 150 days. The decrease in growth for YOY rockfish could be the result of an increase in temperature accompanied by a decrease in food resources due to the end of the upwelling season and the onset of winter storms.

This potential dependence of growth on environmental conditions could have profound effects on recruitment. As growth slows, size-specific mortality increases, lowering the survival and subsequent recruitment of juvenile rockfishes. It would be interesting to know if the increase in temperature and decrease in growth had a significant effect on the subsequent survival of juveniles of these three species.

Birthdate Distributions

Birthdate distributions back-calculated from daily growth rings have been used to assess yearly survival of YOY rockfish (Methot 1983, Boehlert and Yoklavich 1985, Woodbury and Ralston 1991, Yoklavich et al. 1996). Dependent on the time of sampling, birthdate distributions back-calculated from juveniles are often skewed towards newer recruits, as older recruits have been subject to more age-specific mortality (Yoklavich et al. 1996). Distributions can be adjusted if size specific rates of mortality during larval and pelagic juvenile stages are known. For this study, the mortality rates are unknown. Once fish have settled they are subject to the same rate of mortality, which is presumed to be substantially lower than earlier stages. Therefore, correction for mortality that has occurred after settlement should not be necessary (Ralston and Howard 1995).

The peak in birthdates for all three dominant species corresponded to a pronounced drop in SST and increase in offshore transport, which occurred during summer months. For *S. elongatus* this time period exactly matches the narrow range predicted from timing of parturition (Echeverria 1987). This provides support for the occurrence and correct interpretation of daily growth rings in YOY rockfish. For *S. saxicola* a small peak in the distribution of back-calculated birthdates matches the peak months predicted from adults. However, a much larger peak occurred between April and August, completely outside the predicted range. All of *S. levis* birthdates occurred beyond the predicted dates for parturition. Moser and Boehlert (1991) also found *S. levis* larvae produced as late as July in one of five CalCOFI sampling years between San Francisco and Baja California. This timing of parturition for surviving benthic rockfish is most likely a result of higher survival of those individuals born between April and August.

Highest survival of YOY rockfish occurred for individuals spawned late in the season, after the onset of upwelling. During the end of 1994 and beginning of 1995, temperatures in the California Current were anomalously high, with conditions characteristic of an El Niño year (Hayward et al. 1996). Woodbury and Ralston (1991) demonstrated that during years with normal upwelling intensity, there is successful early-parturition for rockfishes. During years with reduced or delayed upwelling, successful parturition occurs later in the season. Ralston and Howard (1995) found highest survival of *S. mystinus* and *S. flavidus* when SST and upwelling were at intermediate levels, with low survival during years of extreme temperatures. During a two year El Niño event, only larvae released late in the year were represented in birthdate distributions of juveniles of *S. jordani* (Yoklavich et al. 1996). The high temperatures seen early in the 1994-95 parturition season, coupled with late successful parturition agree with findings of

these previous studies. Those larvae born after the transition to upwelling experienced lower mortality rates and higher survival, possibly due to increased food conditions, leading to faster growth, and offshore transport away from nearshore predators.

Another explanation of late successful parturition is that YOY from earlier spawning survived to the stage of settlement, but died after they had settled, or settled outside of Monterey Bay. During March of 1995, unusual flood conditions that occurred in the Salinas Valley altered the conditions of the bay. During this time the Salinas and Pajaro Rivers, which typically have low flows, were pouring large amounts of water, silt and debris into Monterey Bay. Waters throughout Monterey Bay were brown and turbid. Unusual amounts of silt, mud and debris were present in the samples, and fewer fish of all species were caught during this time. These conditions could have been unsuitable for juvenile rockfish survival. Assuming juveniles born earlier in the year settle at the same size and age as those that settle later in the year, YOY born during peak periods of spawning for *S. saxicola* and *S. levis* would have been recruiting to benthic habitats during these conditions of poor water quality. This could explain survival of only those individuals born later in the season when conditions for recruitment had improved.

Because birthdates for *S. elongatus* were similar to predicted months of parturition, the timing of recruitment might be typical of other years. However, peak recruitment was probably late this year for both *S. saxicola* and *S. levis*, corresponding with survival primarily of late season larvae. Mearns et al (1980) first encountered small individuals of *S. saxicola* in May, and Andersen (1983) reported *S. saxicola* recruiting as early as April. Again, low survival during early stages due to the timing of upwelling in 1995 could be responsible for this late recruitment.

SUMMARY

- The juvenile rockfish assemblage over soft bottom habitats in Monterey Bay during 1995 was dominated by three deep-dwelling species, *Sebastes elongatus*, *S. saxicola*, and *S. levis*.
- Rockfish recruited throughout the study area, with increasing densities and sizes at greater depths (60-100 m).
- Highest densities were associated with the interface between fine sand and clay sediments.
- Recruitment began in late August, with peak densities between September and October, corresponding to ocean conditions characterized by alternating periods of both strong and relaxed upwelling. Densities declined at the onset of winter storms.
- Growth rates during the benthic juvenile stage ranged from 0.17 mm/d to 0.35 mm/d.
- Highest survival occurred for those individuals born later in the parturition season, corresponding with periods of high upwelling.

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Table 1. Number of tows (samples), total catch and cpue (fish/ha) at fixed and random stratified stations by depth and general location in Monterey Bay, CA.

Sampling Strata	South Bay			North Bay		
	Samples	Total catch	cpue	Samples	Total catch	cpue
Fixed stations						
40-60 m	14	25	1.8	16	53	3.3
60-80 m	17	288	16.9	19	167	8.8
80-100 m	16	959	59.9	14	267	19.1
Total	47	1272	27.1	49	487	9.9
Random stations						
40-60 m	10	44	4.4	16	208	13.0
60-80 m	11	261	23.7	25	1005	40.2
80-100 m	12	436	36.3	27	460	17.0
Total	33	741	22.5	68	1673	24.6
Grand Total	80	2013	25.2	117	2160	18.5

Table 2. Species composition and length of juvenile rockfish caught on soft bottom habitats in Monterey Bay between March 1995 and February 1996 using an otter trawl. (* represents <0.05% of total rockfish catch)

Species	Common Name	Abundance			Percent of Total	Standard Length (mm)	
		North bay	South bay	Total		Range	Mean SL \pm SE
<i>Sebastes elongatus</i>	Greenstripe	1308	502	1810	43.18%	30-80	41.2 \pm 1.0
<i>S. saxicola</i>	Stripetail	471	1265	1736	41.41%	32-116	65.8 \pm 1.6
<i>S. levis</i>	Cowcod	136	153	289	6.89%	49-104	66.3 \pm 3.9
<i>S. goodei</i>	Chilipepper	132	50	182	4.34%	65-152	92.5 \pm 6.9
<i>S. semicinctus</i>	Halfbanded	53	30	83	1.98%	50-140	85.1 \pm 9.3
<i>S. crameri</i>	Darkblotched	32	5	37	0.88%	48-139	70.2 \pm 11.5
<i>S. diploproa</i>	Splitnose	31	0	31	0.74%	44-78	57.3 \pm 10.3
<i>S. wilsoni</i>	Pygmy	8	0	8	0.19%	40-95	57.0 \pm 20.2
<i>S. paucispinis</i>	Bocaccio	3	3	6	0.14%	85-111	94.5 \pm 38.6
<i>S. miniatus</i>	Vermillion	3	1	4	0.10%	85-102	92.0 \pm 46.0
<i>S. hopkinsi</i>	Squarespot	0	3	3	0.07%	43-108	85.0 \pm 49.1
<i>S. pinniger</i>	Canary	1	0	1	*	94	-
<i>S. jordani</i>	Shortbelly	0	1	1	*	84	-
<i>S. eos</i>	Pink	1	0	1	*	22	-
<i>S. entomelas</i>	Widow	1	0	1	*	92	-
Grand Total		2180	2013	4193	100%		

Table 3. Kolmogorov-Smirnov results on size distribution comparisons of juvenile benthic rockfish between depth strata. Depth ranges referred to as shallow, intermediate and deep represent 40-60 m, 60-80 m and 80-100 m respectively. Significant differences ($p < 0.05$) are denoted by (*).

Species	Shallow vs. Intermediate	Shallow vs. Deep	Intermediate vs. Deep
<i>S. elongatus</i>	$p < 0.001$ *	$p = 0.003$ *	$p = 0.004$ *
<i>S. saxicola</i>	$p < 0.001$ *	$p < 0.001$ *	$p < 0.001$ *
<i>S. levis</i>	$p = 0.628$ ns	$p = 0.025$ *	$p = 0.002$ *

Table 4. The relationship between standard length and age in days of benthic YOY rockfish, as determined from daily growth rings of the sagittal otoliths, was determined using linear regression and a Gompertz growth function.

Species	Linear Regression			Gompertz Growth Function	
	equation	r^2	MSE	equation	MSE
<i>S. elongatus</i>	$L_t = 0.17t + 20.71$	0.68	8.35	$L_t = 5.0 \times e^{2.31(1-e^{-0.021t})}$	9.89
<i>S. saxicola</i>	$L_t = 0.32t + 12.95$	0.65	47.35	$L_t = 4.5 \times e^{3.18(1-e^{-0.011t})}$	26.08
<i>S. levis</i>	$L_t = 0.25t + 27.03$	0.76	30.71	$L_t = 5.0 \times e^{2.84(1-e^{-0.016t})}$	33.95

