DISTRIBUTIONS OF PLANKTONIC FISH EGGS AND LARVAE OFF TWO STATE ECOLOGICAL RESERVES IN THE SANTA BARBARA CHANNEL VICINITY AND TWO NEARBY ISLANDS IN THE CHANNEL ISLANDS NATIONAL MARINE SANCTUARY, CALIFORNIA

WILLIAM WATSON, RICHARD L. CHARTER, H. GEOFFREY MOSER, DAVID A. AMBROSE,
SHARON R. CHARTER, ELAINE M. SANDKNOP, LARRY L. ROBERTSON, AND ERIC A. LYNN

National Marine Fisheries Service
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla, California 92037-1508
william.watson@noaa.gov

ABSTRACT

We conducted a study in 1998–99 to identify planktonic fish eggs and larvae, and to describe their temporal and spatial distributions, in the vicinities of Vandenberg and Big Sycamore Canyon Ecological Reserves and two nearby islands, Anacapa and San Miguel, in Channel Islands National Marine Sanctuary. We conducted surveys in late winter and early summer each year using an underway sampler and a bongo net towed vertically at fixed stations. A neuston sampler was added in 1999. We used bongo net data, thought to give the best estimates of ichthyoplankton abundance, as the primary data to identify distributions.

Cluster analyses showed that season was the major environmental signal in the ichthyoplankton data, with clear indications of the El Niño/Southern Oscillation events of 1998 and 1999, and more tenuous suggestions of adult habitat preferences and faunal affinities. Between- and within-site adult habitat preferences were apparent in analyses of individual taxa. Eggs and larvae of rocky-bottom and kelp forest taxa were most abundant at the islands where those habitats are available, and the eggs and larvae of soft-bottom taxa were more abundant at the Big Sycamore Canyon site, where that habitat predominates. It appears that no significant production of planktonic fish eggs and larvae occurred in the vicinity of Vandenberg Ecological Reserve. At the Big Sycamore Canyon site, eggs of a few taxa clearly are produced from the reserve but probably not in higher numbers than from adjacent nonreserve areas.

INTRODUCTION

The California Marine Resources Protection Act of 1990 required the establishment of marine reserves along the California coast. Two reserves created in 1994 are Vandenberg Ecological Reserve, centered on Point Arguello, and Big Sycamore Canyon Ecological Reserve, in the southeastern Santa Barbara Channel near Point Mugu. An argument often cited in favor of marine reserves is that they provide protected areas for adults of exploited species. Planktonic propagules of these species presumably disperse from the reserve to "reseed" adjacent fished areas outside the reserve, thereby helping to maintain or augment stocks of the exploited species outside the reserve (e.g., Agardy 1994; Sladek Nowlis and Yoklavich 1998, 32–40; Sladek Nowlis and Roberts 1999). Commonly, it is simply assumed that the reserves must function in this way; studies designed to quantify the abundances and distributions of planktonic propagules in the reserve vicinities rarely are undertaken. This study addresses the lack of information about ichthyoplankton in the immediate vicinities of Vandenberg and Big Sycamore Canyon Ecological Reserves by producing quantitative descriptions of the small-scale temporal and spatial distributions of planktonic fish eggs and larvae around the reserves. These data also provide a baseline against which any future ichthyoplankton studies in the area can be compared.

To accomplish the primary goal of our study we adapted sampling techniques commonly used for large-scale studies in deep coastal and offshore waters (e.g., Smith and Richardson 1977; Checkley et al. 1997) to a small-scale study in shallow inshore waters; we also developed criteria for identifying the planktonic shorefish eggs (Moser [1996] provided descriptions of the larvae of most of the taxa expected, as well as descriptions of some of the eggs). Watson et al. (1999) addressed these points, described temporal spawning patterns, and provided preliminary descriptions of spatial distributions of the eggs of several taxa using data from the first year of the study. Here, we focus on the distributional information obtainable from the ichthyoplankton assemblage and on the specific spatial distributions of some individual taxa selected for their fishery value and/or abundance. Coincidentally, the strong El Niño and La Niña events of 1998 and 1999 occurred during the study, and we note apparent affects of those events on the ichthyoplankton as well.

MATERIALS AND METHODS

We conducted four surveys aboard the NOAA research vessels *David Starr Jordan* (JD) and *McArthur* (M4) in 1998 and 1999, during late winter (9803JD, 19 Feb.–4 Mar. 1998; 9903M4, 25 Feb.–10 Mar. 1999) and early summer (9806JD, 12–24 June 1998; 9907JD, 28 June–11 July 1999). We sampled four sites: the vicinities of
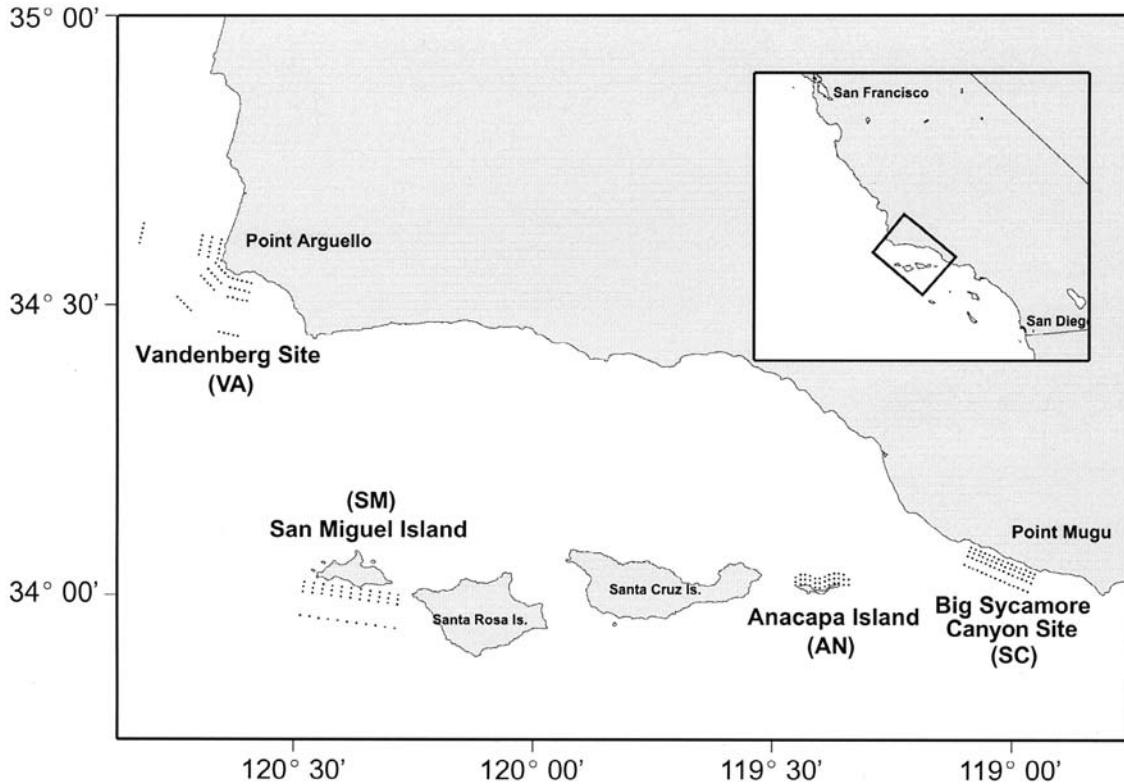
Figure 1. Study site showing station array at each site.

Big Sycamore Canyon and Vandenberg State Ecological Reserves, and Anacapa and San Miguel Islands in the Channel Islands National Marine Sanctuary (fig. 1). Big Sycamore Canyon is a low-relief site adjacent to a sandy beach, and it contains little hard-bottom or kelp habitat; the reserve itself is entirely a soft-bottom habitat. Vandenberg also contains little kelp but does have rocky headlands, somewhat more hard bottom than Big Sycamore Canyon, and some patchy surf grass. Coastal currents at both sites flow primarily alongshore, predominantly southerly in spring and summer and northerly in autumn and winter (Hendershott and Winant 1996). Both of the island sites have more hard-bottom habitat than the mainland sites (about 20% compared with < 5% shoreward of the 100 m isobath; Cochrane et al. 2002) and more extensive kelp coverage.

