OCEANOGRAPHIC ASSOCIATIONS OF NEUSTONIC LARVAL AND JUVENILE FISHES AND DUNGENESS CRAB MEGALOPAE OFF OREGON

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ABSTRACT

The larval and juvenile fishes and crabs inhabiting the neustonic zone within 50 km of the coast were sampled biweekly from April through July 1984, with a Manta net (mouth 1.0 m wide × 0.7 m deep), and a large neuston trawl (mouth 3.5 m wide × 1.0 m deep). The Manta net was an efficient sampler for larval fishes and crabs, while the neuston trawl collected larger juvenile fishes that had rarely been observed in previous studies.

Nocturnal sampling accounted for nearly all the ichthyoneuston and zooplankton taken. Dungeness crab megalopae were the most abundant species. Although present throughout the survey, the great majority were found in very large aggregations along visible convergence zones or in association with *Velella velella*. Discrete groups of abundant larval and juvenile fishes were found prior to upwelling (*Parophrys vetulus*, *Scorpaenichthys marmoratus*, *Hemilepidotus spinosus*, *Hexagrammos* sp., and *Anoplopoma fimbria*) and after its onset (*Engraulis mordax* and *Sebastes* spp.). These species had distinct zonal (east-west) distribution patterns and were generally associated with, or affected by, hydrographic characteristics such as convergences, upwelling, and the Columbia River plume.

Recent studies of the ichthyoplankton off the northwest coast of the United States have contributed new information on the temporal and spatial occurrences of larvae of coastal and pelagic fish species (Richardson 1973; Richardson and Pearcy 1977; Laroche and Richardson 1979; Richardson et al. 1980; Kendall and Clark 1982a, b; Clark 1984; Bates 1984; Mundy 1983; Brodeur et al. 1985; Boehlert et al. 1985). These surveys focused on larvae occurring below the surface layer of the ocean, although concurrent neustonic samples were occasionally collected (Kendall and Clark 1982 a, b; Clark 1984; Bates 1984; Richardson[2]). Comparison of simultaneous surface and subsurface samples demonstrated that many species were found in both depth strata, while an additional group of species was collected only from the neustonic zone. Brodeur et al. (1987) examined the larval fish and invertebrate components of the neuston in the northeast Pacific, and determined that these organisms were frequent prey items of juvenile salmonids.

Standard plankton and neuston nets used in these studies were effective in collecting the relatively slow-moving early larvae. However, net avoidance by larger larvae and juvenile stages (Barkley 1972; Murphy and Clutter 1972) suggests that use of traditional collecting gear is inappropriate for more mobile fishes. This paper describes the results of a neustonic survey conducted off the Oregon coast in the spring and summer of 1984 that focused on the larger ichthyoneuston. Conventional sampling gear and a new net designed specifically for sampling juvenile fishes were used to characterize the temporal and spatial distribution patterns of both larval and juvenile ichthyoneuston and Dungeness crab, *Cancer magister*, megalopae.

MATERIALS AND METHODS

Sampling was conducted at approximately 2-wk intervals from early April through July 1984, on an east-west transect along the 44°40′N parallel, 3 km north of Newport, OR (Fig. 1). Stations were located at distances of 1, 5, 10, 15, 20, 30, 40, and 50 km from shore. The stations were occupied twice during each 24-h cruise, once during the day and once at night. On one cruise (8–10 June), the 50 km station was occupied for 27 hours to assess diel variation in abundance of neustonic organisms. In response to several

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[2]Richardson, S. L. Oregon's coastal ichthyoneuston - a preliminary report. Unpubl. rep. Presented at American Society of Ichthyologists and Herpetologists, Williamsburg, VA, June 1975.

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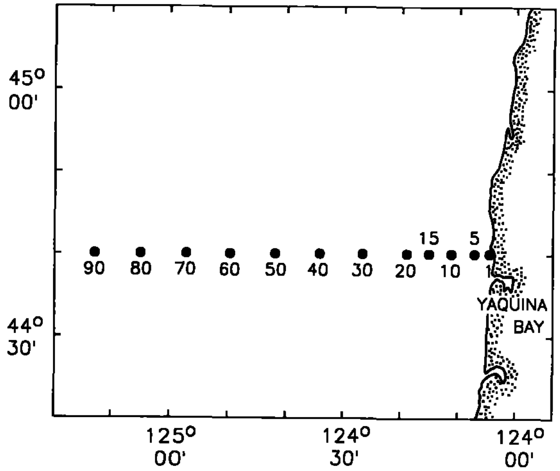

FIGURE 1.—Location of stations along the transect off Newport, OR. The numbers indicate distance offshore in kilometers.

weeks of strong upwelling, during which very few larvae were collected close to the coast, the sampling scheme was modified for the two July cruises by eliminating some of the inshore stations and extending the transect as far offshore as 90 km. Only night samples were collected during July.

One of the primary considerations of the survey was to collect samples while minimizing net avoidance by the target organisms. Reduction of vessel-induced disturbance was accomplished by deploying the collecting gear from the ends of 12 m-long outriggers on the FV *Cumberland Trail*, a chartered 23 m commercial scallop-fishing vessel.

Two different nets were used to collect the samples. Larval fish and zooplankton were collected with a Manta neuston net (Brown and Cheng 1981), modified to have a mouth 1.0 m wide × 0.7 m deep. The Manta frame was equipped with a green-colored 0.333 mm mesh net, PVC cod end bucket, and General Oceanics model 2030 digital flowmeter[3]. A two-point bridle was attached to the upper corners of the frame. Drag on the net while towing kept the entire bridle and towing wire assembly out of the water.

The second net was designed to collect the larger juvenile fishes that were assumed to avoid the smaller Manta net. The neuston trawl was constructed with a mouth 3.50 m wide × 1.05 m deep (Fig. 2a). The frame consisted of 43 mm (outside diameter) heavy-duty galvanized pipe, with towing points welded at the four corners. Flotation for the frame was provided by three inflatable spar buoy floats. These 40 cm diameter floats had hollow tubes running through their centers and were fitted onto the upper bar of the frame. The 8.5 m-long net was made of 4.8 mm green-colored woven mesh, with a 15 cm-wide cloth collar around the mouth, PVC cod end bucket and General Oceanics model 2030 flowmeter. The net had a mouth slightly larger than the frame (3.70 m × 1.20 m) so the net could be laced around the outside of the frame and flotation buoys. The ends of six 12 mm polypropylene rope riblines running the length of the net were shackeled to the frame for additional support. A 4-point bridle of 6.4 mm wire was attached to the corners of the neuston trawl (Fig. 2b). Drag forces kept the entire bridle and towing wire (except for the two short segments attached to the bottom of the frame) out of the water. A length of 5 cm polypropylene rope was attached between the upper towing points on the frame, as a bridle for use in deploying and retrieving the net. A line attached to the retrieval bridle was passed to a hydraulic capstan through a block tied in the rigging over the deck. During a tow, this retrieval line was slackened, but remained attached to the vessel, and floated in a broad arc behind the net mouth.

At each station, the neuston trawl and Manta net were towed simultaneously from the port and starboard outriggers, at approximately 1–1.5 m/second. Tows were generally made either against or with the direction of the prevailing swells. The Manta net was usually fished for approximately 8–9 minutes/tow and filtered about 300–400 m^3. The neuston trawl generally filtered 2,000–3,000 m^3 during a 10–11 minute tow. Additional tows with the neuston trawl were frequently made at a station to assess small-scale patchiness and to sample visible "structures" in the surface layer, such as convergence zones marked by foam lines and rafts of the pleustonic hydroid *Velella velella*.

On several cruises, onset of high winds and rough sea conditions prevented use of the Manta net during the daytime sampling of the transect as we returned toward shore. However, we were able to fish the neuston trawl in winds up to an estimated 40–45 km/hour, and in white-capped seas of 2–3 m. Neuston trawl samples were collected at alternate stations during the periods of adverse weather.

[3]References to trade names do not imply endorsement by the National Marine Fisheries Service, NOAA.

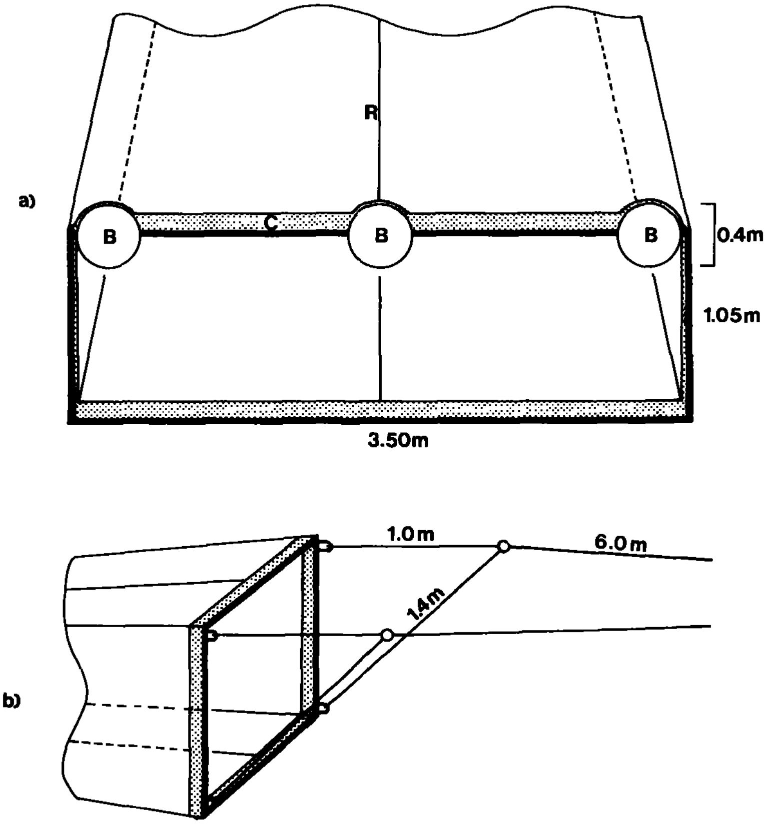

FIGURE 2a.—Front view of the neuston trawl; B = inflated 40 cm diameter spar buoys; C = cloth collar around mouth of net; R = polypropylene rib lines.
FIGURE 2b.—Side view of the neuston trawl showing construction of the towing bridle. Floats were removed for clarity.