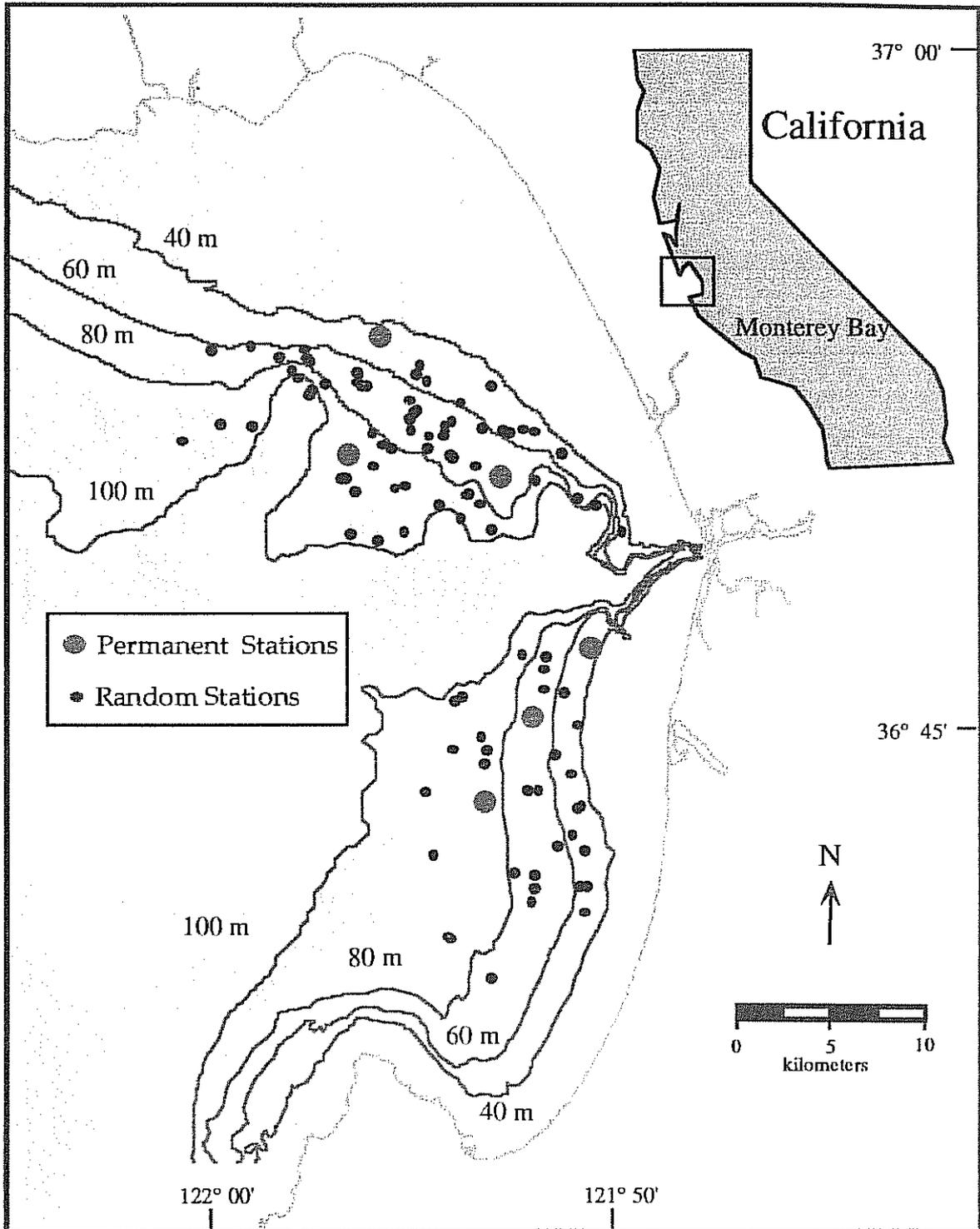


Figure 1. Otter trawls were used to sample juvenile rockfish at a combination of stratified random and permanent stations between March 1995 and February 1996 in Monterey Bay, CA.

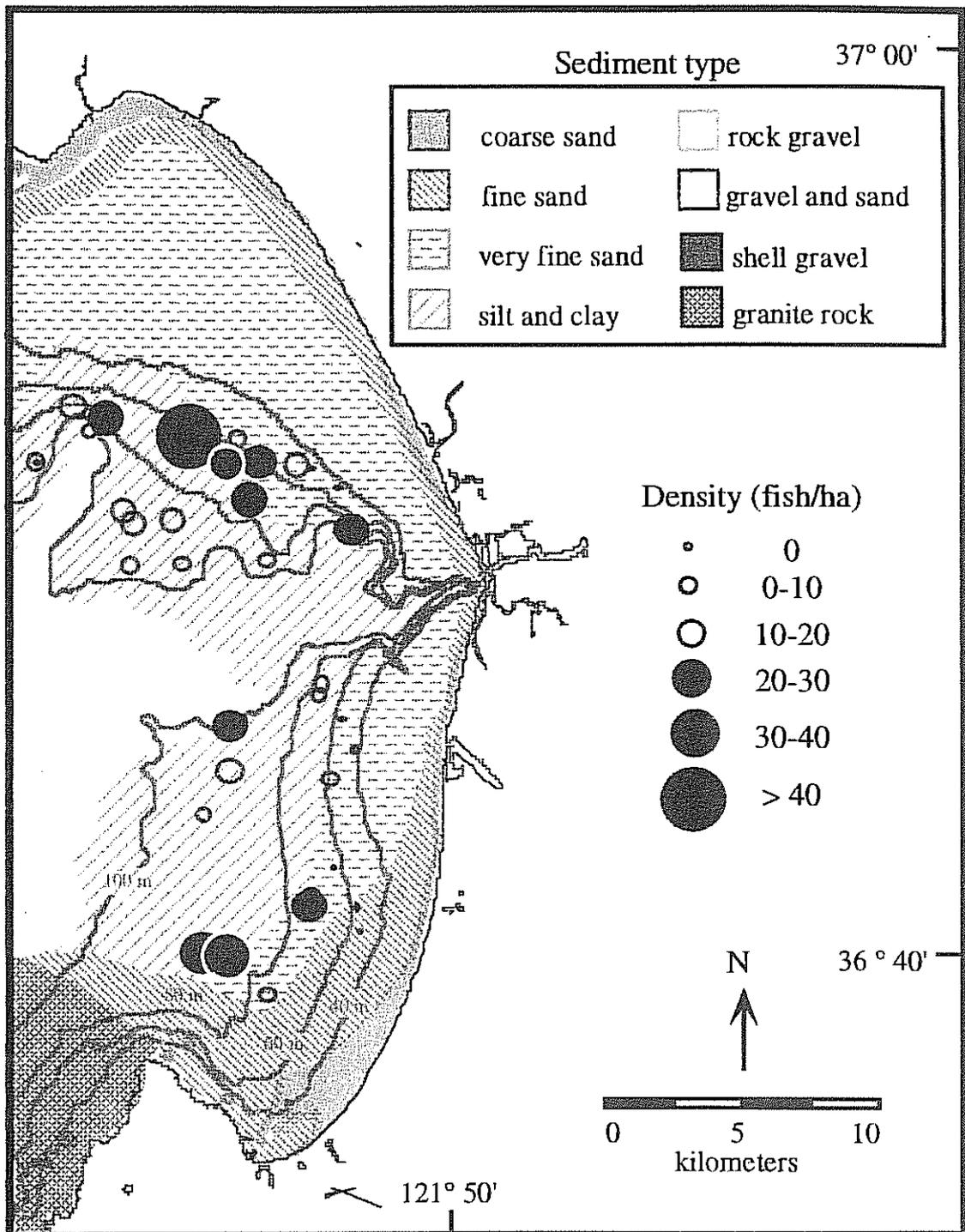


Figure 2. Spatial distribution of *Sebastes elongatus* caught between March 1995 and February 1996. Sediment types from Galliher (1932).

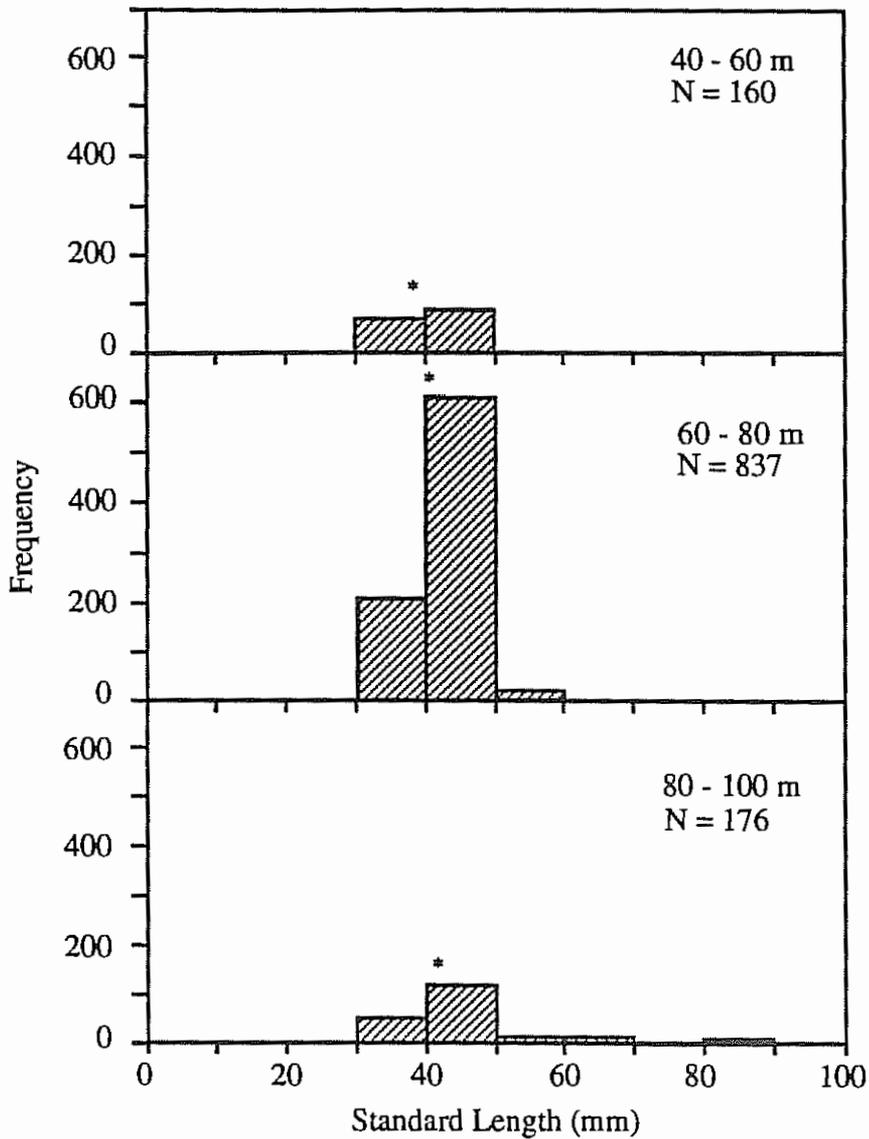


Figure 3. Length frequency of *Sebastes elongatus* by depth. Fish were caught over soft bottoms in Monterey Bay, CA between March 1995 and February 1996. Each depth range was sampled throughout the sampling period. (N denotes number of fish, * denotes mean length per depth stratum.)