A station grid was established at each site (fig. 1). Station placement is described in Watson et al. (1999, 2002). Briefly, four lines of stations were placed approximately parallel to shore in the vicinities of the 20, 40, 60, and 200 m isobaths. There were three groups of five stations each corresponding to "downcoast," "reserve," and "upcoast" blocks along each line, for a total of 60 stations each at Big Sycamore Canyon and Vandenberg. There were 44 stations at San Miguel Island (11 per line), and 35 at Anacapa Island (12 each on the two shoreward lines, 11 on the next line; the most

offshore line was not occupied). The reserve at Big Sycamore Canyon extends seaward to the 37 m (20 fm) isobath and the inshore line passes through the reserve. The reserve at Vandenberg extends offshore to approximately the 18 m (10 fm) isobath; concern for vessel safety precluded sampling within it.

Two samplers, an underway pump system (continuous underway fish egg sampler, CUFES; Checkley et al. 1997) and a bongo net, were used on all surveys. Watson et al. (1999, 2002) describe the use of both. Briefly, the CUFES drew water continuously from a depth of 3 m, and samples usually were collected at 10 min intervals as the vessel steamed along the station lines at about 2.5 m/s (5 kn). With few exceptions, a full CUFES pattern (all station lines) was sampled twice during the day and twice at night at each site (Watson et al. 2002). The 71 cm bongo net (McGowan and Brown 1966), equipped with 0.333 mm mesh nets and cod ends and a calibrated flowmeter, was used to make a vertical plankton tow at each station. Sampling was done without regard to day or night. Nearly all scheduled bongo samples were collected (Watson et al. 2002). A CUFES sample usually was collected with each bongo sample for calibration between the gear types.

A manta net (Brown and Cheng 1981) was added as a surface sampler in 1999 because the eggs of some taxa are strongly positively buoyant, and the larvae of some

are neustonic (e.g., cabezon, *Scorpaenichthys marmoratus*; lingcod, *Ophiodon elongatus*) and may be poorly sampled by the vertically towed bongo net. The standard CalCOFI manta net used (see Moser et al. 2002) was equipped with a 0.333 mm mesh net and cod end and a calibrated flowmeter. There were 12 manta stations at each site: 3 per line at Big Sycamore Canyon, Vandenberg, and San Miguel Island, and 4 per line at Anacapa Island. Use of the manta net is described in Watson et al. (2002). All scheduled manta samples were collected.

Samples were preserved in 10% sodium borate-buffered seawater-formalin. In the laboratory, fish eggs and larvae were sorted from whole samples and stored in 2.5% sodium borate-buffered formalin. All fish eggs and larvae were identified to the lowest possible taxon and counted. Eggs were assigned to 11 developmental stages according to the criteria of Moser and Ahlstrom (1985), and larvae were assigned to yolk-sac, preflexion, flexion, or postflexion stages (Moser 1996). All fish eggs and larvae and all collection and count data are archived at the National Marine Fisheries Service Southwest Fisheries Science Center (SWFSC). These data ultimately will be made available through the SWFSC Fisheries Resources Division Web site.

Count data were converted to concentration (number per 1 m^3 or per 100 m^3 of water filtered) for the CUFES and manta samples, and to abundance (number under 10 m^2 of sea surface) for the bongo samples. For most analyses only "total eggs" and "total larvae" categories were used for each taxon; for some analyses egg stages were pooled into "early" (stages I–III), "middle" (stages IV–VII), and "late" (stages VIII–XI) categories. The standardized count data were transformed by log ([abundance or concentration] + 1) prior to statistical analyses (results evaluated at $\alpha = 0.05$) using ANOVA and the Bonferroni multiple comparisons procedure (Mathsoft, Inc. 2000) to examine between- and within-site distributions of selected taxa. Taxa were selected for analysis on the basis of their sport or commercial fishery value and/or abundance. Results for the eggs of six taxa and the larvae of two collected with the bongo net are presented here. Most of the fish eggs and larvae collected have little or no direct fishery value, or were relatively rare, or both. To explore alongshore abundance patterns, we grouped stations into the "downcoast," "reserve," and "upcoast" blocks at the reserve sites as described above, and into "east," "center," and "west" blocks at the islands (four stations per line in each block, except three in the "east" block on the offshore line at Anacapa Island; four per line in the "east" and "center" blocks, and three per line in the "west" block at San Miguel Island). CUFES data were used for supplemental descriptions of egg distributions but were not analyzed statistically.

Agglomerative hierarchical clustering of Euclidean distance values with complete (furthest-neighbor) linkage was performed on the bongo and manta net data to examine the organization of the egg and larval assemblages. Taxa used in the bongo cluster analyses were those that occurred on ≥ 2 cruises, at ≥ 10% of the stations at ≥ 1 site. Criteria for the manta data were the same except that occurrence on only one cruise was sufficient. This resulted in deletion of the rare taxa; the "unidentified" and "disintegrated" categories were deleted as well. Three egg categories, *Atractoscion nobilis*, *Sphyraena argentea*, and their indistinguishable early stages ("Perciformes"), were combined. This left 21 egg and 25 larval taxa for analysis in the bongo data set, and 26 egg and 19 larval taxa in the manta data set. The mean number of "total eggs" or "total larvae" of each taxon under 10 m^2 (bongo) and per 100 m^3 (manta) along each station line was calculated, and the means were log-transformed prior to analysis.

A secondary goal of the study was to assess the utility of the CUFES in generating descriptions of small-scale distributional patterns and in estimating abundances of nearshore planktonic fish eggs. This was done with linear regressions of CUFES catch data on bongo catch data. The rationale for using the bongo catch data as the independent variable was that the bongo sampled nearly the entire water column and thus was thought to provide the best estimate of egg abundance in the water column. We analyzed untransformed count data (number per minute for CUFES; number per 10 m^2 for bongo net) for four taxa regularly collected with both samplers. We included only stations with a positive collection for at least one of the samplers.

RESULTS

Ichthyoplankton Assemblage

In total, 236,596 fish eggs of at least 48 taxa, and 8,932 fish larvae of 109 taxa were collected with the three samplers during the four cruises (Watson et al. 2002). Overall, northern anchovy (*Engraulis mordax*), Pacific hake (*Merluccius productus*), white croaker (*Genyonemus lineatus*), speckled sanddab (*Citharichthys stigmaeus*), and California halibut (*Paralichthys californicus*) eggs occurred most frequently and were among the most abundant during the winter surveys. In summer, señorita (*Oxyjulis californica*), California sheephead (*Semicossyphus pulcher*), and white seabass (*Atractoscion nobilis*) plus California barracuda (*Sphyraena argentea*) eggs were among the most common, although during the cool summer of 1999 northern anchovy, speckled sanddab, and California halibut eggs remained common. Northern anchovy, California smoothtongue (*Leuroglossus stilbius*), northern lampfish (*Stenobrachius leucopsarus*), Pacific hake, and rock-

fishes (*Sebastes* spp.) were the most common fish larvae during both winter surveys; larval northern anchovy remained relatively common during summer (especially 1999), and rockfishes were common in summer 1999. The most common shorefish eggs at the mainland sites were white croaker, speckled sanddab, and California halibut during winter, with señorita replacing white croaker in summer. Common shorefish larvae at the mainland sites in winter included rockfishes, white croaker, and English sole (*Parophrys vetulus*); none was particularly common during summer. At the islands the most common shorefish eggs included speckled sanddab and California halibut in winter, and white seabass plus California barracuda (primarily at Anacapa), señorita, and California sheephead during summer, with speckled sanddab and California halibut remaining common in summer 1999. Common shorefish larvae at the islands during winter were rockfishes, white croaker (1999), and, at Anacapa Island, blackeye goby (*Coryphopterus nicholsii*); during summer larval blacksmith (*Chromis punctipinnis*) were common at Anacapa Island.

In the cluster analyses of bongo net egg data, when collections were classified according to the similarity of the egg catches within each collection, the primary separation was between winter and a group predominantly (94%) of summer collections (fig. 2). Within the summer collection group, a subgroup mostly (82%) of 1998 (El Niño) collections was distinguished from another of exclusively 1999 (La Niña) collections, probably reflecting mainly the higher abundances and frequencies of occurrence of the eggs of northern anchovy and several flatfish species (e.g., California halibut, speckled sanddab) in 1999. Within these subgroups smaller sets of exclusively island collections were distinguished from sets predominantly of mainland collections (91% in 1998, 80% in 1999). In the El Niño subgroup the island collections were characterized by more señorita and California sheephead eggs—both taxa require the hard-bottom/kelp habitats that are common at the islands but rare at the mainland sites. The mainland collections, especially those at Big Sycamore Canyon, had higher abundances of California halibut eggs—a soft-bottom species. In the La Niña subgroup the island collections were characterized by more labrid, white seabass, and California barracuda eggs, while the predominantly mainland subset contained somewhat more eggs of a few flatfish species.