Several very large catches of Dungeness crab megalopae in the neuston trawl were subsampled by volume, with the majority of the megalopae being returned alive to the ocean. Samples from both nets were preserved in 10% formalin/seawater and sent to the laboratory for analysis. All larval and juvenile fishes were identified to the lowest practical taxonomic level. After extrapolating catch sizes from subsample counts, the data were normalized to produce density estimates of organisms/1,000 m^3. As an indicator of patchiness of abundant taxa, the coefficient of dispersion (C.D. = $S^2/\overline{X}$) was calculated for the samples in which each taxon was present.

Hydrographic and meteorological data were collected at each station. Surface water temperature was determined with a handheld bucket thermometer. Water samples were collected for laboratory analysis of surface salinity using a Model 8400 Guildline Autosalinometer. A 200 mL surface water sample was filtered through a 0.3 μm pore size Gelman A/E glass fiber filter for determination of chlorophyll a concentration. The filters were stored in dessicant over dry ice at sea, and then in a freezer, before acetone extraction of the chlorophyll a and analysis with a Turner Designs Model 10 Fluorometer. During the daytime, Secchi depths were estimated, using a 30 cm disc, and surface irradiance was measured with a handheld General Electric Model 214 Light Meter. Other data collected included weather and sea state conditions at each station.

RESULTS

Hydrographic Data

The neustonic realm was characterized by distinct temporal and spatial patterns that reflect the highly dynamic springtime oceanographic processes of the Oregon coastal zone. Daily upwelling indices derived from barometric pressure data (Fig. 3; A. Bakun[4]) indicated that in April and May, local winds varied in direction and strength, with one extended period of stormy weather with southwest winds (negative index values). Temperature and salinity profiles during these months showed relatively little variation along the transect within a sampling period (Fig. 4a, b, c). Chlorophyll a peaks and low salinity near shore may have been due to the influence of water exiting Yaquina Bay. The highest chlorophyll a values were observed following periods of northwest winds, and the highest temperatures occurred after a period of very light winds and high insolation.

The hydrographic regime was altered by the onset of northwest winds in June (Fig. 3), which induced the upwelling of cold, more saline nutrient-rich water along the coast. Strong upwelling [defined by Small and Menzies (1981) as a daily index value >50] was sporadic in June but nearly continuous in July. Temperature, salinity, and chlorophyll a profiles rapidly changed in response to the upwelling-favorable winds (Fig. 5a, b, c).

During the 8–10 June cruise, low temperature and high salinity water was found within 5 km of the coast. Low salinity, warm water more than 15 km offshore apparently was the plume of the Columbia River. By 19–20 June, continued offshore transport of the surface layer pushed the inshore edge of the plume to 40 km off the coast. Low chlorophyll a concentrations, low temperatures, and high salinity near shore on 19–20 June indicated the occurrence of active upwelling.

Upwelling persisted through the end of July. Temperature and salinity profiles were similar to those observed during the second June cruise, with the patterns of increasing temperature and decreasing salinity farther offshore continuing to the limits of sampling of 90 km on 8 and 9 July and to 70 km on 23 and 24 July. During the upwelling in July, a dramatic phytoplankton bloom occurred in the surface waters within 30 km of the coast. Chlorophyll a concentrations here were denser and broader in offshore extent than the surface and subsurface biomass concentrations previously observed off Oregon (Small and Menzies, 1981).

[4]A. Bakun, Pacific Environmental Group, National Marine Fisheries Service, Monterey, CA 93940, pers. commun. August 1984.

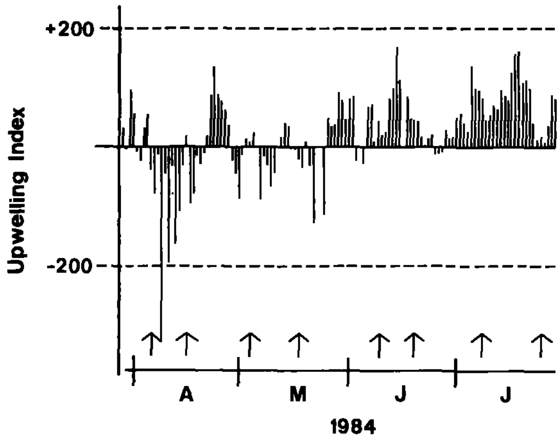

FIGURE 3.—Daily upwelling indices for spring-summer 1984. Positive values >50 indicate occurrence of winds inducing strong upwelling. Arrows indicate dates of sampling cruises.

Ichthyoneuston

A total of 107 Manta net and 142 neuston trawl samples collected 48 taxa of larval, juvenile, and adult fishes. Larvae ≤10 mm and a few juveniles were collected by the Manta net, while large numbers of juvenile fishes up to 60–70 mm were taken by the neuston trawl. Size-frequency data for three of the commonest species (Fig. 6 a, b, c) illustrate the relative ability of the nets to capture different sizes of fishes.

Nighttime sampling (59% of the Manta net tows and 62% of the neuston trawl tows) accounted for 93.3% of all fishes in the Manta net catch and 96.5% of the fishes taken in the neuston trawl (Table 1). Four Manta net and 8 neuston trawl tows made during twilight collected 5.4% and 2.9%, respectively, of the total number of fishes taken with each gear type (Table 2). Only 1.3% of the Manta net catch and 0.6% of the neuston trawl catch was made during daytime (Table 2).

Only two species were not collected predominantly at night. Larval Pacific saury, *Cololabis saira*, were taken in both day and night Manta net samples. Larval northern lampfish, *Stenobrachius leucopsarus*, were abundant only in the twilight samples from early June (Tables 1, 2).

Arbitrary criteria on frequency of occurrence (in >15% of the night samples of either net) or abundance (peak densities >40/1,000 m^3) indicated that nine taxa of larval, juvenile, and adult fishes were dominant components of the ichthyoneuston. Most taxa were characterized by dis-

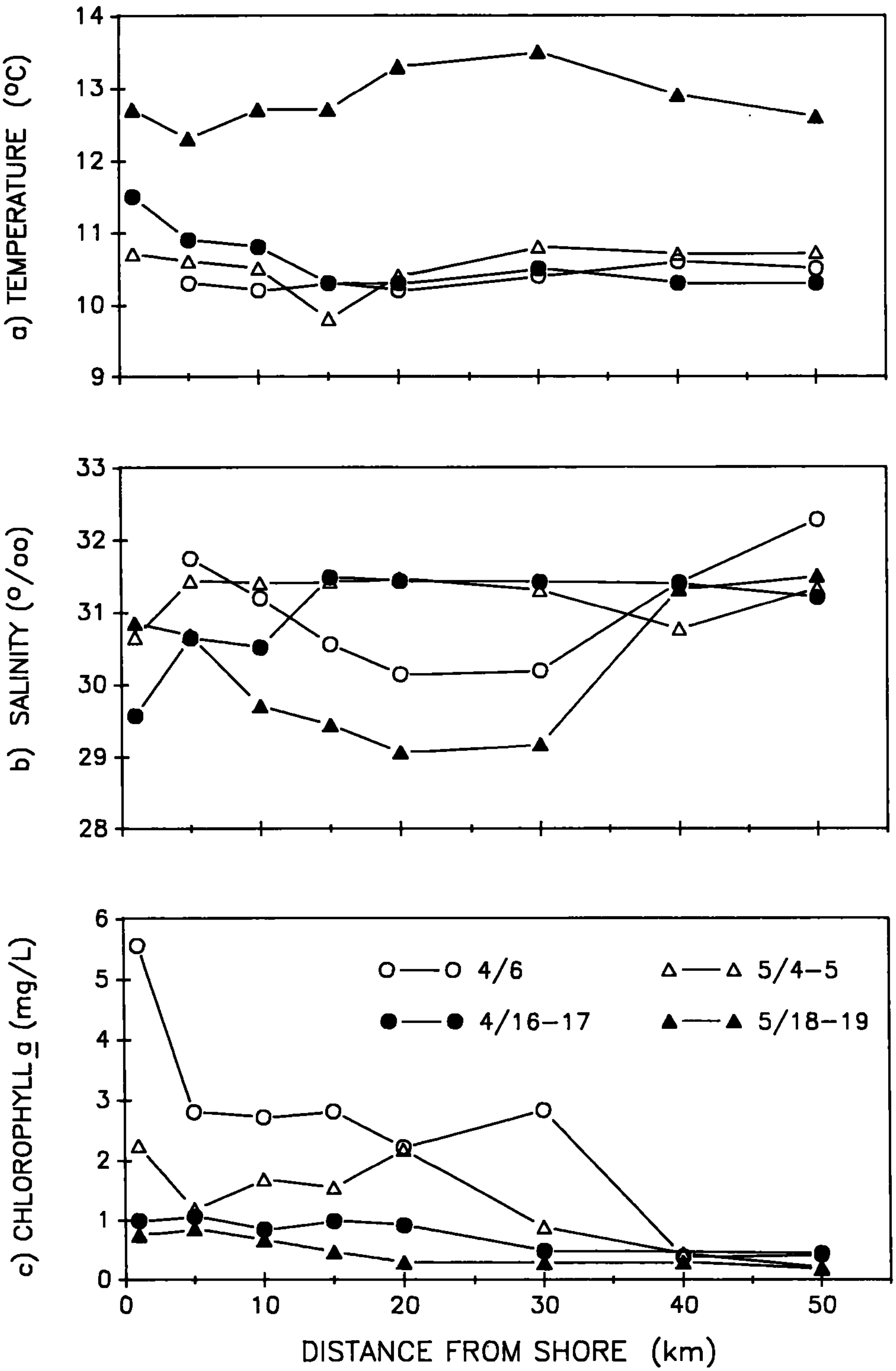

FIGURE 4a-c.—Nighttime environmental conditions observed on each cruise during the pre-upwelling period. a = temperature; b = salinity; c = chlorophyll *a* concentration.