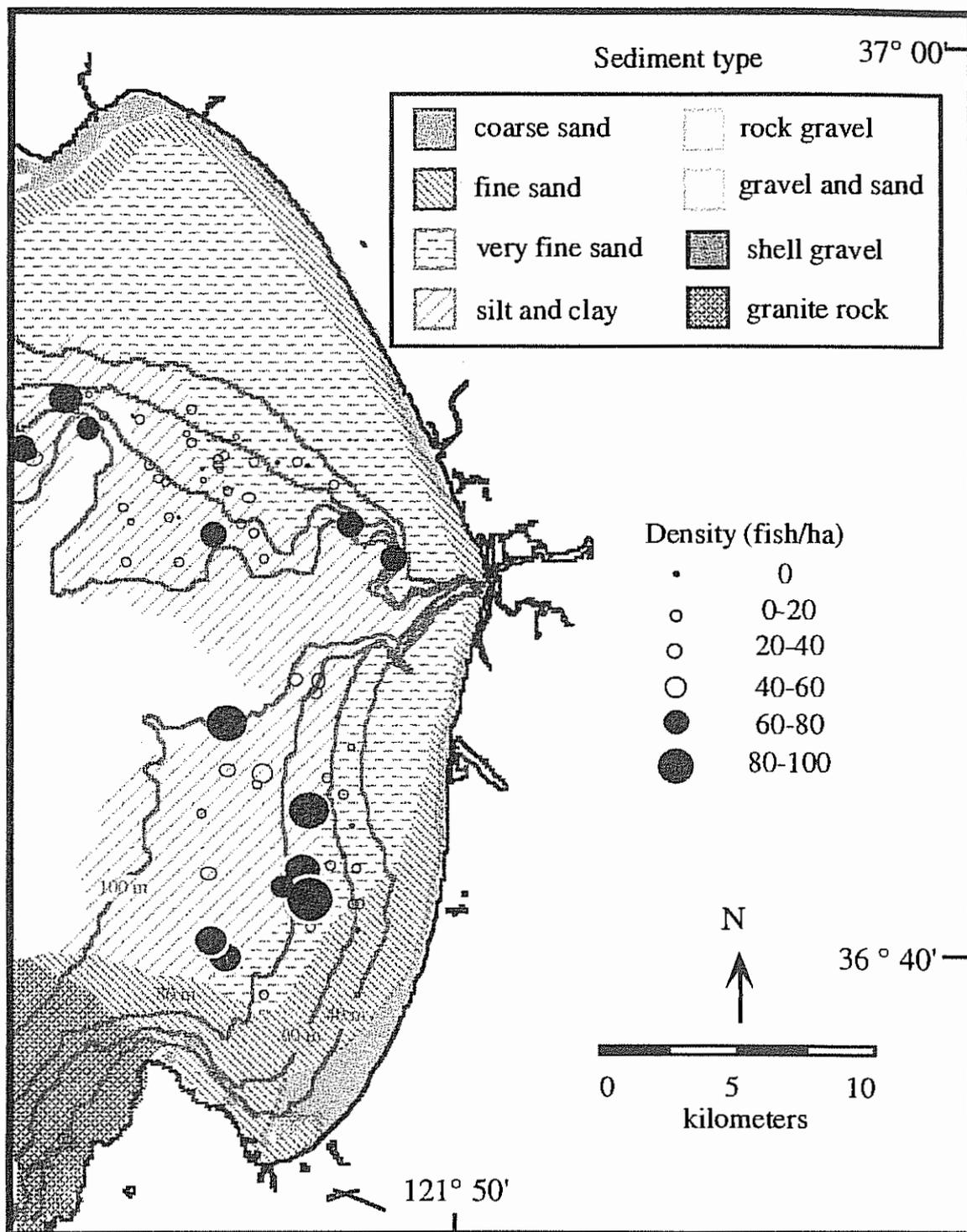


Figure 4. Spatial distribution of *Sebastes saxicola* caught between March 1995 and February 1996. Sediment types from Galliher (1932).

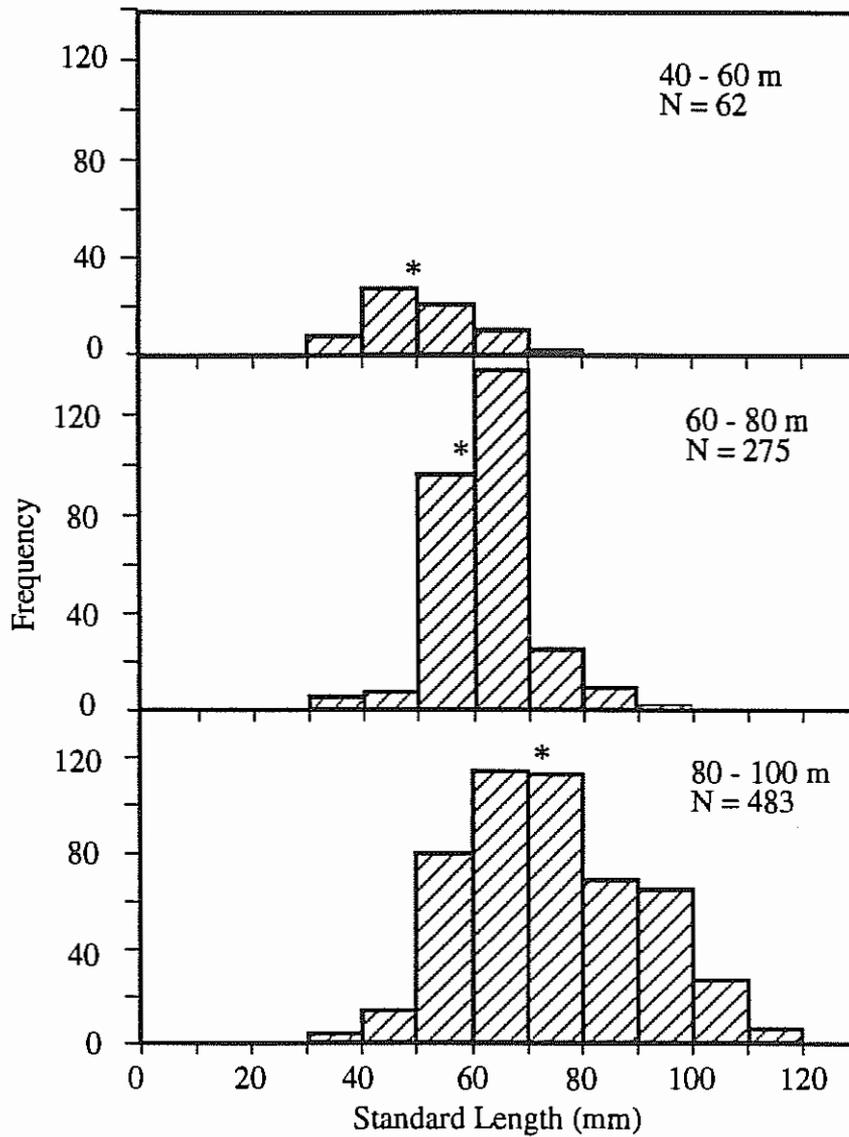


Figure 5. Length frequency of *Sebastes saxicola* by depth. Fish were caught over soft bottoms in Monterey Bay, CA between March 1995 and February 1996. Each depth range was sampled throughout the sampling period. (N denotes number of fish, * denotes mean length per depth stratum.)

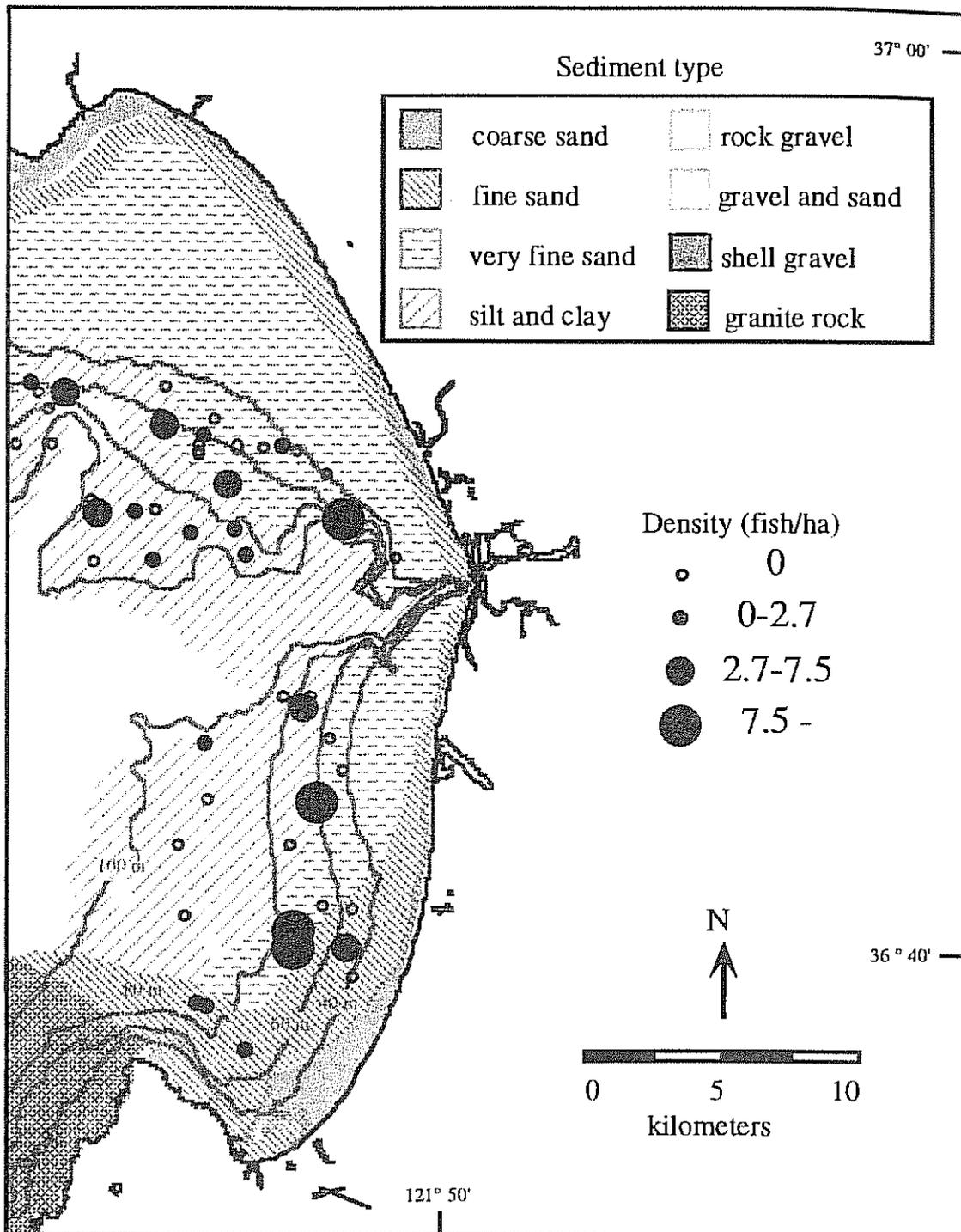


Figure 6. Spatial distribution of *Sebastes levis* caught between March 1995 and February 1996. Sediment types from Galliher (1932).