Within the winter group collections tended to form chains, but four subgroups could be distinguished: (1) the two offshore station lines at Big Sycamore Canyon in 1999, perhaps reflecting an unusually high abundance of white croaker eggs; (2) San Miguel Island and the offshore two lines at Vandenberg in 1999, characterized primarily by a lack of northern anchovy eggs and very
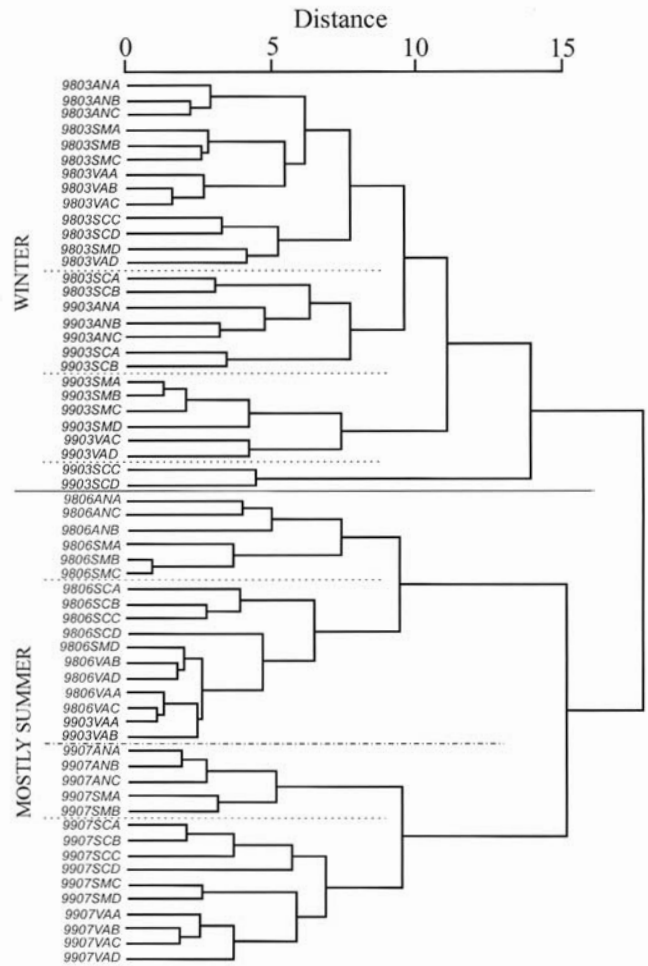

Figure 2. Dendrogram of bongo collections classified according to the similarity of fish egg catches within the collections. "Distance" refers to the Euclidean distance value and is a measure of dissimilarity. Collections are identified by numbers indicating the year and month of the cruise plus letters indicating sampling site (AN = Anacapa Island, SC = Big Sycamore Canyon, SM = San Miguel Island, VA = Vandenberg) and station line (A, nearest to shore, through D, farthest from shore).

low abundances of white croaker eggs; (3) the inshore two lines at Big Sycamore Canyon plus all three lines at Anacapa Island in 1999, all with high abundances of California halibut eggs; and (4) a catch-all group containing the remaining 1998 collections. The reverse classification, of taxa by the collections in which they occurred, yielded little information apart from spawning season, with three or four groups: year-round spawners; species that spawn primarily in winter and spring; summer-autumn spawners; and a mixed group with peak spawning during some period from spring through autumn (Watson et al. 2002).

The primary separation in the classification of manta net egg collections was between summer collections and a group mostly (83%) of winter collections (fig. 3). The summer group contained a subgroup of mainland collections and one predominantly (71%) of island collec-
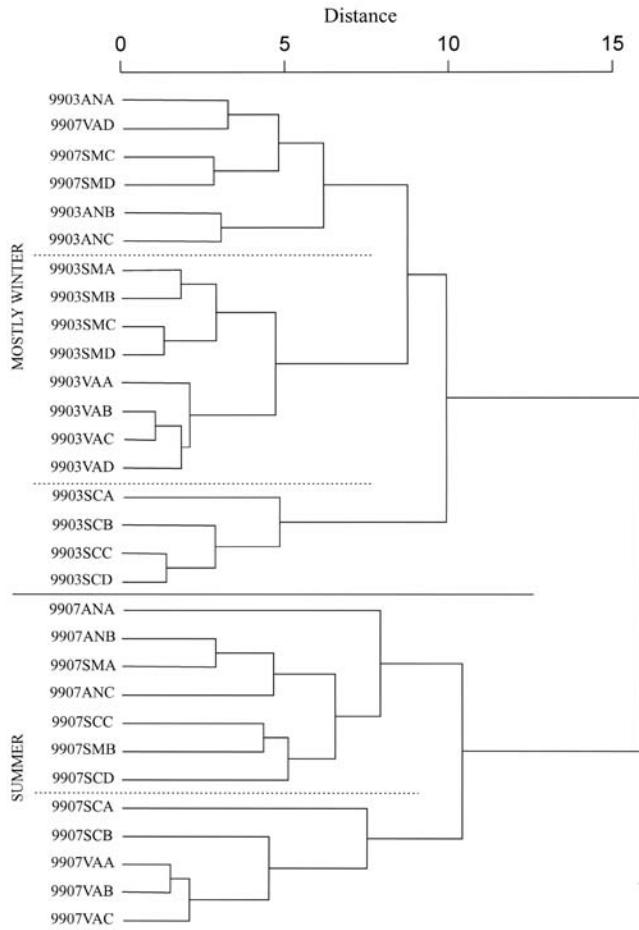
Figure 3. Dendrogram of manta collections classified according to the similarity of fish egg catches within the collections. "Distance" refers to Euclidean distance and is a measure of dissimilarity. For key to collection codes, see fig. 2.
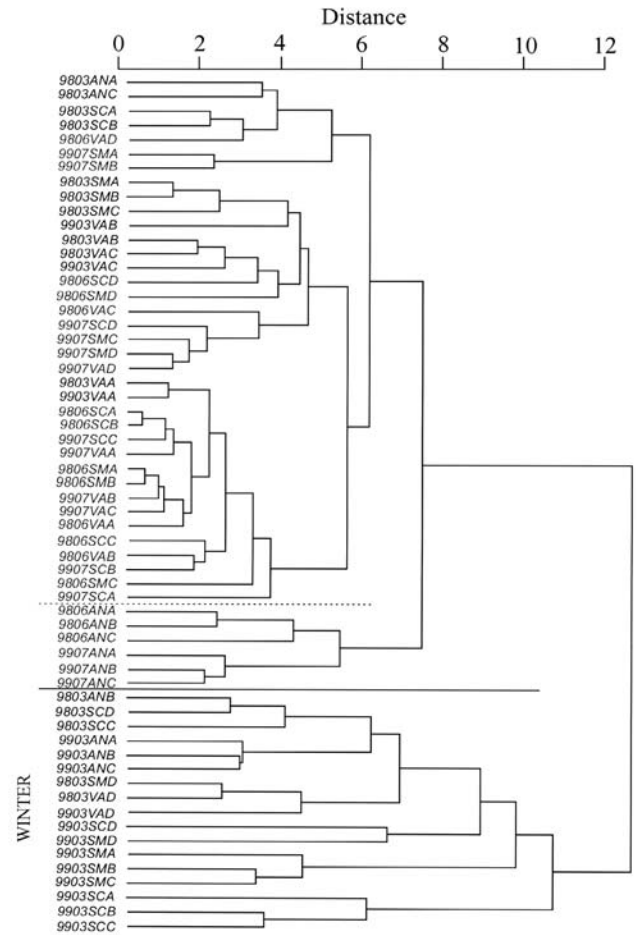

Figure 4. Dendrogram of bongo collections classified according to the similarity of larval fish catches within the collections. "Distance" refers to Euclidean distance value and is a measure of dissimilarity. For key to collection codes, see fig. 2.

tions. The mainland subgroup was characterized by higher abundances of some flatfish eggs, primarily hornyhead turbot (*Pleuronichthys verticalis*) and California tonguefish (*Symphurus atricaudus*). The island subgroup was characterized primarily by higher abundances of labrid and C-O sole eggs but also had somewhat higher abundance of northern anchovy and cusk-eel (Ophidiidae) eggs, which may account for inclusion of the two offshore Big Sycamore Canyon station lines in the island subset. Within the winter group the Big Sycamore Canyon collections formed a subgroup characterized by high abundances of soft-bottom species, including speckled sanddab, English sole, hornyhead turbot, and especially white croaker. Another subgroup contained the winter collections at San Miguel Island and Vandenberg, characterized by low abundances of the eggs of several taxa (e.g., speckled sanddab, California halibut, English sole), the near absence of white croaker eggs, and complete absence of northern anchovy eggs. A third subgroup included the remaining collections.

