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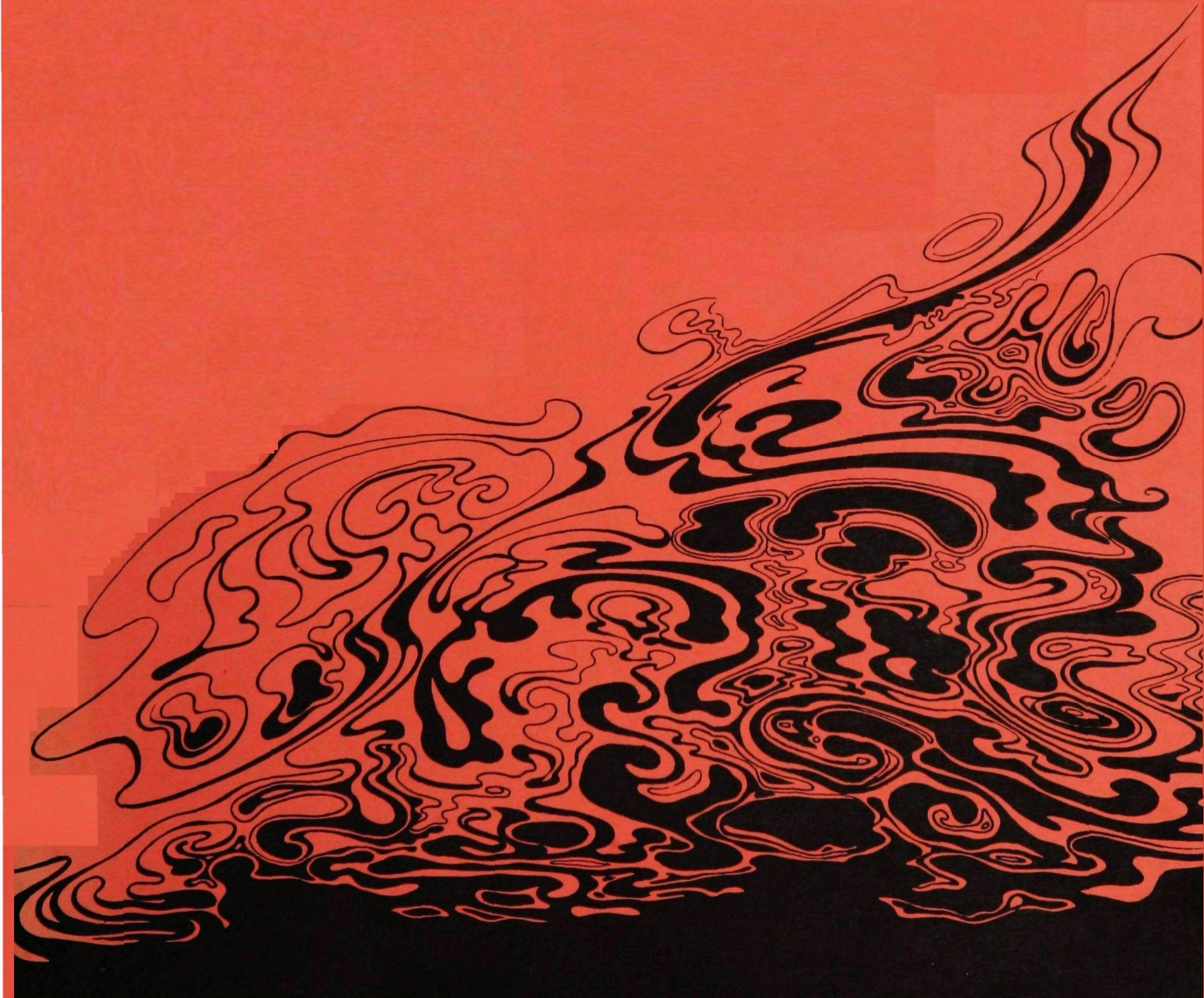

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SANTA BARBARA OIL SPILL: SHORT-TERM ANALYSIS OF MACROPLANKTON AND FISH

by

University of California, Santa Barbara
Department of Biological Sciences
Santa Barbara, California 93106

for the

OFFICE OF WATER QUALITY RESEARCH

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ABSTRACT

Collections of deep and shallow macroplankton from the Santa Barbara Channel area of the 1969 oil spill and from the Santa Cruz Basin further offshore were compared with others from previous years for possible oil damage. Spring and summer collections from nearshore bottom communities of fishes and large invertebrates around kelp beds near the blowout area were compared with collections made either prior to the spill or from an extrinsic area. Because no noticeable fish kills followed the blowout, less obvious criteria of possible damage to the macroplankton and bottom communities were investigated: decreased species diversity, numerical evenness, and abundance; increased patchiness of species distributions; changes in community composition favoring the more tolerant species; and correlations with amounts of oil and tar estimated on station.

Most observed changes, apparently unrelated to the spill, corresponded with various climatic anomalies during March through August, 1969. The bottom-fish communities resembled their counterparts in "not oiled" environments; sampling bias and environmental heterogeneity probably caused the observed minor differences in community structure. Larvae of common fishes and invertebrates were abundant in the offshore plankton.

After the blowout, the composition and mode of the Channel Island sport fishery (as analyzed from Oxnard and Port Hueneme catch reports, in lieu of reports from the temporarily debilitated Santa Barbara fishery) changed with seasonal trends and probably not as a direct effect of the spill. Of all subtidal events examined during the present short-term study, only the temporary disappearance of tiny mysid shrimps inhabiting the kelp canopy was a likely direct effect.

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SECTION I

CONCLUSIONS

Species abundance, diversity, evenness, and distributional patchiness, along with representations of community composition, provided contrasts between sublittoral habitat groups of fishes and invertebrates exposed to the Santa Barbara Oil Spill and their "not oiled" counterparts sampled either prior to the spill or near Zuma Beach south of Santa Barbara. Sampling problems generally limited the precision of estimates of these parameters. Populations were usually heterogeneous; sampling by trawl was necessarily non-random; strict schedules were imposed during the short-term study; comparative collections from "not oiled" environments were often incomplete; and sample sizes varied because missing data could not be replaced. All correlation coefficients computed for the community analyses, however, were based on more than 50 observations appropriately transformed to square roots or logarithms, so their probability estimates were reasonably precise. For example, correlation coefficients approaching $\pm .30$ were significant at the $P = .05$ level. And many contrasts were made non-parametrically, obviating the assumption of equal samples of random variates.

Consequently, the following conclusions were based on objective and subjective interpretations of the data. Some statistics inadequate by themselves were reinforced by our general knowledge of the local marine environment, which resembles other southern Californian habitats described in previous studies. For example, the single observation of fish biomass from the deep nearshore locality off Zuma Beach seemed comparable to the average of 19 such observations made off Santa Barbara, even though it has no confidence limits.

About one month after the blowout, midwater trawl collections of macroplankton (small fishes and invertebrates) from different depths in the Santa Barbara Channel and the Santa Cruz Basin showed no significant decreases in species diversity, evenness of abundance, overall abundance, or increase in patchiness, relative to similar collections from previous years. Deep and shallow macroplankton communities either showed little change or showed increased diversity and greater abundances of some species in the Channel. These few detectable changes seemed to be caused by oceanographic anomalies, rather than to the oil whose effects should be detrimental. Strong offshore winds with severe winter storms ventilated the basins. Also, deep intrusions of water from the south may have affected the distribution and abundance of a few deep-sea species. Shallow collections contained apparently healthy fish and crab larvae.

The shallow bottom fish fauna about the "oiled" kelp beds off Santa Barbara was more diverse and abundant than its counterpart near Zuma Beach, where the environment appeared to be less productive. Collections made off Santa Barbara in 1969 generally did not differ significantly in abundance from those made in 1967 before the spill.

Collections of nearshore bottom animals trawled off Santa Barbara in spring, 1967 resembled those trawled after the blowout in 1969. Statistical comparisons of fish collections between the two years revealed only 5 significant differences in 11 possible contrasts. These differences were attributable to but two extraordinary collections, one from 1967 containing large numbers of rockfishes, the other from 1969 containing an unusual diversity of rare flatfishes. These were unlikely results of oil damage.

A multivariate analysis of species abundances and other environmental variables revealed probable occurrences of three overlapping bottom-fish communities in the area. A fourth factor related seasonal change in the Channel Island sport fishery to various oceanographic and biological trends. The variable of "surface oil amount" recorded on station had a very low communality (interaction) with the others. Because the oil accumulated around kelp beds over a community dominated by seaperches, it correlated weakly and positively with seaperch abundances only. No species correlated negatively with oil accumulation.

Diversity and composition of the three communities were similar between "oiled" and "not oiled" environments. The abundance hierarchies of species in the Deep Sandy Mud Community (depth of 100-200 ft), which included several flatfishes, rockfishes, a seaperch, and midshipman fish, did not differ significantly. Minor differences in the Seaperch and Shallow Flatfish communities (depth of 15-40 ft) probably reflected habitat differences because comparable "not oiled" collections from appropriate shallow localities were scarce or unavailable.

The Seasonal Sportfish Factor indicated a change in fishing effort with the arrival of large migratory fishes in the Channel during the period of spring and summer warming. Because these preferred game fishes are caught near the surface, deep fishing effort and, consequently, the rockfish catch naturally decreased, a typical seasonal changeover unrelated to the oil spill.

Environmental heterogeneity and sampling bias accounted for most of the observed differences between the "oiled" and "not oiled" collections. Oceanographic trends distinguishing the spring and summer following the blowout may have accounted for all but one of the remaining differences: the slightly higher biomass and diversity of Channel macroplankton in 1969, the late arrival of half-banded rockfish nearshore, the decreased diversity of the Shallow Flatfish Community, the slight delay in onset of the surface sport fishery for shallow game fishes, and the seasonal decline in canopy mysids. Small mysid shrimps, normally abounding over the kelp fronds, may have died or left as advancing oil slicks fouled the canopy. Their population density then rose steadily during the spring and summer.

SECTION II

RECOMMENDATIONS

Because short-term oil damage to the sampled plankton and bottom communities was apparently negligible or undetectable by the present methods, we commend the prudent handling of the Santa Barbara oil spill. The laborious mechanical cleanup after the blowout was motivated by the previous damaging usage of noxious chemical dispersants both offshore and nearshore after the wreck of the tanker TORREY CANYON off the Plymouth Coast of England. Therefore, we recommend extension of the present method of mechanical removal of crude oil as it drifts onshore. This could be implemented by trapping the floating oil over the leak and removing most of it before it drifts ashore.

Refined petroleum products containing relatively high concentrations of volatile fractions may present as great or greater danger to sea life than crude oil. Both crudes and refined products vary so widely in their composition that it is impossible to generalize their relative effects. (Dr. Max Blumer and associates suggest that the heavier fractions of crude oils present a much longer term threat of damage than do the lighter ends.) Tanker traffic in the Channel, made even more hazardous by the oil platforms, may create a greater danger in the future. Perhaps this traffic should be diverted seaward of the Channel Islands.

Studies like the present are valuable only insofar as they can be compared with similar studies in unpolluted environments. In the absence of obvious extensive kills of fish and other subtidal organisms, oil damage is detectable only by contrasting the polluted with similar unpolluted systems that serve as controls. In the present study, the requisite comparisons were fortuitously provided through previous, completely unrelated studies. But these were at best barely adequate for the assessment of nearshore bottom communities near the kelp beds. Therefore, we recommend increased support for extensive quantitative analyses of marine environments before major accidents of pollution. Using such studies as controls, initial covert damage to ecosystems might be detected in time for correction.

Even when short-term effects of an oil spill are difficult to detect, long-term effects may be cumulative and ultimately disastrous. Periodic environmental monitoring over long periods of time should be used to detect possible cumulative effects. With the early detection of cumulative damage, appropriate corrective measures may save the natural ecosystem, which might otherwise be destroyed.

At the onset of the Santa Barbara spill more communication and cooperation among local and federal agencies might have hastened preliminary cleanup and assessment of environmental damage. Considerable confusion and duplicated effort seemed to plague the period immediately after the blowout.

SECTION III

INTRODUCTION

Following the oil blowout on January 28, 1969, concern was expressed for the fate of Santa Barbara's fisheries. Even after no obvious fish kill was reported, commercial and sport fishermen alike feared that the oil might decimate populations of small planktonic animals. Plankton sustain the anchovy, an important bait and forage fish of the area. Even surface pollution may ultimately damage bottom communities, because many fishes that live on the bottom as adults bear tiny planktonic larvae.

Typical of dire predictions were such statements as (Santa Barbara News Press, 2-5-69): "Pollution of the offshore and inshore waters could kill off plankton and other marine life necessary to a marine biology teaching program ..." and from Henry Ewald's column, "sport fishing and commercial fishing will be ruined for years." Oil contamination "...will keep out the migratory fish for years. Anchovies will die, and this is the food supply for the migratory fish. We may not see any local fish, either, if the spill kills the remaining food supply." Many feared that dispersants used to cut the oil would kill plankton, small fish and various other marine life. Mindful of the disastrous oil spill from the TORREY CANYON off Plymouth, England, the Federal Water Pollution Control Administration limited chemical spraying to the offshore concentrations of the main slick (News Press, 2-22-69). A noted marine biologist predicted that the oil would kill all marine life along 20 miles of coast (ibid., 2-10). Mr. Charles Ireland, News Press staff writer, summarized much of the public reaction (ibid., 6-15): "It has been a bleak year... for Santa Barbara Fisheries..." "Looking back over nearly half a century of local fishing, Albert Castagnola said he could not remember when it was as bad as it has been since the oil spill." Until a few weeks ago there had been virtually no anchovies in the Channel---"no anchovy, no plankton, no larva, no halibut--nothing." A commercial gill netter, Mr. Tom Farmer, speaking of spawning sea bass and halibut, observed that, "Those fish come up here and spawn. This year apparently they're not coming here to spawn and if they did come the eggs might die because they're so sensitive to an environment..."