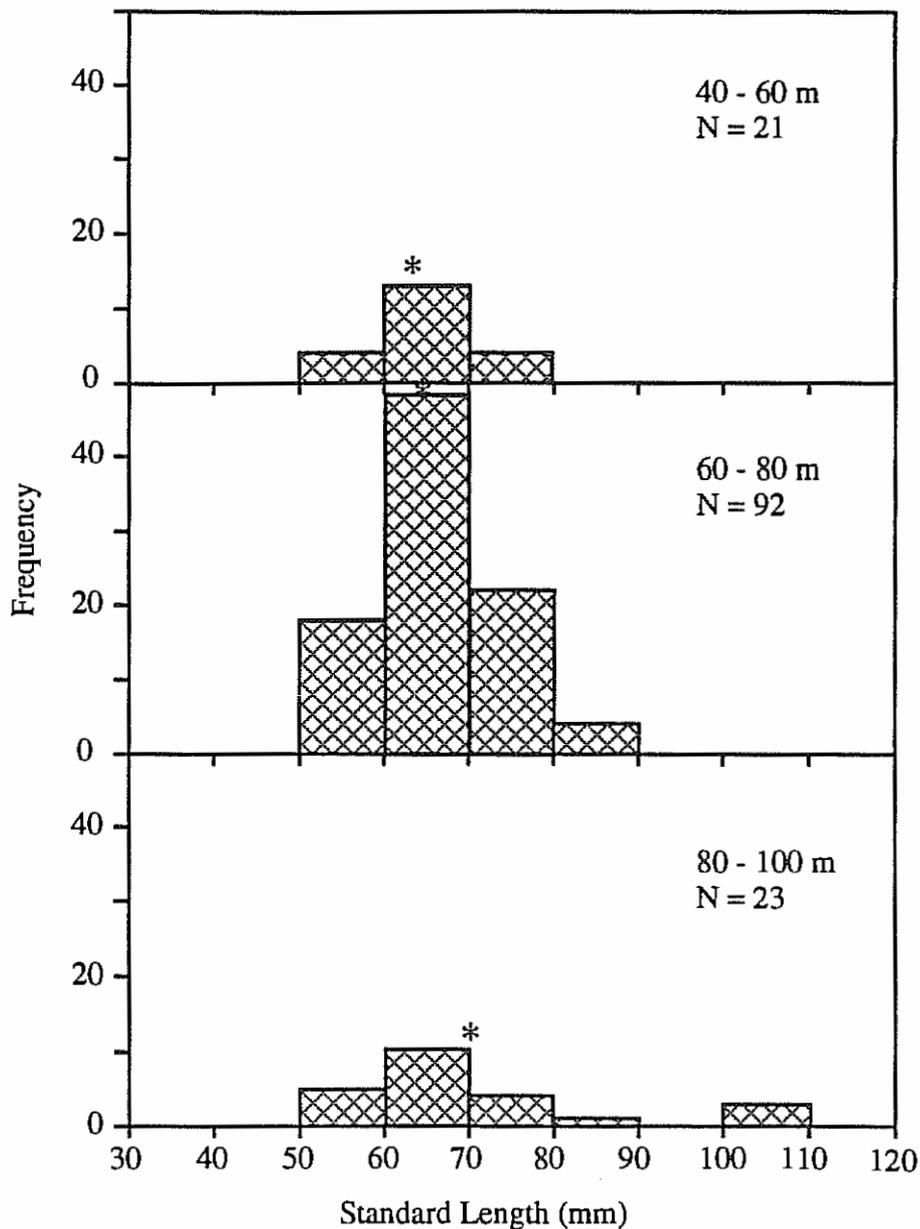


Figure 7. Length frequency of *Sebastes levis* by depth. Fish were caught over soft bottoms in Monterey Bay, CA between March 1995 and February 1996. Each depth was sampled throughout the sampling period. (N denotes number of fish, * denotes mean length per depth stratum.)

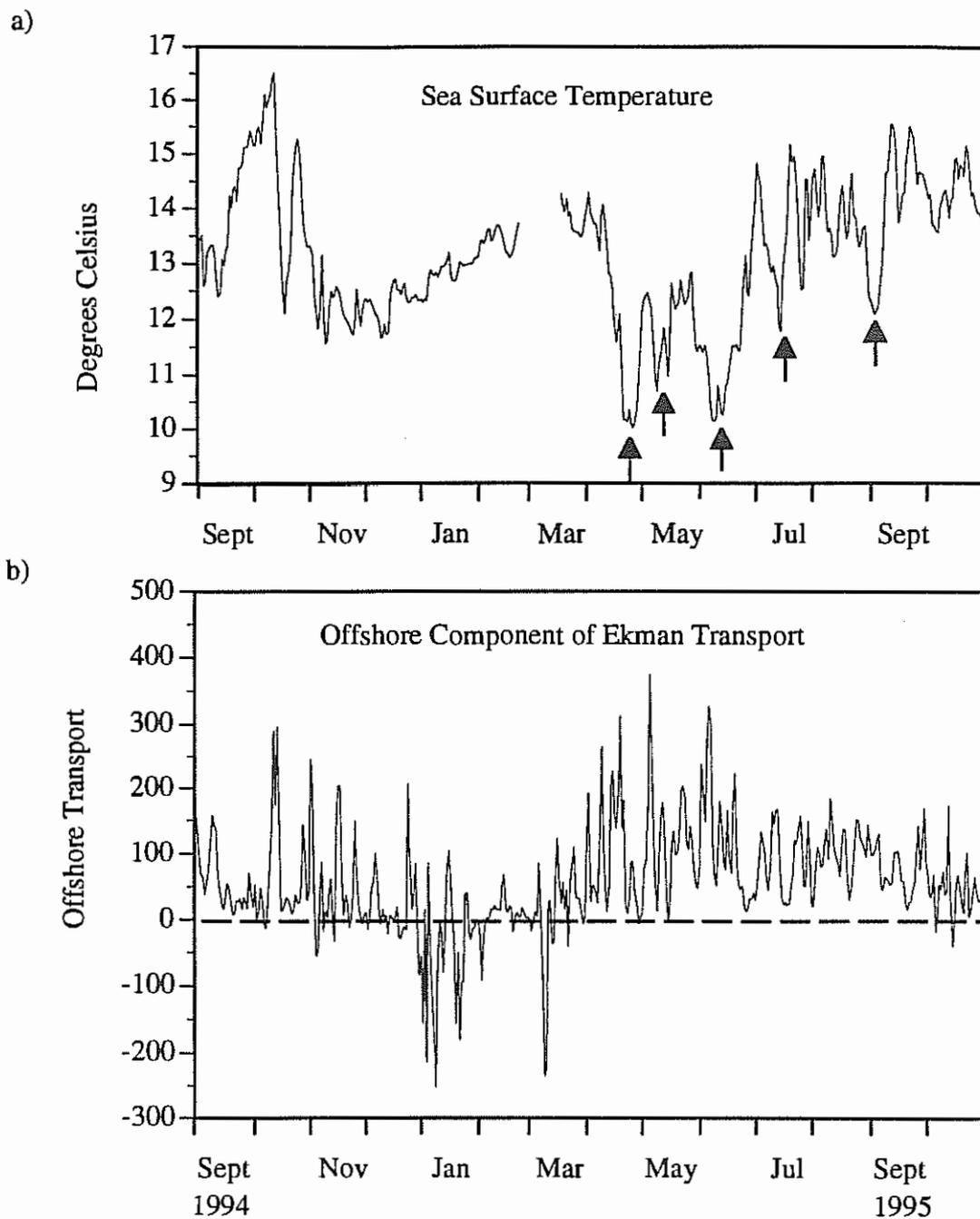


Figure 8. Degree of upwelling off central CA from September 1994 through October 1995 as represented by daily averages of (a) sea surface temperature and (b) offshore transport. Arrows indicate distinct periods of upwelling.