Thus, in the fish egg data seasonal spawning and El Niño/La Niña influences were apparent, with some suggestions of spawner habitat preferences and perhaps faunal affinity. Cluster analyses of the larval fish data yielded more ambiguous results. In the classification of bongo collections (fig. 4) the primary separation was between a winter group and a large, poorly defined group containing a mixture of seasons (67% summer) and sites (58% mainland). The winter group consisted primarily of 1999 collections (71%) at all sites, possibly reflecting higher abundances of larval California smoothtongue, northern lampfish, Pacific hake, white croaker, and rockfishes in winter 1999, except that Vandenberg was poorly represented (12%), possibly reflecting the very low abundance of larval white croaker at that site. Collections within the other group formed two subgroups: (1) Anacapa Island in summer, where all of the larval blacksmith collected during the study were taken; and (2) the remainder, with no readily interpretable pattern or subgroups.

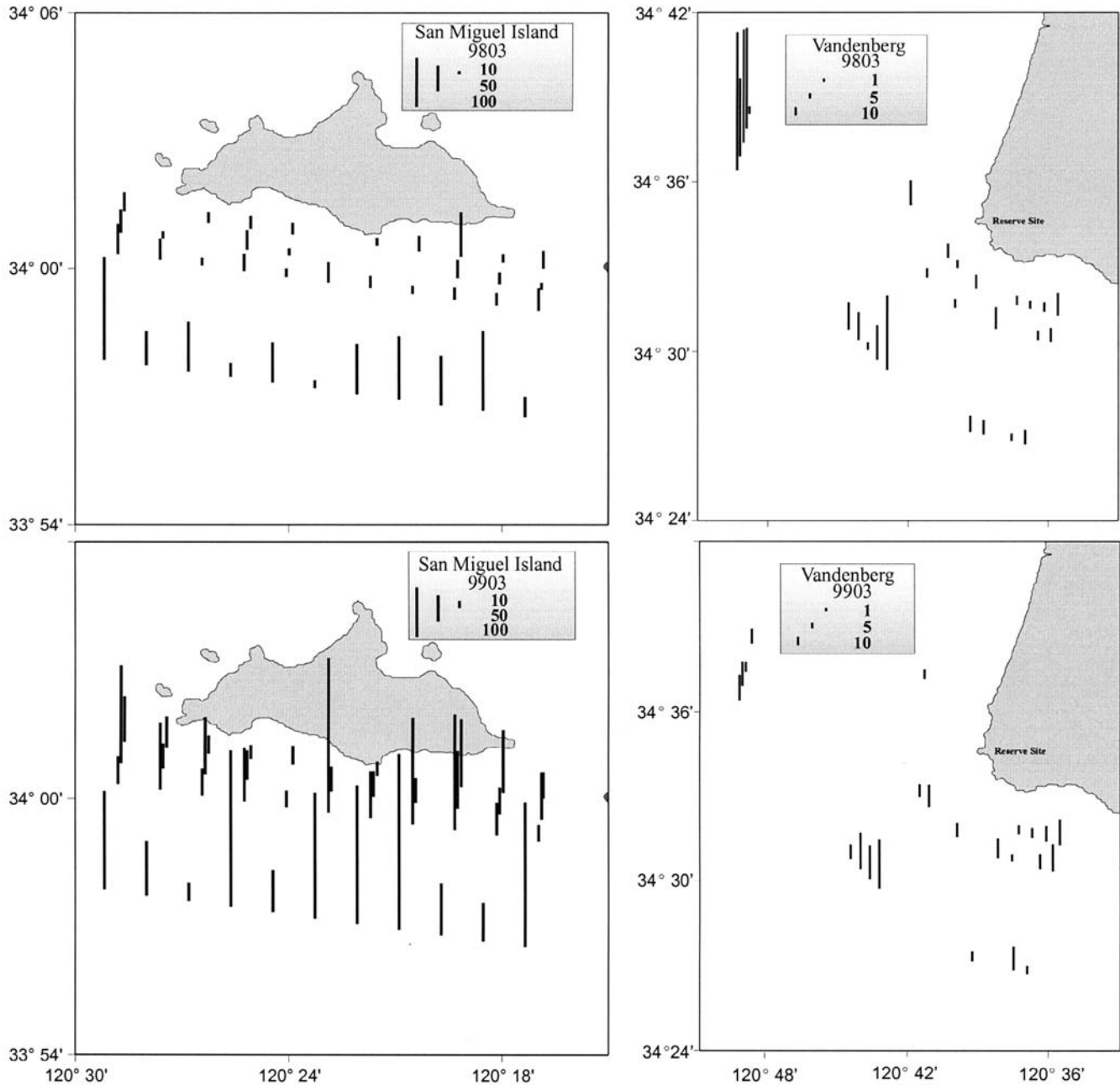In the reverse classification the primary separation was

Figure 5.   Abundance (number per 10 m²) of larval rockfishes (*Sebastes* spp.) collected with a vertically towed bongo net at the Vandenberg and San Miguel Island study sites in February–March 1998 (*upper*) and 1999 (*lower*).

between: (1) six taxa that were most abundant and oc-curred most frequently in winter; and (2) all the others. The first group contained three subsets: the ubiquitous northern anchovy; three flatfish species, white croaker and Pacific argentine (*Argentina sialis*), all most abundant at Big Sycamore Canyon; and the remainder, most of which were more abundant at the islands (Watson et al. 2002). Owing to the numerous "zero" observations, no meaningful results were obtained in the analyses of manta larval fish data.

Individual Taxa

Sebastes **spp.**   Most *Sebastes* larvae cannot be identi-fied to species, and the composite could include as many as 40–50 species in this data set. Abundances of rockfish larvae differed significantly among sites: there were more at the islands than at the mainland sites and more at Vandenberg than at Big Sycamore Canyon (tab. 1). No statistically significant spatial patterns were detected at Anacapa Island, and no significant alongshore patterns were detected at the other sites, but at all three abun-

TABLE 1
Summary of ANOVA and Multiple Comparisons Tests on Bongo Net Abundance Data

Taxon	Site	df	rmse	F	P	Bonferroni Abundance least ⟷ most			
Sebastes spp.	All	3 site	107.64	42.43	< .01	SC	VA	AN	SM
		781 residual	2.54						
	SM	3 line	15.56	3.96	.01	A	B	C	D
		163 residual	3.93						
	VA	3 line	42.77	26.66	< .01	A	B	C	D
		219 residual	1.60						
	SC	3 line	20.00	20.01	< .01	A	B	C	D
		225 residual	1.00						
Genyonemus lineatus Eggs	All	3 site	383.15	190.67	< .01	SM	AN	VA	SC
		392 residual	2.01						
	SC	3 line	12.00	4.58	< .01	D	A	C	B
		105 residual	2.62						
	VA	2 position	15.22	6.33	< .01	R	U	Do	
		108 residual	2.41						
G. lineatus Larvae	All	3 site	60.24	31.68	< .01	SM	VA	AN	SC
		392 residual	1.90						
	SC	3 line	12.89	2.99	.03	D	B	C	A
		105 residual	4.31						
Atractoscion nobilis + *Sphyraena argentea*	All	3 site	284.70	231.91	< .01	VA	SM	SC	AN
		385 residual	1.23						
	AN	2 position	13.81	6.70	< .01	E	W	Ce	
		61 residual	2.06						
Oxyjulis californica	All	3 site	322.36	119.41	<< .01	SC	VA	SM	AN
		385 residual	2.70						
	SM	3 line	86.35	23.44	<< .01	D	C	B	A
		76 residual	3.68						
Semicossyphus pulcher	All	3 site	153.59	68.87	< .01	VA	SC	SM	AN
		385 residual	2.23						
	SM	3 line	33.53	12.23	< .01	D	C	B	A
		2 position	10.82	3.95	.02	E	Ce	W	
		76 residual	2.74						
	SC	3 line	2.66	3.07	.03	D	C	A	B
		2 position	12.18	14.04	< .01	R	U	Do	
		6 interaction	2.11	2.43	.03	no	test		
		108 residual	0.87						
"Early eggs"	SC	3 line	2.03	4.29	<< .01	D	C	B	A
		2 position	3.82	8.06	<< .01	U	R	Do	
		6 interaction	2.03	4.29	<< .01	no	test		
		108 residual	0.47						
Citharichthys stigmaeus	All	3 site	129.41	24.50	<< .01	SM	VA	AN	SC
		781 residual	4.87						
	SM	3 line	15.08	4.46	< .01	D	C	B	A
		2 position	3.92	1.16	.32				
		165 residual	3.38						
Paralichthys californicus	All	3 site	298.94	69.54	< .01	VA	SM	AN	SC
		781 residual	4.30						
	SC	2 position	17.99	5.87	< .01	U	R	Do	
		225 residual	3.06						
"Early" eggs	SC	3 line	20.26	6.35	<< .01	D	C	B	A
		2 position	29.89	9.37	<< .01	U	R	Do	
		225 residual	3.19						
	SM	2 position	20.85	5.52	< .01	W	C	E	
		163 residual	3.78						