During May and June, however, scattered reports implied no such disaster. Plankton and certain fishes appeared plentiful, if not as abundant as in previous years. Dr. Robert Holmes of UCSB concluded that phytoplankton appeared normal (Holcomb, 1969). Even in late February, Mr. Fred Hartley, in his report to the Union Oil Company share holders, noted that the California Department of Fish and Game could find no visible damage to fish life (News Press, 2-21). Dr. William Clarke of the Westinghouse Corporation (personal communication), who dove in the polluted region, saw no dead fish in the kelp beds, and, from a deep submersible, observed many normally shallow fishes in deep water off Anacapa Island. Although Santa Barbara commercial fish landings remained subnormal, this may have reflected reduced fishing effort. Before the spill slackened, oil driven onshore by the severe winter storms befouled the harbor. Fishing gear was apparently rendered useless in the oily waters. Some commercial fishermen consider May and June as normally slow months and the general negative consensus generated little enthusiasm for fishing. Anchovies had provided a small, but workable sport fishery until the local fleet went out of business for a variety of reasons. By early June, Mr. Ewald had reported a few halibut caught around the Channel Islands and fair calico bass fishing at Naples Reef off Santa Barbara (News Press, 6-6). In contrast to the fin fisheries, lobster and abalone catches were fair to good (ibid., 6-15). By July, SCUBA divers had reported plentiful halibut; successful grunion runs were continuing, even on "polluted" beaches, and barracuda and bonito had enhanced the sport fishery (Henry Ewald in the News Press, 7-11, 7-30). Finally in September, Mr. Ewald observed that "it has been years since local fishermen have been able to catch albacore so close to home" (ibid., 9-16).

A short cruise by the U. S. Bureau of Commercial Fisheries Research Vessel DAVID STARR JORDAN detected no immediate damage to offshore plankton (U. S. Fish and Wildlife Service, 1969a); on February 11, the La Jolla Fishery-Oceanography Center, under the direction of Dr. Paul Smith, investigated possible effects of the oil spill on the pelagic ecosystem in the Santa Barbara Channel. A direct and rapid series of observations of fresh plankton from water covered by oil and oil-detergent mixtures, compared with others outside the polluted areas, revealed no gross evidence of dead or deformed fish eggs and larvae and no significant departure from the expected composition of fish larval catches, established from ten years' sampling at a nearby station. The ratio of anchovy eggs to larvae indicated no apparent increase in larval mortality and more than 2% of all larvae in the plankton tows in oiled water had been spawned before the spill, a normal abundance of older larvae for unpolluted samples. The relative abundances of others, e.g., hake, rockfish, and flatfish larvae were typical of the area. The investigators cautioned, however, that analyses of catches under the oil slick may be misleading because the slick moves downwind much faster than the water some meters deeper where the larvae live: the captured larvae may not have been under the slick very long. Concentrations of dissolved nutrients, e.g., nitrates and phosphates resembled those from nearby clear water.

The measurements also showed possible adverse effects of the oil slick (U. S. Fish and Wildlife Service, 1969a). Under the brown crude oil, ambient light was reduced at two meters to only .3-10% of that in nearby clear water. Therefore, crude oil absorbs considerable light, which could chronically reduce photosynthesis and thereby severly deplete the standing crop of phytoplankton. In fact, pump samples of phytoplankton taken across the Channel were considerably poorer than others from a nearby station in January. Because little oxygen diffuses through an oil film, concentrations were lower under the heavy oil, although still sufficient for respiration.

The prudent and limited use of dispersants may have avoided severe damage to plankton and fish communities. Dr. Reuben Lasker (U. S. Fish and Wildlife Service, 1969a) found that 2 ppm of COREXIT 7664, previously acclaimed non-toxic to marine life, increased mortality of fish eggs and larvae some 57%. Nelson-Smith (1967) concluded that only two groups of constituents account for almost all crude oil toxicity: volatile aromatics like benzene, and phenolic substances like naphthenic acids, comprising only 1-2% of the total oil volume. Although these fractions kill fish at very low concentrations, the most noxious aromatics evaporate quickly and naphthenic acids are very soluble in water, so quickly diffuse to harmless concentrations. Horn et al. (1970), however, found that low-boiling fractions are retained in petroleum lumps floating at the mid-Atlantic sea surface. Holcomb (1969) observed that "When a spill occurs at sea, a large portion of both (aromatic hydrocarbons -- benzene, toluene, xylene -- and low-boiling saturated hydrocarbons) ... evaporates before reaching shore. This is probably the main reason that the Santa Barbara Blowout was not more disastrous to shore life other than birds." The dispersants and emulsifiers, on the other hand, poison fish and invertebrates (Nelson-Smith, 1967). They usually contain the same solvents comprising the more lethal fractions of crude oil, as well as detergents, which at very low concentrations kill fish. Emulsified oil, moreover, clings to the surfaces of fish gills and gut, which repel untreated oil. These oil particles enter various filter feeders, in turn eaten by larger animals. Nelson-Smith concluded of the TORREY CANYON disaster, "...the lavish application of emulsifiers without adequate agitation and often several hours in advance of any means of dilution or washing with water was not only ineffective in removing the stranded oil but also contributed considerably to mortalities amongst animals and plants..." Jones (1964) observed that volatile tar and gas wastes in low concentrations first induce intoxication in fishes. Finally, after losing their equilibrium, fish turn over and die or are narcotized. Unfortunately the fish usually does not avoid the toxic area, but on the contrary, is often attracted to it, especially if the pollutant is preserved as an emulsion. Judging from past experience, therefore, the indiscriminate use of dispersants does more harm than good (e.g., Manwell and Baker, 1967).

Previous oil spills causing immediate widespread fish kills either were of preliminarily refined oil containing the noxious fractions in relatively high concentrations or were treated with noxious dispersants. The 117,000 tons of crude oil from the TORREY CANYON were widely treated at sea and shore with various detergents, sinking the oil to accumulate on the bottom. Fish that appeared initially healthy weakened and died later on. The sublittoral habitat suffered severe decimation. Dying and dead crabs, lobsters, and shellfish littered the bottom. Smaller inshore fishes died by the thousands, while many of the larger species apparently fled the polluted area (Spooner, 1967). Diving observations substantiated the large-scale destruction along the Plymouth Coast (Potts, et al., 1967). Benthic crabs, starfish, shell-fish, shrimps, and fishes appeared moribund or dead as far as a quarter mile from shore in about seven fathoms. Large kelp beds of Laminaria, however, often protected animal communities under their canopies. O'Sullivan and Richardson (1967) described the almost complete devastation of the intertidal zone, where nearly all invertebrates except some sea anemones died and where multitudes of dead fish were washed ashore.

North et al. (1964) described the biotic decimation by oil spill of a small rocky cove on the Pacific coast of northern Baja California, Mexico. Wreckage of the tanker S/S TAMPICO MARU, which ran aground in March of 1957, released 59,000 barrels of dark diesel oil. Except for intertidal sea anemones, almost the entire flora and fauna succumbed to the spill, although by June the more mobile animal species had re-entered the cove in small numbers. By 1964, a stable biota had repopulated the cove; the initial elimination of grazers allowed the profusion of giant kelp and other plants to become more luxuriant than the surrounding flora. They noted that the initial kill was probably intensified by emulsification of the oil in the heavy surf.

Other, more recent spills further indicate that some crude oils spare subtidal organisms, as long as their spread is checked by means other than widespread chemical dispersion. The Louisiana Oil Spill of March 20, 1969 in the Gulf of Mexico was blown away from the shore and reportedly constituted little danger to marine life, because the crude oil quickly became tar (Smithsonian

Institution Center for Short-lived Phenomena, 1969). The Wisconsin spill of fuel oil into the Mississippi River on June 19, however, killed thousands of fish, which floated to the surface with oil-coated gills (ibid., 1969). Also, a spill of diesel fuel off West Falmouth, Massachusetts on September 18 killed at least 24 species of fishes, including the young of several game fishes, in tidal creeks and shallow bays (ibid., 1969). Even in West Falmouth Harbor, where the oil could be neither seen nor smelled, fish and invertebrates died by the thousands. On the other hand, Foster et al. (1969) concluded that, except for certain sea grasses, the intertidal biota of Santa Barbara survived the crude oil spill surprisingly well. Because detergents were generally banned the sand protected some burrowing species, and the giant kelp canopies offshore restricted onshore oil movements. In fact, the restriction of rocky habitats by layers of tar, which is also attributable to natural seeps west of Santa Barbara, may have caused most of the damage.

But, Mr. Harold Bernard (personal communication) pointed out that both crudes and refined products vary so widely in their composition that it is impossible to generalize their relative effects on marine life. The composition of the Santa Barbara crudes was not analyzed. Dr. Max Blumer, an authority on marine oil pollution, presumed that the crude oil drifting ashore had actually lost little of its acute toxicity and probably none of its long-term toxicity (News Press, 4-30-71). He believes that many of the more stable and heavier fractions are toxic to marine organisms and may have a cumulative effect over a long period of time. Such tarry constituents persist in the bottom sediments and may be concentrated in the food chain. He has also suggested that these constituents may interfere with the chemical communication sense of bottom organisms.

From the foregoing it seems that the Santa Barbara spill did not immediately and extensively decimate the shallow and deep plankton and fish communities of the Channel. Then, will future cumulative damage to local subtidal ecosystems be detectable? Will covert and chronic interactions of oil with the complex ecosystems ultimately degrade some or all of the important offshore and nearshore animal communities? Such questions, of course, remain unanswerable in the present short-term study. But, are any of the few minor anomalies observed in the present study related to the oil spill or to natural seasonal cycles and oceanographic trends?

North (1963) recognized the difficulty in distinguishing possible artificial pollution effects from natural changes in the complex ecosystems of the California rocky sublittoral zone and beds of giant kelp. After studying cycles of ecological succession, he concluded that storms, grazers, turbidity, and high temperatures destroy kelp and alter the associated animal communities, so that the disappearance over the last 20 years of the extensive kelp beds near Los Angeles and San Diego may be due to complex causes: e.g., overgrazing by sea urchins, waste pollution, rising temperatures, or even interactions of all these.

Complex and subtle alterations of marine ecosystems should be carefully assessed relative to natural as well as artificial causes. Inspired by Manwell and Baker's (1967) discussion of possible ecological change wrought by oil and detergent pollution, we assumed the following criteria of biological damage, realizing full well that any or all could occur naturally.

1. Decreased species evenness of abundance, then diversity: sensitive species may be decimated quickly, so that communities will eventually comprise fewer species in more disproportionate numbers (e.g. Patrick, 1970).

2. Initially decreased abundance as measured by catch rates and volumes: many species may be initially depleted and the relatively short period between the Santa Barbara blowout and the present study may have been insufficient for repopulation. (Chronic pollution may allow an ultimate net increase in biomass as the resistant species multiply at the expense of decreasing community diversity--Manwell and Baker, 1967; Margalef, 1968.)

3. Consequently, the specialized species most narrowly adapted to unpolluted natural environments may differentially decrease in abundance.

4. And, sensitive types, like fish larvae that have just lost their yolk sacs, may disappear first.

5. All this should effect a noticeable change in community composition measured by, e.g., numerical hierarchies of the member species. Certain individuals may appear unhealthy as their species dwindles in number.

6. Correlations of measures of oil pollution with certain community variables may warn of impending damage.

7. Many species and measures of biomass will assume more "patchy" distributions because of environmental disruption.

8. Oil may contaminate bottom fishes trawled from the Channel.

Certain fractions may be more toxic than others. Dr. Max Blumer suggested that high-boiling, saturated hydrocarbons interfere with chemical communication among animals. Oil, therefore, may alter the behavior of large numbers of commercial species (Holcomb, 1969). (We did not analyze the oil or investigate contamination in the present study, although the stomach contents of many trawled fishes appeared normal and were uncontaminated by oil. Also, as far as we could tell, all fishes were distributed in their usual patterns.)

9. Oceanographic anomalies and other natural perturbances of the ecosystem may cause changes resembling pollution damage. Climatic trends should be considered in rationalizing observed faunal changes.

In the present study, we investigated possible alterations of offshore macroplankton communities and of nearshore shallow-bottom fish communities near kelp beds by comparing "oiled" collections trawled after the blowout with "not oiled" collections trawled concurrently in unpolluted areas or during the same seasons in previous years. Our sampling universe, of course, included only those animals that could be caught in our small trawls. It necessarily excluded large and active species. Because we investigated the interactions of many species and other environmental variables, we used multivariate statistical techniques to compose "factors" defining communities and other environmental systems. We have tried to detect changes in these communities and systems and to determine their cause.

SECTION IV

OFFSHORE MACROPLANKTON COMMUNITIES

The nearshore Santa Barbara Channel and Santa Cruz Basin seaward of the Channel Islands are two of a series of 13 deep basins that pit the relatively narrow continental shelf off southern California and Mexico (Emery, 1960). Because intrusions of vast water masses from the north, south, and west, as well as local heating and runoff, influence their oceanography, these basins support a heterogenous fauna with northern, southern, western, and endemic components (e.g., Lavenberg and Ebeling, 1967; Ebeling et al., 1970a). Any changes in community structure, therefore, may follow oceanographic trends. During the spring and early summer, water masses may change abruptly as the offshore California Current intensifies and disrupts a counterclockwise gyre of warmer water that dominates local conditions off southern California during late summer and fall (Brown, 1969).

Ebeling et al. (1970b) described midwater communities of macroplankton in the basins. Some are more characteristic of the Santa Barbara Channel, some of the Santa Cruz Basin. Relatively shallow planktonic groups containing transparent or silvery species occupy the lighted zones in both basins. One contains several fish larvae, abundant during the spring and summer.

Methods

From February 27 through March 1, 1969, the General Motors Research Vessel SWAN made 10 midwater trawl hauls that produced 34 collections from discrete depth intervals at stations in the Santa Barbara Channel and Santa Cruz Basin (Fig. 1). All samples were taken in a 6-foot Isaacs-Kidd midwater trawl equipped with an electronically closing 4-chambered cod-end sampler (Aron et al., 1964). The trawl's spreader bar contained electronic sensing units that recorded depth of trawl and ambient temperature. A flow-meter mounted on the spreader bar measured trawling effort as expressed by water flow through the trawl mouth. The gates of the chambered sampler were closed one at a time from shipboard.

Each collection optimally provided two discrete and two oblique samples, which were sorted to fishes and invertebrates whose respective displacement volumes were measured. Each subsample was preserved separately in 10% formalin and later washed, transferred to 45% isopropanol, sorted, identified to species, and counted. An environmental data sheet, completed during the trawl, accompanied each collection.

