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Ecological Studies during Project Sealab II

A sand-bottom community at depth of 61 meters and the fauna attracted to "Sealab II" are investigated.

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During August, September, and October, 1965, the U.S. Navy's Special Projects Office and Office of Naval Research conducted Project Sealab II off La Jolla, California. The main purpose of the project was to evaluate the performance of men and equipment in a high-pressure, underwater environment (*1*). *Sealab II,* an underwater habitat, was placed on the bottom for 45 days. Three ten-man teams lived in *Sealab II* for about 2 weeks each. The men lived at ambient pressure for the entire period and had access to the surrounding water through an open entryway in the bottom of *Sealab II.*

We participated as divers, one of us on each team. Thus our observations cover the entire period during which *Sealab II* was on the bottom. During this time we studied the ecology of the sand bottom around the site and observed on a day-by-day basis the organisms attracted to the site. We recorded abundances, behavior, and food habits. Most of our observations were of areas adjacent to *Sealab II,* but we were also able to make several surveys of the sand bottom at locations well removed from the site. Thus we are able to compare the fauna attracted to *Sealab II* with the normal sand-bottom community. We believe this was the first opportunity biologists have had to conduct a continuous underwater study of marine organisms.

Site and Environment

Sealab II was placed approximately 1400 meters from shore at a depth of 61 meters in a small, gently sloping valley (slope of 10 degrees) near the main axis of Scripps Submarine Canyon (Fig. 1). The bottom sediments at the site were silty-sand, and the bottom was essentially featureless, with only minor hummocks, 1 to 2 centimeters in vertical relief. Thirty-five meters northwest of *Sealab II,* the bottom steepened, and slightly beyond, at a depth of 76 meters, a vertical rock cliff dropped into a tributary of the main canyon. Other than the canyon walls, the nearest rocky bottom was 1500 meters away, near shore.

The largest object on the bottom was *Sealab II,* a cylinder 17.5 meters long, 3.7 meters in diameter, and 9.1 meters high at the central conning tower. The entire structure was painted white. There were 11 circular viewing ports 60 centimeters in diameter. These viewing ports permitted more or less constant monitoring of events occurring outside. Six of them were equipped with external 1000-watt incandescent lamps with reflectors. Various combinations of these external lights were on during the project. Less intense light from inside was visible through all the viewing ports.

Three other large objects were placed on the bottom: the personnel transfer chamber, used to transport men to the surface under pressure; the benthic lab, which housed a communications transformer; and a power transformer. All were cylinders about 4 meters high and 2 meters in diameter and were colored orange. Only the transfer chamber was lighted. Slightly smaller objects in the assemblage included a wire-mesh fish cage, three underwater instrument stations, and an emergency breathing chamber.

Sealab II was lowered to the bottom on 26 August 1965. The following day the personnel transfer chamber and power transformer were lowered, and *Sealab II* was inspected by divers.

On 28 August, day 1, the first team of divers descended to *Sealab II.* Some of the viewing port covers were not removed until day 2, and few outside observations were made before day 3. The first team returned to the surface on 12 September. The second team was down from 12 September to 26 September; the third, from 26 September to 10 October, day 44. *Sealab II* and the other large structures were raised the following day. A brief dive was made to inspect the site 19 days later.

During the project the water temperature on the bottom ranged between 10° and 13°C. Visibility was often poor near the bottom, owing to suspended detritus and sediment stirred up by the activity of divers; it ranged from 0 to 10 meters. Wave surge was rarely noted, but it once reached a horizontal displacement of 20 centimeters. Speeds of persistent currents ranged from 0 to 30 centimeters per second but were usually less than 10 centimeters per second.

Methods

Since the atmosphere in the living quarters was at ambient pressure, divers were able to work in the water for long

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periods at depths between 50 and 90 meters without having to undergo decompression. Individual divers averaged about 1 hour per day in the water. Most diving activity occurred during the daylight hours and within 10 meters of *Sealab II*.

The smaller bottom organisms were sampled with a hand corer that took a 35-square-centimeter sediment sample to a depth of 5 centimeters. We estimated the densities of larger organisms from counts made along transects by means of a fish rake (*2*), and also from counts made within 1-meter-square quadrats. The locations of the transects and core samples are shown in Fig. 1. Zooplankton were sampled by divers with hand nets or push nets. Estimates of total abundances for mid-water fishes were obtained by extrapolation from counts for a representative volume. Fish were collected by spear for identification and stomach-content analysis, but none were speared until the final 2 weeks of the project.

In addition to the zooplankton and smaller benthic invertebrates, 11 species of larger invertebrates, 43 species of fishes, and one species of mammal (sea lion) were observed during the project. Of these, ten invertebrates and 17 fishes appeared to be normal inhabitants of the sand bottom, while two invertebrates, 17 fishes, and the sea lion were attracted to and associated with *Sealab II*. The remaining species of fishes were observed so rarely that they cannot be assigned to either group (*3*).

