Migrant Sound Scatterers: Interaction with the Sea Floor

Abstract. *Studies on the coast of Baja California show that oceanic zooplankters carried into shallow water provide abundant food for resident predators. The vertically migrating zooplankters apparently are vulnerable when they encounter the sea floor in shoal areas. This ecologically significant mechanism may be of importance to fisheries and military operations.*

Aggregations of sound-scattering organisms in the sea are an interesting and conspicuous phenomenon. In some regions dense aggregations are the most striking aspect of distribution. Such aggregations may be noisy and sufficiently dense and numerous to present sonar search with a plethora of false targets or obfuscating clouds that complicate antisubmarine measures. Aggregations are frequently associated with high density of fish. Where fisheries are highly developed, the fishing boats also are part of the environmental and sonic conditions. Aggregations are thus important to ecology, undersea warfare, and fisheries.

The broad, Pacific-wide distribution of zooplankton correlates quite well with the concentration of plant nutrients in the near-surface waters (*1*). But within this broad correlation sonic probing, net sampling, and fishing experience all show that the distribution is complex. There are many distribution inhomogeneities. Many individual organisms tend to school and thus to show clumped or contagious distributions in small-scale sampling; indeed most predators, including fishermen, depend on the schooling behavior of their prey. Moreover, the frequency of these small-scale aggregations varies sharply between adjacent areas tens to hundreds of kilometers apart, even where little difference in the physical and chemical nature of the water is discernible; mechanical interactions, such as those between circulation of waters, topography of the sea floor, and behavior of the organisms, may be implicated.

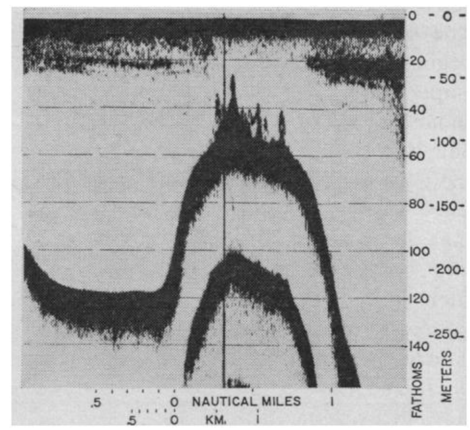

Fig. 2. Precision sonic record showing sound-scattering organisms obscuring the bottom trace and the discontinuity of the scattering layer over the ridge; 1711 hours P.S.T., 20 May 1964.

We have explored two instances of mechanical interaction. One concerned the water motion that results from diurnal fluctuations of wind on continental coasts, and the interaction of this motion with the diurnally migrating zooplankters; here a sort of "rectification" of motion apparently can ensue.

The second concerned the interaction of the vertically migrating zooplankton with the ocean floor where it is shallower than their usual diurnal migrations in offshore regions. Where currents continually sweep from oceanic areas over shallow coastal regions and over shallow seamounts, a large, resident, benthic or epibenthic community may live by feeding on the diurnally vertically migrating zooplankton. Such an area lies off Cape Colnett, Baja California (Fig. 1).

Off Cape Colnett occurs an interesting feature of the normally southeastward-flowing California Current. Here the current turns eastward toward the coast; as the water nears shore, part of it turns northward into the Southern California gyre and part turns south-