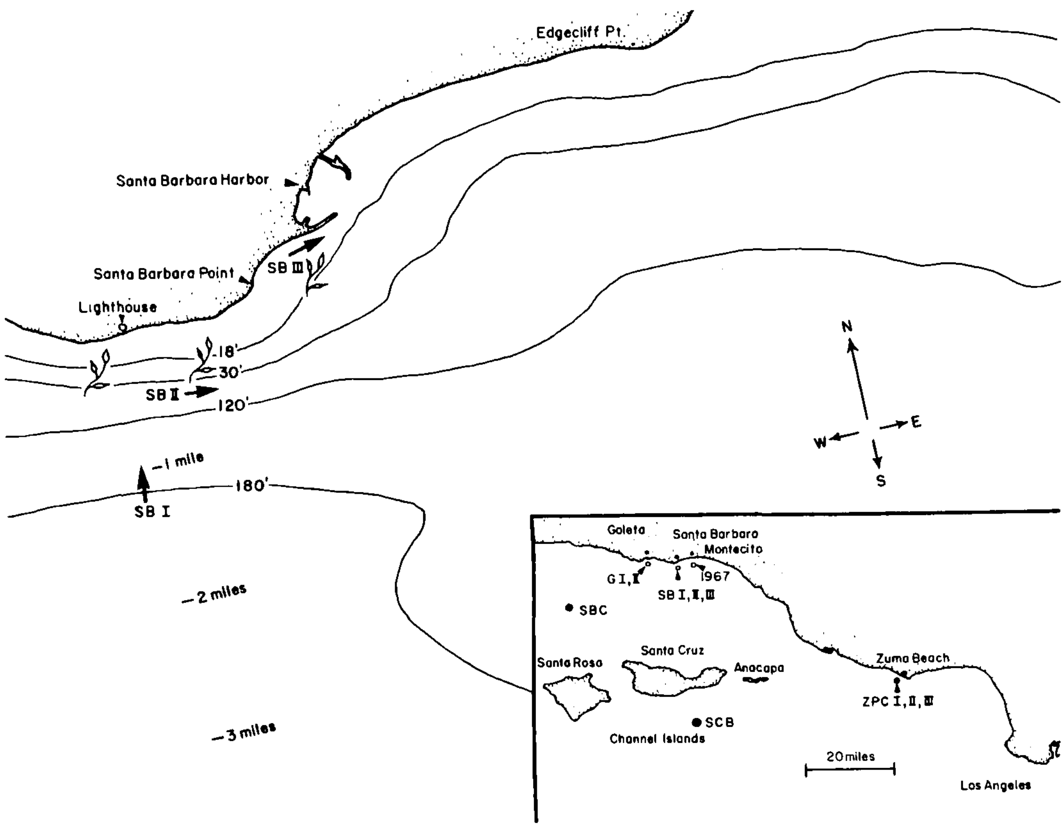

FIGURE 1. SAMPLING LOCALITIES IN THE SANTA BARBARA CHANNEL AND VICINITY

Two offshore localities provided macroplankton collections from the Santa Barbara Channel (SBC on inset) and Santa Cruz Basin (SCB). Nearshore localities provided bottom fish and invertebrate collections from a relatively deep sandy-mud habitat (SB I, with arrow in direction of trawl haul), a sandy habitat (SB II) near the outer margin of kelp beds (leaf-like figures), and a relatively shallow sandy habitat littered with detached seaweed near the harbor (SB III). Other bottom collections were trawled in similar but "not oiled" localities off Zuma Beach and Paradise Cove (ZPC I-III on inset). Three "oiled" collections were trawled slightly west of the others (G I,II on inset). Pre-blowout collections were trawled slightly east of the others (1967) or off the Harbor. Depth contours in feet.

Corresponding with the generally accepted ecological depth zonation off southern California (Ebeling et al., 1970a), sampled depths were designated as shallow (0-150 meters), upper middepth (200-300 m), lower middepth (300-500 m), and deep (below 550 m in the Santa Cruz Basin only). Only shallow and middepth trawls could be made in the inshore Santa Barbara Channel, whose maximum depth of about 600 m precludes the deep zone. Samples were taken both day and night. All physical and biological data were punched on computer data cards for later transcriptions and analyses.

Characteristics of the present collections were compared with those of others made during February and March 1965, 1967, and 1968 (Brown, 1969; Ebeling et al., 1970b). All captures or volumes were standardized as number of individuals or milliliters per "kilometer flow," a measure of trawling effort derived from the revolutions registered by the trawl's flow meter. On board the ship, each 1000 revolutions was registered as a tick on the time-depth recording for each trawl. The meter was so calibrated that the number of ticks (e.g., between closure of the two gates) multiplied by .155 approximated the absolute number of linear kilometers sampled by the trawl (Brown, 1969). Total effort as kilometers flow in the Santa Barbara Channel was 80.56 for February - March 1965, 25.83 for 1967, 27.19 for 1968, and 58.69 for the present study; in the Santa Cruz Basin, total kilometer flow was 29.58, 156.09, 28.49, and 55.69, respectively. Possible yearly changes in the observed communities were measured as: (1) species diversity, expressed either as the average number of species per kilometer flow (S) or as diversity per individual (H'), which takes into account the distribution of individuals among species as well as total species (Lloyd et al., 1968) and was computed as

$$H' = - \sum_{i=1}^{S} p_i \ln p_i \ ,$$

where p_i = proportion of individuals belonging to the i^{th} species, and $\ln p_i$ = its natural logarithm; (2) species evenness (E), which measures the distribution of numbers of individuals among species, was computed as $H'/\ln S$, and reaches a maximum of unity when all species are represented by equal numbers of individuals (cf. Buzas and Gibson, 1969); (3) abundance, expressed as the average number of individuals taken per kilometer flow and as the average displacement volume; (4) composition, expressed as the abundance rankings of all species listed by community or ecological group; and (5) distributional patchiness of species or plankton volumes, expressed as an index, $1+1/k$, where k is the negative binomial parameter, so that the index increases with skewness (indicating patchiness) of the distributions of observations among samples (Lloyd, 1967). All statistics were computed at UCSB using the IBM 360-70.

Standard oceanographic observations were made insofar as they might account for any biological anomalies. A bathythermograph measured temperature from the surface to about 200 m at each trawl. Two hydrographic casts, one each from the Santa Barbara Channel and Santa Cruz Basin, provided series of ten water samples each for measurements of temperature, salinity, and oxygen at different depths. Curves of temperature vs. salinity and oxygen vs. depth identified the water masses during the study period. Standard observations supplemented each trawl: date and time, position, sea state, swell height, phase of moon, and surface temperature.

Results

Species diversities in both the severely "oiled"Santa Barbara Channel and the slightly "oiled" Santa Cruz Basin did not differ significantly between the pooled series of February-March periods before (1965-68) and after (1969) the blowout (Table 1). The average diversity of fish per kilometer flow from the Channel was slightly higher in 1969 (.88) than in previous years (.61). Species evenness was virtually unchanged after the blowout. Captures of invertebrates, which were more diverse than fishes but less evenly distributed in individuals per species, varied as did the fishes: the captures made after the blowout were slightly more diverse in the Channel and slightly less so in the Basin, although both differences were non-significant. (In general, the fauna of the relatively deep Basin is more diverse than that of the shallower Channel because it is more directly associated with typical oceanic habitats--Brown, 1969.)

Abundances after the blowout generally resembled those before and indicated no gross changes in standing crop. After the spill the macroplankton standing crop, as measured by average volumes per kilometer flow, was significantly higher for invertebrates but about the same for fishes (Table 1). This was also reflected in the capture rates of individuals.

Since diversity, evenness, and abundance showed no gross changes in 1969 after the blowout, we investigated the composition of communities and other ecological groups, which vary between the two basins and among depth zones. All fish and invertebrate species were ranked in order of abundance, regardless of community or group. Differences in relative abundance were then compared within communities or groups, either between basins or among years

Table 1

Analysis of macroplankton trawled from the Santa Barbara Channel and Santa Cruz Basin in February-March of years before and during the oil spill. Species diversity (H') and evenness (E) are defined in the text. All statistics are averaged over all samples per kilometer flow per year group. 95% confidence limits of statistics for collection numbers greater than 20 are about ±25% of the listed values.

Year	Number of trawls	Number of collections	Total species collected	Mean number species per kilometer flow (S)	Diversity index (H')	Species evenness (E)	Individuals per kilometer flow	Mean volume per kilometer flow (ml.)	Mean volume of individuals (column 10 ÷ 9) (ml.)
Santa Barbara Channel fish									
1965	8	16	15	3.1	.53		17.1	32.3	1.9
1967	2	8	15	4.9	.94		13.4	28.6	2.1
1968	3	11	12	2.7	.55		18.5	32.3	1.7
1965-68	13	35		3.3	.61	.56	16.2	30.6	1.9
1969	7	23	22	4.5	.88	.53	22.5	33.5	1.5
Santa Cruz Basin fish									
1965	4	8	15	4.3	.82		12.8	13.2	1.1
1967	10	36	39	7.9	1.40		22.5	14.0	.62
1968	2	8	16	6.9	1.34		13.5	21.9	1.5
1965-68	16	52		7.2	1.30	.53	19.6	15.1	1.1
1969	3	11	19	6.2	1.27	.58	11.9	18.2	1.5
Santa Barbara Channel invertebrates									
1965	8	16	22	12.1	1.34		120.5	57.9	.46
1967	2	8	27	11.9	1.10		223.6	54.7	.25
1968	3	11	17	9.2	1.30		70.8	36.0	.20
1965-68	13	35		11.1	1.27	.32	128.4	50.3	.39
1969	7	23	27	11.3	1.34	.34	173.4	72.1	.42
Santa Cruz Basin invertebrates									
1965	4	8	24	12.5	1.61		55.6	19.9	.36
1967	10	36	31	16.3	1.43		205.5	354.1	1.7
1968	2	8	25	15.5	1.79		52.1	33.3	.64
1965-68	16	52		15.6	1.51	.29	53.9*	26.6*	.50*
1969	3	11	25	12.1	1.38	.33	76.6	40.0	.52

*Excluding the abnormally large 1967 collections.,which contained many bulky salps.

prior to and after the blowout.

As measured by the relatively high ranks of its common species, the Inshore Middepth Community was most "successful" in the Santa Barbara Channel (Table 2, "Mean rank"). The fishes Leuroglossus stilbius and Stenobrachius leucopsarus usually outnumbered all others trawled from the Channel, while the shrimp Pasiphaea

Table 2

Relative abundance of macroplankton species, ranked by year for the Santa Barbara Channel (SB) and Santa Cruz Basin (SC) and listed by community or ecological group. Species are classified as: A, amphipod shrimps; C, arrowworms; Ct, ctenophores; D, decapod shrimps; E, euphausiid shrimps; F, fish; M, medusae; S, siphonophores; and Sa, salps. Under each community or group, species are ranked within each category (basin, fish, invertebrate, year) by their catch rates (ranks 1-5, highest-lowest for fish; 1-10 for invertebrates). If a species did not enter the rankings in a particular category, it was assigned rank 6 (fish) or 11 (invertebrates). Ranks are averaged by species, basin, and year.

Selected Representatives of Prevailing Communities Comprising the Bulk of the Captures

Inshore Middepth Community (150-500 m)

	F. Leuroglossus stilbius		F. Stenobrachius leucopsarus		D. Pasiphaea pacifica		D. Pasiphaea emarginata		M. Aegina, sp.		Mean rank	
Year	SB	SC	SB	SC	SB	SC	SB	SC	SB	SC	SB	SC
1965	1	1	2	2	6	11	7	5	9	11	5.0	6.0
1967	2	5	1	6	11	11	5	11	7	11	5.2	8.8
1968	2	3	1	2	9	11	5	9	3	11	4.0	7.2
1969	2	5	1	3	11	11	3	11	11	11	5.6	8.2
Mean rank	1.8	3.5	1.2	3.3	9.3	11.0	5.0	9.0	7.5	11.0	5.0	8.0

Shallow Invertebrate Community (0-300 m)

	E. Euphausia pacifica		S. "pointed siphonophores"		E. Nematocilis difficilis		D. Sergestes similis		Ct. Euplokamis californiensis		Mean rank	
Year	SB	SC	SB	SC	SB	SC	SB	SC	SB	SC	SB	SC
1965	1	1	2	2	3	4	4	3	5	7	3.0	3.4
1967	2	3	1	2	11	6	3	11	11	11	5.0	6.6
1968	1	11	2	1	7	4	4	6	6	11	4.0	6.6
1969	1	1	2	2	8	7	4	11	5	5	4.0	5.2
Mean rank	1.25	4.0	1.75	1.75	7.3	5.25	3.8	7.75	6.8	8.5	4.0	5.5

Offshore Middepth Community (150-550 m)

	F. Triphoturus mexicanus		F. Cyclothone signata		M. Atolla wyvillei		D. Gennadas propinquus		Mean rank	
Year	SB	SC	SB	SC	SB	SC	SB	SC	SB	SC
1965	6	3	3	4	11	10	11	11	7.7	7.0
1967	6	1	3	3	11	9	11	10	7.7	5.8
1968	6	4	3	6	11	2	11	11	7.7	5.8
1969	4	4	3	2	11	11	11	11	7.3	7.3
Mean rank	5.5	3.0	3.0	3.75	11.0	8.0	11.0	10.75	7.6	6.5

Offshore Deep Community (550 m, +)

Year	F. Cyclothone acclinidens		D. Hymenodora frontalis		M. Crossota rufobrunnea		Mean rank	
	SB	SC	SB	SC	SB	SC	SB	SC
1965	6	5	11	8	9	11	8.7	8.0
1967	6	2	11	5	11	11	9.3	6.0
1968	4	1	11	3	11	11	8.7	5.0
1969	6	1	11	3	11	11	9.3	5.0
Mean rank	5.5	2.25	11.0	4.8	10.5	11.0	9.0	6.0

Selected Representatives of Relatively Shallow-Living Planktonic Groups

Arrowworm-Salp Group (0-300 m)

	Sa. Salpa fusiformis		F. Cyclothone signata		C. arrow-worms (Chaetognatha)		Mean rank	
Year	SB	SC	SB	SC	SB	SC	SB	SC
1965	11	11	3	4	11	11	8.3	8.7
1967	4	1	3	3	8	7	5.0	3.7
1968	11	11	3	6	10	5	8.0	7.3
1969	11	6	3	2	9	4	7.7	4.0
Mean rank	9.3	7.25	3.0	3.75	9.5	6.8	7.3	5.9

Larvae Group (0-300 m)

	A. Paraphronima crassipes		F. Engraulis mordax		F. Merluccius productus		F. Sebastodes sp.		D. Emerita analoga		D. Blepharopoda occidentalis (crab larva)		Mean rank	
Year	SB	SC	SB	SC	SB	SC	SB	SC	SB	SC	SB	SC	SB	SC
1965	11	9	6	6	4	6	6	6	8	6	11	11	7.2	7.3
1967	11	11	6	6	6	6	5	6	10	4	11	11	8.2	7.3
1968	11	10	6	6	6	6	6	6	8	7	11	11	8.0	7.7
1969	11	11	5	6	6	6	6	6	6	8	10	11	7.3	8.0
Mean rank	11.0	10.0	5.8	6.0	5.5	6.0	5.8	6.0	8.0	6.3	10.7	11.0	7.7	7.6

Selected Representatives of the Offshore Fish Group (0-550 m)

	A. Vibilia, sp		F. Diaphus theta		F. Lampanyctus ritteri		Mean rank	
Year	SB	SC	SB	SC	SB	SC	SB	SC
1965	11	11	6	6	6	6	7.7	7.7
1967	11	8	4	4	6	6	7.0	6.0
1968	11	11	6	6	6	5	7.7	7.3
1969	11	9	6	6	6	6	7.7	7.7
Mean rank	11.0	9.8	5.5	5.5	6.0	5.75	7.5	7.2

emarginata was one of the larger and more abundant middepth invertebrates. For the Channel, member species ranked slightly lower in 1969 (5.6) than in previous years (4.0-5.2) because the shrimp *Pasiphaea pacifica* and jellyfish *Aegina* were relatively scarce then (see also Table 6). Santa Cruz Basin representatives, especially *Pasiphaea emarginata*, were slightly less abundant after the blowout (8.0) than in previous years (6.0-8.8). However, relative overall "success" of the community as measured by the sum of ranks of its member species did not differ significantly among years in either basin (Table 3).