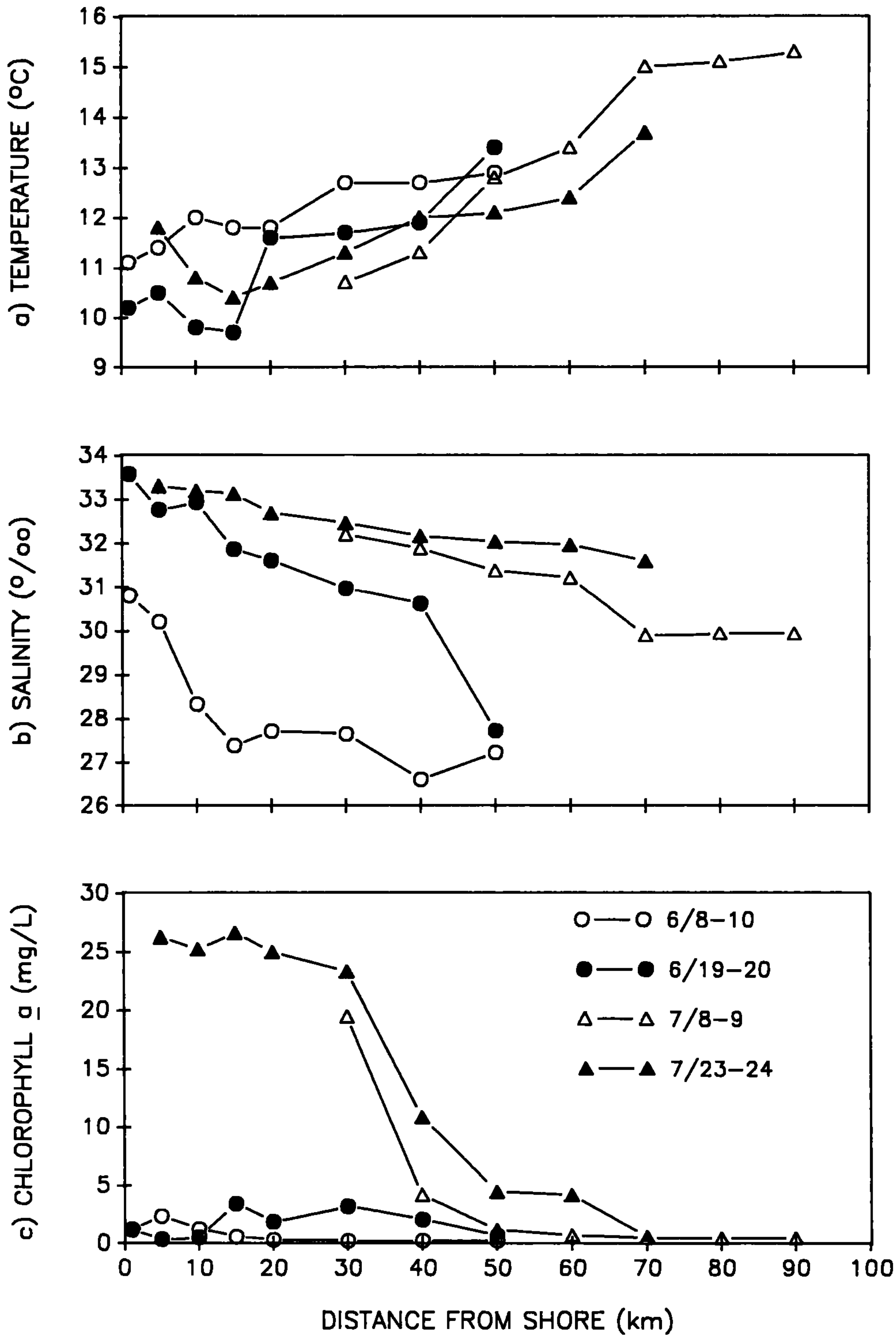

FIGURE 5a-c.—Nighttime environmental conditions observed on each cruise during the upwelling period. a = temperature; b = salinity; c = chlorophyll *a* concentration.

tinct temporal shifts in occurrence: Five taxa were abundant only prior to the onset of continuous upwelling in mid-June, three taxa were sporadically abundant following the beginning of upwelling, and one species (*Ronquilus jordani*) was present throughout the survey.

Pre-upwelling Species

The numerically dominant species in the nearshore region in spring was larval English sole, *Parophyrys vetulus*. These larvae were patchily distributed (C.D. = 32.5) within 30 km offshore, reaching densities of 75/1,000 m^3 in Manta net collections. Larval abundance declined rapidly after April (Table 1). Size-frequency distributions indicated that the Manta net was more effective than the neuston trawl for collecting fish ≤15 mm (Kolmogorov-Smirnov test, $P < 0.01$). Eye migration in the larger fish (20–24 mm) was nearly complete, indicative of their impending shift to a benthic existence. Similar-sized juveniles were taken nearshore in April in benthic tows (B. Mundy[5]).

Cabezon, *Scorpaenichthys marmoratus*, larvae were most abundant in Manta catches in the spring (Table 1), although newly hatched larvae were collected near shore through June. The smallest larvae (4–6 mm) were taken only at the 1–15 km stations, while larvae up to 10 mm were found along the entire transect. These larvae were patchily distributed, with April densities reaching 207/1,000 m^3 (C.D. = 92.7). Frequency of occurrence and larval density declined through early July. Large juvenile cabezon (26–38 mm) were collected by the neuston trawl (Fig. 6a). These juveniles were encountered all along the transect from April to mid-June.

Two dominant taxa found at all stations prior to upwelling were greenling (*Hexagrammos* sp.) and brown Irish lord, *Hemilepidotus spinosus*. Juvenile greenlings were the most frequently collected species, occurring in 44.8% of the nighttime neuston trawl samples (Table 1), although they were rarely taken by the Manta net (Fig. 6b). They were the most evenly dispersed of the abundant fish collected (C.D. = 2.2), and never exceeded densities of 10/1,000 m^3. The two largest catches of greenling were made in association with distinct hydrographic features. Nineteen ju-

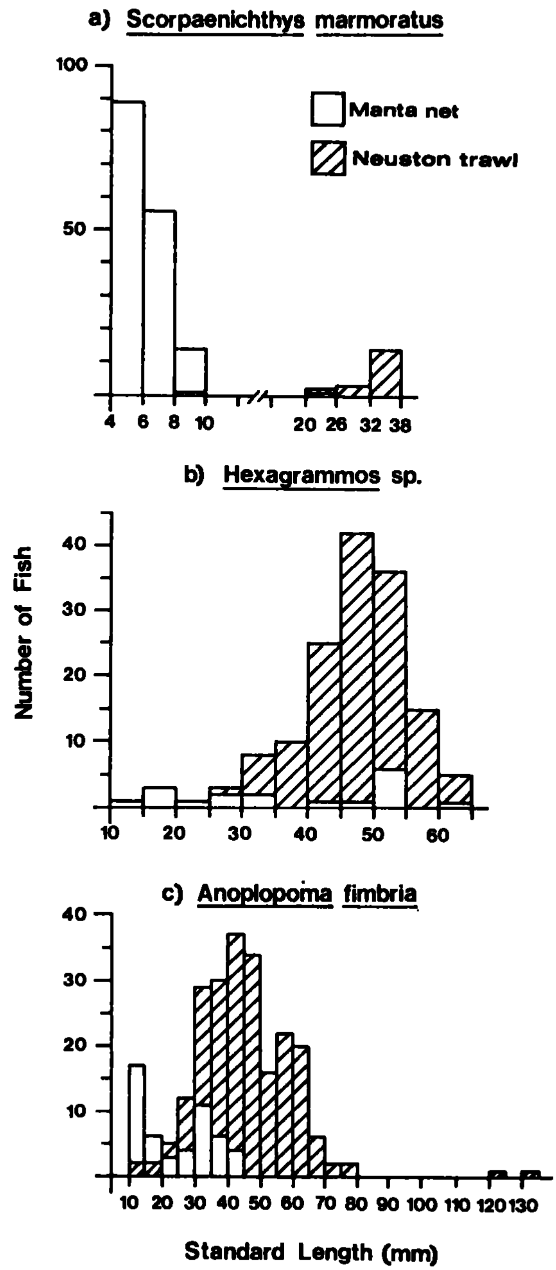

FIGURE 6a-c.—Length-frequency data of larval and juvenile fishes collected by each net. a = *Scorpaenichthys marmoratus*; b = *Hexagrammos* sp.; c = *Anoplopoma fimbria*.

veniles were collected from a convergence zone near shore in mid-May (along with 150,000 Dungeness crab megalopae) and 20 juveniles were taken from Columbia River plume water 50 km offshore in early June. Mean lengths of greenling from the neuston trawl samples increased from

[5]B. C. Mundy, Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, 2570 Dole Street, Honolulu, HI 96822, pers. commun. May 1984.

TABLE 1.—Nighttime abundance (A = mean of all catches/1,000 m³) and frequency of occurrence (F = number of catches) of all ichthyoneuston taxa collected by each net during each month of the survey in 1984.