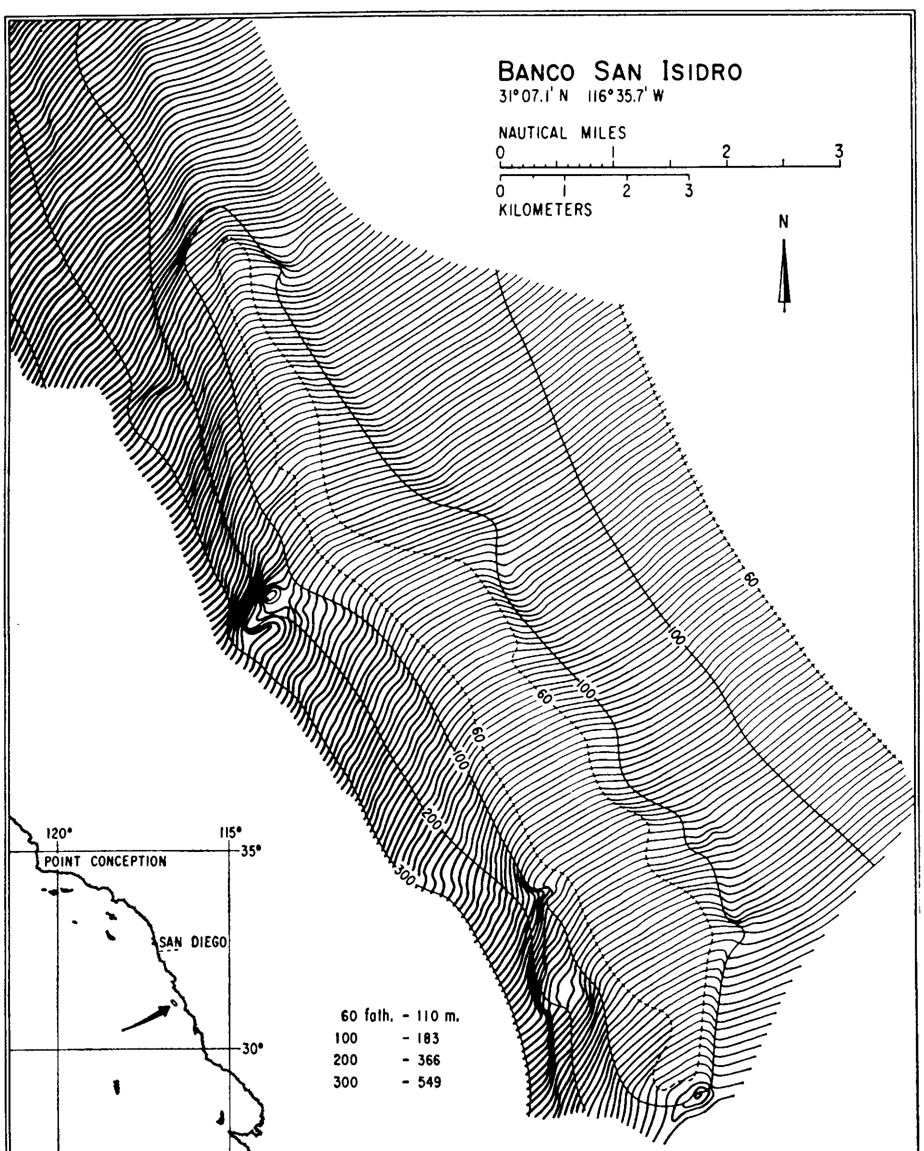

Fig. 1. Bathymetry of the area studied.

ward along the Mexican coast (*2, 3*). The southward turn of the circulation begins about 25 km west-northwest of Cape Colnett. Here the ocean floor shoals from 730 m to the 90-m Banco San Isidro within 1.5 km. On this shoal there are dense bottom and near-bottom sonic scatterers. Surveys of other areas that are similar except for the current and topographic features have found no such dense sonic patterns.

Six cruises through the region have collected sonic records with a precision depth recorder; some also obtained current measurements, collected fish and plankton with 10-foot (3-m) Isaacs-Kidd mid-water trawls and Brown-McGowan opening-and-closing plankton nets, captured fish with free-vehicle fish traps and set lines, photographed and dredged the bottom, and obtained records with an AN/UQS-1 mine-hunting sonar.

Figure 1 shows the topography of the area studied. The seaward side of Banco San Isidro rises steeply from about 730 m to a nearly level ridge, 1 km wide and about 9 km long, at 93 to 106 m. On the shoreward side of the ridge the sea floor falls to 219 m, creating a nearly flat valley about 1.5 km wide; it then rises to the shallow coastal shelf.

Two cruises directly observed the current, using parachute drogues (*4*). From these and other observations (*3, 5*) it appears that the surface currents sweep down and eastward across the ridge and then turn northward or southward.