Note: Only statistically significant ANOVA results are shown. Abundances at underlined locations in the multiple comparisons results do not differ significantly.
Site codes: AN = Anacapa Island, SC = Big Sycamore Canyon Ecological Reserve, SM = San Miguel Island, and VA = Vandenberg Ecological Reserve.
Station lines are sequential from A (nearest to shore) to D (farthest from shore).
Alongshore position codes: Ce = center, Do = downcoast, E = east, R = reserve, U = upcoast, and W = west.
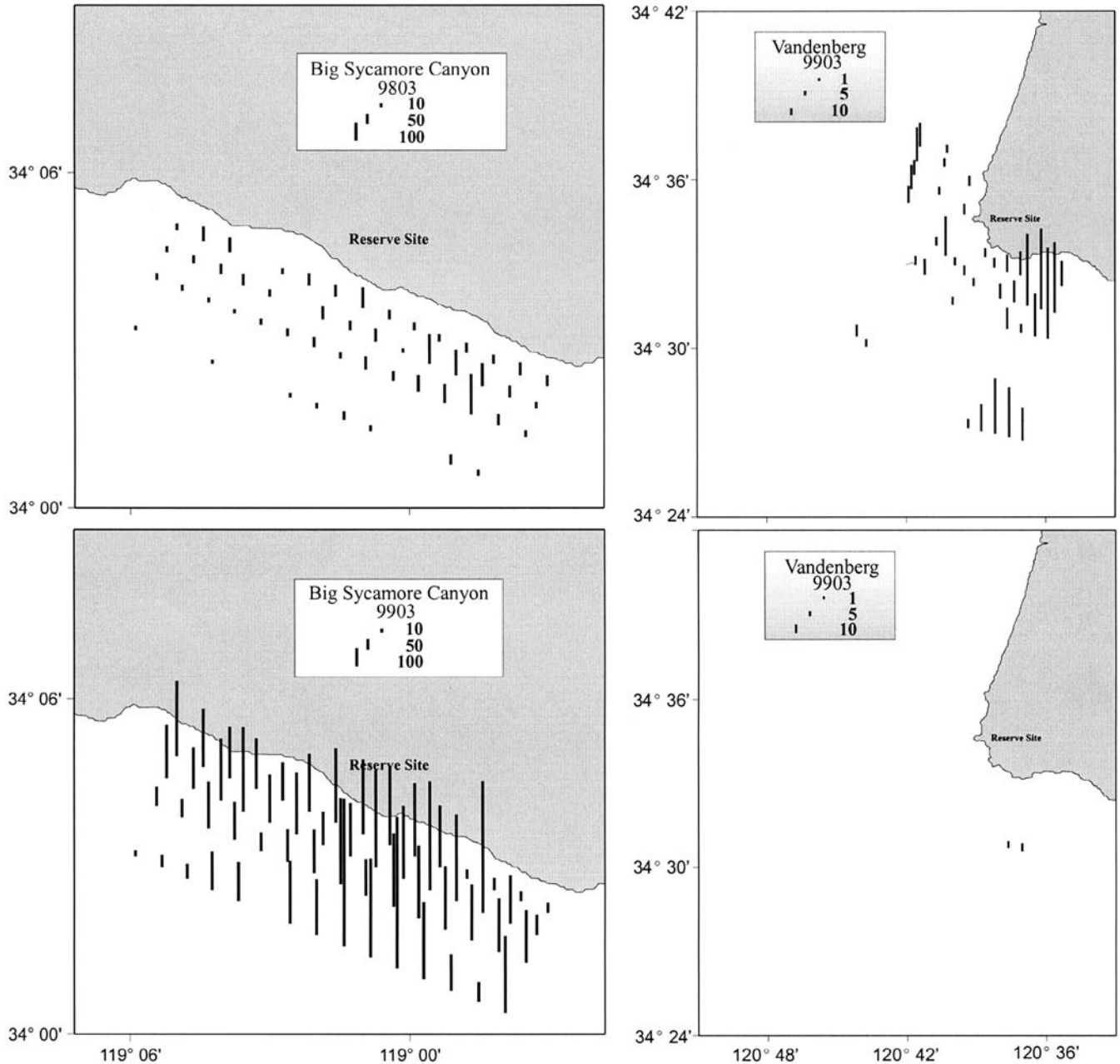
Figure 6. Abundance (number per 10 m²) of white croaker (*Genyonemus lineatus*) eggs collected with a vertically towed bongo net at the Big Sycamore Canyon and Vandenberg study sites in February–March 1998 (*upper*) and 1999 (*lower*).

dance increased significantly in the seaward direction. At Vandenberg (fig. 5) and Big Sycamore Canyon abundance was higher along the most offshore station line than on the other three lines. At San Miguel Island (fig. 5) the change was more gradual, with abundance along the most offshore line significantly higher than along the most inshore line, but not significantly different from the other two station lines (tab. 1).

Genyonemus lineatus. White croaker eggs and larvae were much more abundant at Big Sycamore Canyon than elsewhere (tab. 1). Eggs were significantly rarer at

San Miguel Island than at Anacapa Island and Vandenberg, but larval abundances were low at all three sites and did not differ significantly among them. At Big Sycamore Canyon statistically significant cross-shelf patterns were apparent for eggs and larvae, but no alongshore patterns were detected. Egg abundance was significantly lower along the most offshore line but did not differ significantly among the other three lines (tab. 1; fig. 6). Larvae were significantly more abundant along the most inshore line than along the most offshore line but did not differ significantly between other pairs of
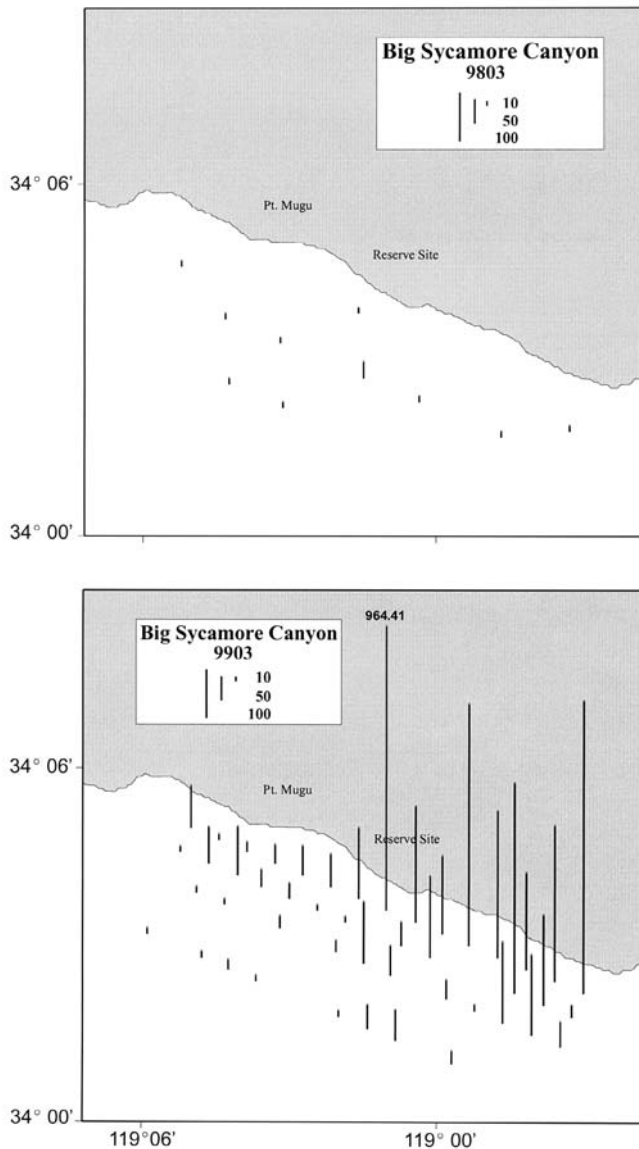
Figure 7. Abundance (number per 10 m²) of white croaker (*Genyonemus lineatus*) larvae collected with a vertically towed bongo net at the Big Sycamore Canyon site in February–March 1998 (*upper*) and 1999 (*lower*).

station lines (tab. 1; fig. 7). At Vandenberg, there were significantly more eggs at the "downcoast" stations in the western Santa Barbara Channel than in the other station blocks (tab. 1; fig. 6), but no significant cross-shelf pattern. No statistically significant patterns were detected for eggs at Anacapa Island, and low abundances of larvae at Anacapa Island and of both eggs and larvae at San Miguel Island precluded analyses of those data.