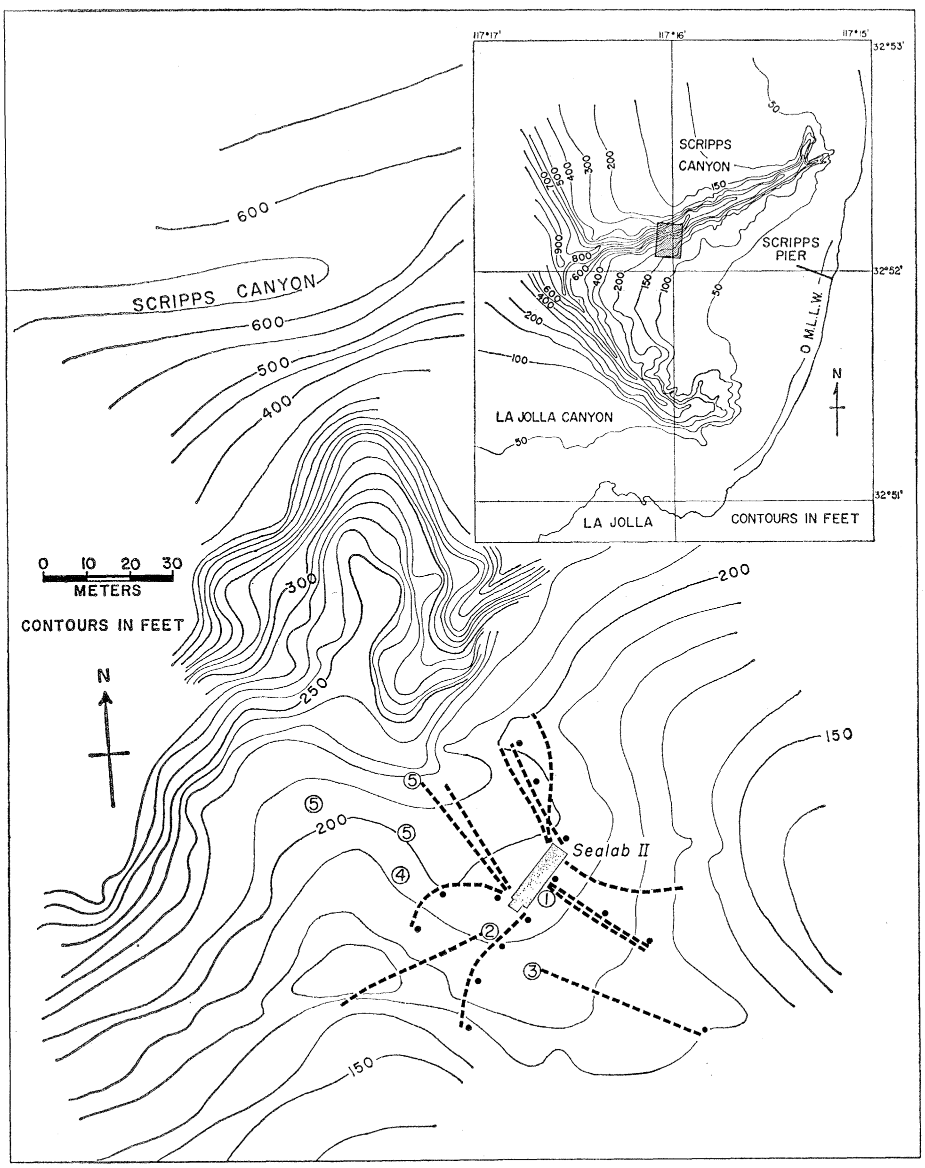

Fig. 1. *Sealab II* site. Shaded rectangle on inset shows area of large map. 1, Power transformer; 2, personnel transfer chamber; 3, benthic laboratory; 4, fish cage; 5, instrument stations. Dashed lines and black dots show locations of fish-rake transects and paired core samples, respectively.

The Sand-Bottom Community

Although the site area was generally typical of local sandy bottoms at these depths in terms of sediment, relief, and currents, the proximity of the canyon may have influenced the types and numbers of organisms present, especially as many sand-bottom organisms are locally more abundant along the canyon edges than on the open sand.

The most abundant organisms in the core samples were polychaetes, especially errant species (Table 1). Next in order of abundance were nematodes, foraminifera, crustacea, and ophiuroids. Seaweed debris was found in almost all cores. The commonest large invertebrates (Table 2) were the sea stars *Petalaster foliata* and *Astropecten verrilli*, the sea urchin *Lytechinus pictus*, and the sea pen *Stylatula elongata*. A small octopus was also a member of the sand-bottom community, but it aggregated in large numbers on *Sealab II* and other structures and, therefore, our observations do not reflect its normal density. Except for the octopus, the normal distribution and abundances of bottom invertebrates were apparently unaffected by the presence of *Sealab II*.

Push-net samples of zooplankton taken just above the bottom contained mostly mysids and amphipods. The average volume of the plankton obtained in four such tows was 0.4 cubic centimeter per cubic meter of water sampled.

Small flatfishes were the most abundant fishes on the open sand. The common species, in order of decreasing abundance, were the longfin sand dab, *Citharichthys xanthostigma;* the hornyhead turbot, *Pleuronichthys verticalis;* the Pacific sand dab, *C. sordidus*; and the California tongue fish, *Symphurus atricauda*. The densities recorded (Table 2) are similar to those recorded for flatfishes in shallower water (*4*). The fishes' stomachs contained mostly small benthic organisms and, to a lesser extent, hypoplanktonic mysids and amphipods. The bluespot goby, *Coryphopterus nicholsi*, was occasionally observed on the open sand in densities up to 50 per square meter. We do not, however, have a reliable estimate of their normal density, either because their distribution was extremely patchy or because they were often overlooked on account of their small size. In addition to these bottom species, schools (*5*) of five to 25 pink sea perch, *Zalembius rosaceus*, were seen just above the bottom. Individual fish would occasionally dip

Table 1. Data for small invertebrates from the core samples. Only subgroups that appeared in more than 60 percent of the cores are included; those present in over 90 percent of the cores are starred. Density is based on combined data from 28 cores. Biomass is given for the major groups only.

Group	Density (No./m²)	Wet wt. (g/m²)
Seaweed debris*		
Foraminifera*	6,660	
Nemertea	316	
Nematoda*	7,920	0.374
Polychaeta (total)*	10,360	4.660
Errantia (total)*	8,200	
Nephthydidae*	6,600	
Phyllodocidae	656	
Glyceridae	184	
Sedentaria (total)*	2,160	
Spionidae	1,288	
Cirratulidae	449	
Mollusca (total)	1,449	
Gastropoda	459	
Pelecypoda	990	
Crustacea (total)*	3,840	5.950
Ostracoda	530	
Copepoda	1,202	
Amphipoda*	1,162	
Decapoda	612	
Others	334	
Ophiuroidea*	1,350	57.000

down and peck at the sand. This pecking left behind a characteristic pattern of pockmarks on the sand that was often seen even when the fish were not. Owing to the patchy distribution and wariness of the fish, we were unable to reliably estimate their density. All of the fishes mentioned above were apparently repelled from the *Sealab II* site. They were seen only over the open sand and never within 10 meters of *Sealab II* (Fig. 2).

Carnivores that preyed on larger organisms were rare on the open sand. Pacific angel sharks, *Squatina californica,* were seen most often (Table 2). Several California halibut, *Paralichthys californicus*, were seen momentarily near *Sealab II* but were not seen on the open sand, probably because of their extreme wariness. The California lizard fish, *Synodus lucioceps,* was seen occasionally both on the open sand and near *Sealab II.*

Table 2. Data for commonly occurring larger invertebrates and fishes of the open sand bottom (*16*). Size is in terms of total length or maximum radius. Density is based on combined data from all transects. Biomass was estimated by weighing preserved fish of modal size.