In this area the offshore daytime scattering layers are usually at depths of 150 to 180 m and 250 to 325 m. On all six cruises the precision depth recorder showed many clumps of dense sonic spires extending along and across the ridge and through the water column for 15 to 40 m above bottom. Figure 2 shows an example of sound-scattering organisms sufficiently dense to obscure the bottom trace; these are much denser scatterers than are ordinarily observed elsewhere (*6*).

Surveys made at dawn and dusk observed events over the ridge and in the valley at the times of diurnal migrations. Figure 3 shows examples from a sequence of alternate shoreward and seaward depth-recorder sections taken across the area from 0400 hours through 0700 P.S.T., 20 May 1964 (*6*). Figure 3*a* is a typical night picture taken 30 minutes before the first light of dawn; it shows some scattering in the valley, a small amount on the ridge,

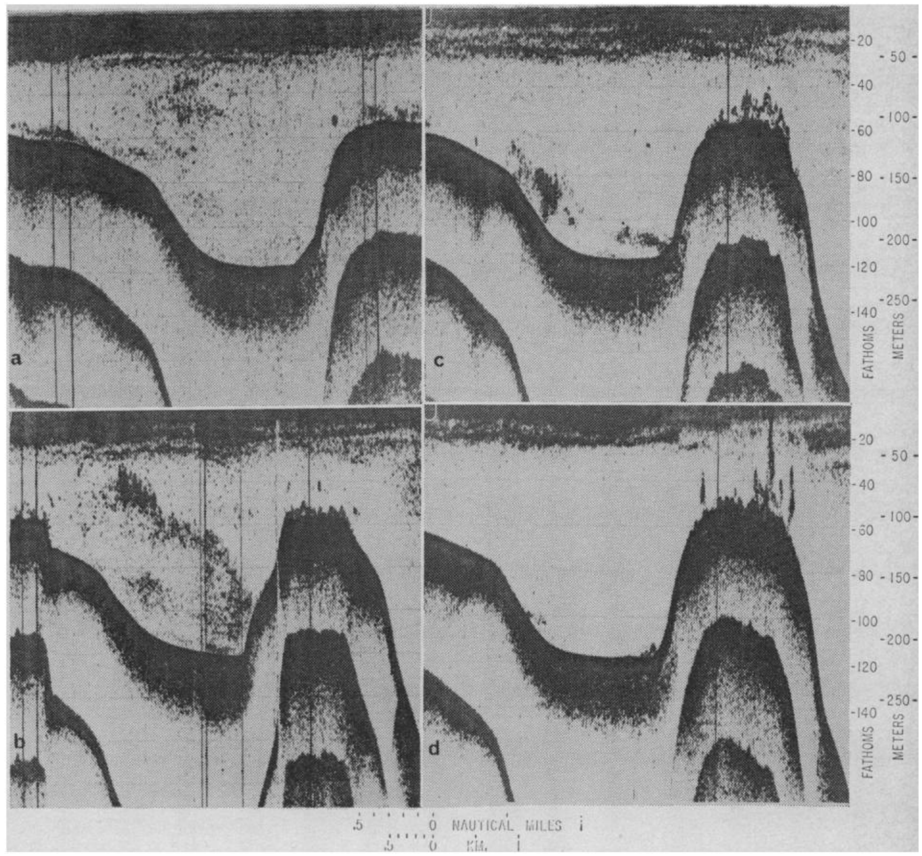

Fig. 3. Precision sonic records showing scattering organisms migrating downward; a series from darkness through daylight, 20 May 1964: *a*, 0400; *b*, 0430, dawn; *c*, 0500; *d*, 0700.