	April				May				June				July				Total			
	Manta		Trawl		Manta		Trawl		Manta		Trawl		Manta		Trawl		Manta		Trawl	
Species	A	F(15)	A	F(23)	A	F(16)	A	F(22)	A	F(19)	A	F(24)	A	F(15)	A	F(18)	A	F(65)	A	F(87)
Clupeidae																				
Clupea harengus	3.67	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3.67	2	—	—
Engraulidae																				
Engraulis mordax	—	—	—	—	—	—	—	—	1.98	1	0.25	1	127.90	5	0.28	1	106.91	6	0.27	2
Salmonidae																				
Oncorhynchus keta	—	—	—	—	—	—	0.51	1	—	—	—	—	—	—	—	—	—	—	0.51	1
O. kisutch	—	—	—	—	—	—	0.73	2	—	—	—	—	—	—	0.41	3	—	—	0.54	5
Salmo gairdneri	2.59	1	—	—	—	—	0.60	2	—	—	—	—	—	—	—	—	2.59	1	0.60	2
Osmeridae																				
unidentified	8.78	2	0.40	1	—	—	0.37	1	—	—	—	—	4.32	2	—	—	6.55	4	0.39	2
Sternoptychidae																				
Danaphos oculata	—	—	—	—	—	—	—	—	—	—	—	—	1.68	1	—	—	1.68	1	—	—
Myctophidae																				
Diaphus theta	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.71	1	—	—	0.71	1
Stenobrachius leucopsarus	—	—	0.43	1	2.36	1	—	—	2.16	1	—	—	2.82	2	—	—	2.54	4	0.43	1
Symbolophorus californianus	—	—	—	—	—	—	—	—	—	—	—	—	1.81	1	0.52	3	1.81	1	0.52	3
Tarletonbeania crenularis	—	—	—	—	—	—	0.43	1	6.28	1	0.38	1	153.11	5	42.71	5	128.64	6	30.62	7
Gadidae																				
Microgadus proximus	—	—	—	—	—	—	—	—	—	—	1.02	1	—	—	0.42	1	—	—	0.72	2
Scomberesocidae																				
Cololabis saira	2.76	3	0.36	2	—	—	0.43	1	7.27	3	0.34	4	2.33	5	1.30	3	3.79	11	0.64	10
Gasterosteidae																				
Gasterosteus aculeatus	—	—	—	—	—	—	0.32	1	—	—	—	—	—	—	1.29	1	—	—	0.81	2
Bathymasteridae																				
Ronquilus jordani	4.50	5	—	—	5.59	6	—	—	4.53	11	—	—	15.54	5	0.33	2	6.80	27	0.33	2
Cryptacanthodidae																				
Delolepis gigantea	2.63	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.63	1	—	—
Lyconectes aleutensis	5.00	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5.00	1	—	—
Ammodytidae																				
Ammodytes hexapterus	2.58	4	—	—	9.71	1	—	—	1.64	1	—	—	—	—	—	—	3.61	6	—	—
Stromateidae																				
Icichthys lockingtoni	—	—	—	—	—	—	—	—	—	—	—	—	5.36	3	—	—	5.36	3	—	—
Scorpaenidae																				
Sebastes crameri	—	—	0.44	1	—	—	0.75	3	2.65	2	0.94	9	—	—	—	—	2.65	2	0.86	13
S. melanops	—	—	—	—	—	—	—	—	—	—	0.42	3	—	—	1.01	1	—	—	0.57	4
S. pinniger	—	—	—	—	—	—	0.38	1	—	—	0.28	1	—	—	0.53	2	—	—	0.43	4
S. reedi	—	—	—	—	—	—	—	—	1.74	3	—	—	—	—	0.34	1	1.74	3	0.34	1
Sebastes spp. larvae	19.42	4	—	—	10.42	4	—	—	18.58	8	—	—	238.28	6	—	—	77.07	22	—	—
Sebastes spp. juveniles	—	—	0.43	2	8.99	4	1.62	6	—	—	0.49	7	1.42	2	—	—	6.47	6	0.93	15
Anoplopomatidae																				
Anoplopoma fimbria	3.09	4	1.35	4	10.35	6	3.18	3	8.68	5	11.73	7	—	—	0.34	2	7.86	15	5.97	16
Hexagrammidae																				
Hexagrammos sp.	3.85	4	0.79	13	3.60	5	1.31	11	1.83	4	1.80	15	—	—	—	—	3.07	13	1.33	39
Ophiodon elongatus	12.91	2	—	—	6.28	2	—	—	—	—	—	—	—	—	—	—	9.59	4	—	—
Oxylebius pictus	—	—	0.61	1	—	—	—	—	1.64	1	0.52	1	1.61	1	0.30	1	1.63	2	0.48	3

TABLE 1.—*Continued*.

Species	April				May				June				July				Total			
	Manta		Trawl		Manta		Trawl		Manta		Trawl		Manta		Trawl		Manta		Trawl	
	A	F(15)	A	F(23)	A	F(16)	A	F(22)	A	F(19)	A	F(24)	A	F(15)	A	F(18)	A	F(65)	A	F(87)
Cottidae																				
Artedius harringtoni	3.44	3	—	—	9.71	1	0.36	1	4.51	3	—	—	1.74	1	—	—	4.39	8	0.36	1
Cottus asper	15.68	2	—	—	—	—	—	—	4.47	2	—	—	—	—	—	—	10.07	4	—	—
Hemilepidotus spinosus	5.45	3	1.05	12	7.39	7	6.11	15	2.40	3	3.77	6	—	—	—	—	5.79	13	3.84	33
Leptocottus armatus	19.09	1	—	—	2.22	1	—	—	—	—	—	—	—	—	—	—	10.66	2	—	—
Scorpaenichthys marmoratus	47.19	10	0.47	5	15.16	5	0.37	3	3.11	10	0.76	5	2.66	2	—	—	21.63	27	0.56	13
Agonidae																				
Agonopsis vulsa	—	—	0.37	1	—	—	0.45	2	—	—	0.46	4	—	—	0.34	2	—	—	0.42	9
Liparididae																				
unidentified	3.99	2	1.28	1	—	—	—	—	2.91	6	0.57	7	3.85	4	0.34	3	3.39	12	0.57	11
Bothidae																				
Citharichthys sordidus	—	—	0.41	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.41	1
C. stigmaeus	—	—	0.43	4	—	—	0.67	2	1.98	1	1.24	7	—	—	0.50	4	1.98	1	0.81	17
Pleuronectidae																				
Eopsetta jordani	—	—	—	—	—	—	0.39	2	—	—	0.71	2	—	—	—	—	—	—	0.55	4
Glyptocephalus zachirus	2.50	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.50	1	—	—
Isopsetta isolepis	—	—	0.41	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.41	1
Parophrys vetulus	22.38	6	4.42	9	2.53	3	0.68	5	1.59	1	0.25	1	—	—	—	—	14.35	10	2.89	15
Pleuronichthys sp.	—	—	—	—	—	—	—	—	—	—	0.51	1	—	—	—	—	—	—	0.51	1
Psettichthys melanostictus	9.48	3	—	—	—	—	—	—	8.04	1	6.61	2	2.20	1	—	—	7.74	5	6.61	2
Unidentifiable	7.92	4	—	—	—	—	0.51	1	2.32	3	—	—	3.89	3	—	—	5.29	10	0.51	1
Total number of taxa	22		16		13		20		21		20		17		17		33		34	
Mean abundance/1,000 m³	63.53		3.39		22.68		6.43		20.64		7.48		199.91		12.81		72.49		7.24	

TABLE 2.—Daytime abundance (A = mean of all catches/1,000 m³) and frequency of occurrence (F = number of samples) of all ichthyoneuston taxa collected by each net during the first 3 months of the survey. Daytime samples were not collected in July. Twilight sampling (45 minutes before and after sunset and sunrise) was conducted at the 50 km station on 8-10 June, 1984.

	April				May				June				Daytime total				June twilight			
	Manta		Trawl		Manta		Trawl		Manta		Trawl		Manta		Trawl		Manta		Trawl	
Species	A	F(15)	A	F(17)	A	F(8)	A	F(12)	A	F(13)	A	F(18)	A	F(36)	A	F(47)	A	F(6)	A	F(8)
Engraulidae																				
Engraulis mordax	—	—	—	—	—	—	—	—	2.41	4	—	—	2.41	4	—	—	—	—	—	—
Osmeridae																				
unidentified	—	—	—	—	—	—	—	—	1.56	1	—	—	1.56	1	—	—	—	—	—	—
Myctophidae																				
Stenobrachius leucopsarus	—	—	—	—	—	—	—	—	1.89	1	—	—	1.89	1	—	—	27.62	3	—	—
Scomberesocidae																				
Cololabis saira	2.48	4	—	—	—	—	—	—	2.44	4	—	—	2.46	8	—	—	2.75	3	—	—
Bathymasteridae																				
Ronquilus jordani	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.71	3	—	—
Cryptacanthodidae																				
Lyconectes aleutensis	2.54	1	—	—	—	—	—	—	—	—	—	—	2.54	1	—	—	—	—	—	—
Ammodytidae																				
Ammodytes hexapterus	—	—	—	—	—	—	—	—	—	—	0.33	1	—	—	0.33	1	—	—	—	—
Scorpaenidae																				
Sebastes crameri	—	—	—	—	—	—	0.32	1	—	—	—	—	—	—	0.32	1	—	—	0.97	2
S. mystinus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.50	1	—	—
Sebastes spp. larvae	—	—	—	—	—	—	—	—	5.39	2	—	—	5.39	2	—	—	4.59	2	—	—
Sebastes spp. juveniles	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4.50	1	0.50	2
Anoplopomatidae																				
Anoplopoma fimbria	2.60	1	—	—	2.87	1	0.38	1	—	—	—	—	2.74	2	0.38	1	2.30	2	1.48	5
Hexagrammidae																				
Hexagrammos sp.	2.74	2	0.81	2	—	—	—	—	—	—	—	—	2.74	2	0.81	2	—	—	1.10	3
Ophiodon elongatus	2.52	2	—	—	—	—	—	—	—	—	—	—	2.52	2	—	—	—	—	—	—
Cottidae																				
unidentified	—	—	—	—	1.57	2	—	—	—	—	—	—	1.57	2	—	—	—	—	—	—
Clinocottus globiceps	—	—	—	—	—	—	—	—	1.57	1	—	—	1.57	1	—	—	—	—	—	—
Hemilepidotus spinosus	—	—	—	—	—	—	0.35	1	—	—	—	—	—	—	0.35	1	10.30	2	1.17	7
Scorpaenichthys marmoratus	2.52	2	—	—	—	—	—	—	1.58	1	—	—	2.20	3	—	—	1.93	1	0.46	1
Liparididae																				
unidentified	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.37	1
Pleuronectidae																				
Eopsetta jordani	—	—	—	—	—	—	—	—	1.61	1	—	—	1.61	1	—	—	—	—	—	—
Parophrys vetulus	2.76	1	0.94	1	—	—	0.32	1	—	—	—	—	2.76	1	0.63	2	—	—	—	—
Unidentifiable	—	—	—	—	—	—	—	—	1.89	2	—	—	1.89	2	—	—	—	—	—	—
Total number of taxa	7		2		2		4		9		1		15		6		9		7	
Mean abundance/1,000 m³	2.22		0.15		0.75		0.11		3.24		0.02		2.26		0.08		24.60		2.83	