Atractoscion nobilis + Sphyraena argentea. Eggs of these species often are indistinguishable in field collections until about midway through development (stage VII) when diagnostic embryonic pigmentation forms. Because the older, identifiable embryonic stages of both had similar distributions, the two were combined. Eggs of both

were common in summer, but only one larval white seabass and no larval California barracuda were collected during the study. (No larvae of either species were collected at nearby stations during the 1998 and 1999 summer CalCOFI cruises, although larvae of both were collected south of our study area in 1998: Charter et al. 1999; Ambrose et al. 2001). Eggs were significantly more abundant at Anacapa Island than elsewhere, and significantly more abundant at Big Sycamore Canyon than at San Miguel Island and Vandenberg (tab. 1). There were no significant alongshore or cross-shelf patterns at Big Sycamore Canyon and San Miguel Island, and the Vandenberg data were not tested because too few eggs were collected at that site. There was no cross-shelf pattern at Anacapa Island, but abundance was significantly higher in the center of the pattern (tab. 1; Watson et al. 2002).

Oxyjulis californica. Señorita eggs were most abundant at the islands, especially Anacapa Island, and least abundant at Big Sycamore Canyon (tab. 1). A statistically significant spatial pattern was detected only at San Miguel Island where abundance was highest inshore, decreasing in the seaward direction (tab. 1). Only a few larval señorita were collected, all at the islands during the 1999 summer survey.

Semicossyphus pulcher. California sheephead eggs were common in summer, but only three larvae were collected (few were collected anywhere during the 1998 summer CalCOFI cruise, but they were more abundant in autumn; no larvae were collected in 1999; Charter et al. 1999; Ambrose et al. 2001). Eggs were more abundant at Anacapa Island than elsewhere, and more abundant at San Miguel Island than at the mainland sites, which differed insignificantly (tab. 1). There were no significant spatial patterns at Anacapa Island, and very low abundance at Vandenberg precluded analyses at that site. At San Miguel Island abundance was significantly higher on the inshore station line than on the offshore two lines, and higher along the next most inshore line than on the most offshore line (tab. 1; fig. 8). Abundance also was higher at the "west" stations than at the "east" stations; neither block differed significantly from the center (the same alongshore pattern was observed for señorita eggs but was not statistically significant: $p = 0.06$). At Big Sycamore Canyon almost all of the eggs taken with the bongo net were collected from the inshore three lines at the "downcoast" stations (fig. 9). They were significantly more abundant "downcoast" (tab. 1), but did not differ significantly in the cross-shelf direction. Abundance of "early" stage eggs was significantly highest on the most inshore line and in the "downcoast" block (tab. 1). CUFES data confirmed that eggs were more abundant toward shore and downcoast, but also suggested a broader distribution at Big Sycamore Canyon.

Citharichthys stigmaeus. Speckled sanddab eggs were among the most abundant collected and larvae occurred
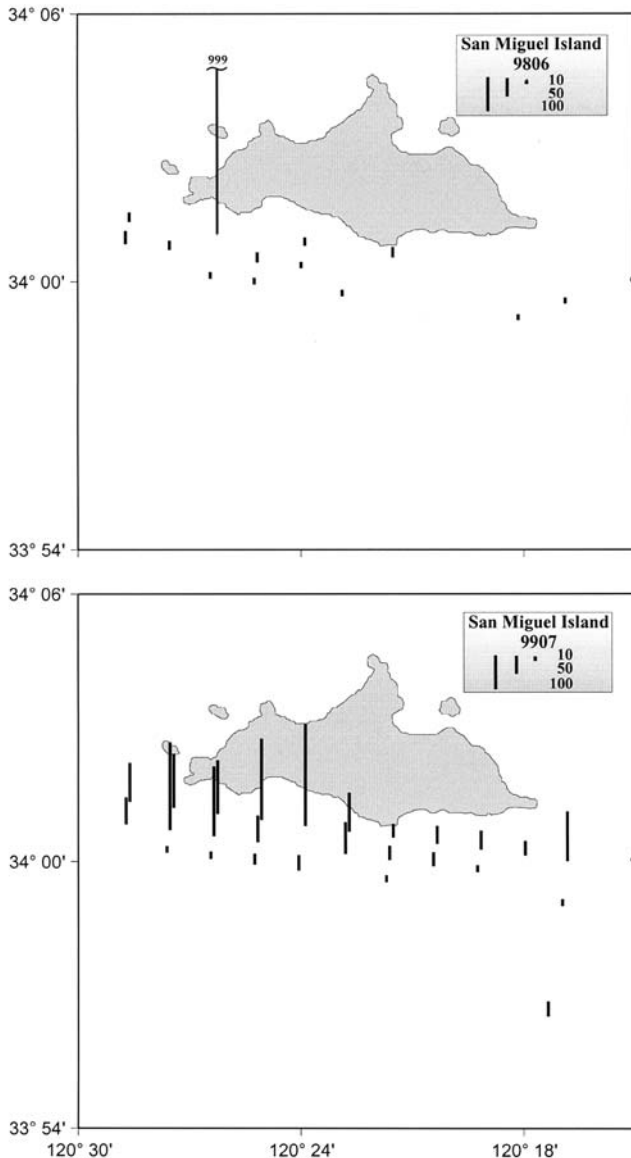
Figure 8.   Abundance (number per 10 m²) of California sheephead (*Semicossyphus pulcher*) eggs collected with a vertically towed bongo net at San Miguel Island in June 1998 (*upper*) and June–July 1999 (*lower*).
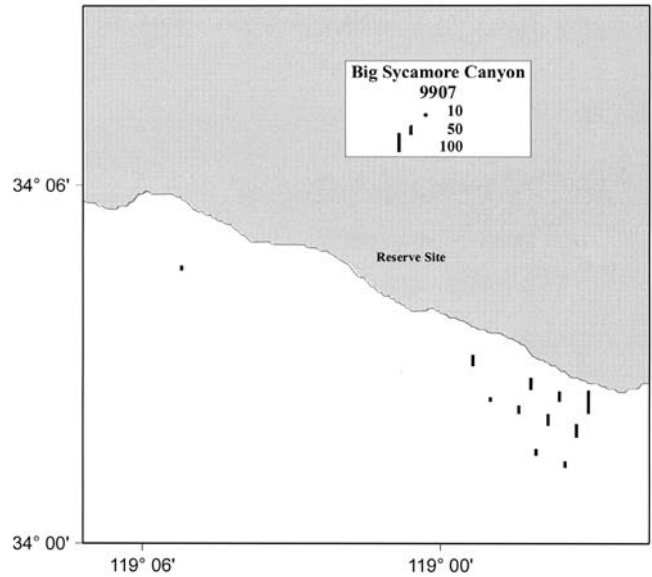

Figure 9.   Abundance (number per 10 m²) of California sheephead (*Semicossyphus pulcher*) eggs collected with a vertically towed bongo net at the Big Sycamore Canyon site in June–July 1999.

relatively commonly as well, but in small numbers. Eggs were more abundant at Big Sycamore Canyon than elsewhere (tab. 1); abundances differed insignificantly among the other sites. Statistically significant alongshore patterns were not detected at any site, and a significant cross-shelf difference was detected only at San Miguel Island, where abundance was higher along the two inshore lines than on the most seaward line (tab. 1).