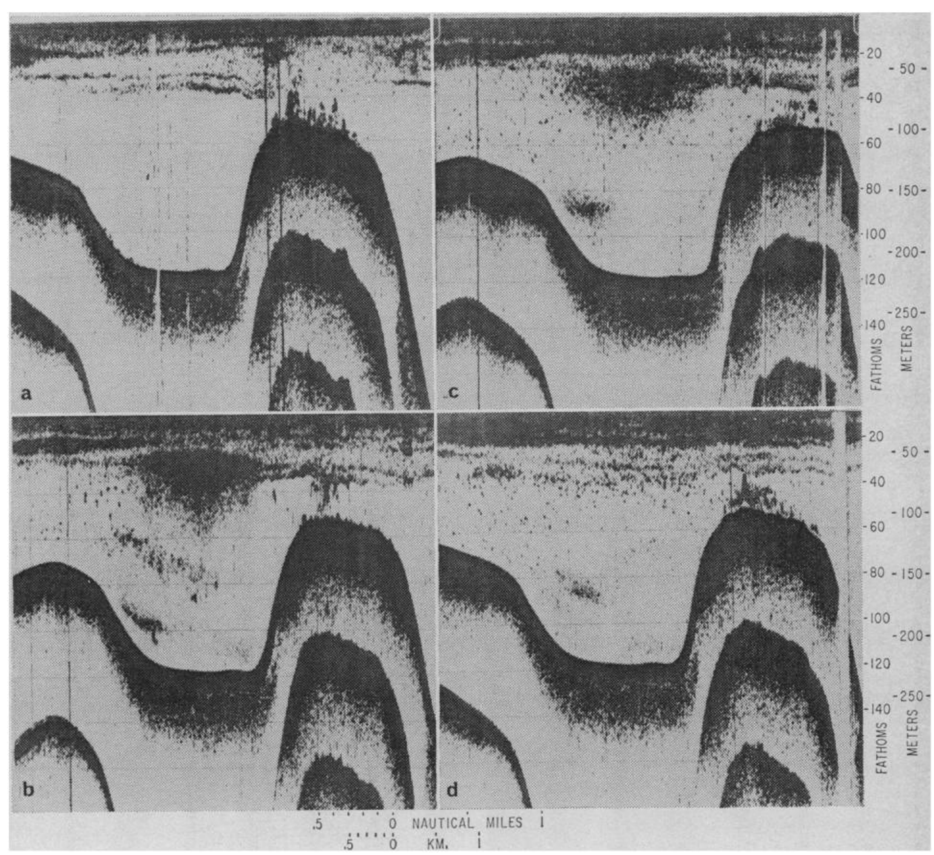

Fig. 4. Precision sonic records showing scattering organisms migrating upward; a series from daylight through darkness, 19 May 1964: *a*, 1800 hours P.S.T.; *b*, 1900 dark; *c*, 1930; *d*, 2100.

Table 1. Preserved zooplankton samples. In parentheses are the weight percentages (of total samples) accounted for by Copepoda, Euphauseacea, and Chaetognatha. Stations: 5, 1.5 km west of the ridge, 1831 hours P.S.T., 18 November 1964; 6, over the ridge, 2032; 7, over the valley, 2229; 8, over the ridge, 0916, 19 November; 9, over the valley, 1225.

Station	Zooplankton ($g\ m^{-3}$) at four depths				Column content ($g\ m^{-2}$)
	10 m	30 m	60 m	90 m	
			Night		
5	0.133 (93)	0.02384 (80)	0.04239 (54)	0.01591 (62)	5.1
6	.02111 (85)	.01261 (59)	.01430 (73)	.01371 (75)	1.6
7	.07488 (89)	.01433 (78)	.00650 (66)	.01585 (65)	2.6
			Day		
8	.01064 (83)	.02562 (90)	.01581 (74)	.04520 (35)	2.8
9	.0225 (82)	.00822 (58)	.00719 (52)	.04882 (91)	2.4

and a dense, continuous, near-surface layer about 55 m thick. The dawn section (Fig. 3*b*) shows scatterers descending from the surface layer toward the bottom in the valley and on the ridge. Figure 3 (*c* and *d*) was taken later during increasing daylight: by 0500 hours the scattering layer had nearly completed its descent; by 0700 only a few patches were left and were just off the bottom; during this period the dense spires on the ridge had gradually concentrated and extended upward.