Table 3

Among-year differences in composition of three ecological groups of macroplankton in the Santa Barbara Channel (SB) and Santa Cruz Basin (SC). From Table 2, differences between observed and expected abundance rank sums for representative species are summed as chi-square with 2 degrees of freedom. Non-significance (NS) was determined at the P=.05 level. The observed ("Obs.") rank sum for 1965 Channel captures of common Middepth Community members, for example, equals the rank sum in the "SB" columns of Table 2, across the row for 1965; i.e., 1+2+6+7+9=25. The expected sum ("Exp.") was calculated from ranks pooled for all years.

Middepth Communities

	Year	Obs.	Exp.		Chi-square
SB	1965	25	23		.17
	1967	26	23		.39
	1968	20	23		.39
	1969	29	23		1.56
				(NS)	2.51
SC	1965	30	41		2.96
	1967	44	41		.22
	1968	36	41		.61
	1969	41	41		0
				(NS)	3.79

Shallow Invertebrate Community

	Year	Obs.	Exp.		Chi-square
SB	1965	15	17		.24
	1967	28	17		7.12
	1968	20	17		.53
	1969	20	17		.53
				(P=.02)	8.42
SC	1965	17	26		3.12
	1967	33	26		1.88
	1968	33	26		1.88
	1969	26	26		0
				(P=.03)	6.88

Arrowworm-Salp Group

	Year	Obs.	Exp.		Chi-square
SB	1965	25	26		.04
	1967	15	26		4.67
	1968	24	26		.15
	1969	23	26		.35
				(NS)	5.21
SC	1965	26	16		6.25
	1967	12	16		1.00
	1968	22	16		2.24
	1969	12	16		1.00
				(P=.005)	10.49

The Shallow Invertebrate Community abounds in and above the mid-depths of both basins and contains common forage animals like the small euphausiid shrimp *Euphausia pacifica* and decapod shrimp *Sergestes similis* (Ebeling et al., 1970b). (Tiny copepods, which are even more abundant, generally pass through the trawl mesh and so were excluded from this analysis.) In 1969 the mean ranks of community members in Channel and Basin (Table 2: 4.0, 5.2) resembled those of previous years (3.0-5.0, 3.4-6.6). Overall community "success" differed significantly among years in the Channel because members were unusually abundant in 1967 (Table 3).

Most members of the Offshore Middepth and Deep communities are poorly represented in Channel collections (Brown, 1969; Ebeling et al., 1970b). They are more common in deep oceanic waters and so were poor indicators of possible oil damage. Offshore deep species occurred in about the same relative abundance in 1969 as in previous years (Table 2). Surprisingly in 1969, the Offshore Middepth Community appeared to be equally successful in the Channel and Basin: the offshore lanternfish Triphoturus mexicanus was trawled in unusually large numbers in the Channel (Table 6), while the jellyfish Atolla wyvillei was relatively scarce in the Basin.

The relatively shallow-living planktonic groups vary with season and are usually well-represented in the Santa Cruz Basin (Ebeling et al., 1970ab). However, the Larvae Group was more "successful" in the Channel in 1969 after the blowout (Tables 4, 5, 6). The Arrowworm-Salp group rank sum did not differ significantly from expected in either area (Table 3, chi-square 1969, 1 d.f.).

Distributional patchiness of common species varied little or inconsistently before and after the blowout (Table 4). In the Santa Barbara Channel, patchiness indices for ten species did not change appreciably, five decreased, and only one increased. Catch rates were generally greater: ten increased, seven were about the same, and only six decreased. Patchiness of Inshore Middepth Community members generally decreased, while as many catch rates increased as decreased. Patchiness of standing crops was about the same. In the Santa Cruz Basin, indices for seven species did not change appreciably, seven decreased, and two increased. Catch rates were generally less: 18 decreased and only five were about the same or less. But the average volume of an individual fish was significantly larger (Table 1). Patchiness of fish standing crop was about the same (Table 4). Pre-blowout invertebrate patchiness reflected the large influx of salps in 1967.

Table 4

Average catch rates and patchiness indices of species representing macroplankton groups and of plankton volumes in the Santa Barbara Channel (SB) and Santa Cruz Basin (SC) for late February and early March before and after the oil blowout. Letters classify the species as in Table 2.

Species	Locality	Period	Catch rate	Patchiness index
F. Leuroglossus stilbius	SB	1965-68	4.9	5.55
		1969	1.7	2.24

		SC	1965-68	1.7	3.69
			1969	.31	.64
	F. Stenobrachius leucopsarus	SB	1965-68	6.9	2.97
			1969	7.8	1.75
Inshore Middepth Commun.		SC	1965-68	1.3	2.90
			1969	1.1	1.48
	D. Pasiphaea emarginata	SB	1965-68	2.2	2.46
			1969	15.8	3.41
		SC	1965-68	.35	2.49
			1969	.09	...
	D. Pasiphaea pacifica	SB	1965-68	1.3	3.57
			1969	.48	1.94
		SC	1965-68	.05	...
			1969	0	...
	M. Aegina, sp.	SB	1965-68	1.9	5.48
			1969	.66	4.82
		SC	1965-68	.05	...
			1969	0	...
	A. Paracallisoma coesus	SB	1965-68	.08	4.15
			1969	.55	3.64
		SC	1965-68	.04	...
			1969	.04	...
	A. Hyperia galba	SB	1965-68	.73	4.31
			1969	.58	2.68
		SC	1965-68	.03	...
			1969	0	...
	E. Euphausia pacifica	SB	1965-68	37.1	7.02
			1969	20.3	6.17
		SC	1965-68	8.4	4.61
			1969	25.4	3.65
Shallow Invert. Commun.	E. Nematocilis difficilis	SB	1965-68	2.6	5.42
			1969	2.8	5.70
		SC	1965-68	4.2	2.87
			1969	.75	5.12
	D. Sergestes similis	SB	1965-68	3.5	2.52
			1969	3.9	2.69
		SC	1965-68	1.3	6.00
			1969	.14	.95
	Ct. Euplokamis californiensis	SB	1965-68	2.3	3.82
			1969	3.5	3.09
		SC	1965-68	.43	8.70
			1969	1.2	4.68
	S. "pointed siphonophores"	SB	1965-68	12.4	3.04
			1969	16.4	3.47

		SC	1965-68	14.9	2.55
			1969	6.1	2.12
Offshore Middepth Commun.	F. Cyclothone signata	SB	1965-68	.61	2.33
			1969	1.3	2.84
		SC	1965-68	1.1	2.20
			1969	1.0	1.86
	M. Atolla wyvillei	SB	1965-68	0	...
			1969	0	...
		SC	1965-68	2.2	4.39
			1969	.23	1.38
	M. Colobonema sericeum	SB	1965-68	.14	...
			1969	.09	...
		SC	1965-68	.11	...
			1969	.14	...
	C. Gennadas propinquus	SB	1965-68	.02	...
			1969	.02	...
		SC	1965-68	1.2	1.17
			1969	0	...
Offshore Deep Commun.	F. Cyclothone acclinidens	SB	1965-68	.07	...
			1969	.07	...
		SC	1965-68	2.1	3.13
			1969	2.9	1.69
	D. Hymenodora frontalis	SB	1965-68	0	...
			1969	.02	...
		SC	1965-68	4.1	3.05
			1969	2.9	1.50
	M. Crossota rufobrunnea	SB	1965-68	.19	...
			1969	0	...
		SC	1965-68	.23	4.45
			1969	.04	...
Arrowworm-Salp Group	F. Cyclothone signata	SB	1965-68	.61	2.33
			1969	1.3	2.84
		SC	1965-68	1.1	2.20
			1969	1.0	1.86
	Sa. Salpa fusiformis	SB	1965-68	1.0	25.9
			1969	0	...
		SC	1965-68	36.4	18.22
			1969	1.0	11.78
Larvae Group (excluding fish)	D. Emerita analoga (larvae)	SB	1965-68	1.0	3.55
			1969	3.4	4.14
		SC	1965-68	4.1	4.77
			1969	.63	6.14
	D. Blepharipoda occidentalis (larvae)	SB	1965-68	.03	...
			1969	.78	5.55

		SC	1965-68	.07	...
			1969	0	...
	A. Paraphronima crassipes	SB	1965-68	.19	2.96
			1969	.20	.82
		SC	1965-68	.55	1.72
			1969	.14	.94
Fish volumes	...	SB	1965-68	30.6 ml	2.07
			1969	33.5 ml	1.51
		SC	1965-68	15.1 ml	2.52
			1969	18.2 ml	1.42
Invertebrate volumes	...	SB	1965-68	50.3 ml	1.68
			1969	72.1 ml	2.01
		SC	1965-68	253.3 ml*	32.32
			1969	40.0 ml	2.58

*Including abnormally large salp collections in 1967.

Larval fish were significantly more abundant after the blowout than in 1968 (Table 5). Catch rates for 6 of 11 species increased in the Channel. The 1969 abundance was significantly greater than that of 1968, but not those of 1965 and 1967 ("U" test, Table 5). In the Basin, the 1967 abundance was significantly greater than those of 1965 and 1968, but not that of 1969.

In the Channel, the relative abundances of invertebrates, fish larvae, and other common fishes showed no major changes after the blowout (Table 6). Pre-blowout abundance rankings of invertebrates were significantly correlated with post-blowout rankings (tau test, Table 6). Although fish ranks were not significantly correlated, they showed some similarities. The deep-sea smelt Leuroglossus stilbius ranked highest among the fish larvae, while three species led all fishes for the two periods. Larval rockfishes (Sebastodes sp.) and anchovies (Engraulis mordax) were relatively abundant in 1969. The lanternfish Triphoturus mexicanus, large midwater shrimp Pasiphaea emarginata, and larval sandcrab Emerita analoga were also unusually high in the 1969 rankings.

Fresh caught animals that were not seriously injured appeared as lively as ever. After each trawl was retrieved, the contents of the cod-end chambers were immediately washed into buckets of cold seawater and observed in the ship's laboratory. Most of the

Table 5

Abundances and catch rates of larval fishes trawled in the basins during February-March of years before and after the blowout. Species include some that are surface pelagic as adults and whose larvae live above 100 m: anchovy Engraulis mordax, Spanish mackerel Trachurus symmetricus, sardine Sardinops caerulea; upper middepth both as adults and larvae: hake Merluccius productus; typical deep-sea fish of upper and lower middepths (100-550 m) as adults, shallower depths as larvae: Leuroglossus stilbius; deep and shallow benthic species whose larvae usually inhabit the upper middepths: channel rockfishes Sebastolobus altivelis and S. alascanus; sanddabs and flounders Citharichthys stigmaeus, C. sordidus, and Microstomus pacificus, combfish Zaniolepis sp.; and benthic species of moderate to shallow depths whose larvae occur near the surface: rockfishes Sebastodes sp., cabazon Scorpaenichthys marmoratus. In each column by year, the first entry is the total individuals captured, the second is the catch per kilometer flow. Using the Wilcoxon-Mann-Whitney "U" statistic at the P=.05 level (Sokal and Rohlf, 1969), the 1969 Channel larval abundance was significantly greater than that of 1968, but not those of 1965 and 1967; the 1967 Basin abundance was significantly greater than those of 1965 and 1968, but not that of 1969.

Santa Barbara Channel:	1965		1967		1968		1969	
Engraulis mordax	3	.037	2	.077	0	...	6	.102
Merluccius productus	14	.174	1	.039	1	.037	27	.460
Leuroglossus stilbius	8	.099	19	.730	2	.073	49	.834
Sebastolobus altivelis	0	...	0	...	0	...	0	...
S. alascanus	0	...	1	.039	0	...	0	...
Sebastodes spp.	1	.012	3	.116	1	.037	40	.680
Scorpaenichthys marmoratus	0	...	0	...	0	...	2	.034
Zaniolepis sp.	2	.025	0	...	1	.037	1	.017
Citharichthys stigmaeus	2	.025	1	.039	0	...	4	.068
C. sordidus	0	...	0	...	0	...	1	.017
Microstomus pacificus	1	.012	1	.039	1	.037	1	.017
Santa Cruz Basin:								
Engraulis mordax	0	...	8	.051	0	...	0	...
Merluccius productus	0	...	4	.026	0	...	4	.072
Leuroglossus stilbius	0	...	4	.025	0	...	2	.035
Sebastolobus altivelis	0	...	1	.006	2	.070	1	.018
S. alascanus	0	...	1	.006	0	...	0	...
Sebastodes spp.	0	...	7	.045	0	...	1	.018
S. marmoratus	0	...	1	.006	0	...	0	...
Citharichthys stigmaeus	1	.034	8	.051	0	...	1	.018
C. sordidus	0	...	0	...	0	...	0	...
Microstomus pacificus	0	...	1	.006	0	...	0	...

animals remained active for hours. One surface plankton tow through a fresh oil slick near the site of the blowout yielded a good catch of tiny animals appearing lively and active.