38.8 mm ($N = 10$) in early April to 51.2 mm ($N = 72$) during the first June cruise.

Brown Irish lord juveniles were the numerically most abundant and the second most frequently occurring species (Table 1). Early juveniles (10–20 mm) were taken with both nets in April and May only at the offshore (40–50 km) stations. Larger juveniles (20–30 mm) were patchily distributed from April through mid-June all along the transect (C.D. = 14.1). Although 47% of the total number of trawl caught specimens were taken in densities below 15/1,000 m^3, repeated sampling in one large aggregation accounted for the bulk of the catch. Three sequential tows at the 50 km station on 5 May had juvenile densities of 15–39/1,000 m^3, but distinctive hydrographic characteristics at the station were not detected.

The only species with a characteristic offshore distribution prior to upwelling was sablefish, *Anoplopoma fimbria*. Small juveniles (10–45 mm) were effectively taken by the Manta net, while the neuston trawl was more efficient at collecting 30–70 mm specimens (Fig. 6c). The 10–50 mm fish were collected primarily at the 50 km station from April through mid-June, although several specimens were taken closer inshore. The 50–75 mm fish were captured only on 8–10 June from the Columbia River plume water at the 50 km station. After the onset of upwelling, two individuals (120–130 mm) were taken 80–90 km from shore.

Upwelling Species

Three taxa were abundant on only one of three cruises made after the onset of upwelling in mid-June (Table 1). Distributions of northern anchovy, *Engraulis mordax*, larvae; rockfish (*Sebastes* spp.) larvae; and adult blue lanternfish, *Tarletonbeania crenularis*, overlapped at some offshore stations on 8 and 9 July. The offshore portion of the transect was characterized by a drop in salinity and an increase in temperature between 60 and 70 km offshore (Fig. 5a, b), indicating a transition from coastal to Columbia River plume water.

Of the 814 rockfish larvae collected throughout the survey, 87% were taken at the 50–90 km stations on this cruise, with a peak density of the 3.5–7.0 mm larvae of 684/1,000 m^3. Adult blue lanternfish were present in densities up to 315/1,000 m^3 at the 60–90 km stations. Lanternfish from simultaneous Manta and neuston trawl tows displayed no difference in length-frequency distributions, although a significant change in the size structure of the catches between stations was observed (K-S test, $P < 0.01$). Mean size of the fish decreased approximately 10% between adjacent stations, from 50.9 mm at 60 km to 37.8 mm at 90 km. Anchovy larvae (3–9 mm) were restricted to the lower salinity plume water at the 70–90 km stations, with peak and mean densities of 368 and 210/1,000 m^3, respectively.

Persistant Species

Only northern ronquils, *Ronquilus jordani*, were abundant in both pre-upwelling and upwelling periods. The elongate larvae and juveniles were collected with the Manta net starting in mid-April, with abundances peaking at 40/1,000 m^3 in July. Mean lengths over this time interval increased from 8.7 mm ($n = 8$) to 26.6 mm ($n = 43$). Ronquils were relatively dispersed along the transect (C.D. = 7.6), and size or seasonal patterns of distribution were not detected.

Dungeness Crab Megalopae

Dungeness crab megalopae were the dominant component of the catches throughout the survey, with an estimated total of 350,000 megalopae collected in 249 hauls. The megalopae were found at most stations during all cruises (Fig. 7), although they were rare seaward of 50 km in July. Megalopae were present in 71.4% of the Manta net daytime tows and 93.8% of the nighttime tows, and in 90.9% and 98.9% of the day and night neuston trawl collections, respectively. All twilight hauls captured megalopae.

Despite the higher frequency of occurrence of megalopae in the neuston trawl, the Manta net was a more accurate estimator of their abundance. For 58 pairs of nighttime catches with densities under 2,000/1,000 m^3, the Manta net caught approximately 3 times as many megalopae per m^3 as the neuston trawl. The 4.8 mm mesh of the neuston trawl apparently enabled some megalopae to pass through the mesh, and some escapement was observed while the trawl was sitting on deck after retrieval. More similar estimates between the nets were obtained when higher densities of megalopae were sampled, probably because of clumping of the large (11 mm total length) spiny megalopae into large masses which clogged the mesh.

In general, densities of megalopae caught by

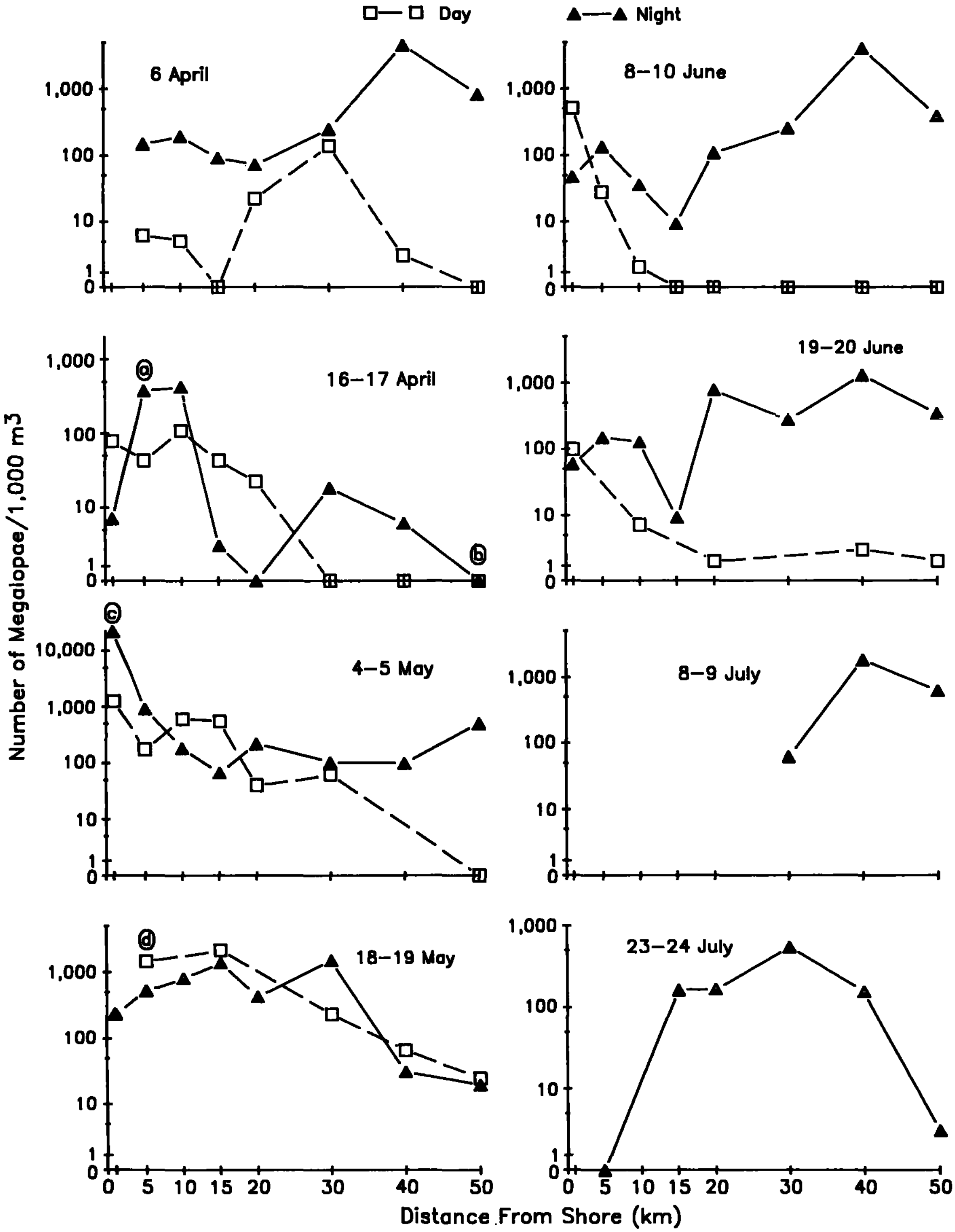

FIGURE 7.—Daytime and nighttime densities of megalopae collected by the Manta net. Rough weather prevented the use of the Manta net during the day of 19 May; neuston trawl data for this portion of the cruise are presented. Circled letters refer to events discussed in the text.

the Manta net in the daytime were lower than at night for each station (Fig. 7). The differences between day and night were particularly apparent on bright sunny days and at the offshore stations. Only one of 13 samples of megalopae collected when light intensity exceeded 4,000 lux had a density over 200/1,000 m^3, while 12 of 24 day samples collected at lower light levels exceeded this density. Highest daytime densities (1,600–2,400/1,000 m^3 in neuston trawl samples) were observed on 19 May when a sudden shift in weather before daybreak resulted in very dark, overcast and rainy skies, with 40–45 km/hour winds and 2–3 m breaking waves.