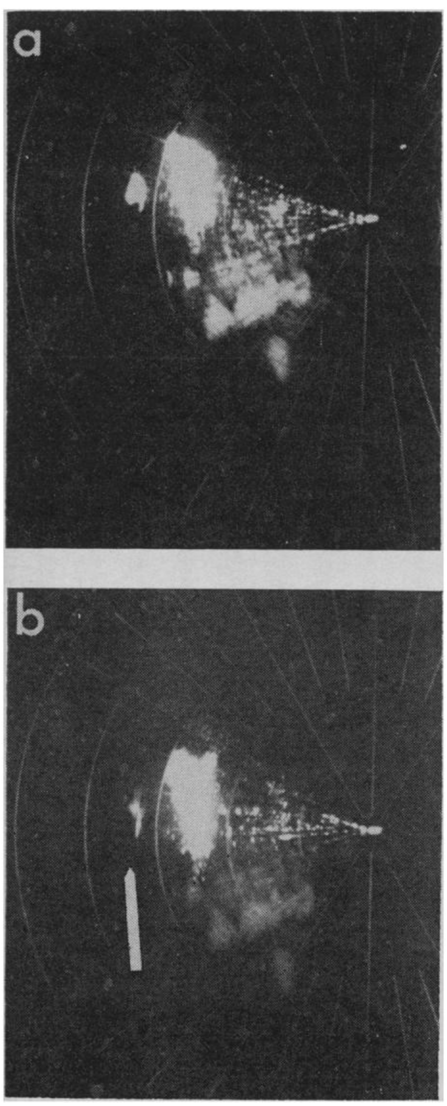

Fig. 5. Sonar-scope photographs. *a*, Mid-water trawl hidden among sonic scatterers at 013207 hours; *b*, trawl emerged, 013210.

Figure 4 shows an evening sequence that typifies the action of the scatterers at dusk. Figure 4*a* is still characteristic of daytime—a shallow and diffuse scattering layer to 55 or 65 m, a few scatterers just off bottom in the valley, and concentrations and spires of dense targets extending many meters above the ridge. At dark (Fig. 4*b*) the scatterers rise from the bottom, mainly from the valley, and form a denser layer near the surface. Figure 4 (*c* and *d*), following the upward progress of migration, shows decreasing density in mid-water and increasing density at the surface. The targets on and just above the ridge begin to dissipate at dark (Fig. 4) and are never so concentrated as in daylight [Figs. 2, 3 (*c* and *d*), and 4*a*]. Also conspicuous is the discontinuity in the scattering layer over the ridge during the day (Figs. 2, 3*d*, and 4*a*); at night the scattering layer extends across the ridge without a break [Figs. 3*a* and 4 (*c* and *d*)].

U.S.S. *Conquest* accompanied R.V. *Horizon* in one survey of this area. The AN/UQS-1 sonar of *Conquest* was used for simultaneous observation of the sonic scatterers and of a mid-water trawl that was hauled by *Horizon* and directed by *Conquest* through the spire-like concentrations. Figure 5 (*a* and *b*) is typical of photographs of the sonar scope of *Conquest* [each ring is 100 yards (90 m) in range]. In Fig. 5*a* the trawl is hidden in a small mass of sonic scatterers near some larger masses; 3 seconds later (Fig. 5*b*) the small mass is somewhat dispersed, and the trawl (shown by arrow) has emerged and is visible. The trawl catches were primarily euphausiids (*E. pacifica*), adult anchovies (*Engraulis mordax*), and small Pacific hake (*Merluccius productus*).

Total mass of preserved zooplankton in the area of current inflow to Cape Colnett was measured by oblique sampling on one cruise at about 0.030 g m^{-3}, indicating an influx of about 4.2 g m^{-2} day^{-1} over the area studied. In another survey, stratified samples were taken successively with opening-and-closing nets west of the ridge, over the ridge, and over the valley; disappearance of about 3 g of zooplankton per square meter within this distance was indicated (Table 1).