Paralichthys californicus.   California halibut eggs were common, but few larvae were collected (larvae were more common in CalCOFI collections in 1998, primarily north and south of our study area, but none was collected in 1999; Charter et al. 1999; Ambrose et al. 2001). Significantly more eggs were collected at Big

Sycamore Canyon than elsewhere, and more at Anacapa Island than at San Miguel Island and Vandenberg, which did not differ significantly (tab. 1). No statistically significant spatial patterns were detected at Anacapa Island and Vandenberg, and no significant cross-shelf patterns were apparent at Big Sycamore Canyon and San Miguel Island, but significant alongshore differences were detected at both sites (tab. 1). At Big Sycamore Canyon abundance was higher at the "downcoast" stations than at the "upcoast" stations (fig. 10) but was not significantly different in either group from the "reserve" stations. After deletion of two offshore "downcoast" stations with extremely high abundances (fig. 10, lower left panel) the alongshore pattern remained, and a significant cross-shelf pattern, with higher abundance toward shore, resulted. CUFES data also showed higher abundance toward shore and downcoast (more apparent in 1998 than in 1999). Analyses of "early" stage eggs yielded essentially the same results (tab. 1). At San Miguel Island abundance was significantly higher at the eastern stations than in the other blocks (tab. 1), which differed insignificantly.

CUFES-Bongo Net Comparison

In the evaluation of CUFES catch data, the regressions of CUFES catches on bongo net catches (tab. 2) showed a strong relationship between the CUFES and bongo for northern anchovy, a moderate relationship for speckled sanddab, a weak relationship for California halibut, and no relationship for C-O sole. Thus the CUFES is a good sampler for the eggs of some taxa and a poor sampler for others; its utility must be assessed on a species-by-species basis.
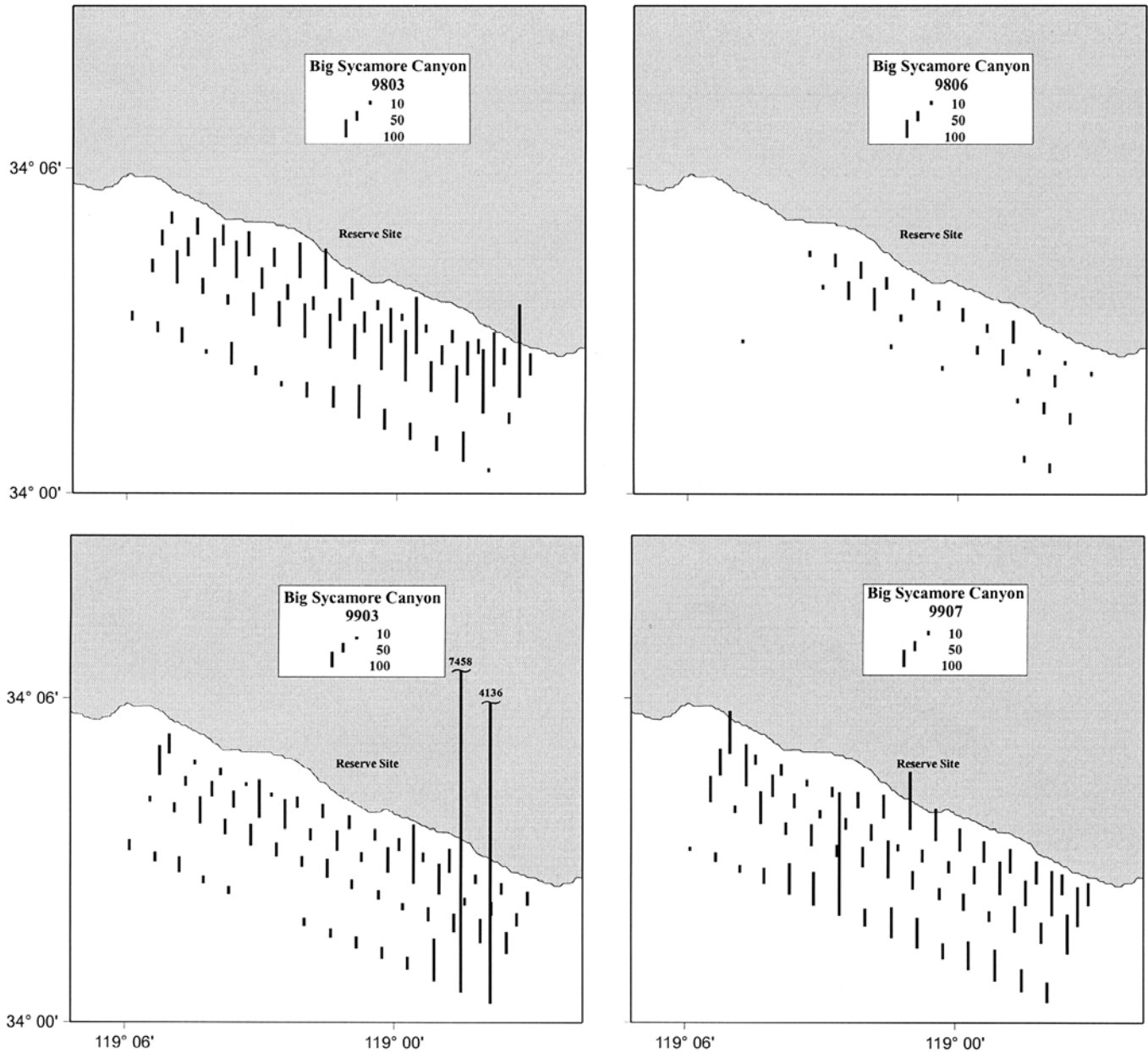
Figure 10.   Abundance (number per 10 m²) of California halibut (*Paralichthys californicus*) eggs collected with a vertically towed bongo net at the Big Sycamore Canyon site in February–March (*upper left*) and June (upper right) 1998, and February–March (lower left) and June–July (*lower right*) 1999.

DISCUSSION

At the level of the ichthyoplankton assemblage the dominant environmental signal was season: winter versus summer. Within summer the 1998–99 El Niño/ Southern Oscillation (ENSO) events were apparent in the bongo data. There were hints of adult habitat preference, most apparent in summer, when the rocky-bottom/kelp habitats at the islands tended to separate from the soft-bottom habitats at the mainland sites. Faunal affinity was apparent, more so in winter, with Anacapa Island and Big Sycamore Canyon in the San Diegan fau-

nal province tending to group in the bongo data set, and San Miguel Island and Vandenberg at the southern limit of the Oregonian faunal province tending to group in the manta and bongo net data sets. All these patterns were apparent primarily based on the eggs, which are well sampled by both vertical bongo and manta net tows. The more ambiguous results for larvae may reflect, in part, the fact that vertical bongo net tows are not the most effective method for sampling fish larvae.

In addition to our study, only Lavenberg et al. (1987) and McGowen (1993) addressed the distributions of

TABLE 2
Results of Linear Regressions of CUFES Fish Egg Catches (number per minute)
on Bongo Net Fish Egg Catches (number per 10 m²)

Taxon	R^2	df	F	P	Regression equation
Engraulis mordax	0.630	1,394	671.9	<< 0.05	CUFES = 0.005 (bongo) − 0.175
Citharichthys stigmaeus	0.408	1,378	260.4	<< 0.05	CUFES = 0.008 (bongo) + 0.303
Paralichthys californicus	0.027	1,442	12.2	<< 0.05	CUFES = 0.005 (bongo) + 0.610
Pleuronichthys coenosus	0.005	1,126	0.7	0.42	

planktonic fish eggs in coastal waters of the Southern California Bight (SCB). This small number of studies probably is largely attributable to the difficulty of identifying to species the eggs of the majority of planktonic spawners. Coastal fish larvae in the SCB have been studied more extensively (e.g., Gruber et al. 1982; Schlotterbeck and Connally 1982; Barnett et al. 1984; Lavenberg et al. 1986; Walker et al. 1987; McGowen 1993). Two studies in the nearshore zone (Walker et al. 1987; McGowen 1993) included analyses of the whole assemblage, and both identified season as a dominant environmental signal, as we did. McGowen (1993) demonstrated characteristic cross-shelf distributions for different groups but found little evidence for alongshore patterns within the SCB, and Gruber et al. (1982), whose study included stations near shore and seaward of the shelf, showed that on-offshore location is at least as important as season in determining larval fish assemblages. These results contrast somewhat with ours: we found little evidence for cross-shelf pattern at the assemblage level in that inshore and offshore collections did not form separate groups, although alongshore pattern was suggested in the tendency for winter collections at the northwestern sites (San Miguel Island and Vandenberg) to group separately from those at the southeastern sites (Anacapa Island and Big Sycamore Canyon). The difference between McGowen's (1993) study and ours with respect to alongshore pattern may reflect location in the SCB: the former was located entirely within the San Diegan faunal region, whereas ours included a transitional zone between the San Diegan and Oregonian faunal regions. There was an indication of cross-shelf location for two larval fish groups in our classification of taxa collected with the bongo net. The six primarily winter taxa (group 1) are broadly distributed across the shelf and tend to be more abundant over the outer shelf; this group is essentially the same as McGowen's (1993) STENOBRACHIUS assemblage, described as most abundant in winter and spring in the seaward half of his study area, and it includes all four Group 01 taxa of Gruber et al. (1982), described as an offshore/cosmopolite, winter to summer group. All but one (*A. sialis*) of the five taxa identified as a possible subset of larval group 2 in our analysis are most abundant over the inner shelf; among these only white croaker was included in

McGowen's (1993) study, as part of an assemblage (GENYONEMUS) described as most abundant within the 15–36 m depth zone.