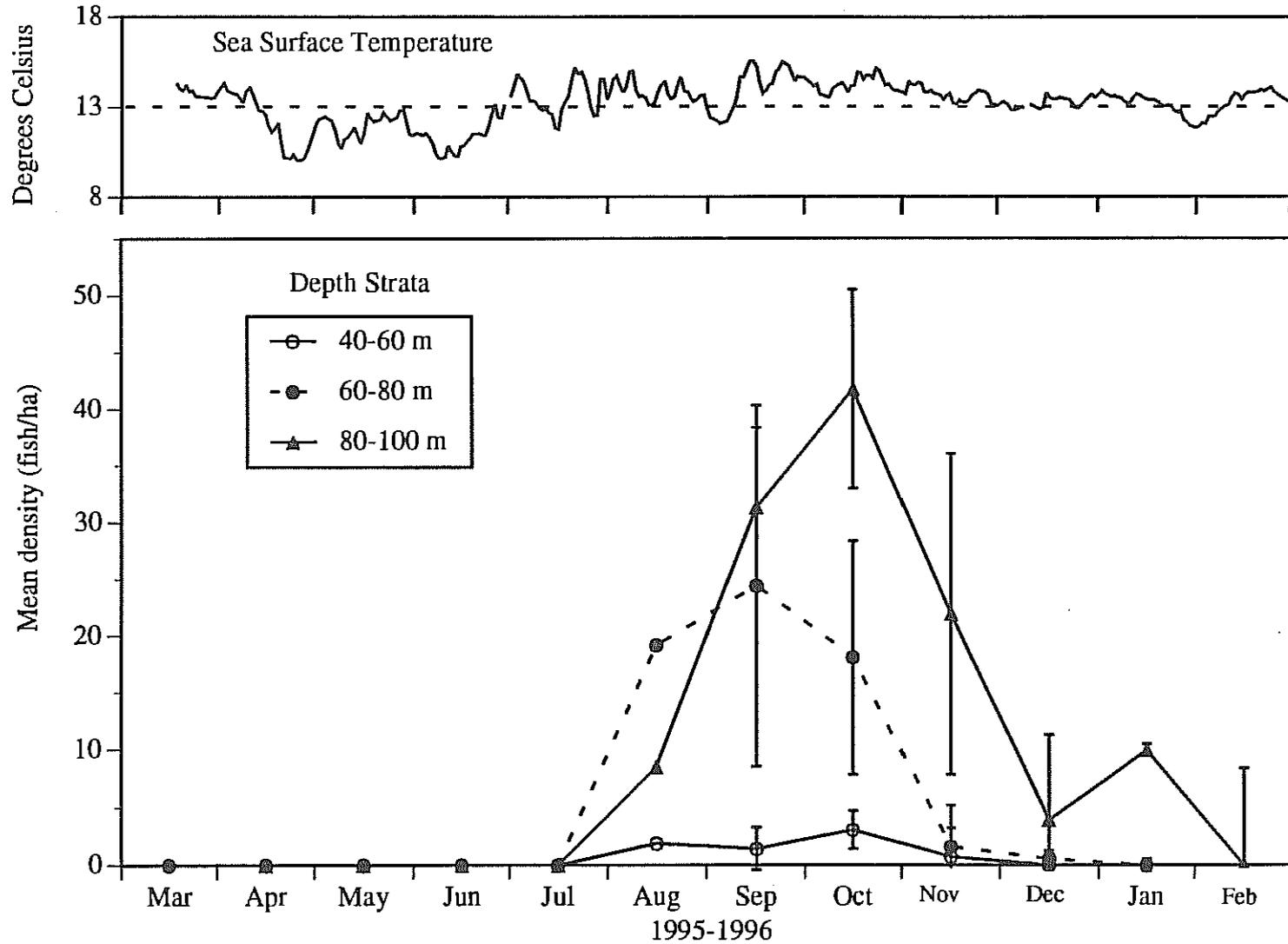


Figure 9. Mean density (fish/ha) of YOY, benthic *Sebastes elongatus* at fixed stations, relative to sea surface temperature. Two to five trawl tows were completed per depth strata per month. Error bars denote one standard error.

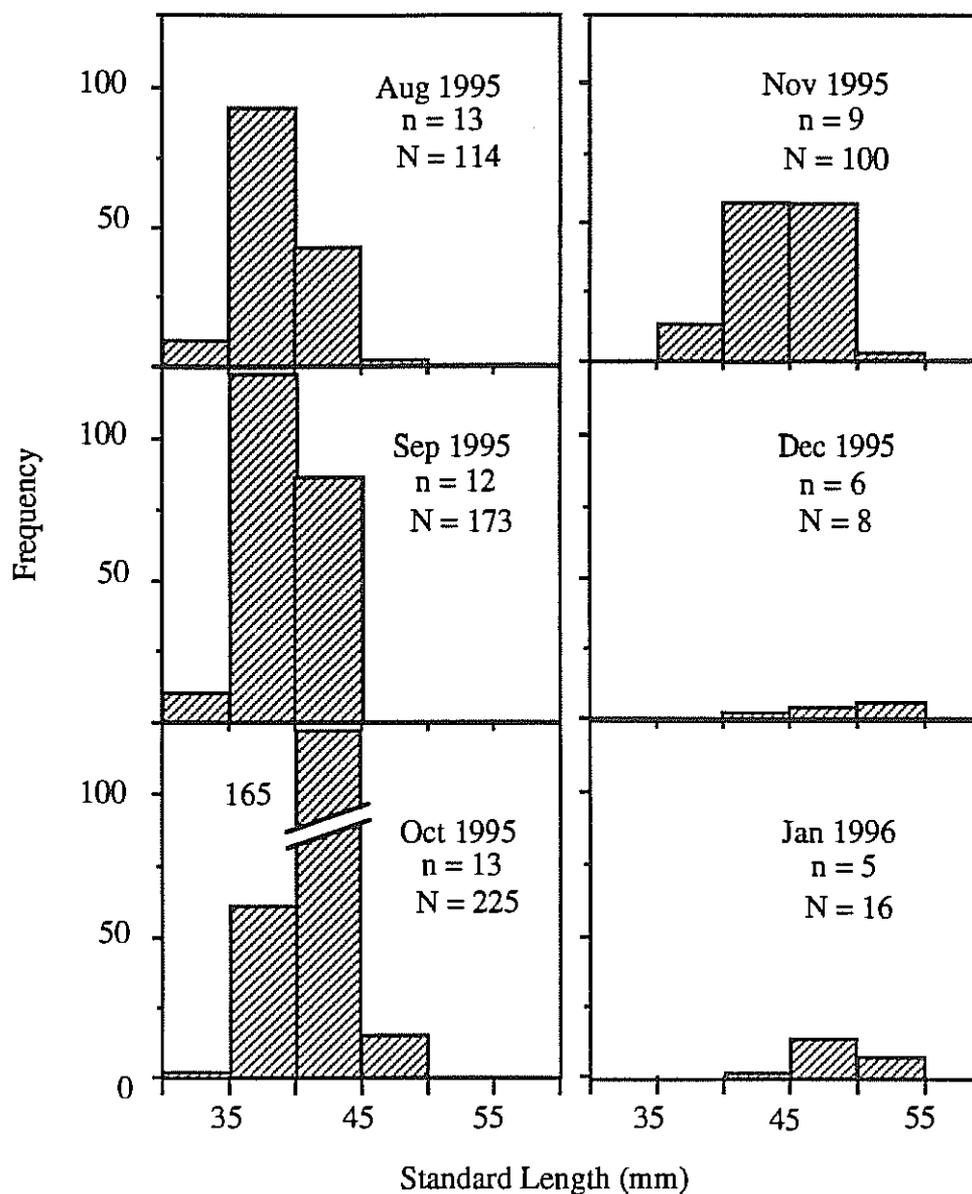


Figure 10. Length frequency histograms by month (depth strata combined) for *Sebastes elongatus* caught over soft bottoms in Monterey Bay, CA between April 1995 and January 1996. The number of tows taken (n) and number of fish measured (N) is provided for each sampling period.

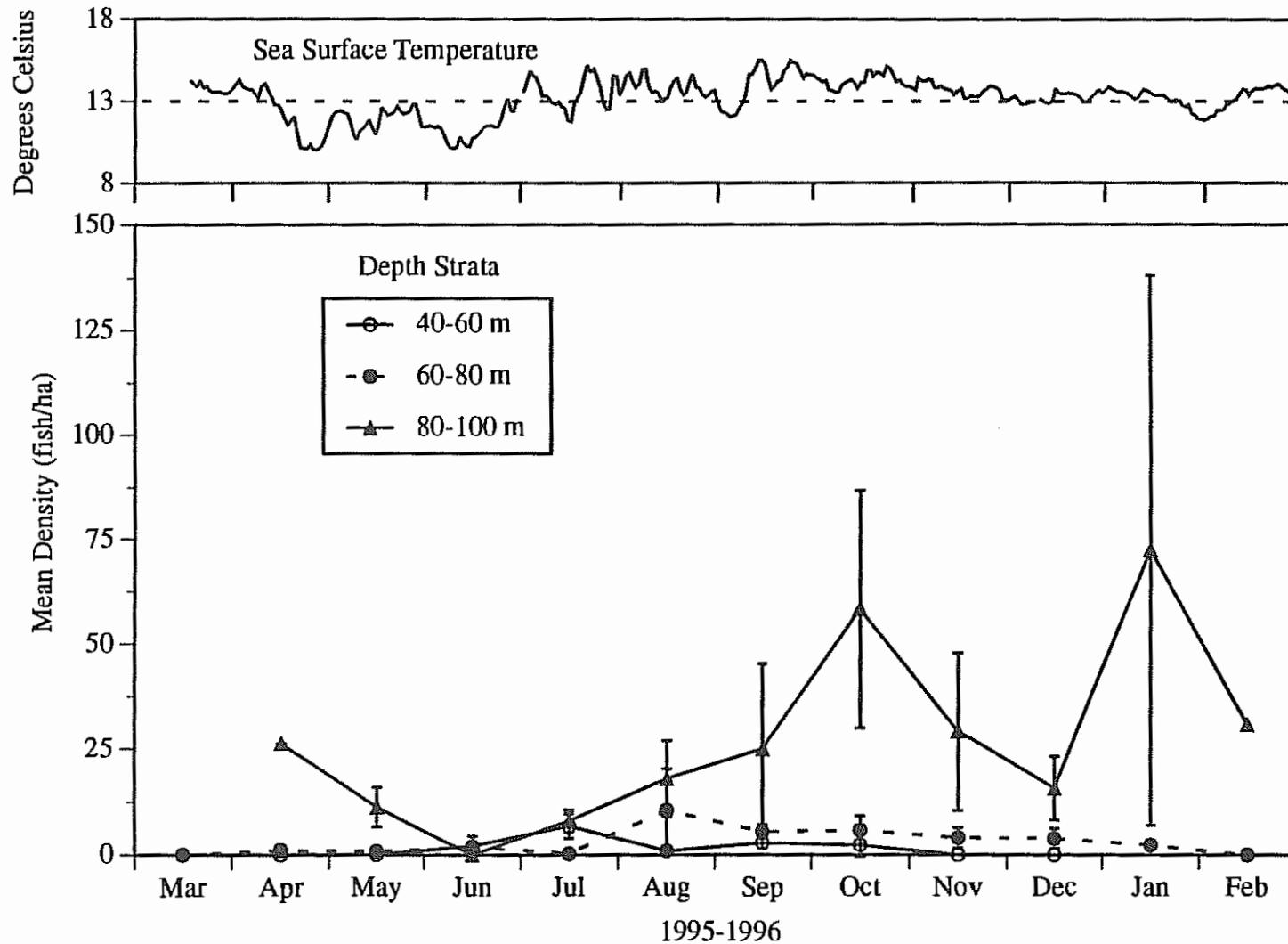


Figure 11. Mean density (fish/ha) of *Sebastes saxicola* at fixed stations, relative to sea surface temperature. Two to five tows were completed per depth strata per month. Error bars denote one standard error.