Discussion

About one month after the blowout, macroplankton trawled from the "oiled" Santa Barbara Channel and mostly "not oiled" Santa

Table 6

Abundance ranks and catch rates of macroplankton trawled from the Channel during February-March in years before and after the blowout. Ranks, before and after, of larvae and other fishes were not significantly correlated; ranks of invertebrates were correlated at the P=.01 level, using Kendall's tau rank correlation (Sokal and Rohlf, 1969).

Pre-blowout collections (1965-68)		Post-blowout collections (1969)	
Species	Catch rate	Species	Catch rate
Larval fishes			
1. *Leuroglossus stilbius*	.22	1. *L. stilbius*	.83
2. *Merluccius productus*	.12	2. *Sebastodes*, sp.	.68
3. Flatfish larvae (3 spp.)	.05	3. *Merluccius productus*	.46
4. *Sebastodes* sp.	.04	4. *Engraulis mordax*	.10
5. *Engraulis mordax*	.04	5. Flatfish larvae (3 spp.)	.10
All fishes			
1. *Stenobrachius leucopsarus*	6.9	1. *S. leucopsarus*	7.8
2. *Leuroglossus stilbius*	4.9	2. *L. stilbius*	1.7
3. *Cyclothone signata*	.61	3. *C. signata*	1.3
4. *Diaphus theta*	.41	4. *Triphoturus mexicanus*	.29
5. *Merluccius productus* (larv.)	.12	5. *Engraulis mordax* (larvae)	.27
Invertebrates			
1. *Euphausia pacifica*	37.1	1. *E. pacifica*	20.3
2. "pointed siphonophores"	12.4	2. "pointed siphonophores"	16.4
3. *Sergestes similis*	3.5	3. *Pasiphaea emarginata*	15.8
4. *Nematocilis difficilis*	2.6	4. *Sergestes similus*	3.9
5. *Euplokamis californiensis*	2.3	5. *E. californiensis*	3.5
6. *Pasiphaea emarginata*	2.2	6. *Emerita analoga* (larvae)	3.4
7. *Aegina*, sp.	1.9	7. *Thysanoessa spinifera*	3.3
8. *Pasiphaea pacifica*	1.3	8. *Nematocilis difficilis*	2.8
9. *Emerita analoga* (larvae)	1.0	9. arrow worms	1.7
10. *Salpa fusiformis*	1.0	10. *Blepharipoda* (sand-crab l.)	.78

Cruz Basin showed no major changes in species diversity, evenness, standing crop, or patchiness in the shallow, middepth, or deep collections. In the Channel, diversity and abundance of invertebrates, larval fishes, and a few offshore fishes were significantly higher in 1969 after the blowout. While average fish size increased in the Basin catches, however, it decreased in the Channel. Perhaps the severe storms drove many of the smaller surface forms inshore.

We could detect a few notable changes in the composition of communities and ecological groups, as represented by their more common species. Such changes, however, did not appear to be likely effects of oil pollution. In the Channel, the large shrimp Pasiphaea emarginata and offshore lanternfish Triphoturus mexicanus were relatively abundant. The Shallow Invertebrate Community was scarcely altered after the blowout, while the Larvae Group was significantly more abundant in the Channel. Rockfish, anchovy, and sandcrab larvae were more abundant in 1969 than in previous years.

Perhaps these changes were caused by climatic anomalies characterizing the first half of 1969. The worst part of the oil spill coincided with a series of severe winter storms during the wettest rainy season in recent years (Foster et al., 1969a). Considerable fresh water flowed into the Channel, increasing turbidity and decreasing surface salinity. We contrasted oceanographic trends after the blowout with previous conditions to see if water-mass anomalies could account for the observed changes in community composition.

A counterclockwise gyre of water subject to local climatic effects dominates the area of basins and islands off southern California (Reid et al., 1958; Emery, 1960; Brown, 1969). Here, during summer and fall, warmer southern water replaces the cool California Current, which is deflected offshore at Point Conception just above Santa Barbara. In the spring, upwelling of nutrient-rich deep water accompanies the shoreward movement of the intensifying California Current. Consequently, three oceanographic periods influence the Santa Barbara area: an upwelling period of surface enrichment during May through July, a stratification period of surface warming during August through December, and a mixing period of surface cooling during January through April (Brown, 1969). Kolpack (1971) showed that surface water of the Santa Barbara Channel flows in a counter-clockwise cell in the western part and converges with water entering the channel from the east over a shallow sill. From this we infer that the Channel usually has a more or less "contained" circulation in its deeper western part, which may explain some of the peculiarities of its macroplankton communities and groups. Kolpack added that surface nutrients were relatively high in May following the blowout. This may have been caused by an accumulation of unusually heavy land runoff, rather than by upwelling which was delayed by the intense and prolonged mixing period of winter storms.

These periods may influence the distribution of some macroplankton species belonging to "transitory groups" more than they do others belonging to "resident communities" (Ebeling et al., 1970b). Abundances of southerly species increase in late summer and fall, while those of northerly species increase in the winter and spring (Lavenberg and Ebeling, 1967; Ebeling et al., 1970a). During the mixing period, members of the Inshore Middepth Community are usually abundant because they seem to be specifically adapted to the prevailing local conditions nearshore. On the other hand, some members of the Offshore Middepth Community, such as the lanternfish Triphoturus mexicanus, are usually scarce because they thrive during the stratification period when the influence of the California Current is minimal.

In the present study, therefore, the relatively high Channel abundance of certain fish larvae and Inshore Middepth shrimp was not surprising for the period after the blowout. In general, pelagic larvae become abundant during the early spring when tiny zooplankton are also abundant (Ebeling et al., 1970a; cf. Isaacs et al., 1969). Ahlstrom (1961, 1966) observed that young rockfish and anchovy larvae are most abundant in plankton collections made in late winter and early spring. After the blowout, some larvae may have been carried into the Channel from the southeast during storms, and then retained in the western gyre.

The first half of 1969 was oceanographically atypical. After the blowout, the prolonged mixing period extended into May, when surface water temperatures abruptly rose in the absence of the usual spring upwelling (Flittner, 1969ab; U. S. Fish and Wildlife Service, 1969b). The water masses in the Channel and Basin, as identified by temperature-salinity and oxygen-depth curves, differed from those of 1967 and 1968. In 1969, low surface temperatures and salinities reflected the effects of the cold winter storms (Figs. 2, 3). A slight salinity increase in deep water suggested that southern water had recently entered the basins at depth. This might account for the unusual seasonal occurrence of Triphoturus mexicanus in the Channel.

The extraordinarily high measurements of deep oxygen concentration were certainly unexpected (Figs. 4, 5). Perhaps they are erroneous, although their remarkable correspondence between channel and basin indicates otherwise. Kolpack (1971) noted that oxygen profiles in the Channel were "normal" in May, 1969, except for a decrease in the upper 30 meters beneath an oil slick. If our oxygen measurements are correct, the Channel environment is indeed, as Kolpack suggested, "more dynamic than previously expected." Perhaps the Channel and Basin waters above sill depth had become temporarily oxygenated and partially flushed of stagnant water during the

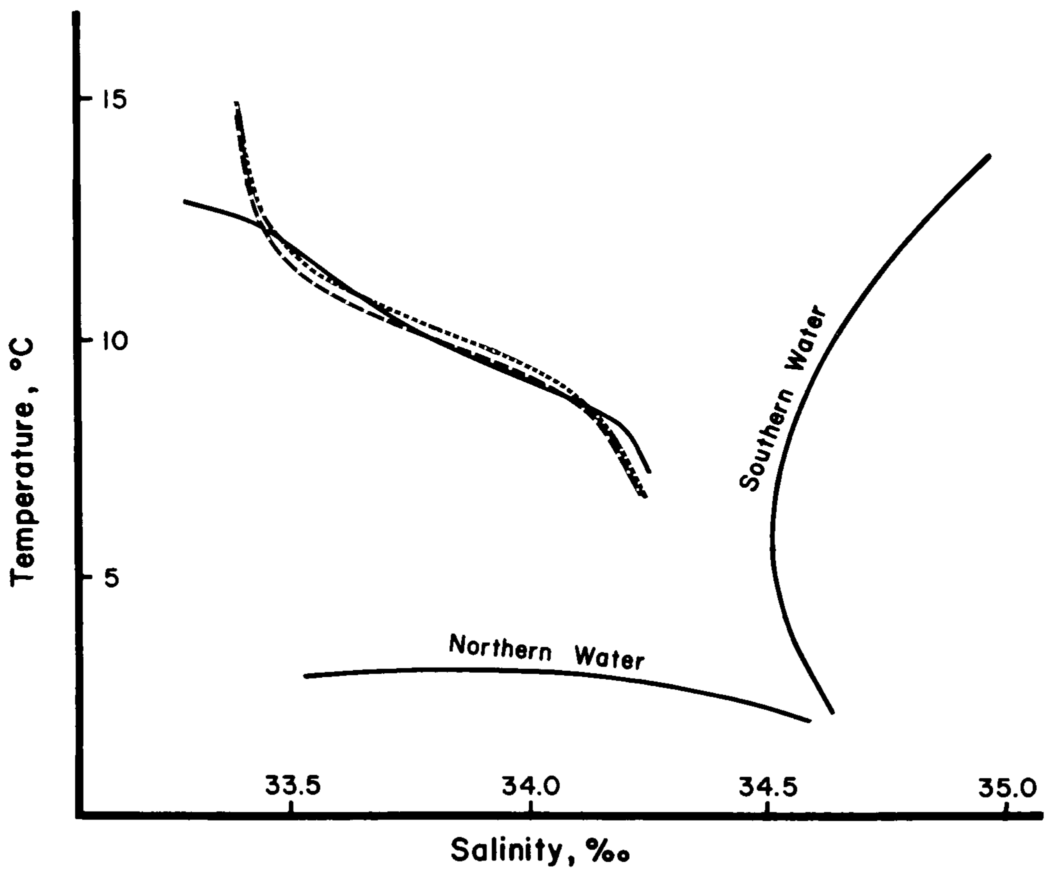

FIGURE 2. TEMPERATURE-SALINITY WATER-MASS CURVES FOR THE SANTA BARBARA CHANNEL DURING FEBRUARY-MARCH OF YEARS PRIOR TO AND AFTER THE BLOWOUT

Observed at 10 depths between the surface and 500 m during 1967 (dotted line), 1968 (dashed line), and 1969 (solid line), and compared with standard curves for subarctic (northern) and equatorial (southern) waters.

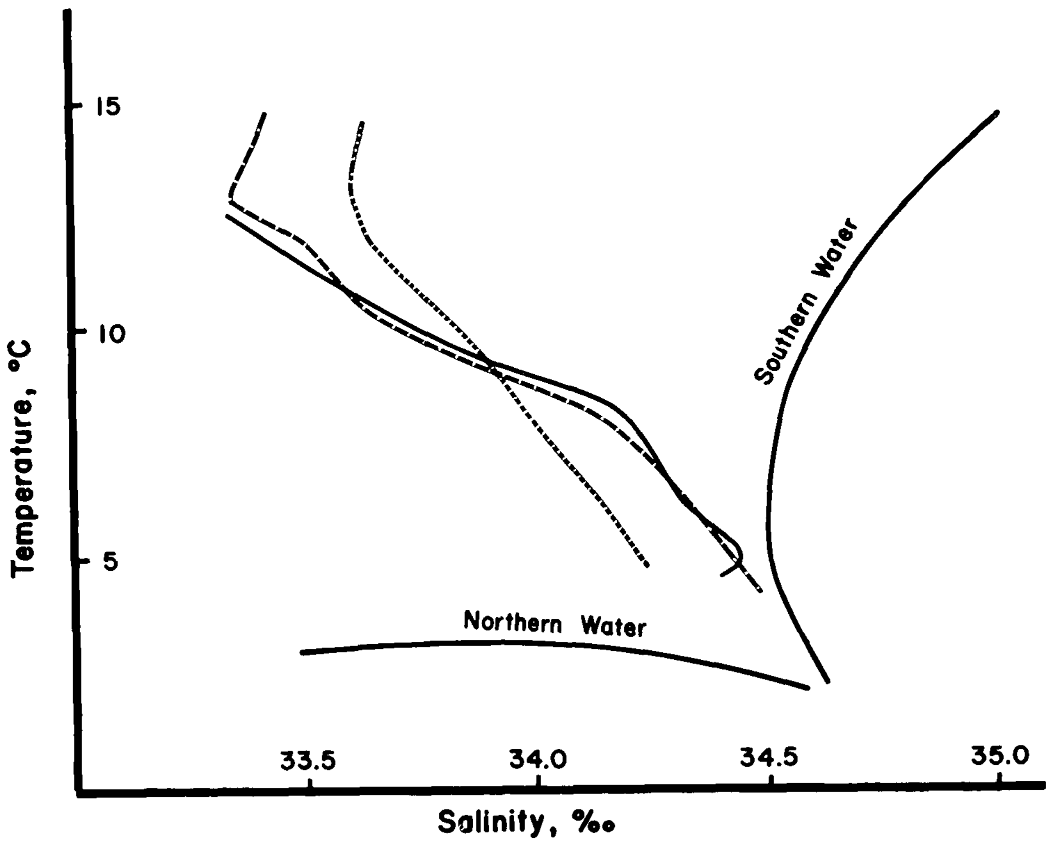

FIGURE 3. TEMPERATURE-SALINITY WATER-MASS CURVES FOR THE SANTA CRUZ BASIN DURING FEBRUARY-MARCH OF YEARS PRIOR TO AND AFTER THE BLOWOUT

Observed at 10 depths between the surface and 1000 m during 1967 (dotted line), 1968 (dashed line), and 1969 (solid line), and compared with standard curves for subarctic (northern) and equatorial (southern) waters.