Cross-shelf and habitat-specific distributions were more apparent for individual taxa, both among and within sites. Señorita and California sheephead eggs were most abundant at the inshore stations at one or more sites, and broader distributions encompassing all three shoreward lines were apparent for white croaker eggs and larvae (highest egg abundance in the vicinity of the 40 m isobath and highest larval abundance in the vicinity of the 20 m isobath at Big Sycamore Canyon suggests that larvae concentrated shoreward of the principal spawning zone, as has been suggested elsewhere: e.g., Watson 1982; Barnett et al. 1984). Early stage California halibut eggs were significantly more abundant toward shore at Big Sycamore Canyon despite very large catches of stage I and II eggs offshore on the night of 26 February 1999, but total eggs were not significantly more abundant inshore, perhaps reflecting some dispersal after spawning. Rockfish larvae were more abundant offshore than inshore. These distributions generally are consistent with results of other studies of SCB coastal ichthyoplankton (e.g., Gruber et al. 1982; Barnett et al. 1984; McGowen 1993).

Habitat-specific distributions were apparent primarily for taxa with strong adult habitat affinity. Generally, eggs and larvae of soft-bottom taxa, such as white croaker and California halibut, were most abundant at the largely soft-bottom Big Sycamore Canyon site, while the eggs and larvae of taxa with strong rocky-bottom and kelp forest affinity, such as rockfishes and California sheephead, were most abundant at the islands where that habitat is located. Faunal affinity was apparent for some taxa. For example, California halibut, white seabass, and California barracuda have warm-water affinity, and their eggs were most abundant at the warmer, southeastern sites. California sheephead has warm-water affinity, and its eggs were more abundant at Anacapa Island than at San Miguel Island; rockfishes and lingcod have cool-water affinities, and their larvae were more abundant at San Miguel Island than at Anacapa Island. Within-site habitat specificity was apparent for California sheephead eggs at Big Sycamore Canyon, where the largest collections were at the eastern stations in the vicinity of the only suitable adult habitat. Señorita eggs, another rocky-bottom/kelp forest

species, also tended to be more abundant at the eastern stations than elsewhere at Big Sycamore Canyon, but like California sheephead, they were relatively rare at that site compared with the islands.

Influences of the 1998–99 ENSO events on egg and larval abundances were most apparent for taxa with cool-water affinity, such as rockfishes and white croaker, which were most abundant in 1999 (La Niña). Interestingly, eggs of California sheephead and señorita were more abundant in 1999 as well, despite the warm-water affinity of those species, perhaps reflecting a greater influence of the increased plankton production (e.g., Bograd et al. 2000), expanding kelp coverage at the islands, and generally improved, albeit cooler, conditions in 1999.

A striking feature of the two state reserves is their relatively low productivity in eggs and larvae of most commercially and recreationally valuable shorefishes, which they were intended to protect. This especially was the case at Vandenberg, which seemingly provided poor habitat even for the soft-bottom species that might have been expected there. In contrast, production of eggs and larvae of many of the shorefishes of fishery value was high at the islands, especially at Anacapa Island. To provide some crude perspective on the mainland reserve-island contrast, we calculated the mean abundances of total eggs or larvae of a few species taken in the vertical bongo net tows within hypothetical reserves at the four sites. These hypothetical reserves were 3.7 km alongshore and extended offshore to the second station line (~ 40 m isobath)—similar to the actual Big Sycamore Canyon Ecological Reserve. Two were sited where the two existing state reserves are, one was at Anacapa Island on the northern side of East Anacapa, continuing along about the eastern third of Middle Anacapa, and one was centered along the southern side of San Miguel Island. Relative to the hypothetical Big Sycamore Canyon reserve, the hypothetical Vandenberg reserve was 85% as large, the hypothetical San Miguel Island reserve 55% as large, and the hypothetical Anacapa Island reserve 40% as large (the Anacapa "reserve" includes an actual no-take reserve at East Anacapa, in place since 1978, that constitutes about 10% of the area of the hypothetical reserve). Within these areas, the mean number of California sheephead eggs in summer was 71.6 million (130.2 eggs per 10 m^2) at Anacapa Island, 78.5 million (103.9 eggs per 10 m^2) at San Miguel Island, and none at Big Sycamore Canyon and Vandenberg. Respective values for white seabass plus California barracuda eggs were 216.5 million (393.7 eggs per 10 m^2) at Anacapa Island, 1.6 million (2.1 eggs per 10 m^2) at San Miguel Island, 32.2 million (23.5 eggs per 10 m^2) at Big Sycamore Canyon, and none at Vandenberg. There would have been 76.3 million rockfish larvae (138.8 larvae per 10 m2) on average during winter-spring in the hypothetical Anacapa Island reserve, 24.7 million (32.7 larvae per 10 m^2) at San Miguel Island, 1.5 million (1.1 larvae per 10 m^2) at Big Sycamore Canyon, and 5.7 million (4.9 larvae per 10 m^2) at Vandenberg. California halibut would have fared better at the mainland sites: 281.2 million eggs (205.3 eggs per 10 m^2) at Big Sycamore Canyon compared with 138.7 million (252.1 eggs per 10 m^2) at Anacapa Island (but recall that the hypothetical Anacapa Island reserve is less than half the size of the hypothetical Big Sycamore Canyon reserve), and 92.8 million (79.3 eggs per 10 m^2) at Vandenberg compared with 42.4 million (56.1 eggs per 10 m^2) at San Miguel Island.

The vicinity of Vandenberg Ecological Reserve, as noted, apparently is not a particularly productive area in planktonic fish eggs and larvae. Many taxa were least abundant, and only a few uncommon taxa were most abundant, at that site, for example, eggs of smalleye squaretail (*Tetragonurus cuvieri*), an epipelagic species, and larvae of pricklebreast poacher (*Stellerina xyosterna*), an inshore, soft-bottom benthic species, whose rare occurrence happened to be at Vandenberg. The Vandenberg site is a high-energy area with strong currents, strong sand transport, and relatively poor fish habitat. We found no evidence to suggest significant production of planktonic fish eggs or larvae from the vicinity of the Vandenberg Ecological Reserve.

The Big Sycamore Canyon Ecological Reserve vicinity is a more benign environment, and soft-bottom shorefish species of fishery value, such as California halibut (Moser and Watson 1990; Barsky 1990; Helvey and Witzig 1990), might, a priori, be expected to benefit from the exclusively inshore, soft-bottom reserve. California halibut and other soft-bottom species including white croaker, a species of modest, primarily sport fishery, value (Love et al. 1984; Aseltine-Neilson 2000, 23–24) clearly spawn in the reserve; however, egg abundance is higher outside the reserve, suggesting that more are produced outside the reserve than inside. Furthermore, the soft-bottom species are unlikely to have much site fidelity to a small reserve surrounded by extensive, similar habitat, and it seems unlikely that production of eggs or larvae of these species from the reserve will be significantly enhanced relative to adjacent areas in the future. As an exclusively soft-bottom, inshore site, Big Sycamore Canyon Ecological Reserve has little potential to function as a reserve for most nearshore species subject to fishery exploitation because most of them (e.g., nearshore rockfishes, cabezon, lingcod, California sheephead) have rocky-bottom habitat affinities. Placement of a large artificial reef in the reserve could dramatically alter its potential value for these species, especially if the reef were colonized by giant kelp, *Macrocystis*. If such a reef, with kelp, were present, high abundances of California sheephead eggs, probably sim-

ilar to those at Anacapa Island, eventually might be expected. Alternatively, expansion of the reserve southeastward to include the rocky-bottom/kelp habitat downcoast from the present reserve may have a similar effect (Cochrane et al. 2002). Nearshore rockfishes, cabezon, white seabass, and California barracuda also might be expected to benefit from either method of including a reef within the reserve.

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