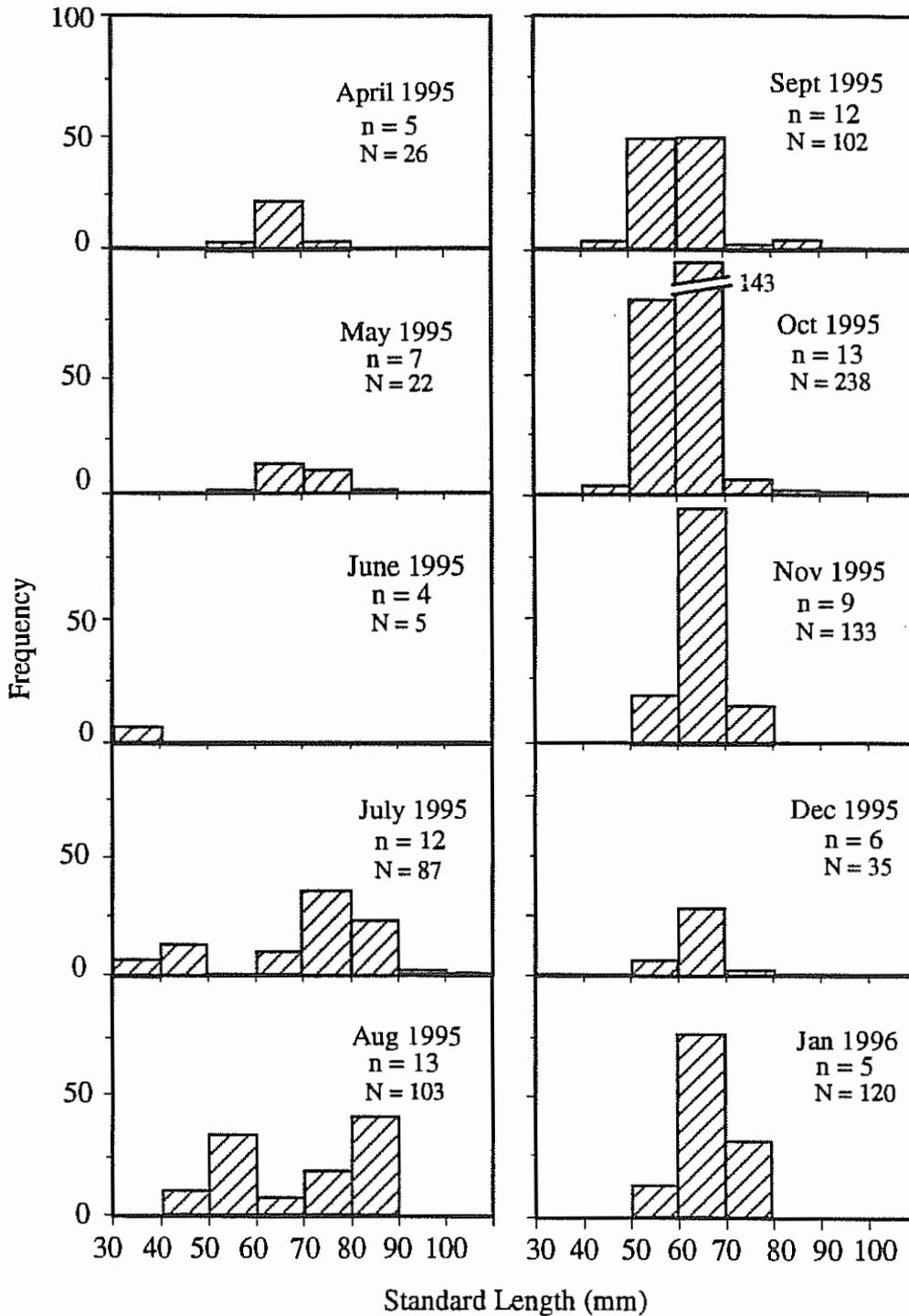


Figure 12. Length frequency histograms by month (depth strata combined) for *Sebastes saxicola* caught over soft bottoms in Monterey Bay, CA between April 1995 and January 1996. The number of tows taken (n) and number of fish caught and measured (N) is provided for each sampling period.

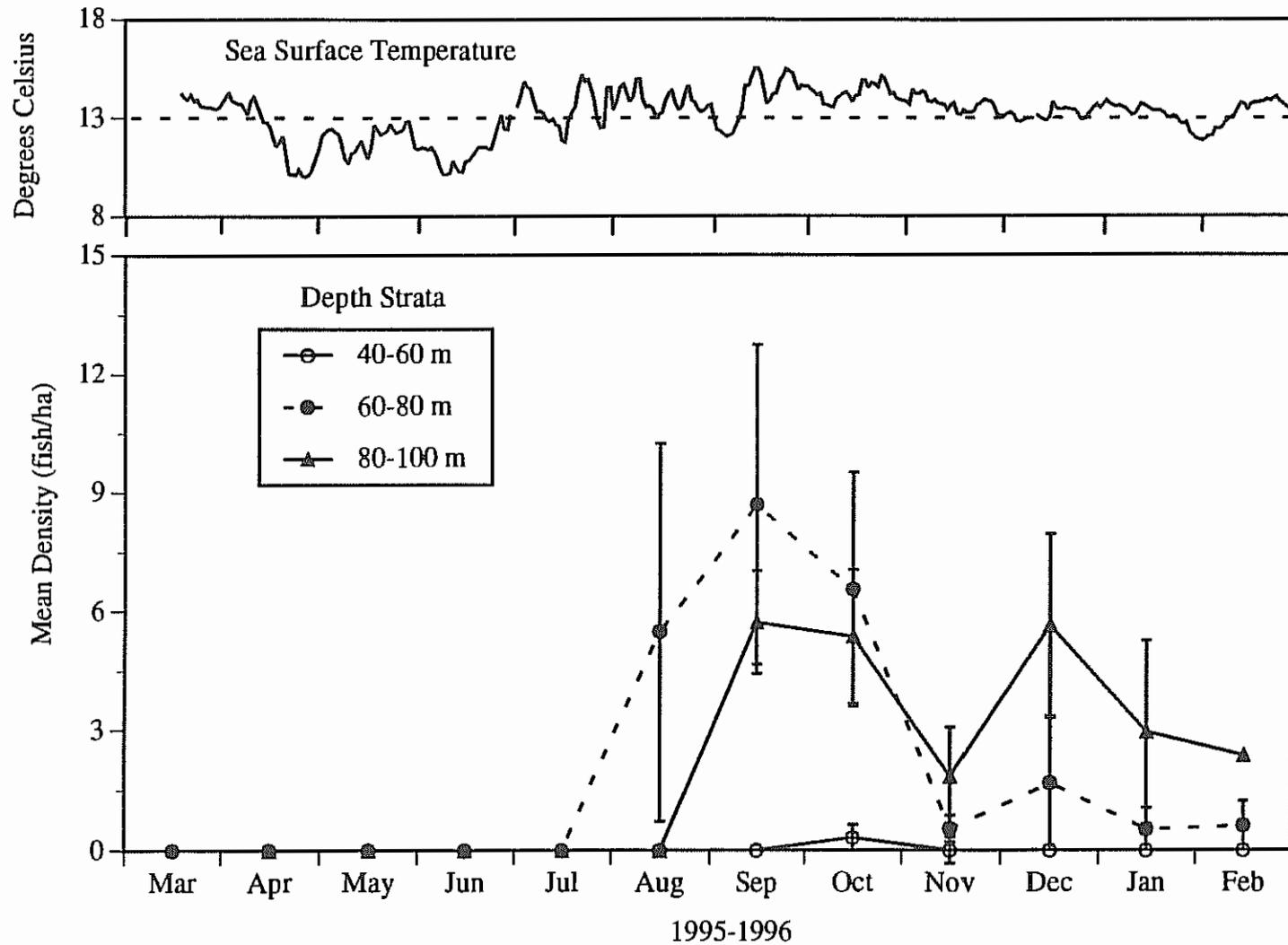


Figure 13. Mean density (fish/ha) of *Sebastes levis* at fixed stations, relative to sea surface temperature. Two to five tows were completed per depth strata per month. Error bars denote one standard error.

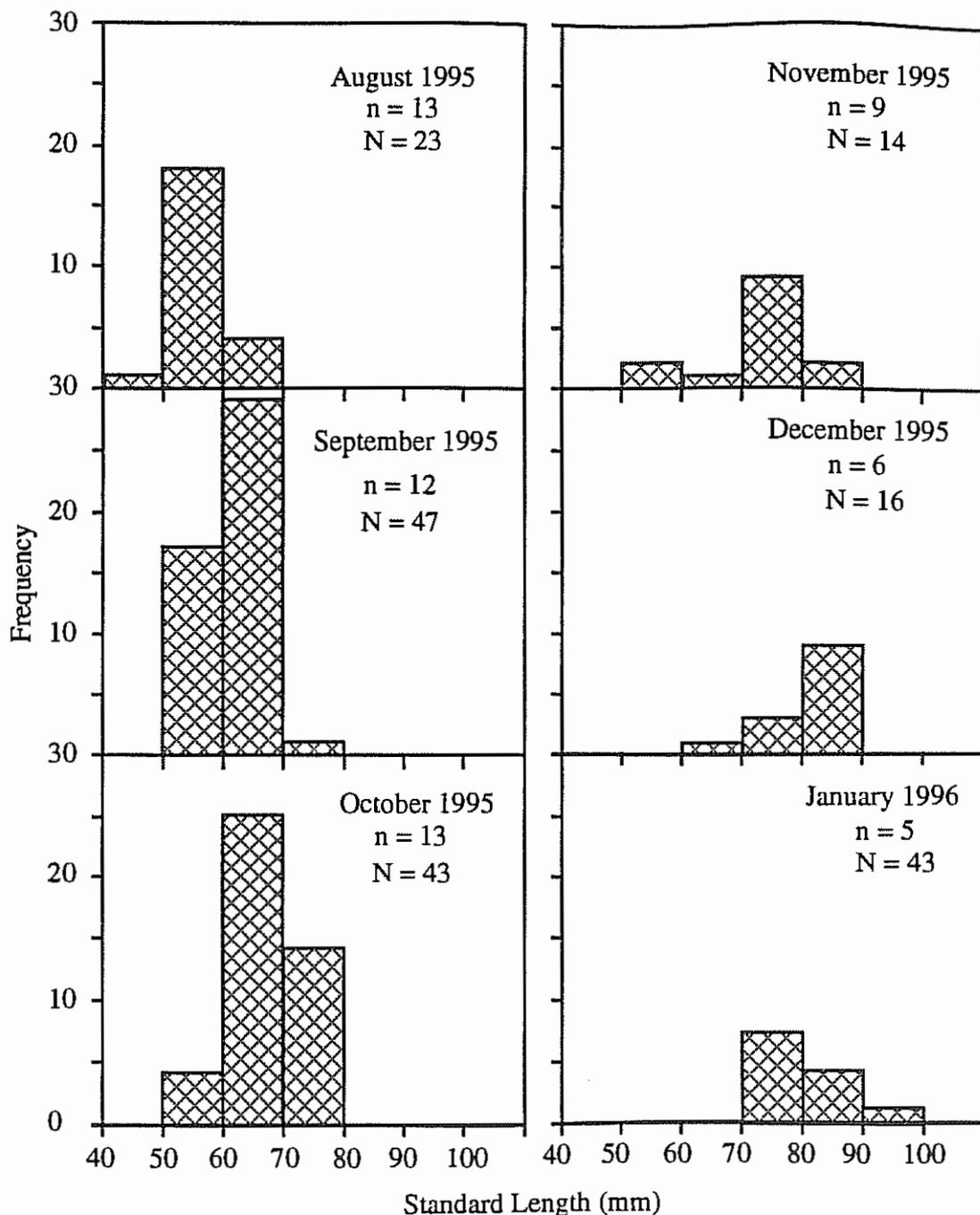


Figure 14. Monthly length frequency of *Sebastes levis* caught over soft bottom habitats (depth strata combined) in Monterey Bay, CA from August 1995 through January 1996. The number of tows taken (n) and number of fish caught and measured (N) is provided for each sampling period.