Species	Length or radius (cm)	Density (No./ 100 m²)	Biomass (g/ 100 m²)
Sea pen			
Stylatula elongata	10–15	5.0	
Sea stars			
Astropecten verrilli	3–5	6.6	
Petalaster foliata	8–10	2.8	
Sea urchin			
Lytechinus pictus	1–3	5.0	
Octopus	10		
Pacific angel shark	60–100	1.3	3794
Flatfishes			
Pacific sand dab	14–20	3.2	182
Longfin sand dab	12–20	5.4	254
Hornyhead turbot	9–15	3.8	133
California tonguefish	5–10	1.0	6

California scorpion fish, *Scorpaena guttata*, and calico rockfish, *Sebastodes dalli*, two species that usually inhabit rocky bottoms, were also found on the sand but were usually associated with mats of seaweed debris. A mat approximately 4 square meters in area would often harbor about six of each species. Scorpion fish were attracted to *Sealab II*, but the calico rockfish were neither repelled from, nor particularly attracted to, the site. We do not have precise estimates of the normal density for either species on the sand bottom, but they were at least as numerous as all other higher carnivores of the sand bottom.

There were three general trophic levels in the sand-bottom community (Fig. 3). Most of the invertebrates probably fed on seaweed debris on or buried in the sand. The primary carnivores, largely small fishes, fed mostly on the benthic invertebrates. The standing crop of small benthic and hypoplanktonic invertebrates was about 70 grams per square meter. The standing crop of those primary carnivores for which we have reliable estimates was 5.75 grams per square meter. The ratio of standing crops suggests that the primary carnivores could be supported primarily by resident food.

The higher-order carnivores had a much greater biomass than the primary carnivores. The estimated density of angel sharks, the only large predator sampled reliably, was only one individual per 100 square meters, but their biomass was 38 grams per square meter—almost seven times that of the primary carnivores. Inclusion of the other higher carnivores would at least double this biomass. This high biomass suggests that the higher carnivores depended on a nonresident food supply. It is possible that these predators were attracted to the area by *Sealab II* and fed on the other fishes attracted there, but, with the exception of the scorpion fish and a few lizard fish, they were seen only momentarily near the site and were not observed feeding. A great deal of previous field experience indicates that such predators are normally more abundant near the canyon edges and that their prey are primarily fishes from mid-water or the canyon.

The Attracted Fauna

Organisms were immediately attracted to *Sealab II* when it was lowered. On 27 August, the day before *Sealab II* was occupied, cabezon (*Scorpaenichthys marmoratus*) and schools of northern anchovy (*Engraulis mordax*) were seen at the site by surface divers. By day 1, blacksmith (*Chromis punctipinnis*) had taken up positions around *Sealab II*, and shiner perch (*Cymatogaster aggregata*), sharpnose sea perch (*Phanerodon atripes*), and white croaker (*Genyonemus lineatus*) were concentrated at the lights. Small octopus were hiding in many sheltered corners on *Sealab II*.

That night a swarm of zooplankton and a brown rockfish, *Sebastodes auriculatus*, appeared at the illuminated entryway. On day 2, all the viewing-port covers were removed and vermilion rockfish (*Sebastodes miniatus*) and California scorpion fish (*Scorpaena guttata*) were first seen; the scorpion fish were already abundant (approximately one per square meter) over a wide area around the site but were not yet concentrated close to *Sealab II*. On day 3, sand bass (*Paralabrax nebulifer*) and rubberlip sea perch (*Rhacochilus toxotes*) were seen during the day, and schools of squid (*Loligo opalescens*), jack mackerel (*Trachurus symmetricus*), and California bonito (*Sarda lineolata*) were seen from the ports at night. California sea lions (*Zalophus californicus*) appeared midway in the project. Other species (*6*) appeared later, but all of

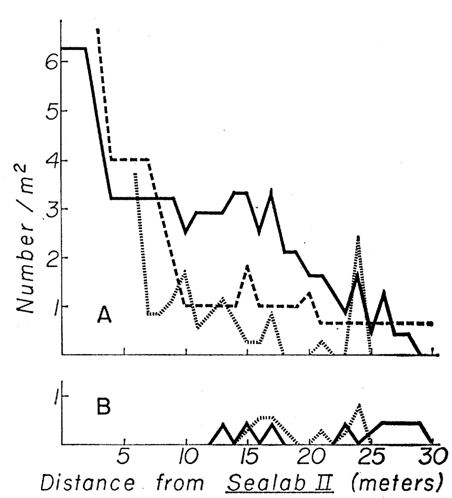

Fig. 2. Distribution and density of two bottom fishes. A, Scorpion fish, the most abundant attracted species; B, longfin sand dab, the most abundant sand-bottom fish. (Dotted line) Data for days 1–15; (dashed line) days 16–19; (solid line) days 30–43.

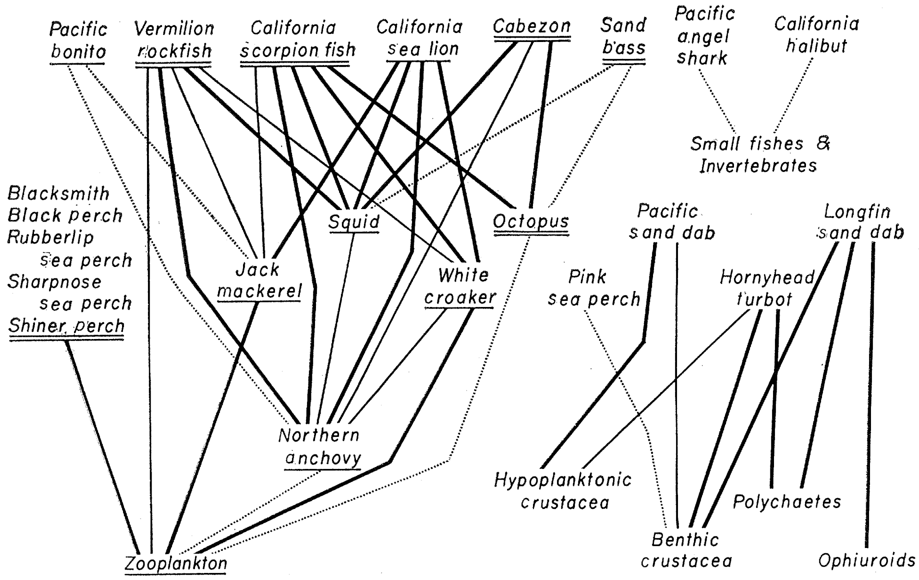

Fig. 3. Food web of the sand-bottom community and the attracted fauna. Heavy solid lines indicate predominant links. All solid lines are based on direct observation or analysis of stomach contents; dotted lines are inferred links. Attracted species are underlined—visitors singly, residents doubly.

the common species were present in large numbers by day 3.