Water clarity may also affect the daytime abundance estimates of megalopae in the neuston along the transect. Daytime densities were always low seaward of 30 km where Secchi depths exceeded 9 m, while higher densities were observed in the more turbid near-coastal waters with Secchi depths of 4–9 m.

The 27-h occupancy of the 50 km station on 8–9 June provided additional evidence of a distinct diel pattern in utilization of the neustonic habitat by megalopae (Fig. 8). Abundance of megalopae peaked during the twilight periods of dawn and dusk. A significant decrease in abundance was noted in the middle of the night, while midday samples did not collect any megalopae.

In addition to the wide distribution of megalopae along the transect, sampling occasionally detected the aggregation of very large numbers of megalopae (denoted by letters over station blocks in Figure 7). These aggregations were typically associated with hydrodynamic or biological structures in the surface layer.

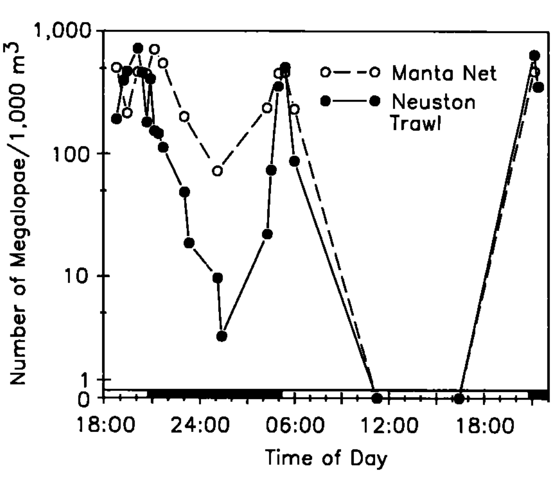

FIGURE 8.—Density of megalopae collected by both nets during a 27 h sampling period 50 km offshore on 8–9 June.

Event A: Simultaneous tows with the Manta net and neuston trawl caught megalopae in densities of 373 and 325/1,000 m^3. The neuston trawl was then redeployed and towed along a foam line marking a surface convergence. An estimated 60,000 megalopae were collected from the convergence zone (24,000/1,000 m^3).

Event B: A series of five consecutive tows with the trawl net was made. Each tow covered a linear distance of approximately 1 km in a westward direction, with an estimated distance of 300 m between tows. Megalopae were very sparse in the simultaneous Manta and trawl tows at the beginning of the series, with densities of 0 and 1.9/1,000 m^3, respectively. The subsequent neuston trawl tows produced density estimates of 79, 3,555, 2,414 and 187/1,000 m^3. Apparently, the megalopae were aggregated over an area extending at least 5 km in the east-west direction.

Event C: Following a period of southwest winds, a large raft of *Velella velella* was found around the inshore station. *Velella velella* were generally found at offshore stations but at densities far lower than the 36 kg/1,000 m^2 level taken here. Although the overall extent of the raft could not be determined at night, the density of megalopae was estimated by both nets at 21,500/1,000 m^3.

Event D: The density of megalopae sampled by the Manta net was 790/1,000 m^3, while a simultaneous neuston trawl tow along a convergence zone only 30 m away collected 150,000 megalopae (46,400/1,000 m^3).

Census estimates of megalopal abundance were computed from nighttime samples for each date (Fig. 9). A modification of Smith's regional census estimate (1972) was used to compute the total number of megalopae occurring in a 1 m wide × 1 m deep track along the surface from the coast to 55 km offshore:

$$C_k = \sum_{i=1}^{n} (A_i D_i)$$

where C_k = estimate of abundance of megalopae per meter of coastline during cruise k

A_i = volume of water in the track surrounding station i, computed from

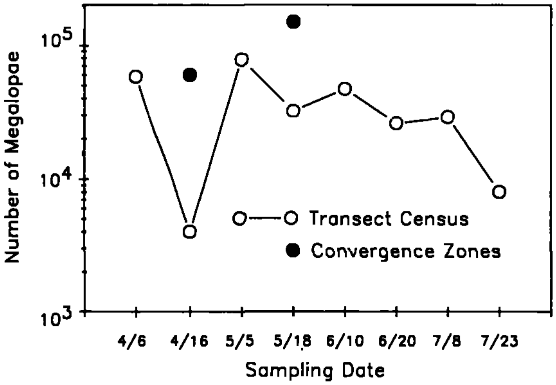

FIGURE 9.—Census estimates of Dungeness crab megalopae at night from Manta net samples for each cruise in a 1 m wide × 1 m deep track extending from the coast to 55 km offshore (30–95 km offshore on 7/8). Single samples from convergence zones sampled with the neuston trawl contained more megalopae than the entire census estimates for the respective cruises.

the midpoints of the distances between the adjacent stations

D_i = density of megalopae at station i.

Although census estimates varied between cruises from approximately 4,000–78,000, these estimates ignored the concentrations of megalopae in convergence zones or other aggregations that were sampled by the neuston trawl. The convergences alone contained 5–15 times more megalopae than the entire census estimates for their respective cruises.

DISCUSSION

The neustonic habitat off Oregon is a dynamic environment that supports an abundant and diverse fauna including Dungeness crab larvae and numerous fish species. The large mouth size of the neuston trawl and minimal disturbance from the vessel probably contributed to larger catches of surface-dwelling ichthyofauna than have been made in previous studies in the same region (Boehlert et al. 1985).

Several species of neustonic organisms were associated with specific oceanographic features such as convergence zones and water masses like the Columbia River plume. These aggregations of Dungeness crab megalopae and several fish species accounted for the major portion of the total catch of each taxon. Recent studies by Shanks (1983, 1985) and Kingsford and Choat (1985, 1986) further emphasize the importance of aggregation of neustonic organisms in oceanic convergences, surface slicks, and around floating objects. This information clearly demonstrates that randomized or grid sampling plans will often fail to detect micro- or meso-scale features of the environment. Surveys may thus severely underestimate the abundance of species, and important data on ecological characteristics such as predator-prey interactions may not be obtained. This is particularly important in understanding the role of spatial co-occurrence of patches of larval fishes and their prey on larval survival and growth (Lasker 1975, 1981; Grover and Olla 1986).

Diel patterns in abundance were striking. Most of the neustonic organisms were collected at night, and their absence from daytime collections may be attributed to vertical migration out of the surface layer or to visual avoidance of the nets. The fact that very few larval or juvenile sablefish and greenlings were collected in subsurface samples in earlier studies (e.g., Richardson and Pearcy 1977; Richardson et al. 1980; Kendall and Clark 1982a; Clark 1984), suggests that these fishes are obligate inhabitants of the neuston, and their low abundance in daytime hauls indicates substantial visual avoidance of the nets.

Conversely, other species may be facultative neuston that undergo diel migrations into the surface layer (Hempel and Weikert 1972), where they can most easily be assessed. Dungeness crab megalopae, in particular, disperse to at least 50 m during the day, but concentrate at the surface at dawn and dusk (Booth et al. 1985). Still other species (the pseudoneuston) may have depth ranges that overlap with the surface layer.

Previous studies on northwest ichthyoplankton have defined basic coastal, transitional, and offshore assemblages of species during different seasons (Richardson and Pearcy 1977; Richardson et al. 1980; Kendall and Clark 1984a, b; Clark 1984). In general, the transitional region roughly parallels the shelf break (approximately 30–40 km offshore in the vicinity of Newport, OR). Richardson et al. (1980) ascribed the consistency of these zonal assemblages to the spawning habits of adults and larval transport in the alongshore coastal circulation. According to Parrish et al. (1981), the spatial and temporal patterns of spawning, and durations of pelagic larval stages of these species, should correspond with the surface drift patterns of the region to minimize larval advection out of suitable habitats. In the Pacific Northwest, species with larvae adapted to the nearshore zone should spawn from fall through early spring when net surface drift is primarily northward and onshore. Oceanic larvae, however, should be spawned following the spring-summer transition when upwelling results in southward and offshore transport.

The onshore/offshore distributions of several abundant fish species in 1984 were similar to those described earlier, and their seasonal occurrence usually coincided with the constraints discussed by Parrish et al. (1981). However, four species had distributions that crossed the previously described zonal boundaries (Fig. 10). Early cabezon larvae appeared to disperse offshore as they grew. In contrast, early juvenile brown Irish lords were collected offshore in the early spring, while the larger juveniles spread inshore across all stations. Larval greenlings have only been collected close to the coast in late fall (Bates 1984), while the juveniles collected in this study were found at all stations prior to upwelling. Juvenile ronquils were also distributed along the transect, during both non-upwelling and upwelling conditions.

The dispersion of organisms across the transition zone may have been accomplished by several mechanisms. Physical transport of the organisms by mesoscale hydrographic events (e.g., eddies, offshore jets, and meanders in the alongshore currents) (Ikeda and Emery 1984; Mooers and Robinson 1984; Abbott and Zion 1985; Davis 1985) undoubtedly play important roles in the onshore/offshore dispersal of planktonic organisms. Transport with these events may be accelerated or hindered by diel vertical migration into water layers with different zonal flow patterns. Additionally, several species (especially greenling and sablefish) are rapid swimmers whose mobility can contribute to their dispersal or aggregation.