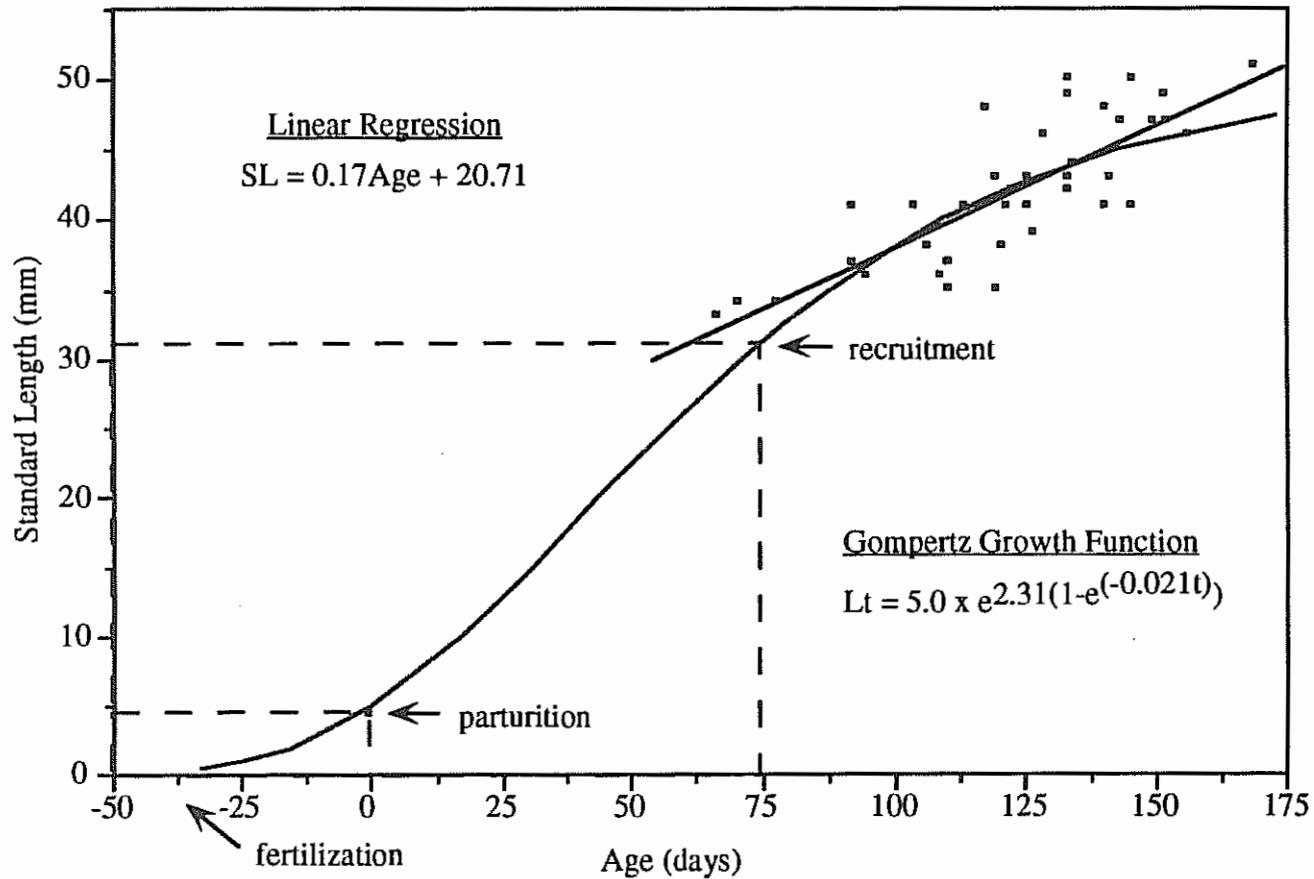


Figure 15. Gompertz growth function and linear regression for daily growth of benthic, YOY *Sebastes elongatus*. Specimens were caught over soft bottom habitats between 40-100 m in Monterey Bay, CA from March 1995 through February 1996. Ages were estimated using daily growth increments of the sagittal otoliths.

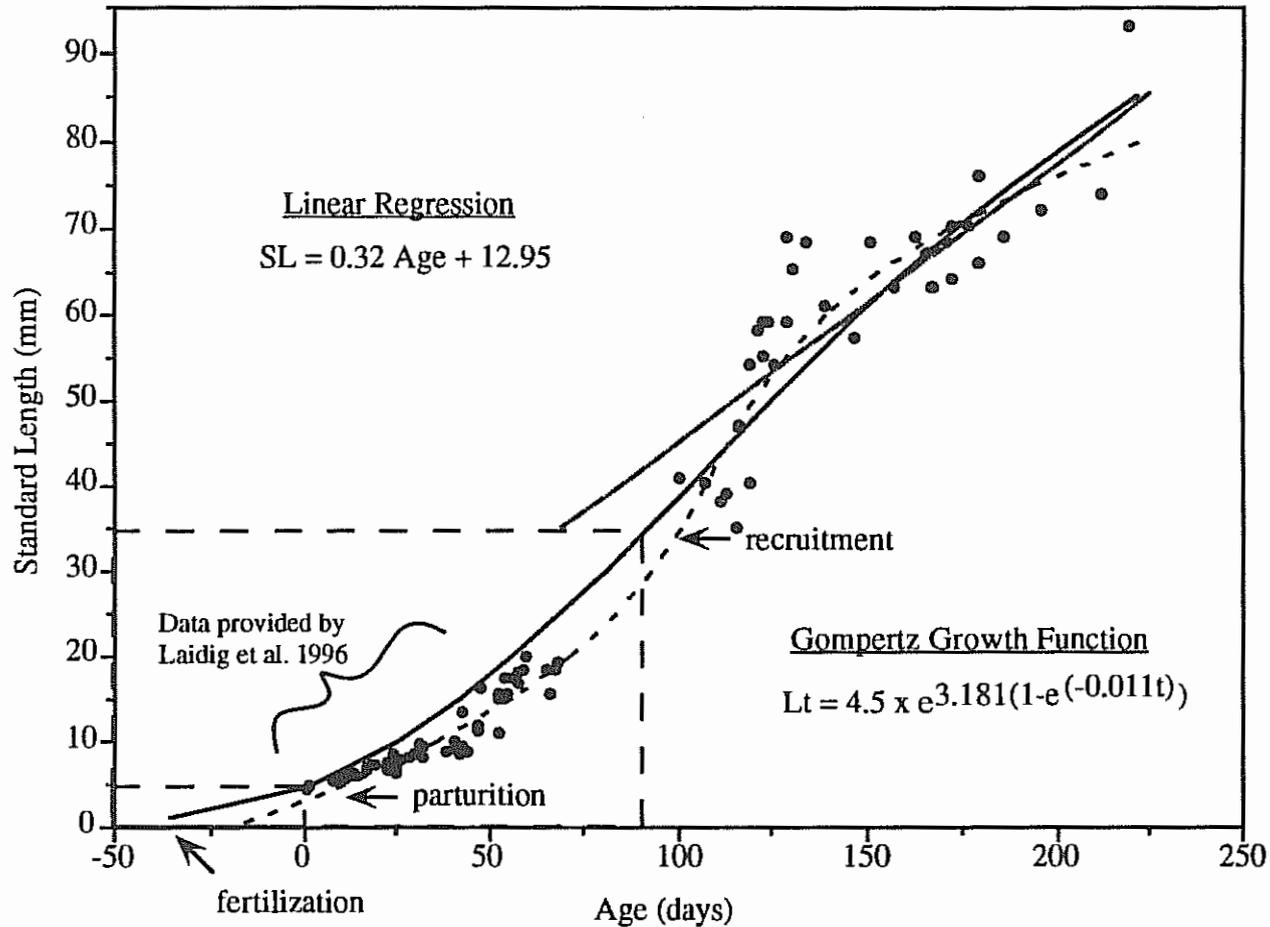


Figure 16. Gompertz growth function and linear regression for daily growth of benthic, YOY *Sebastes saxicola*. Dotted line represents the best fit curve given unlimited parameters. Specimens were caught over soft bottom habitats between 40-100 m in Monterey Bay, CA from March 1995 through February 1996. Ages were estimated using daily growth increments of the sagittal otoliths.