The attracted organisms were of two types, species resident at the site and nightly visitors. The common resident species—octopus, sand bass, the embiotocid perches, scorpion fish, vermilion rockfish, and cabezon—were to be found, both day and night, either on or within a few meters of *Sealab II*. With the exception of the octopus, these are species that normally inhabit rocky bottoms, although three of the species—sand bass, scorpion fish, and cabezon—also wander over open sand and were seen there occasionally during the project. None of the other resident species were ever observed over the open sand. Residents as a group increased steadily throughout the project (Fig. 4). By day 43, over 5800 individuals were present over a 500-square-meter area around the *Sealab II* site, a density of 11.6 individuals per square meter or 2.86 kilograms per square meter (Table 3). This biomass is 35 times greater than our maximum estimate for the biomass of fishes in the sand-bottom community. Nineteen days after *Sealab II* was raised, only four scorpion fish, two calico rockfish, and one rubberlip sea perch were observed at the site over a 250-square-meter area.

The visiting species appeared at the *Sealab II* lights in the evening as natural illumination diminished and were rarely seen during the day, even though lights were on at all times. The common visitors were zooplankton, squid, anchovy, jack mackerel, bonito, white croaker, and sea lions. Except for the croaker, these are pelagic animals not normally associated with the bottom. Because the visitors appeared irregularly in schools or swarms, our estimates may not be accurate, but for most visiting species the numbers attracted at night appeared to be nearly constant throughout the project. The white croakers were an exception; their numbers increased steadily until midway of the project, when nearly all disappeared, apparently frightened away by sea lions.

The organisms attracted to the site fed almost exclusively on visiting prey (Fig. 3). Because of their greater numbers, the residents consumed more than the visitors did. Of the residents, large predators made up 61 percent of the numbers and 92 percent of the biomass.

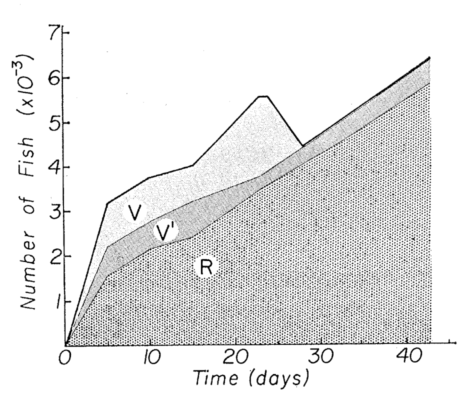

Fig. 4. Total numbers of fishes over a 500-square-meter area around *Sealab II* at various times during the project. Shaded areas show proportion of (*R*) residents, (*V*) white croaker, and (*V'*) other visitors.

Their principal food was anchovy. The remaining residents ate zooplankton. Of the visitors, most ate zooplankton, but squid, bonito, and sea lions ate visiting fish.

Observations on Common Animals

In this section we report some of our observations on behavior and species interactions. Such data can be obtained with relative ease from an underwater installation such as *Sealab II*. Where these observations are compared with "normal" habits, our sources are Limbaugh (*7*) and our own observations during several years of diving experience. Information about only the more abundant species is included.

Zooplankton. Zooplankton swarmed around the lights every night. It consisted mostly of forms attracted from mid-water; there were few hypoplanktonic forms from the sand bottom. Euphausids, copepods, and zoeae formed separate dense swarms around the external lights at various times. All were attracted to the lighted viewing ports. The copepods and zoeae simply aggregated against the glass, but the euphausids formed a definite pattern, with a swarm at the bottom and two "tongues" extending up the perimeter. Those at the perimeter were swimming upward and appeared to be creating a downward current along the edges.

A 0.5-cubic-meter sample taken at night from a dense swarm outside a lighted viewing port contained approximately 30,000 euphausids (*Nyctiphanes simplex*), 8000 copepods (principally *Calanus helgolandicus* and *Paracalanus* sp.), and smaller numbers of other plankton. The volume of zooplankton in the swarm was 528 cubic centimeters per cubic meter. The volume of samples collected over the nearby sand averaged 0.4 cubic centimeter per cubic meter. Thus the abundance of zooplankton around the lights was greater by about three orders of magnitude than that over the open sand. On the basis of only those volumes where zooplankton were densely aggregated, the standing crop at night around *Sealab II* was estimated to be 3 kilograms.

White croaker, jack mackerel, sharpnose perch, shiner perch, and blacksmith ate zooplankton almost exclusively. The perch and blacksmith fed only at the periphery of the dense swarms and not in their midst. Dense swarms were never seen around the lights when croaker and jack mackerel were feeding, but the movement of the fish was probably as great a factor in disrupting swarms as their feeding was.

Octopus. The small octopus of the species observed normally inhabits the sandy bottom. It burrows in the sand or hides under or in solid objects such as shells, bottles, and cans. Large numbers were attracted to *Sealab II* immediately. As many as six were found hiding beneath a single port cover on day 2. Each time the personnel transfer chamber was raised, approximately 40 octopi were still clinging to it when it reached the surface. Because of the secretive behavior of the octopus, no rigorous estimates of abundance were possible, but several hundred individuals were probably hiding on *Sealab II* and other objects at the site. Their rapid accumulation indicates that the species observed is more mobile than rock-bottom species of octopus, which appear to have restricted home ranges.

Initially the small octopus was seen only when equipment was moved or used. Later in the project, as many as 12 at one time were seen at night, suspended in the water in front of the lighted viewing ports, apparently feeding on zooplankton which they caught with outstretched tentacles. We did not observe any predation on octopus, but octopus remains were found in the stomachs of scorpion fish and cabezon.

Squid. Squid (*Loligo opalescens*) were first observed on day 3 and appeared irregularly, but with increasing frequency and numbers, from then on. They were seen only at night; schools of three to five and later up to 20 squid would dart into the lighted area and gradually disperse. Squid fed on anchovy and were in turn eaten by vermilion rockfish, scorpion fish, cabezon, and sea lions. Their common occurrence in predator stomachs indicates that they were present more often than they were observed.