The rapid change in the composition of the ichthyoplankton fauna following the onset of upwelling has not been previously observed. Fishes abundant prior to upwelling may respond to the change in the environment in different ways. The disappearance of greenling and brown Irish lord juveniles suggests upwelling triggered settlement of these fishes to the demersal habitat utilized by older juveniles and adults. A possible stimulus for this transition is the breakdown of the thermocline, which has been identified as a

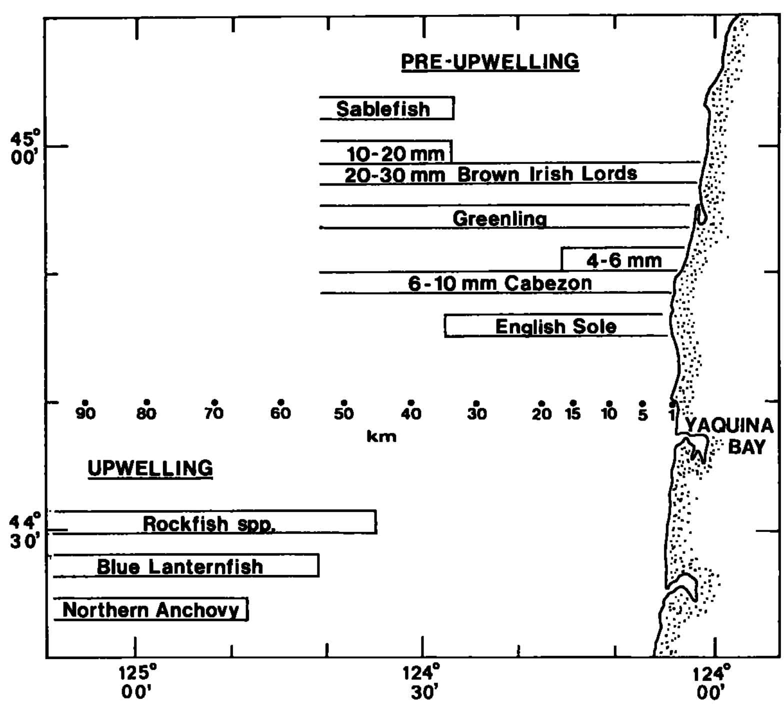

FIGURE 10.—Summary of the zonal distributions of larval and juvenile neustonic fishes in the pre- and early upwelling period (April through mid-June) and the strong upwelling period (July).

barrier to settlement to neustonic juvenile red hake, *Urophycis chuss*, (Steiner et al. 1982; Steiner and Olla 1985).

In contrast, juvenile sablefish apparently remain in the water column off Oregon following the transition to upwelling conditions. Small juveniles (<50 mm) have been captured as far as 250 km offshore in the spring (Kendall and Clark 1982a), and specimens up to 250 mm have been collected from the surface waters in late summer with a purse seine (Brodeur and Pearcy 1986). The very rapid growth rates of young juveniles, reaching 2 mm/day (Boehlert and Yoklavich 1985; Shenker and Olla 1986), undoubtedly resulted in their increasing ability to avoid the towed neuston nets used in this study.

The most abundant larvae occurring after the onset of upwelling were northern anchovy and rockfish. As observed in previous studies (Richardson 1973, 1980; Richardson et al. 1980), these larvae were primarily found offshore. The occurrence of these species, along with a high abundance of vertically migrating blue lanternfish, on the periphery of the Columbia River plume 60–90 km offshore on only one cruise, further illustrates the patchy nature of neustonic distributions.

Although the fish fauna in 1984 was generally characterized by discrete temporal and/or spatial limitations, the occurrence of Dungeness crab megalopae transcended these limits through the 4-mo study. Megalopae were the most abundant organisms collected throughout the survey, but their abundance varied widely between adjacent stations, with occasional very dense patches. Similar patchy distributions of megalopae were observed off British Columbia by Booth et al. (1985), who measured horizontal patch dimensions of 2–4 km. Several dense swarms of megalopae were observed in Bodega Bay, CA, during 1985 (Shenker and Botsford[6]). These patches were long, sinuous aggregations extending 10–20 m along the surface, approximately circular in cross section and about 1 m in diameter. Densities were visually estimated to be on the order of thousands of megalopae per m^3.

The temporal occcurrence of crab larvae in the plankton spans two distinctly different oceanic regimes, and the larvae are potentially transported long distances by the seasonal currents. Larvae typically hatch in mid-winter, pass through 5 zoeal stages in approximately 90 days, and then a month-long megalops stage before settling to the bottom (Reilly 1983a). After hatching, zoeae are released into the northerly flowing Davidson Current. Despite a general onshore component of flow of the Davidson Current, older zoeal stages have been found progressively farther offshore (Lough 1976; Reilly 1983a).

About the time of the spring transition in the alongshore currents from a northerly to southerly direction (Huyer et al. 1975), zoeae metamorphose into megalopae. To survive, these megalopae must be transported back toward the shore, and settle to the bottom in depths shallower than 25 m (Reilly 1983b). Larvae have been found at least 100 km from shore (Lough 1976), although it is unclear if these larvae make it back to shore, or are simply lost from the population.

Again, an apparent anomaly exists between the directions of movement of megalopae and surface waters, where the Ekman layer moves offshore in response to upwelling winds. These discrepancies may be explained by mesoscale mixing processes, as cited earlier. Alternatively, the diel vertical movements of the larvae can move them into different water masses with different directions of zonal movement.

The data from this study and previous research on vertical migration indicate that at least the early zoeal stages and megalopae move to the surface during twilight, and below the surface during the day (Reilly 1983a). Surface abundance estimates of megalopae obtained in the 27-h sampling on 8–9 June (Fig. 8), and by Booth et al. (1985), decreased during the middle of the night. This movement away from the surface is an example of "midnight scattering", perhaps resulting from the lack of a light cue to orient planktonic organisms to the surface (Owen 1981). If midnight scattering is typical for megalopae, abundance estimates made by sampling along a transect throughout the night (Figs. 7, 9) probably underestimate the actual abundance of megalopae utilizing the surface habitat. Megalopae have been collected as deep as 50–70 m during the day (Booth et al. 1985; Shenker and Botsford fn. 6). These observations correlate with Jacoby's (1982) laboratory demonstration that megalopae are positively phototactic to dim light, but avoid bright light.

The present study indicates that the phototactic response of megalopae may assist their return to shore in several ways. Downward movement

[6]Shenker, J. M., and L. W. Botsford, University of California, Bodega Marine Laboratory, P.O. Box 247, Bodega Bay, CA 94923, unpubl. data.

during sunny days, when upwelling wind stress and offshore Ekman transport is generally strongest, can move the larvae into the slow onshore flow below the surface Ekman layer (Peterson et al. 1979). In contrast to the usual northerly upwelling winds, occasional storms blow from the southwest, driving the surface layer onshore. The occurrence of megalopae at the surface during the day was most pronounced on these dark stormy days (especially on the second May cruise), and thus may facilitate their onshore transport.

Observations of megalopae entering into embayments and nearshore areas from Washington to northern California in 1984 and 1985 indicated a dramatic increase in the abundance of megalopae and an extended seasonal occurrence in the plankton, as compared to previous years (Shenker and Botsford fn. 6; Armstrong[7]). This high abundance of crab larvae may presage an upswing in the cyclical crab fishery along these coasts.

Numerous mechanisms have been proposed as causes of the 10-yr cycles in crab abundance. Although some hypotheses have been discounted, several models have survived scrutiny as possible causes of the cycles (see Botsford 1986 for review). Potential mechanisms of environmental forcing of the cycles focus on larval transport and survival. Johnson et al. (1986) detected periodic 10-yr cycles in the occurrence and strength of southward stress during the late larval period that significantly correlated with commercial crab catch 4 and 5 years later. This lag corresponds to the time between larval settlement and growth into the adult fishery (Botsford 1984).

Model simulations by Botsford (1986) indicated that nonlinear effects of wind on larval transport can produce the cyclical swings in crab abundance. However, the models do not preclude the possibility that density-dependent phenomena (such as cannibalism by adult crabs on newly settled juveniles, and predation by nemertean worms on egg masses) may act in concert with the environmental forcing to produce the observed cycles.

The water's surface is the only oceanic habitat that is easily accessible to observation using techniques ranging from satellite and aerial scanning to shipboard visual sighting of targets and continuous monitoring of environmental parameters. Because of this accessibility, micro- and mesoscale patterns in distribution of neustonic taxa and their associations with hydrographic and biological characteristics of the surface zone can be determined more easily than in other environments. The neustonic realm thus offers an excellent opportunity to investigate the mechanisms of transport of the early stages into appropriate nursery habitats, and the availability of food for growth that are required for successful recruitment into adult stocks (Hjort 1914; Lasker 1975, 1981; Frank and Leggett 1982; Sinclair et al. 1984).

[7]D. A. Armstrong, School of Fisheries, WH-10, University of Washington, Seattle, WA 98195, pers. commun. October 1984.

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LITERATURE CITED

ABBOTT, M. R., AND P. M. ZION.
1985. Satellite observations of phytoplankton variability during an upwelling event. Cont. Shelf Res. 4:661–680.

BARKLEY, R. A.
1972. Selectivity of towed net samplers. Fish. Bull., U.S. 70:799–820.

BATES, R. D.
1984. Ichthyoplankton off Washington, Oregon and northern California, October-November, 1981. Natl. Mar. Fish. Serv., Northwest and Alaska Fish. Cent. Process. Rep. 84–12, 41 p.

BOEHLERT, G. W., D. M. GADOMSKI, AND B. C. MUNDY.
1985. Vertical distribution of ichthyoplankton off the Oregon coast in spring and summer months. Fish. Bull., U.S. 83:611–622.

BOEHLERT, G. W., AND M. M. YOKLAVICH.
1985. Larval and juvenile growth of sablefish, *Anoplopoma fimbria*, as determined from otolith increments. Fish. Bull., U.S. 83:475–481.