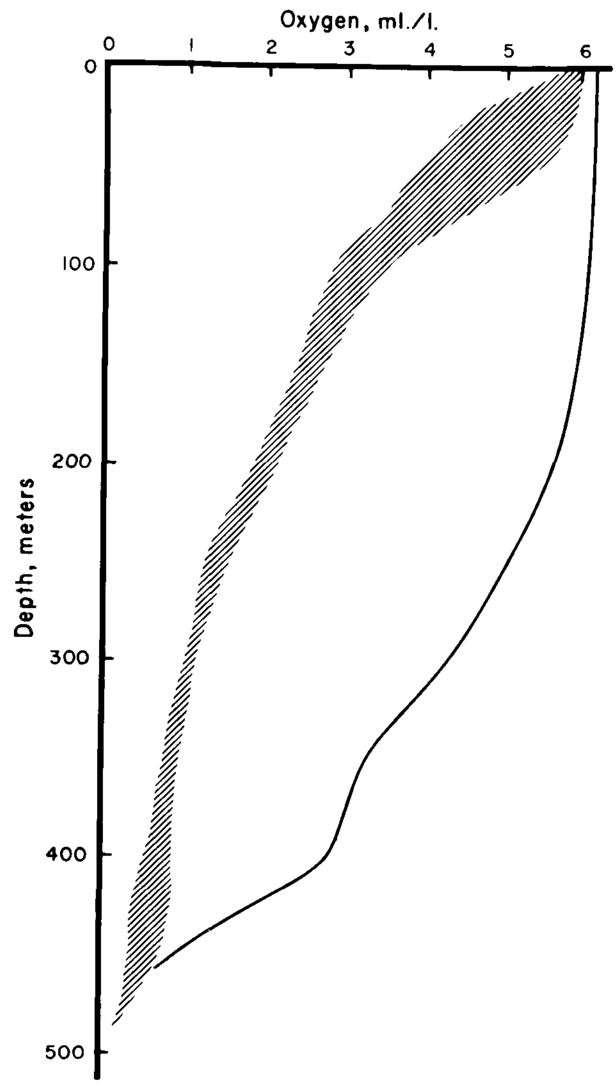

FIGURE 4. DISSOLVED OXYGEN BY DEPTH CURVES FOR THE SANTA BARBARA CHANNEL DURING FEBRUARY-MARCH OF YEARS PRIOR TO AND AFTER THE BLOWOUT

Observed at 10 depths during 1967 and 1968 (range indicated by hatched band) and 1969 (solid curve).

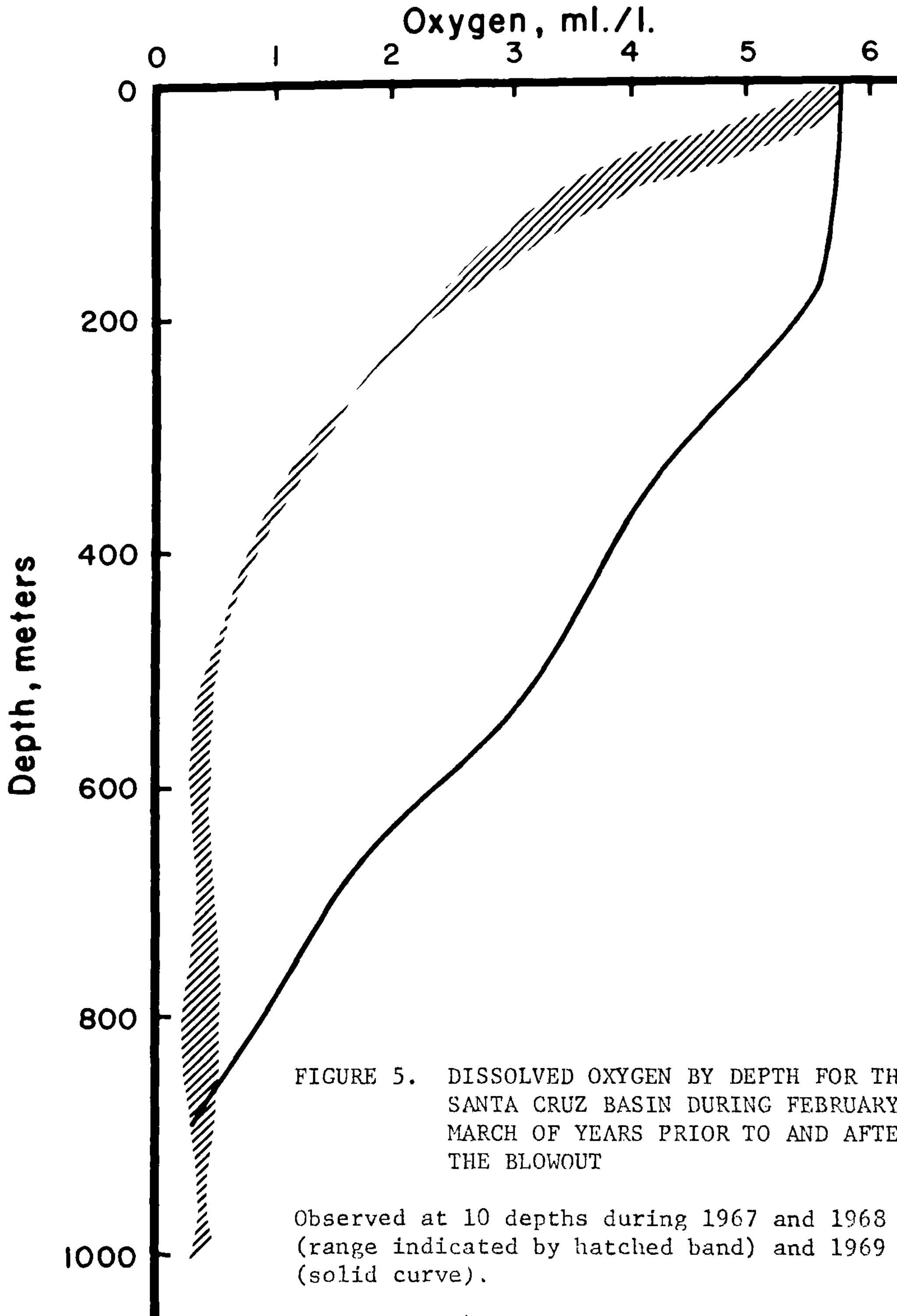

FIGURE 5. DISSOLVED OXYGEN BY DEPTH FOR THE SANTA CRUZ BASIN DURING FEBRUARY-MARCH OF YEARS PRIOR TO AND AFTER THE BLOWOUT

Observed at 10 depths during 1967 and 1968 (range indicated by hatched band) and 1969 (solid curve).

intense winter mixing period, but had returned to "normal" by May.

In summary, climatic anomalies most likely account for the few observed anomalies in macroplankton composition. The offshore lanternfish may have entered the Channel with deep intrusions of southern water, while pelagic larvae and a few Inshore Middepth species expectedly flourished during the prolonged mixing period following the blowout. Dr. Robert Holmes (personal communication) observed unusually dense concentrations of phytoplankton after the storms and consequent nutrient enrichment of the waters by runoff from the land. The unusual bloom may have sustained large numbers of tiny grazers, which in turn were eaten by the macroplankters.

SECTION V

NEARSHORE BOTTOM FISH COMMUNITIES

Beds of giant kelp in the Channel provide cover and food for complex animal communities containing several sport fishes. Resident populations of most species remain active in and about the kelp the year round. The kelp communities intergrade extensively with the surrounding level bottom communities (Quast, 1968b). Therefore, we trawled collections from bottom habitats near the kelp beds in an area repeatedly invaded by oil slicks after the blowout.

The Channel climate influences the composition of the nearshore bottom communities, which occupy a transitional zone between a cold-water faunal region north of Point Conception and a warmer region to the south (Hubbs, 1960; Quast, 1968a; see also Section IV). The Channel communities generally resemble others of the warmer region, although they include several northern species extending slightly below Point Conception. Their northern, southern, and wide-ranging members may react differently to climatic shifts and oceanographic anomalies. Migratory fishes enter and leave the Channel as one oceanographic season follows another. Therefore, seemingly minor anomalies may strongly affect marginal populations of either northern cold-water specialists or southern warm-water specialists, but not noticeably affect many relatively temperature-tolerant generalists. Such natural environmental effects should be considered in assessing possible pollution damage to these communities.

We found surprisingly little unequivocal evidence of previous pollution damage to nearshore bottom fishes of the open Californian coast. Mr. David Valentine (personal communication) has observed the widespread occurrence of morphological abnormalities in sand bass living near sewage outfalls. Stapleton (1968) noted that kelp bass from areas polluted by industrial wastes show considerable liver damage. Carlisle (1969) trawled many bottom fishes from near areas of waste discharge off Los Angeles. Although the sewage outfall itself attracted a few species, most fishes avoided the heavily polluted areas. But he concluded that "It was impossible to show that fluctuations in abundance, as measured by trawl catches, were the result of large-scale waste discharge in the study area, and not due to natural causes." Others have found no gross changes in diversity and abundance of animal communities near, but not directly adjacent, various pollutant sources off southern California (Turner et al., 1965, 1966, 1968; Turner and Strachan, 1969). Carlisle et al. (1964) after extensive observations of animals populating various kinds of artifical reefs, somewhat optimistically concluded that oil drilling platforms actually enhance fishing because, like natural reefs, they provide shelter, food, and landmarks or orientation for kelp and reef species.

We investigated changes in fish diversity, abundance, and community composition between "oiled" and "not oiled" environments, in light of natural environmental changes, environmental heterogeneity, and sampling bias, as well as possible pollution effects of the blowout. The more common species were classified into communities or groups of species living together in the same general habitat. Our fish communities, of course, reflect the limited sampling universe of species that can be caught with a small otter trawl at the localities visited. Sampling difficulties arise because two or more interacting communities may inhabit the same general area like the transitional zone between kelp and level bottom. Fager and Longhurst (1968) classified ecological groups of bottom fishes trawled from various depths off west Africa. Like the present communities, these groups were generally assorted by depth and substrate type, but were broadly overlapping in space and time. That is, members of such groups may migrate both bathymetrically and geographically with seasonal or other temporal changes. Carlisle (1969) noted that a common sanddab occurs in deeper water during the winter off Los Angeles. Day and Pearcy (1968) described bottom fish communities that merged among depths and substrate types off Oregon. The shallowest contained species in two of the present communities.

We did not chemically test for oil contamination. Oil was not detected in the flesh or guts of a few bottom fishes trawled after the blowout from about 110 fathoms inshore of Anacapa Island; extracts of the fish muscle in acetic acid fluoresced no more under varying wavelengths of ultraviolet light than extracts from goldfish controls (Meek et al., 1969). Holcomb (1969), however, reviewed evidence that bottom invertebrates concentrate the relatively stable benzopyrenes, which are petroleum carcinogens with high boiling points. Fish, in turn, may eat the contaminated invertebrates.

Methods

From February 21 to August 7, 1969, 56 trawl hauls sampled the shallow level bottom fauna around kelp beds off Santa Barbara and an area unaffected by the oil spill to the south (Fig. 1). Three localities were sampled at least three times per month, using a 16-foot wide semi-balloon trawl retrieved by power capstan over a portable A-frame, from a 17-foot Boston Whaler skiff. Locality I was about one mile due south of Santa Barbara Lighthouse, west of the blowout, in about 180 (100-240) feet of water. Locality II was farther inshore in about 40 (30-45) feet at the outer margin of the kelp southwest of the lighthouse. Locality III, in about 15 (10-25) feet and often cluttered with seaweed drifting on the bottom, was at the inner margin of the kelp just west of Santa Barbara Harbor. The shallow sandy and occasionally rocky bottom near the kelp merges with the sandy-mud bottom at greater depths. Unlike kelp off Los Angeles and San Diego, which usually attaches to rocky bottom there, kelp off Santa Barbara attaches to either soft or rocky bottom in the protected Channel (North, 1963). Oil slicks entered all three localities at one time or another. On April 15 and July 17, six trawl hauls sampled similar localities off Zuma Beach and Paradise Cove that were not polluted by the blowout oil.

Trawling effort was standardized as much as possible. Deep hauls at Locality I always trawled due north, shoaling toward shore. Shallower hauls at localities II and III trawled along the outer margin of the kelp bed or parallel to the shore. All trawls were adjusted to 15 minutes fishing time on the bottom. At Locality I, the trawl was set rapidly, so that the net would assuredly reach bottom for a full 15 minutes sample, as indicated by normal catches of the abundant sea cucumber Stichopus. Environmental observations accompanied the collections: surface water temperature, sea state, amount of overcast, Secchi disc water transparency, bottom depth, time of day, and estimated oil amount as surface slicks and tar. At Locality II, small mysid shrimps of the kelp canopy were sampled in a measured bucket dipped among the fronds, counted, and released.

All fish and invertebrates were volumetrically measured and preserved, except for the bulky sea cucumbers which were counted and released. The specimens were stored temporarily in large plastic bags, iced, and brought to the laboratory, where they were sorted, identified, and measured before preservation in 10% formalin. The general condition of the fish was noted as they were sorted into size clases. All invertebrates were sorted into taxonomic groups (e.g., crabs, shrimps, sea urchins); most were identified to species. Liquid displacement volumes of total fish and invertebrates (excluding the sea cucumbers) were recorded before preservation.

For later tabulations and statistical treatment, species abundances and size ranges were punched by collection number on one set of computer data cards, environmental observations and other biological measurements on another. "Remote" observations were added insofar as they might meaningfully broaden the environmental study: seasonal advance, expressed as days after the first trawl on February 21; phase of the moon; monthly mean surface temperature off Santa Barbara, as compiled by the U. S. Fish and Wildlife Service (1969b); offshore temperature, as measured by infrared thermometer and compiled by the Tiburon Marine Laboratory, U. S. Fish and Wildlife Service (1969b); nearshore surface salinity, as measured at the Ventura Marina and provided by Mrs. Margaret Robinson of the Scripps Institution of Oceanography; and catches per angler of rockfish, bass, bonito + barracuda, and halibut, from sportfishing boats leaving nearby Oxnard and Port Hueneme and usually fishing the Channel near the islands. These catch rates, compiled from daily records in the Los Angeles Times newspaper, were used because data from the Santa Barbara sport fishery was unavailable. Santa Barbara boats were inactive during periods of the oil spill due to oiling of the harbor and various other problems. (On two occasions during the spill, however, Ebeling caught near-limits of rockfishes and lingcod from a Santa Barbara boat fishing off Santa Rosa and San Miguel Islands.)