Northern anchovy. Anchovy are normally pelagic, schooling fish. Northern anchovy (*Engraulis mordax*) were observed at the site by surface divers on 27 August and were seen from *Sealab II* on day 2. They were seen at the viewing ports most nights thereafter, appearing in small schools at irregular intervals. They schooled according to size; two size classes (length) were seen: 12 centimeters and, less often, 7 centimeters. Most anchovy were visible only at the edge of the light. Those that entered the well-lighted zone darted blindly back and forth across the port

Table 3. Commonly occurring organisms attracted to *Sealab II* and estimates of their abundance over a 500-square-meter area around the site at various times during the project. Biomass was estimated by weighing preserved specimens of modal size.

Species	Abundance (No./500 m²)						Biomass, day 43 (kg/500 m²)
	Day 5	Day 10	Day 15	Day 23	Day 33	Day 43	
	Residents at the site day and night						
Octopus							?
Shiner perch	400	400	400	1000	1200	1650	54.45
Sharpnose sea perch	150	150	150	100	250	500	34 75
Rubberlip sea perch	50	75	75	10	50	50	16 40
Blacksmith	20	20	20	15	25	50	9.80
California scorpion fish	500	750	1000	1600	2300	2800	1092.00
Vermilion rockfish	500	750	750	750	750	750	216.75
Cabezon	10	10	10	5	5	5	7.69
Totals (fishes)	1630	2155	2405	3480	4580	5805	1431.84
	Night time visitors						
Zooplankton							3.00
Squid							?
Northern anchovy	200	200	200	200	300	300	6.15
Pacific jack mackerel	400	400	400	100	200	300	30.60
White croaker	1000	1000	1000	1800	10	10	271.80*
Totals (fishes)	1600	1600	1600	2100	510	610	36.75

* Croaker biomass is for day 23 and is not included in total.

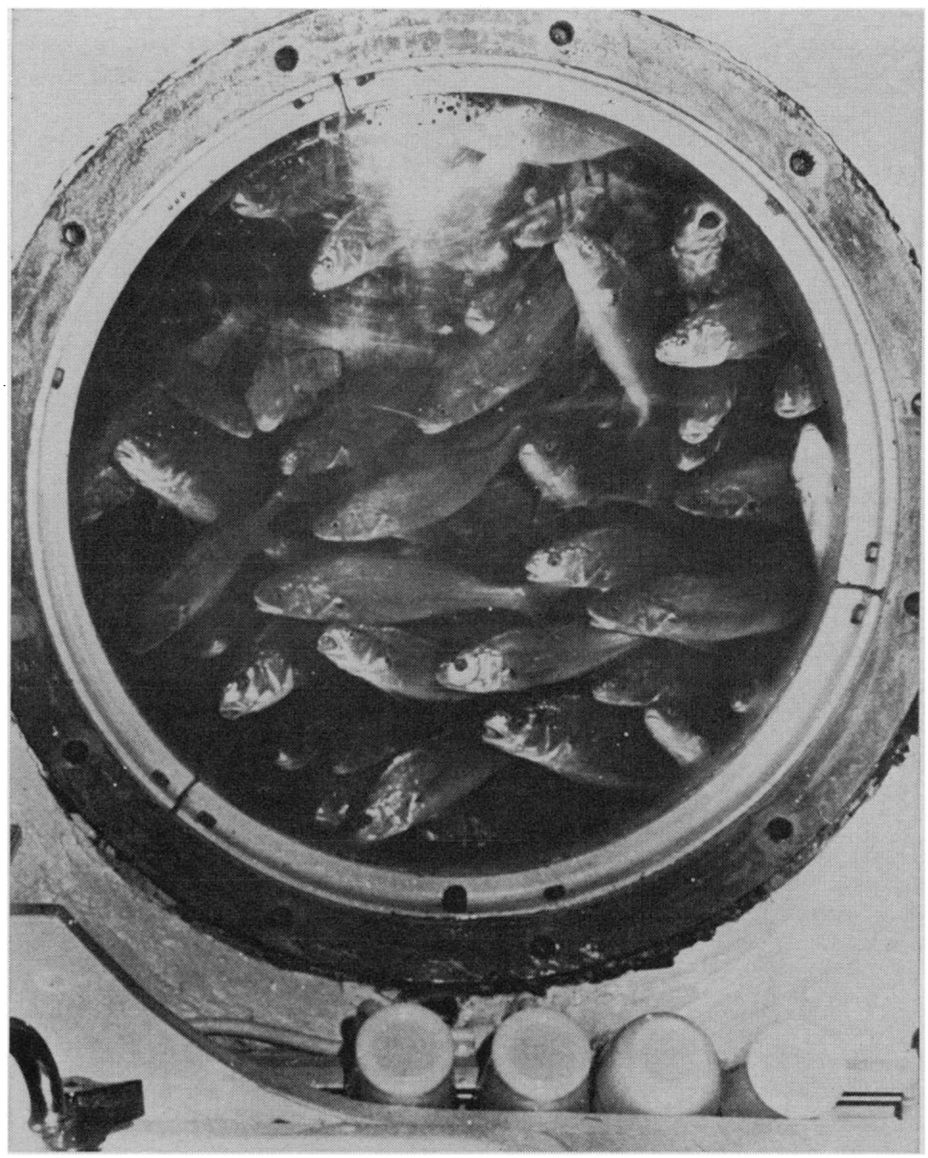

Fig. 5. White croaker, *Genyonemus lineatus*, feeding on zooplankton at a viewing port. [Official U.S. Navy photograph by J. D. Skidmore]

for a few seconds and then vanished quickly or were eaten. Individuals observed in the lighted volume were regularly preyed upon by scorpion fish, vermilion rockfish, and sea lions, and less often by squid and croaker. Anchovy were not seen feeding.

Sometimes, when grasped by a predator, an anchovy would escape and leave the predator disgorging scales. This means of escape was evidently possible because anchovy have deciduous scales; it may be analogous to the escape of lepidopterans from spider webs (*8*). Such a mechanism would have an obvious selective advantage for fishes subject to heavy predation and may, therefore, explain why deciduous scales are characteristic of a number of small, pelagic, schooling fishes.