The fish population was investigated with set lines, fish traps, hook-and-line fishing, mid-water trawls, and photography over the ridge and valley. Set lines, with hooks from surface to bottom and along the bottom, were released in daylight and at night; a number of hooks were subsequently found missing. The free-vehicle fish traps rested on the bottom for several hours before retrieval. The opening-and-closing plankton nets were towed at speeds up to 9 knots through the acoustic targets over the ridge; they caught fish of less than 35 mm. Mid-water trawls captured adult anchovies, juvenile hake, and other larger fish. The principal fish caught were: (surface and mid-water) *Diaphus theta*, *Bathylagus stilbius*, *Engraulis mordax*, *Hypsoblennius* sp., *Sebastodes macdonaldi*, *Triphoturus mexicanus*, *Stenobrachius leucopsarus*, *Merluccius productus*, and *Chromis punctipinnis*; (ridge bottom) *Sebastodes* sp., *S. rubrivinctus*, *S. chlorostictus*, *S. miniatus*, *Ophiodon elongatus*, *Caulolatilus princeps*, and *Eptatretus stoutii*; (valley bottom) *S. eos*, *E. stoutii*, and *Anoplopoma fimbria*.

The ridge and valley floor were investigated with a camera and a mid-water trawl used as a dredge. The ridge is covered with boulders. One to five fish, apparently *Sebastodes*, appear among the rocks in most of the photographs (field of view, about 6 m^2); many crabs and white sponges up to 0.5 m in diameter also appear. The slope from ridge to valley is rock covered, but the valley bottom consists of green mud. Very few fish appear in photographs of the valley, but sediments from cores taken in the valley contain many scales from anchovy and hake—none from sardines; many other scales may be modified scales of the head and nape of *Sebastodes*. The biomass of the *Sebastodes* population

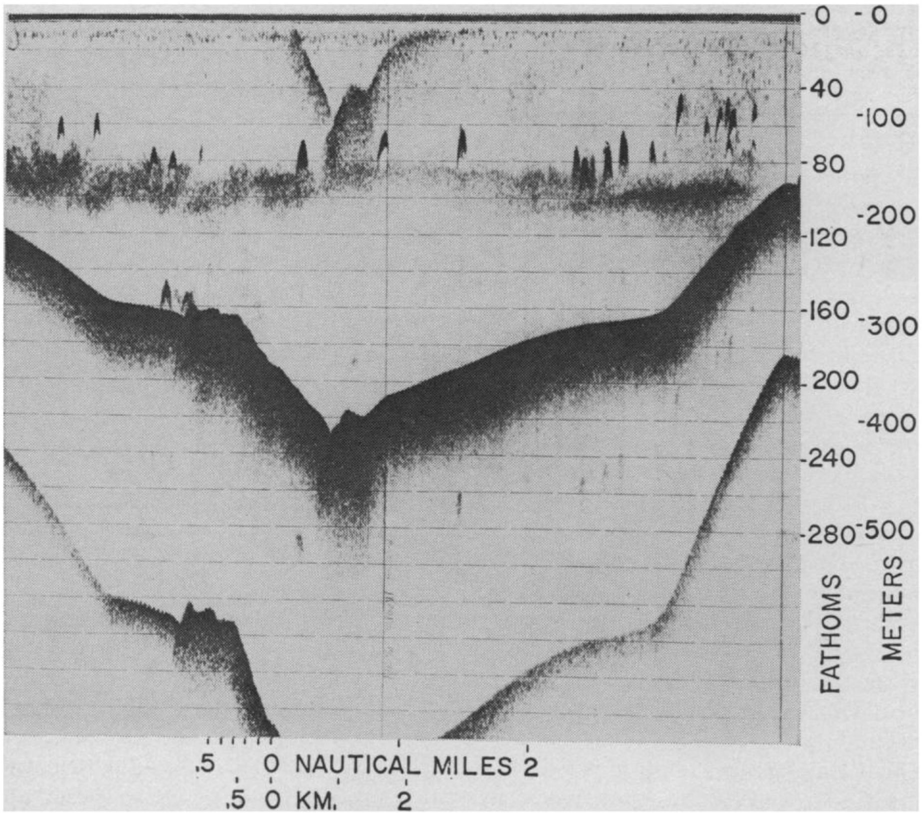

Fig. 6. Predators and the scattering layer over deep water at 1700 hours P.S.T., 11 May 1960. Being a continuous trace to seaward and return, the figure appears to represent a crossing of a valley.

shown in the photographs is estimated at about 200 g m^{-2}; its food requirement may be 2 to 4 percent per day, or 4 to 8 g m^{-2} day^{-1}—of the same order as the estimated consumption of zooplankton over the ridge.