BOOTH, J., A. PHILLIPS, AND G. S. JAMIESON.
1985. Fine scale spatial distribution of *Cancer magister* megalopae and its relevance to sampling methodology. *In* B. R. Melteff (editor), Proceedings of the symposium on Dungeness crab biology and management, p. 273–286. Univ. Alaska Sea Grant Coll. Program, Rep. No. 85-3. Fairbanks, AK 99701.

BOTSFORD, L. W.
1984. Effect of individual growth rate on expected behav-

ior of the northern California Dungeness crab (*Cancer magister*) fishery. Can. J. Fish. Aquat. Sci. 41:99–107.
1986. Population dynamics of the Dungeness crab (*Cancer magister*). *In* G. S. Jamieson and N. Bourne (editors), North Pacific workshop on stock assessment and management of invertebrates. Can. Spec. Publ. Fish. Aquat. Sci. 92:140–153.

BRODEUR, R. D., D. M. GADOMSKI, W. G. PEARCY, H. P. BATCHELDER, AND C. B. MILLER.
1985. Abundance and distribution of ichthyoplankton in the upwelling zone off Oregon during anomalous el Niño conditions. Estuarine Coastal Shelf Sci. 21:365–378.

BRODEUR, R. D., B. C. MUNDY, W. G. PEARCY, AND R. W. WISSEMAN.
1987. The neustonic fauna in coastal waters of the northeast Pacific: Abundance, distribution, and utilization by juvenile salmonids. Oreg. State Univ. Sea Grant Coll. Program, Rep. ORESU-T-87-001. Corvallis, OR 97331.

BRODEUR, R. D., AND W. G. PEARCY.
1986. Distribution and relative abundance of pelagic nonsalmonid nekton off Oregon and Washington, 1979–1984. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 46, 85 p.

BROWN, D. M., AND L. CHENG.
1981. New net for sampling the ocean surface. Mar. Ecol. Prog. Ser. 5:225–227.

CLARK, J. B.
1984. Ichthyoplankton off Washington, Oregon and northern California, May-June, 1981. Natl. Mar. Fish. Serv., Northwest and Alaska Fish. Cent. Process. Rep. 84–11, 46 p.

DAVIS, R. E.
1985. Drifter observations of coastal surface currents during CODE: the method and descriptive view. J. Geophys. Res. 90:4741–4755.

FRANK, W. T., AND W. C. LEGGETT.
1982. Coastal water mass replacement: its effect on zooplankton dynamics and the predator-prey complex associated with larval capelin (*Mallotus villosus*). Can. J. Fish. Aquat. Sci 39:991–1003.

GROVER, J. J., AND B. L. OLLA.
1986. Morphological evidence for starvation and prey size selection of sea-caught larval sablefish, *Anoplopoma fimbria*. Fish. Bull., U.S. 84:484–489.

HEMPEL, G., AND H. WEIKERT.
1972. The neuston of the subtropical and boreal Northeastern Atlantic Ocean. A review. Mar. Biol. (Berl.) 13:70–88.

HJORT, J.
1914. Fluctuations in the great fisheries of northern Europe viewed in the light of biological research. Rapp. P.-v. Réun. Comm. int. Explor. Sci. Mer 20:1–228.

HUYER, A., R. D. PILLSBURY, AND R. L. SMITH.
1975. Seasonal variation of the alongshore velocity field over the continental shelf off Oregon. Limnol. Oceanogr. 20:90–95.

IKEDA, M., AND W. J. EMERY.
1984. Satellite observations and modeling of meanders in the California Current system off Oregon and Northern California. J. Phys. Oceanogr. 14:1434–1450.

JACOBY, C. A.
1982. Behavioral responses of the larvae of *Cancer magister* Dana (1852) to light, pressure, and gravity. Mar. Behav. Physiol. 8:267–283.

JOHNSON, D. F., L. W. BOTSFORD, R. D. METHOT, JR., AND T. C. WAINWRIGHT.
1986. Wind stress and cycles in Dungeness crab (*Cancer magister*) catch off California, Oregon and Washington. Can. J. Fish. Aquatic Sci. 43:838–845.

KENDALL, A. W., JR., AND J. CLARK.
1982a. Ichthyoplankton off Washington, Oregon, and Northern California. April-May, 1980. Natl. Mar. Fish. Serv., Northwest Alaska Fish. Cent. Process. Rep. 82–11, 44 p.
1982b. Ichthyoplankton off Washington, Oregon and Northern California. August, 1980. Natl. Mar. Fish. Serv., Northwest and Alaska Fish. Cent. Process. Rep. 82–12, 43 p.

KINGSFORD, M. J., AND J. H. CHOAT.
1985. The fauna associated with drift algae captured with a plankton-mesh purse seine net. Limnol. Oceanogr. 30:618–630.
1986. Influence of surface slicks on the distribution and onshore movements of small fish. Mar. Biol. (Berl.) 91:161–171.

LAROCHE, J. L., AND S. L. RICHARDSON.
1979. Winter-spring abundance of larval English sole, *Parophrys vetulus*, between the Columbia River and Cape Blanco, Oregon, during 1972–1975, with notes on occurrences of three other pleuronectids. Estuarine Coastal Mar. Sci. 8:455–476.

LASKER, R.
1975. Field criteria for survival of anchovy larvae: the relation between the inshore chlorophyll layers and successful first feeding. Fish. Bull., U.S. 71:453–462.
1981. The role of a stable ocean in larval fish survival and subsequent recruitment. *In* R. Lasker (editor), Marine fish larvae. Morphology, ecology and relation to fisheries, p. 80–87. Wash. Sea Grant Program, Univ. Wash. Press, Seattle.

LOUGH, R. G.
1976. Larval dynamics of the Dungeness crab, *Cancer magister*, off the central Oregon coast, 1970–71. Fish. Bull., U.S. 74:353–375.

MOOERS, C. N. K., AND A. R. ROBINSON.
1984. Turbulent jets and eddies in the California Current and inferred cross-shore transport. Science 223:51–53.

MUNDY, B. C.
1983. Yearly variation in the abundance and distribution of fish larvae in the coastal zone off Yaquina Head, Oregon, from June 1969 to August 1972. M.S. Thesis, Oregon State Univ., Corvallis, OR, 158 p.

MURPHY, G. I., AND R. I. CLUTTER.
1972. Sampling achovy larvae with a plankton purse seine. Fish. Bull., U.S. 70:789–798.

OWEN, R. W.
1982. Fronts and eddies in the sea: Mechanisms, interactions and biological effects. *In* A. R. Longhurst (editor), Analysis of marine ecosystems, p. 197–233. Acad. Press, N.Y.

PARRISH, R. H., C. S. NELSON, AND A. BAKUN.
1981. Transport mechanisms and reproductive success of fishes in the California Current. Biol. Oceanogr. 1:175–203.

PETERSON, W. T., C. B. MILLER, AND A. HUTCHINSON.
1979. Zonation and maintenance of copepod populations in the Oregon upwelling zone. Deep-Sea Res. 26:467–494.

REILLY, P. N.
1983a. Dynamics of Dungeness crab, *Cancer magister*,

larvae off central and northern California. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery, p. 57–85. Calif. Dep. Fish game, Fish Bull. 172.

1983b. Predation on Dungeness crabs, *Cancer magister*, in central California. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery, p. 155–164. Calif. Dep. Fish. Game, Fish Bull. 172.

RICHARDSON, S. L.

1973. Abundance and distribution of larval fishes in waters off Oregon, May-October 1969, with special emphasis on the northern anchovy, *Engraulis mordax*. Fish. Bull., U.S. 71:697–711.

1980. Spawning biomass and early life of northern anchovy, *Engraulis mordax*, in the northern subpopulation off Oregon and Washington. Fish. Bull., U.S. 78:855–877.

RICHARDSON, S. L., J. L. LAROCHE, AND M. D. RICHARDSON.

1980. Larval fish assemblages and associations in the northeast Pacific Ocean along the Oregon coast, winter-spring, 1972–1975. Estuarine Coastal Mar. Sci. 11:671–699.

RICHARDSON, S. L., AND W. G. PEARCY.

1977. Coastal and oceanic fish larvae in an area of upwelling off Yaquina Bay, Oregon. Fish. Bull., U.S. 75:125–146.

SHANKS, A. L.

1983. Surface slicks associated with tidally forced internal waves may transport pelagic larvae of benthic invertebrates and fishes shoreward. Mar. Ecol. Prog. Ser. 13:311–315.

1985. Behavioural basis of internal-wave-induced shoreward transport of megalopae of the crab *Pachygrapsus crassipes*. Mar. Ecol. Prog. Ser. 24:289–295.

SHENKER, J. M., AND B. L. OLLA.

1986. Laboratory feeding and growth of juvenile sablefish, *Anoplopoma fimbria*. Can. J. Fish. Aquat. Sci. 43:930–937.

SINCLAIR, M. F., M. J. TREMBLAY, AND P. BERNAL.

1984. El Niño events and variability in a Pacific mackerel (*Scomber japonicus*) survival index: support for Hjort's second hypothesis. Can. J. Fish. Aquat. Sci. 42:602–608.

SMALL, L. F., AND D. W. MENZIES.

1981. Patterns of primary productivity and biomass in a coastal upwelling region. Deep-Sea Res. 28:123–149.

SMITH, P. E.

1972. The increase in spawning biomass of northern anchovy, *Engraulis mordax*. Fish. Bull., U.S. 70:849–874.

STEINER, W. W., J. J. LUZCKOVICH, AND B. L. OLLA.

1982. Activity, shelter usage, growth and recruitment of juvenile red hake, *Urophycis chuss*. Mar. Ecol. Prog. Ser. 7:125–135.

STEINER, W. W., AND B. L. OLLA.

1985. Behavioral responses of prejuvenile red hake, *Urophycis chuss*, to experimental thermoclines. Environ. Biol. Fish 14:167–173.