Jack mackerel. Jack mackerel (*Trachurus symmetricus*) are common, coastal-pelagic, schooling fish. They were first seen at *Sealab II* on day 3. Schools of 150 to 200 individuals appeared most nights thereafter; they were rarely seen during the day. In some schools as many as one third of the individuals had wounds or scars. Jack mackerel approached the external lights as a tight school but dispersed to feed on individual zooplankters. Individuals assumed all orientations while feeding. Jack mackerel were eaten by scorpion fish, vermilion rockfish, bonito, and sea lions. They reacted differently to different predators. When they were attacked by scorpion fish or rockfish, only the individual actually attacked reacted. In contrast, when they were attacked by bonito or a sea lion, all would school up and dash off as a unit. Sea lions and bonito commonly prey on jack mackerel, while scorpion fish and vermilion rockfish do not. Furthermore, sea lions and schools of bonito attacked with prolonged, high-speed approaches, most often from above. Scorpion fish and rockfish attacked as individuals in short, sudden lunges, usually from below. The alarm response could, therefore, have been determined either by recognition of the particular species as a predator or by the type of attack.

White croaker. The white croaker (*Genyonemus lineatus*) is a schooling species commonly found over sand bottoms in shallow water. Schools of them were seen on day 1, and their numbers increased until day 24, when sea lions began feeding at *Sealab II*. Few were seen during the day, but at night individuals milled around the lights and at times pressed so thickly against the viewing ports that they blocked the view completely (Fig. 5). They fed nonselectively on zooplankton. At viewing ports with strong interior lights, the croakers pressed their heads against the glass and inhaled the swarms of zooplankton.

About 1 percent of the croakers were either parasitized by copepods or had tumors around the mouth and gills. Some bore wounds or scars. Vermilion rockfish and, more often, scorpion fish preyed on croakers, but the croakers seemed little disturbed by these predators. They were, however, often alarmed by the sudden appearance of a school of jack mackerel. Also, if jack mackerel were alarmed and moved off as a school, the croakers that were mixed in with them would join the school and move off, but only for a short distance. Croakers feeding at the viewing port a meter away from schools were unperturbed by these alarms.

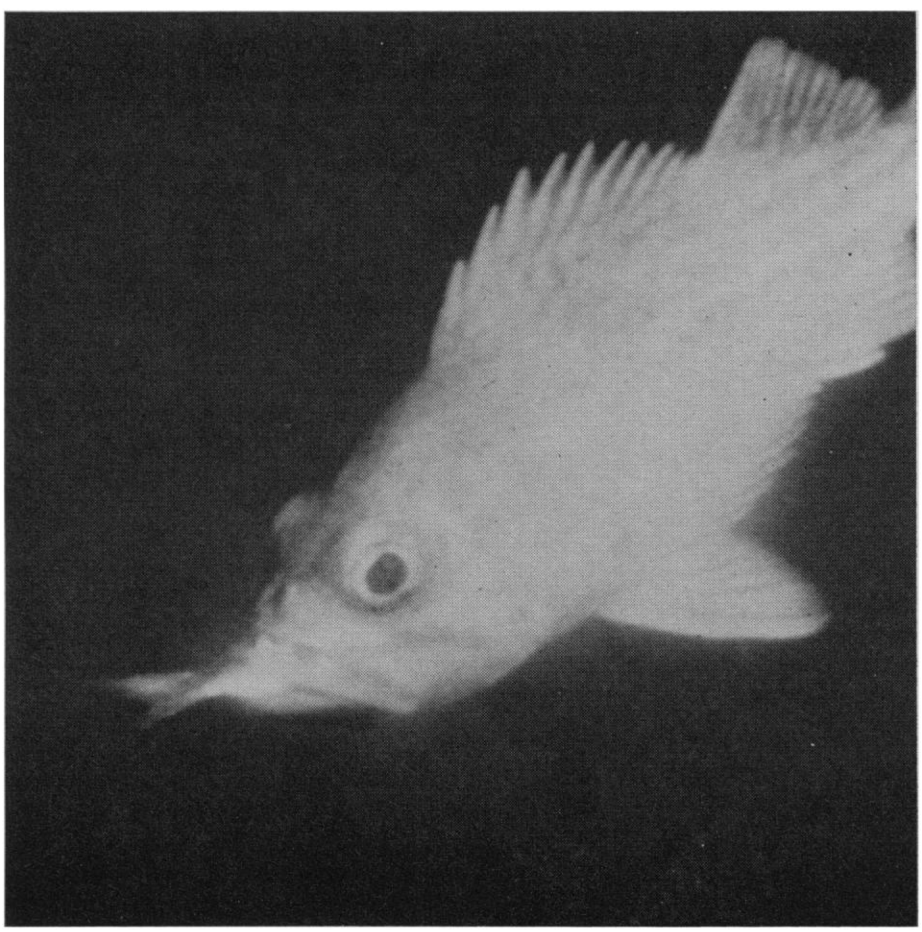

Fig. 6. A vermilion rockfish, *Sebastodes miniatus,* holding a northern anchovy, *Engraulis mordax*, in its mouth.

After sea lions began diving, on day 24, the croakers were seen only in tight, columnar schools. After 4 nights of sea-lion attacks the number of croakers appearing at the lights was less than 1 percent of the former number. The sea lions did feed on croakers, but each of them would have had to consume over 200 fish per night to account for this disappearance. It is more likely that the croakers were frightened away. Their disappearance was responsible for the drop in total estimated number of fishes between days 24 and 28 (Fig. 4).

Sharpnose sea perch. Sharpnose sea perch (*Phanerodon atripes*) were noted at *Sealab II* on day 1, and they increased in abundance slowly throughout the project. They aggregated but did not school. During the day individuals swam in mid-water above and around *Sealab II*. At night they were concentrated around the external lights and viewing ports, where they swam in and out of the lighted volume. Once a sharpnose sea perch was seen cleaning a vermilion rockfish in mid-water.

They did not feed on dense plankton swarms but, rather, selected individual zooplankters. One stomach examined contained mostly one type of crab zoea. The sea perch would occasionally compete with each other or with blacksmith for the same zooplankter.

Shiner perch. Shiner perch (*Cymatogaster aggregata*) inhabit bays or deeper water on the open coast. They were noted at *Sealab II* on day 1 and increased in abundance throughout the project. During the day large aggregations hung above *Sealab II*. Smaller tight schools were also seen around *Sealab II* and the personnel transfer chamber, and at unlighted objects such as the fish cage and an instrument station. At night, shiner perch aggregated around the ports and fed on individual zooplankters, much like the sharpnose sea perch. Shiner perch near the light swam on their sides or even upside-down, keeping their dorsal surfaces toward the light.