The inshore sweep of the California Current over Banco San Isidro transports oceanic zooplankton into water shallower than their normal vertical range of migration. A dense population of predators on the bank is quite unlike that of the coast nearby. Over the bank, the migrants descend to the bottom each morning, and new migrant organisms are carried into the area each night by the current. The descending organisms are probably far more vulnerable to predators over the bank than in the open ocean. Presumably the normal vertical migration of the zooplankters in darkness is a tactic that minimizes daytime predation. Predators that accompany the open-sea migration are limited to predation in balance with production. When the migrants concentrate near an unfamiliar bottom in daylight, however, not only are they more vulnerable to predation, but the resident predators need not be prudent.

The migrants that descend into the valley are apparently not heavily attacked; they can be seen on the bottom by day (Figs. 3*d* and 4*a*) and rising at nightfall (Fig. 4, *b–d*). The depth of the valley is not much less than the depth of their normal diurnal migration at sea; the light intensity resembles that of their daytime refuge at sea, and they are presumably not seriously more vulnerable to predation than in the open sea. The mass of plankton found in the valley (Table 1) suggests predation intermediate between that over the ridge and that in the open sea.

Nutrients are certainly brought up from deeper water by turbulence on the shelf, but this aspect probably does not affect the immediate area because of the water's brief stay in the area. Food available for resident predators from drift is of the order of 4.2 g m^{-2} day^{-1} (perhaps 0.8 g of organic carbon) over the area, with about 75 percent consumed; this advected food is presumably elaborated from at least ten times this quantity of primary phytoplankton productivity. Thus the drift of zooplankton into the area provides food supply equivalent to as much as a steady-state phytoplankton productivity of (carbon) 8 g m^{-2} day^{-1}—40 times that of a highly productive region on the California coast.

The sonic spires are present the year around, but the nature of the organisms composing them has not been ascertained. They are probably *Sebastodes* (which are not thought to school) and other fish. *Sebastodes* are excellent sonic reflectors because of their large air bladders. Anchovies and juvenile hake were taken in trawling through these spires; the scales from the sediments also indicate their presence. The frequent near-absence of the scattering layer over the ridge probably results from predation both on and over the ridge. Moreover, predators occasionally seem to invade the daylight layer a short distance offshore, for some depth-recorder traces in daylight (Fig. 6) show predators, seaward of the ridge, invading the scattering layer.

Thus, in a region of coastal shelf over which an oceanic current flows, sound scatterers may be greatly concentrated. This mechanism of concentration is undoubtedly common over seamounts and over shoals about islands. Oceanic islands and seamounts support large resident populations of fish. The mechanism described must contribute to the maintenance of these populations, and consideration of the mechanism may permit selection of shoal areas that are of particular interest for studies of undersea warfare, fisheries, and ecology.

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6. The second and third traces of the bottom in Fig. 2 and subsequent depth-recorder sonic records result from multiple reflections of the sound pulse between bottom and surface. Some of the scattering targets appear in these subsequent traces; a criterion for very strongly reflecting aggregations. In Fig. 3 and 4 each profile is slightly different because the ship was unable to cross ridge and valley at exactly the same location.
7. Supported by ONR [Nonr 2216(12)] and the Marine Life Research Program of the University of California. We thank participating personnel, especially Daniel Brown, Jan Lawson, Julian Miller and the Biomass Laboratory, Richard Rosenblatt, L. D. Buck, and the officers and men of U.S.S. *Conquest* and R.V's. *Horizon*, *Baird*, and *Agassiz*.

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