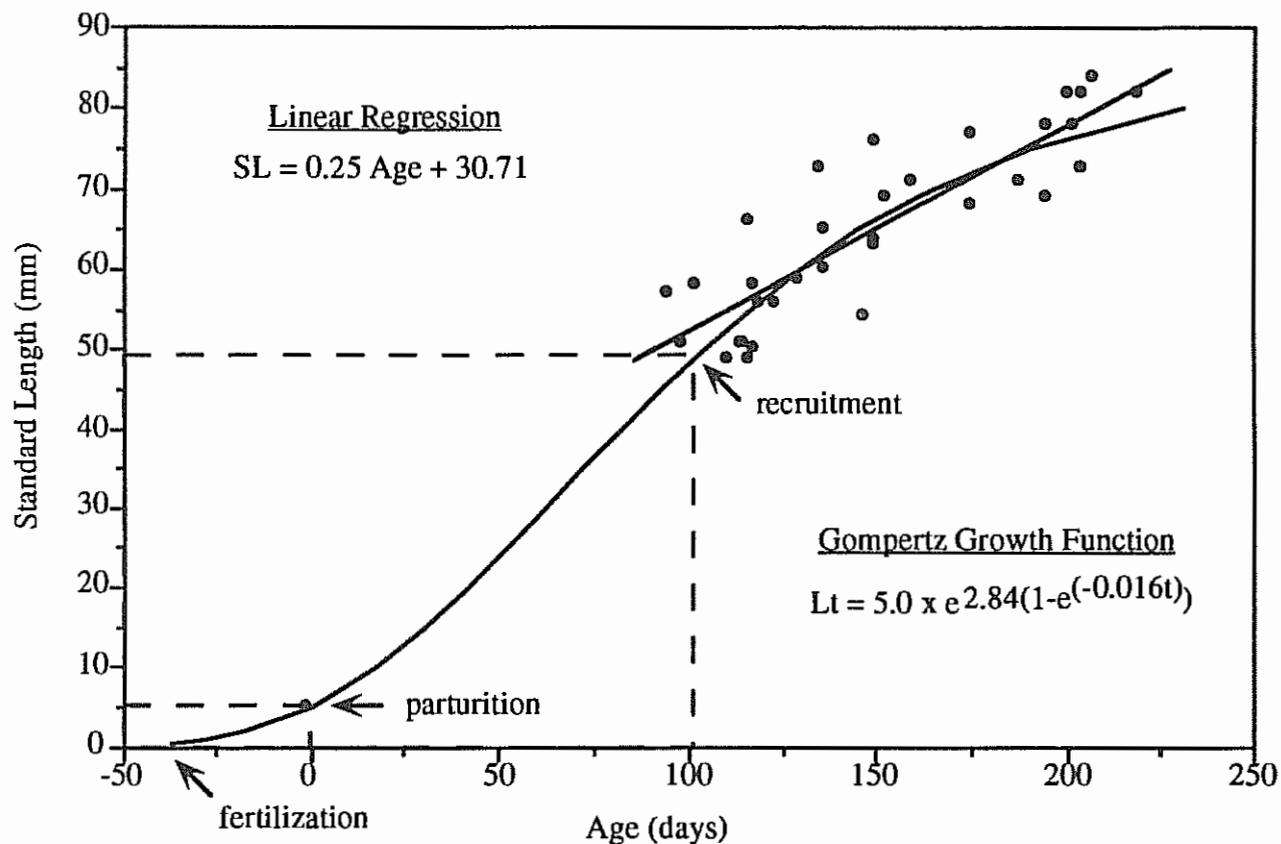


Figure 17. Gompertz growth function and linear regression for daily growth of benthic, YOY *Sebastes levis*. Specimens were caught over soft bottom habitats between 40-100 m in Monterey Bay, CA from March 1995 through February 1996. Ages were estimated using daily growth increments of the sagittal otoliths.

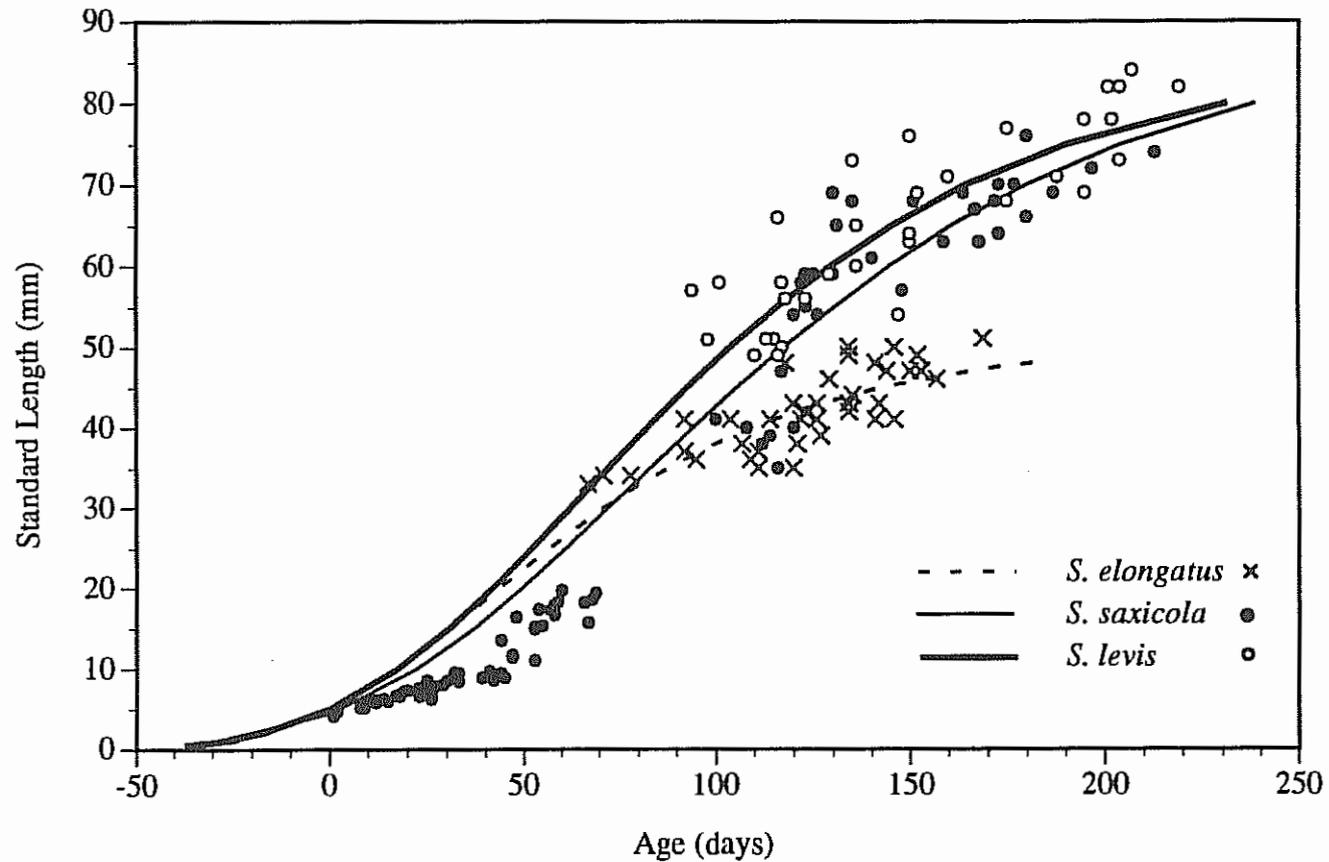


Figure 18. Predicted Gompertz growth functions and size at age data for benthic juvenile *Sebastes elongatus*, *S. saxicola* and *S. levis*. Specimens were caught over soft bottom habitats between 40-100 m in Monterey Bay, CA from March 1995 through February 1996. Ages were estimated using daily growth increments of the sagittal otoliths.

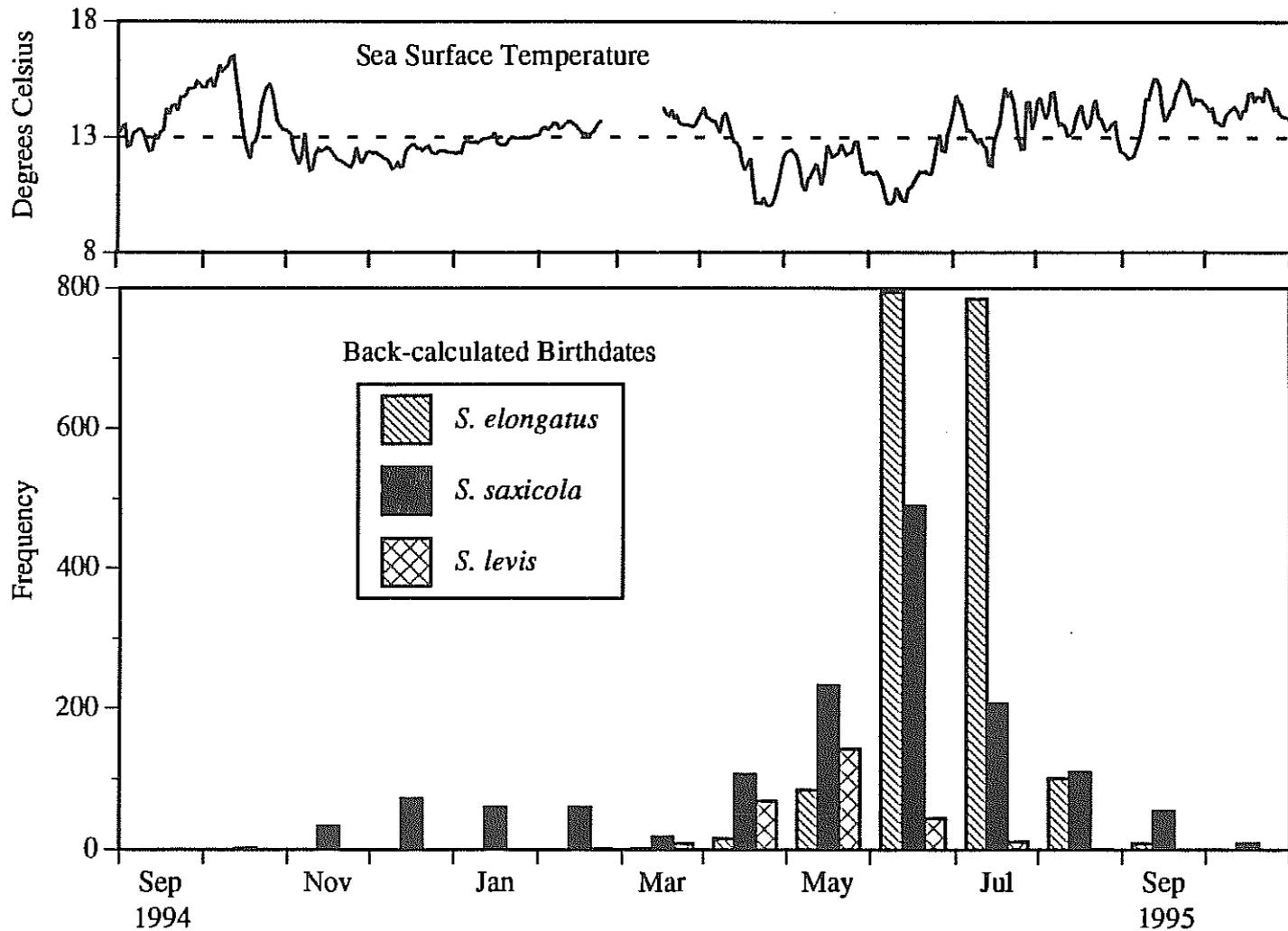


Figure 19. Timing of back-calculated birthdates for *Sebastes elongatus*, *S. saxicola* and *S. levis* in relation to sea surface temperature. Fish were caught over soft bottoms in Monterey Bay, CA between March 1995 and February 1996.