Rubberlip sea perch. Rubberlip sea perch (*Rhacochilus toxotes*) normally inhabit rocky bottoms. They appeared at *Sealab II* on day 3; from day 5 on, 50 to 75 individuals were usually present. Occasionally small schools or individuals would pick at algal detritus on the sand. At night individuals occasionally moved into the lights and fed on zooplankton, but most remained at the edge of the field of view. The stomach from a fish collected in the daytime contained an alpheid shrimp from the bottom and many euphausids and copepods from mid-water.

Blacksmith. Blacksmith (*Chromis punctipinnis*) are rocky-bottom fish and are most abundant in shallower water. They were noted at the site on day 1; by day 5, 20 adults were closely associted with *Sealab II*. Blacksmith were repelled by flashlights and were more numerous at the dimly lighted ports. They fed on individual zooplankters; their stomachs contained euphausids, copepods, and crab zoeae.

In their usual habitat blacksmith school and feed on zooplankton in mid-water by day; at night they retire to crevices in the rocks. In contrast, blacksmith at *Sealab II* did not school and did not move up into mid-water but fed around the ports both day and night. They appeared to have a preferred location which they defended against sharpnose and rubberlip sea perch. They occasionally nipped at each other while competing for food.

Vermilion rockfish. Vermilion rockfish (*Sebastodes miniatus*) are known to be abundant in the canyon and over rock outcrops and cobble patches in deep water. A group of 150 individuals was observed at the edge of the canyon 35 meters away from the *Sealab II* site. Vermilion rockfish were among the first arrivals at the site. By day 10, as many as 750 were present; thereafter their number remained nearly constant. Changes in size frequency, however, suggested that interchange with the canyon aggregations occurred. Most of the rockfish hung in mid-water as a loose aggregation around and above *Sealab II*. Individuals swam around the ports, the external lights, and the entryway, and occasionally rested on *Sealab II*. When the sea lions first appeared, the vermilion rockfish gathered in sheltered areas on *Sealab II*, but within 3 days they had resumed their normal behavior. They were curious and often followed divers. A tapping or rubbing on the port glass from inside would attract several to the port temporarily.

Fig. 7. California scorpion fish, *Scorpaena guttata*, piled in the entry-way of *Sealab II*. Several divers were stung while working in this area. The fish above the bottom are shiner perch, *Cymatogaster aggregata*.

The vermilion rockfish fed all night and were observed eating anchovy, jack mackerel, squid, individual zooplankters, and occasionally croaker. Individuals with swollen guts did not cease feeding; one held an anchovy in its mouth for 2½ hours before it could swallow it (Fig 6). The stomachs of three of five rockfish collected during an afternoon contained fresh anchovies and squid, indicating that they fed during the day as well.

California scorpion fish. Scorpion fish (*Scorpaena guttata*) usually live as solitary individuals on rocky substrate. They also move across open sand and aggregate in kelp debris. Large aggregations are known to occur suddenly during the spring and summer months around both natural and artificial reefs (*9*). At *Sealab II* they were first seen on day 2 and increased in abundance throughout the project. At the end they were the most abundant fish; it was estimated that 2800 individuals were present on the bottom within a 500-square-meter area.

Scorpion fish were strongly thigmotactic and were almost always in contact with solid objects, irregularities of the bottom, or other scorpion fish. They were most abundant in the best-lighted areas, where prey were also most abundant. They literally piled up in and near the entryway of *Sealab II* (Fig. 7), and, because of their poisonous spines, were a hazard to divers. Densities up to 27 individuals per square meter were recorded in this area. Scorpion fish in densities up to 5 per square meter were also noted around smaller unlighted objects such as the instrument stations and fish cage. Figure 2 shows the decline in abundance of scorpion fish with distance from *Sealab II*.

Fresh octopus and anchovy were found in the stomachs of specimens speared during the day. At night, scorpion fish were observed feeding on anchovy, white croaker, jack mackerel, and squid, which they captured by sudden lunges from resting places on *Sealab II* or the bottom. Scorpion fish were not preyed upon.

Cabezon. Cabezon (*Scorpaenichthys marmoratus*) usually inhabit rocky bottoms but are occasionally seen on the open sand. One individual was observed on the sand near *Sealab II*, and two were seen in the nearby canyon. From five to ten cabezon were situated on horizontal surfaces on *Sealab II* throughout the project, each individual fre-

Table 4. Standing crop of fishes for several natural and artificial habitats.

Type of reef or bottom	Area (m^2)	Time on the bottom (days)	Number of resident fishes	Biomass (kg/m^2)
Sealab II, California	500	43	5,800	2.86
Auto bodies, California*	360	910	10,900	?
Concrete blocks, Virgin Islands†	125	850	2,754	0.70
Coral, Virgin Islands†	600	Natural	1,352	.16
Coral, Bermuda‡	10,000	Natural		.049
Rock–kelp bed, Baja California§	1,850	Natural		.014
Sand near *Sealab II*		Natural		.082‖

* See *10*. † See *11*. ‡ See *13*. § See *17*. ‖ Includes estimates for scorpion fish and calico rockfish.

quenting a particular spot or crevice. At night, cabezon fed on anchovy and squid, which they captured by lunging from their resting places. Stomachs of cabezon collected in the daytime contained fish remains and cephalopod beaks, and, in two cases, fresh squid and octopus.

California sea lion. Sea lions (*Zalophus californicus*) are common locally and were observed playing and feeding near the surface support vessels early in the project. Although observers on the surface had seen them diving at the site previously, they were not seen from *Sealab II* until day 26. Almost every night thereafter they appeared at *Sealab II* around 2000 hours. They were seen with increasing frequency, until in the final 2 weeks of the project at least 25 dives each night were observed. They commonly swam into the entryway of *Sealab II*, and on two occasions one surfaced in the open hatch. The latter events are of particular interest because the sea lion inhaled high-pressure gas and thus might well have experienced gas embolism upon its return to the surface. It must have exhaled during ascent, since it showed no signs of distress after returning to the surface.

The sea lions were seen eating anchovy, jack mackerel, white croaker, and squid. When a sea lion appeared, the fish would disperse from the ports; after it left, most fish gradually returned to the ports.