After first comparing abundances and diversities between all 1967 and 1969 catches, we compared seasonally and environmentally matched collections by using chi-square expressions of observed vs. expected numbers of species shared and not shared between 1967-1969 pairs (after Quast, 1968b). Six collections from Locality I, two each from March, April, and May, 1969 were paired with six similar collections trawled in 1967 by Richard M. Ibara and Lawrence T. Penny, using the same gear and method. Only three 1967 collections were available from Locality II. Locality III was unrepresented. Along with five others which could not be adequately paired, however, a total of 14 collections from 1967 allowed detailed comparisons with the present 31 post-blowout collections from Localities I and II. "Expected" terms in the chi-square expressions took into account the commonness or rarity of each fish species in calculating its probability of occurrence in both members of a pair of collections (the square of its probability of occurrence in either). The assumed probability (p_i) of capture of at least one individual of a particular species in a particular trawl collection, therefore, was its proportionate frequency in all comparable collections made at either locality during both years, i.e., its proportionate frequency among 22 collections from I (11 from each year) or among 12 collections from II (nine from 1969, three from 1967). The expected number of species shared by any 1967-1969 collection pair was, for each locality:

$$\sum_{i=1}^{S} p_i^2 \quad ; \text{ where}$$

i = 1, 2, ...,S; S = the number of species recorded for either locality, about 40 from each; and p_i^2 = the probability of joint occurrence of the i^{th} species, ranging from near zero for the rarest species to about 0.8 for the commonest. Collection pairs from deep Locality I expectedly shared about eight species, while those from relatively shallow Locality II expectedly shared but five. The expected number of not shared or "unique" species that occur in but one member of a pair, was assumed to be the average number of species per collection, minus the expected number shared.

In this way, collections were contrasted by pairs between years and among months by shared and unique species for shallow and deep localities (Tables 8, 9). We wanted to test for significant departure from an expected joint collection composition determined intrinsically by the obviously quite different probabilities of catching rare and common species, rather than determined extrinsically by assuming equal probabilities for all species (as used by Quast in a different kind of study). The chance of catching a common species (assuming that it does not escape the trawl) is much greater than catching a rare species. For the deep-locality pairs, however, the expected number of shared species based on unequal capture probabilities approximated those based on equal probabilities: in the deep (but not the shallow) trawls, the good chances of catching the common species balanced the poor chances of catching the rare ones.

The 1969 collections were similarly compared with those trawled from the "not oiled" area off Paradise Cove and Zuma Beach (PCZ). Expected frequencies were heavily biased in favor of the Santa Barbara collections because few PCZ collections were available.

"Communities" and other environmental systems were defined using subgroups of intercorrelated variables within the group of 53 variables (sets of 56 observations each) measured. Variables included: abundances of the 23 commonest fishes and seven commonest invertebrates; 15 measures of the physical environment (substrate, temperatures, oil, season, time, weather, phase of moon, water transparency, salinity, etc.); and eight measures of the biological environment (fish and invertebrate volumes, fish diversity, abundance of surface mysid shrimps, catch rates of sport fishes). All frequency distributions of species abundances were strongly skewed to the right, indicating that the animals occurred in patches. Species abundances, therefore, were transformed by the function log (X+1) for computing a 53 by 53 matrix of correlation coefficients.

Factor analysis was used to identify the subgroups of intercorrelated variables. The factors (new, hypothetical variables) were derived from the correlation matrix in a way that represented the system of original variables as simply as possible; i.e., each factor was "positioned" so that it was strongly correlated with the smallest possible number of original variables (Cattell, 1965; Harmon, 1967). The "contributions" of some variables to a given factor were maximized, while the "contributions" of others were minimized. Optimally, therefore, a given variable contributed substantially to but one factor.

The relative contributions (correlations or "loadings") of the variables to the factors were adjudged "significant" on a somewhat empirical basis (Sokal and Daly, 1961; see Table 11). Loadings of variables on factors, therefore, were either as large or as small as possible. "Non-significant" loadings were usually much less than .20, whereas "significant" loadings were greater than .40 on an absolute scale of zero to one.

Communality expressed the amount of interaction of a variable with the others. It indicated the "importance" of the variable to the limited system studied; variables with low communalities contributed relatively little to the covariance of the other variables. The factor analysis with communalities was completed using the IBM 360-70 computer at UCSB.

Three factors identified communities organized by depth, bottom type, and associations of common species. The subgroups of common species resolved by the factor analysis were later enlarged by adding rare species that frequently occurred with the common ones. The enlarged groups were called "communities." The numerical structure of these communities was depicted as species-abundance curves (see, e.g., Odum et al., 1960), which were compared between "oiled" and "not oiled" representations (Figs. 6-8) by rank correlation tests when possible (Sokal and Rohlf, 1969). The fourth factor related seasonal change with evolution of the sport fishery and fluctuations of seasonal species. The suggested sequence of events from winter through summer was compared with a "not oiled" representation from 1967 (Fig. 9).

Results

The bottom fishes of the relatively deep (I) and intermediate (II) localities off the kelp beds seemed to be more abundant and diverse in the "oiled" series, although the differences were non-significant (Table 7). The 19 "oiled" collections from Locality I averaged 185 individuals of 14.6 species, which did not differ significantly from the averages of 159 individuals of 12.0 species for the 12 "not oiled" collections of 1967 ("t" test, $P > .05$). The 15 "oiled" collections from Locality II averaged 101 individuals of 11.1 species, while two "not oiled" collections of 1967 averaged but 84 individuals of 9.0 species. No shallow Santa Barbara collections were available from 1967. For Locality I, the average volumes of fish and invertebrates resembled those estimated for 1967, considering their state of preservation (Table 7).

The six "not oiled" collections from the Paradise Cove and Zuma Beach area (PCZ) averaged fewer fish species and individuals than the 50 "oiled" collections from Santa Barbara (Table 7). However, the single "not oiled" collection from Locality I off Zuma Beach contained 201 individuals of 13 species, while 19 "oiled" deep collections from Santa Barbara averaged 185 individuals of 14.6 species. The two PCZ Locality II collections averaged but 30% the abundance and 50% the diversity of the 15 Santa Barbara collections. The three PCZ Locality III (shallow) collections averaged but about 50% the abundance and diversity of the 16 comparable Santa Barbara collections. But Localities II and III appeared to be naturally less productive at PCZ. Furthermore, the shallow collections were hardly comparable because the PCZ trawls were made over a relatively sterile bottom, compared with the kelp-littered habitats off Santa Barbara. Relatively few sea cucumbers were taken in the deep trawl off PCZ. These large invertebrates abound on the detritus-covered sandy-mud bottom off the Santa Barbara kelp.

The numbers of species shared between "oiled" collections of 1969 and "not oiled" collections of 1967 did not differ significantly from the expected numbers in either Locality I or Locality II (Tables 8, 9). There were no significant differences among months, whether the "oiled"-"not oiled" pairs of collections were from the periods March-April, April-May, or March-May.

The numbers of species not shared between these "oiled" and "not oiled" collections differed significantly in 5 of 11 contrasts. That is, significantly more unique species were taken in one than in the other collection of five pairs (Table 9). But most of these five contrasts showed the effects of one deep collection made in 1969, which contained one specimen each of six rare flatfishes, and of one heterogeneous intermediate collection made in 1967, which contained a diversity of species from both the intermediate and deep habitats.

The numbers of species both shared and not shared between "oiled" Santa Barbara collections and "not oiled" PCZ collections differed significantly in five of nine contrasts, mostly within the shallow series (Table 10). The deep collections did not differ significantly from expected in either shared or unique species; the intermediate collections did not differ significantly in shared species but differed in unique species; and the shallow collections differed significantly in both shared and unique species. The differences favored the more speciose Santa Barbara collections, which were made in richer habitats near the kelp beds.

Table 7

Catches of bottom fishes and invertebrates trawled in an unpolluted area off Zuma Beach and Paradise Cove (PCZ) during April and July, 1969, compared with catches trawled during February-August, 1969 about the "oiled" kelp beds off Santa Barbara (SB) and with catches trawled in the same area during March-May, 1967 before the spill. Although localities were selected in the PCZ area to correspond with the three SB localities, the shallow localities (II, III) off Zuma Beach were characteristically sandier and less productive. SB Locality III in shallow water with kelp-strewn sandy bottom shoreward of the kelp bed, was not trawled in 1967. Locality II, just seaward of the kelp, was sampled but three times in 1967, so that the most meaningful comparisons between years come from Locality I in deeper water with sandy mud bottom (Fig. 1). Displacement volumes were not measured in 1967, although fish captures were estimated from one haul (queried). Most invertebrates were identified to species; others were recorded by general kind (crabs, urchins, etc.). At Locality III, and to a lesser extent II, many invertebrates clinging to bundles of loose kelp were accidently discarded as the trawl was cleared during retrieval.

	Locality I				Locality II				Locality III			
Date, Area	No. collections	Mean no. "species" per collection	Mean no. individuals per collection	Mean volume, ml.	No. collections	Mean no. "species" per collection	Mean no. individuals per collection	Mean volume, ml.	No. collections	Mean no. "species" per collection	Mean no. individuals per collection	Mean volume, ml.
Fishes												
1969 PCZ	1	13	201	5000	2	5.0	29.5	1450	3	5.3	24.3	1397
1969 SB	19	14.6	185.2	4034	15	11.1	100.7	2756	16	10.7	62.5	2402
1967 SB	12	12.0	159.4	3200?	2	9.0	84.0	...	...	...	...	...
Invertebrates												
1969 PCZ	1	10	758*	3100**	2	3.5	19.0	190	3	3.0	9.3	57
1969 SB	19	9.5	241.7	1250**	15	4.5	20.1	920	16	3.3	20.9	335
1967 SB	9	9.6	182.9	...	2	3.5	24.5	...	...	...	...	...

*Including an extraordinary catch of 720 sea urchins, Lytechinus.

**Excluding volumes of the sea cucumber Stichopus, the dominant invertebrate of the "Deep Sandy-mud Community." Assuming an average volume per individual of about 500 ml, and an average number per collection at Locality I of 96.5 individuals, the average contribution of the sea cucumbers to Locality I invertebrate volumes was 48.2 liters or about 12 times that of all other species combined.

The factor analysis resolved a relatively diverse community of bottom animals, restricted to clearer (offshore) and deeper water over a substrate composed of sand, mud, and decaying refuse from the kelp beds (Table 11). Large sea cucumbers, various deep-water flatfishes, red rockfishes, cottids, midshipmen fishes, and a deep-water seaperch predominated (Table 11). The environmental and species variables defining this "deep sandy-mud" factor were, in order: depth, sandy-mud substrate, water clarity; volumes of fish and invertebrates; total number of fish species; invertebrate

Table 8

Observed and expected numbers of fish species shared and not shared (unique) in pairs of collections, one member trawled in 1967, the other in 1969 during the oil spill. Pairs are matched by locality, deep (I) and shallow (II), and by date, during March, April, or May. Values of chi-square express the deviations from expected numbers of shared or unique species in the pairs as: (observed expected)^2/expected value. Calculation of all expected values is explained in the text. These chi-square values are summed between years, by month and locality in Table 9 to compare catches trawled before with comparable catches trawled after the 1969 oil blowout.

Locality	Month	Matched Collection Pairs 1967-69 (by trawl number)	Species shared			Species unique to 1967			Species unique to 1969			Total species 1967 coll.	Total species 1969 coll.	Mean no. species/coll./locality
			Observed	Expected	Chi-square	Observed	Expected	Chi-square	Observed	Expected	Chi-square			
I Deep	March	12-04	7	8.07	0.14	7	4.68	1.15	2	4.68	1.53	14	9	
		13-08	7	8.07	0.14	5	4.68	0.02	14	4.68	30.77	12	21	
	April	23-13	4	8.07	2.05	5	4.68	0.02	5	4.68	0.02	9	9	
		29-18	7	8.07	0.14	6	4.68	0.37	2	4.68	1.53	13	9	
	May	38-25	12	8.07	1.91	5	4.68	0.02	4	4.68	0.10	17	16	
		48-28	6	8.07	0.53	3	4.68	0.60	9	4.68	3.99	9	15	12.75
II Shallow	April	20-12	1	4.77	2.98	4	7.40	1.56	9	7.40	0.34	5	10	
	May	31-26	7	4.77	1.04	6	7.40	0.26	9	7.40	0.34	13	16	
		36-29	8	4.77	2.19	18	7.40	15.18	9	7.40	0.34	26	17	12.17

Table 9

Comparison of fish catches trawled prior to the oil blowout with comparable catches trawled after the blowout. Chi-square values, summed between years by month and locality (ΣX^2), express the deviations from expected numbers of species shared or not shared (unique) in collection pairs matched by locality and date, one member trawled in 1967, the other in 1969 (see Table 8). All combinations of observed vs. expected chi-squares among months were summed for both years pooled (lower table) to show that monthly catch variability does not preclude the required between-year contrasts. NS = non-significant at the P=.05 level; d.f. = degrees of freedom, usually n-2 (Sokal and Rohlf, 1969).

Analysis	Locality	Calculation	Species shared 1967-69 collection pairs	Species unique to either 1967 or 1969 collections (i.e., not shared): Year 1967	Year 1969	Total years, 1967 + 1969	Months: March	April	May
Between years	I Deep	ΣX^2	4.91	2.18	37.94	40.12	35.67	1.94	4.62
		d.f.	4	4	4	9	2	2	2
		P	NS	NS	< .005	< .005	< .005	NS	NS
	II Shallow	ΣX^2	6.21	17.00	1.02	18.02	...	1.90	16.12
		d.f.	1	1	1	3	...	1	2
		P	.01	< .005	NS	< .005	...	NS	< .005
Among months: March-April, April-May, March-May	I Deep	ΣX^2	2.20	...	...	21.92	10.06	1.84	10.02
		d.f.	1	...	...	4	1	1	1
		P	NS	...	...	< .005	< .005	NS	< .005
	II Shallow	ΣX^2	1.86	...	...	157	1.42	3.82	152
		d.f.	1	...	...	4	1	1	1
		P	NS	...	...	< .005	NS	.05	< .005

Table 10

Comparison of fish catches trawled off Zuma Beach and Paradise Cove (PCZ) with comparable catches trawled in the "oiled" Santa Barbara Channel (SB). Chi-square values, summed between areas by locality, express the deviations from expected numbers of species shared or not shared (unique) in pairs of collections matched by locality and date, one member trawled in the "not oiled" PCZ area, the other in the "oiled" SB area. Because only one collection pair compares the deep locality, all chi-squares shared and unique are pooled as one contrast, observed vs. expected. NS = non-significant at the P=.05 level; d.f. = degrees of freedom, usually n-2.