Discussion

The effect of the presence of *Sealab II* on the biota of the site area was almost immediate. Except for the octopus, the scorpion fish, and a few large predators, species of the sand-bottom community were notably absent from the site. One species, the pink sea perch, was obviously repelled by flashlights and wary of divers, but others—for example, the sand dabs—are not so wary and are known to be attracted to objects on the bottom. Although the smaller sand-bottom fishes were not found in the stomachs of predators, it is possible that some were present and were eaten by the larger predators aggregated around the site. It is also possible that the large numbers of scorpion fish on the bottom near *Sealab II* excluded them physically.

The most striking effect was the attraction of rocky-bottom and mid-water organisms to *Sealab II*. The tremendous increase in biomass of resident fishes (almost 35 times that of the normal sand-bottom community) is similar to results reported for artificial fishing reefs (Table 4). All the resident fishes at *Sealab II* were adults or near-adults. Larger fishes were also the first to appear at several artificial reefs off Southern California (*10*). Both of these observations contrast with observations from an artificial reef in the Virgin Islands (*11*), which was populated primarily by juvenile fishes.

Organisms were attracted to *Sealab II* far more rapidly than they have been to any artificial reef for which observations have been reported. This can in part be attributed to the proximity of a large reservoir of organisms in the canyon, but the light and noise around the site were doubtless important factors also. Since divers could sometimes detect the lights 20 meters away, it is possible that fish could detect them from as far away as the canyon; the noise from the site was probably detectable at greater distances. Thus, organisms within a fairly large area were probably aware of the presence of *Sealab II* almost immediately.

The success of artificial reefs in attracting marine organisms, especially fishes, has been attributed to the food and shelter available on the reef and also to simple thigmotaxis (*10*). There was no food growing on *Sealab II*, and, although there was abundant shelter for the small octopus, there was little for larger fishes. Fishes like the sheephead (*Pimelometopon pulchrum*) and the pile perch (*Rhacochilus vacca*) which live in the canyon but feed predominantly on benthic organisms were rare or absent. Species which apparently require shelter, such as cabezon and blacksmith, never became abundant. Only the scorpion fish were strongly thigmotactic; the remaining residents usually did not seek shelter or contact with solid objects. For them *Sealab II* was apparently a point of orientation on an otherwise featureless bottom. Because the residents remained around the site both day and night, their numbers increased during the project.

The visiting species appeared, for the most part, only at night and did not seek shelter or contact with solid objects. They were apparently attracted by the lights or prey around the lights and dispersed each morning as natural illumination increased. Consequently, their numbers did not increase during the project as did those of the substrate-oriented residents.

The visitors provided a regular source of food for the resident populations. Because the lights attracted the zooplankton and, directly or indirectly, forage fishes from the surrounding water and concentrated them near the site each night, the amount of prey available at *Sealab II* was probably greater than that over an unlighted reef. Consequently, those species that were attracted to the substrate and able to utilize mid-water prey built up large resident populations. The situation was similar to a natural one reported off Baja California (*12*), where a steeply rising ridge intercepts an arm of the California Current. Although no observations were made by divers, investigations from the surface indicated a very large fish population on top of the ridge, apparently supported by vertically migrating zooplankton trapped on the ridge. In both cases the near-bottom fauna depends on a continually renewed and concentrated supply of mid-water organisms.

All of the resident fishes at *Sealab II* were carnivores, and 92 percent were secondary carnivores. The relative abundance of primary and secondary carnivores was apparently determined by the amount and type of attracted prey, since about 92 percent of the prey were small forage fish. Randall (*11*) and Bardach (*13*) also found a high percentage of carnivores in reef fish populations. In both cases many of the resident carnivores foraged over adjacent bottoms and not on the reef. These results illustrate the importance of nonresident food resources in determining the trophic structure of reef communities.

The number of mid-water organisms attracted at night appeared relatively constant, presumably because the lights drew from an approximately constant volume of water. If the supply of attracted organisms remained constant, the standing crop of residents would eventually be limited by a shortage of food. This apparently did not happen during the 44-day period, because the total number of residents and three of the four most abundant species were still increasing at the end of the project. The fourth species, vermilion rockfish, was obviously limited by something other than availability of foods; they reached a peak density early in the project and maintained it even though there apparently was interchange with canyon populations. By the end of the project the estimated biomass of prey attracted each night was about 2.8 percent of the standing crop of residents. This figure is close to daily food requirements that have been reported for fishes at similar temperatures (*14*). Even though our estimates of visiting prey are probably minimal, this figure suggests that the observed rate of increase in standing crop would not have continued much longer.

Seasonal and other long-term changes in the fauna would be expected. The species initially attracted to *Sealab II* were already present nearby in the canyon or along its edges. Undoubtedly other species would eventually wander in from more remote areas or appear as juveniles metamorphosing from planktonic larvae. Such new species could interact with those already present as prey, predators, or competitors. The disappearance of croakers after the sea lions arrived shows that the presence of even a single new species can drastically alter the density and trophic structure of the attracted fauna. It would be interesting to determine whether such marked changes would continue to occur as new species appeared, or whether, as predicted by theories of community diversity (*15*), the changes would become less violent as the diversity of the resident fauna increased. It would also be interesting to determine whether lighted reefs, because they appear to be more immediately effective in concentrating fishes, would also yield a greater sustainable harvest of commercial or sport fishes than unlighted reefs.

References and Notes

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Characteristics of Hurricanes

Analyses and calculations made from measurements by aircraft result in a fairly complete description.

Banner I. Miller

Fully mature tropical cyclones, called hurricanes in the Atlantic and typhoons in the western Pacific, are large rotating storms of extraordinary violence. They are born over the warm waters of all the tropical oceans except the South Atlantic (*1*). Although hurricanes are neither the largest nor the most intense atmospheric storms—they cannot match the concentrated fury of tornados or compare in size with the winter storms of the middle latitudes—their considerable size and great intensity make them the most dangerous and destructive of all storms.

A hurricane is more destructive than any other natural disaster: damage in the United States exceeded \$1 billion in 1954 (*2*) and approached \$2 billion the following year; in 1965 hurricane Betsy alone caused property damage of about \$1.5 billion in Florida and the Gulf states (*3*). The greatest damage and loss of life arise from storm surges that inundate low-lying coastal areas with wind-driven sea water in which all floating objects act as gigantic battering rams, from flooding caused by the heavy rains, and from winds that frequently exceed 240 kilometers per hour.

The great economic impact of hurricanes amply justifies efforts to study them; moreover, scientists find them a challenging subject for investigation. Observation of hurricanes, however, has not been easy. Before World War

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