		Species shared	Species unique to either PCZ or SB collections (i.e., not shared)		
Locality	Calculation	PCZ - SB coll. pair	PCZ	SB	PCZ + SB
Shallow	chi-square sum	18.90	3.65	88.4	91.7
III	d.f.	4	4	4	9
	P	<.005	NS	<.005	<.005
Intermediate	chi-square sum	3.47	1.11	32.7	33.8
II	d.f.	2	2	2	5
	P	NS	NS	<.005	<.005
Deep	chi-square sum	(pooled) →			1.01
I	d.f.				1
	P				NS

abundances of sea cucumbers (Stichopus), brittle stars, starfish (Astropectin), deep seapens; and fish abundances of the Dover sole (Fig. 6, Mp), midshipman fish (Pno), yellowchin sculpin (Iq), longspine combfish (Zl), halfbanded rockfish (Ss), Pacific sanddab (Cso), Pacific tongue fish (Sa), pink seaperch (Zr), long fin sanddab (Cx), bigmouth sole (Hs).

The abundance-diversity curve representing the Deep Sandy-Mud Community of fishes in the "not oiled" environment of 1967 closely resembled that representing this community in the "oiled" environment of 1969 (Fig. 6). This resemblance was substantiated by the strong correlation between the "not oiled" and "oiled" ranked orders of species abundance (P, rank correlation <.001). The only conspicuous differences in the rankings showed that the

Table 11

Factors that group species and other variables into habitat associations and communities or seasonal causal arrays (see text). Identification of variables with the factors is indicated by their loadings on (correlations with) the factors. "Significant" loadings range from ±.40 to ±1.0. Most "non-significant" loadings were close to zero and rarely exceeded ±.20. Factors are named for the variables having highest loadings; physical variables, which are usually causes, before biological, which are usually effects. The communality (0-1.0) measures interactions with the other variables; i.e., variables with many significant simple correlations have relatively high communalities. * = variable loading on more than one factor.

Factor I: Deep Sandy Mud

Variable	Loading	Communality
Greatest depth	.93	.92
Mean depth	.93	.92
Sea cucumbers	.91	.89
Dover sole	.91	.94
N. midshipman	.89	.86
Yellowchin sculpin	.87	.77
Longspine combfish	.87	.78
Substrate (sandy mud)	.86	.78
Sand stars	.84	.78
Halfbanded rockfish (yg.)	.82	.83
Pacific sanddab	.81	.73
Pink seaperch (Ad.)	.79	.66
Depth range	.79	.65
Deep seaperch	.79	.70
Water transparency	.73	.70
Pink seaperch (yg.)	.73	.59
Longfin sanddab	.72	.60
Bigmouth sole	.64	.49
Invertebrate volumes	.63	.46
Fish volumes*	.60	.68
Fish diversity*	.54	.73
Halfbanded rockfish (ad.)	.54	.50

Factor II: Seasonal Temperature Sportfish

Variable	Loading	Communality
Days after Feb. 21	.96	.92
Offshore temperature	.94	.89
Bass catch	.93	.88
Mysid shrimp/liter	.93	.87
On-station temperature	.90	.83
Halibut catch	.77	.64
Rockfish-rockcod catch	-.76	.68
Tiburon temperature	.74	.57
Sea state	-.70	.53
Surface salinity	.65	.48
Bonito-barracuda catch	.68	.52
White croaker	-.43	.30

Factor III: Seaperch

Variable	Loading	Communality
Walleye surfperch	.72	.65
Black perch	.67	.81
Rainbow seaperch*	.64	.76
White seaperch	.54	.58
Fish volumes*	.55	.68
Fish diversity*	.55	.73
California shrimp	.51	.36
Cancer crabs	.50	.43
Oil pollution	.48	.25
Pipefish	.43	.45

Factor IV: Shallow Flatfish

Variable	Loading	Communality
English sole	.81	.68
Curlfin sole	.78	.64
Speckled sanddab	.68	.76
Fantail sole	.55	.44
C-O sole	.45	.30
Rainbow seaperch*	.41	.76

Variables not loading significantly on any factor

Variable	Communality
Dwarf seaperch	.41
Kelp crabs	.39
Time of day (late AM-PM)	.33
Phase of moon	.18
Kelp whelk	.14
Overcast	.07

pink seaperch was relatively more abundant and the yellowfin sculpin was less abundant in the pooled "oiled" collections.

Another factor resolved a community of animals, mostly seaperches, that live among drifting clumps of loose seaweed in a zone of transition between the kelp beds and the deep sandy mud or shallow clean sandy habitats (Table 11). Many of the seaperches are ecological generalists, in that they get by quite well either inside or outside the kelp beds. The species and environmental variables defining this "seaperch factor" were, in order: fish abundances of the walleye surfperch (Fig. 7, Ha), black perch (Ej), rainbow seaperch (Hc), white seaperch (Pf), shiner perch (Ca), pipefish (Sy); invertebrate abundances of California shrimp and cancer crabs; volume of fish; total number of fish species; and amount of oil. Fish volumes were large because individual fish were relatively large and fish diversity was high because members of other communities were commonly caught in this marginal habitat.

The abundance-diversity curve, contrived from captures reported by Carlisle (1969) and representing the Seaperch Community of fishes in the "not oiled" Santa Monica Bay environment differed substantially from that representing this community in the "oiled" Santa Barbara environment (Fig. 7). The rank orders of "not oiled" and "oiled" species abundances were not significantly correlated (Kendall's tau rank correlation). The two habitats are hardly comparable, however, in that the Santa Monica area contains no large kelp beds and so the habitat of the community is associated with artifacts, such as pier pilings, anchorages, and breakwaters. The disparities in the rankings reflected the habitat differences. The shiner perch, which leads the Santa Monica ranks, seems to prefer backwaters and artificial habitats, while the white seaperch, which leads the Santa Barbara ranks, prefers natural habitats in and about the kelp beds. Also, species characteristic of kelp beds and rocky reefs, such as the black perch, cabezon, and grass rockfish were commonly trawled near the Santa Barbara kelp, but were relatively rare in the Santa Monica collections reported by Carlisle.

Another factor resolved a relatively simple community of strictly bottom species, mostly flatfishes, that prefer clean sandy areas in intermediate or shallow habitats (Table 11). Here, shallow-living species of soles and sanddabs replace their deeper-living counterparts of the Deep Sandy-Mud Community. The species variables defining this shallow flatfish factor were, in order: fish abundances of the English sole (Fig. 8, Pv), curlfin sole (Pd), speckled sanddab (Cst), fantail sole (Xl), and C-O sole (Pco).

The abundance-diversity curve representing the Shallow Flatfish Community in the "not oiled" environment off Zuma Beach (PCZ) resembled that representing this community in the "oiled" Santa Barbara environment (Fig. 8). A correlation test of abundance ranks was not meaningful, however, because the speckled sanddab overwhelmingly predominated the community, and all other members were relatively scarce. Also, the two environments were not strictly comparable. The bottom near Zuma Beach is composed mostly of pure sand, while that off Santa Barbara is more complex and is littered by debris from the adjacent kelp beds and reefs. However, the speckled sanddab appeared to be equally abundant in both environments and entered the habitat of the Seaperch Community. It did not have the highest loading on the shallow flatfish factor, even though it was the most abundance member of the Shallow Flatfish Community. This implied that the English and curlfin soles are more typical community members because their loadings were higher (i.e., their abundances were strongly intercorrelated (r = .60) and were significantly correlated with other important members (.36 to .42)). Both the PCZ and Santa Barbara collections averaged about 55 "shallow flatfish" per collection.

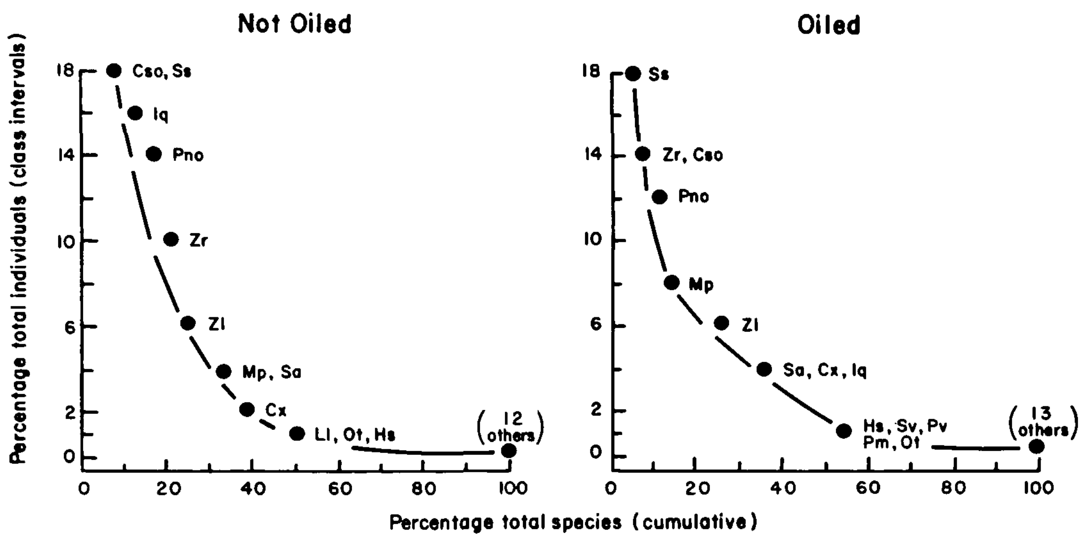

FIGURE 6. ABUNDANCE-DIVERSITY CURVES COMPARING "NOT OILED" AND "OILED" REPRESENTATIONS OF THE DEEP SANDY MUD COMMUNITY OF BOTTOM FISHES

Species are identified, in alphabetical order, as: Cso, Pacific sanddab (Citharichthys sordidus); Cx, longfin sanddab (C. xanthostigma); Hs, bigmouth sole (Hippoglossina stomata); Iq, yellowchin sculpin (Icelinus quadriseriatus); Ll, bay goby (Lepidogobius lepidus); Mp, Dover sole (Microstomus pacificus); Ot, spotted cusk-eel (Otophidium taylori); Pm, slim midshipman (Porichthys myriaster); Pno, northern midshipman (P. notatus); Sa, California tonguefish (Symphurus atricauda); Ss, halfbanded rockfish (Sebastodes semicinctus); Sv, whitebelly rockfish (S. vexillaris); Zl, longspine combfish (Zaniolepis latipinnis); Zr, pink seaperch (Zalembius rosaceus). The rarest species are grouped as "others."

The oil variable had a low communality (.25) with the others (Table 11). It correlated significantly with calmer seas (r=-.32) and increasing fish diversity (.30), and positively though not quite significantly with abundances of most Seaperch Community members (.17 to .25). Therefore, it loaded on the seaperch factor. More oil was noticed on calm days in

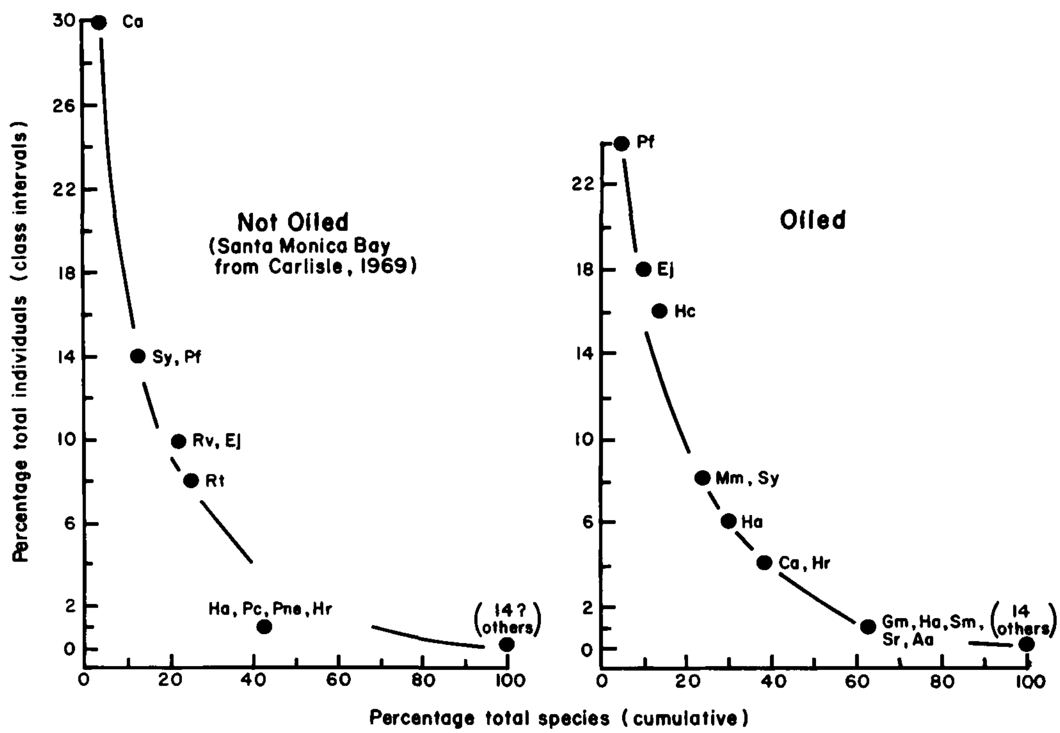

FIGURE 7. ABUNDANCE-DIVERSITY CURVES COMPARING "NOT OILED" AND "OILED" REPRESENTATIONS OF THE SEAPERCH COMMUNITY THAT INHABITS SANTA MONICA BAY AND THE TRANSITIONAL ZONE AT THE MARGINS OF SANTA BARBARA KELP BEDS

Species are identified, in alphabetical order, as: Aa, barred surfperch (Amphistichus argenteus); Ca, shiner perch (Cymatogaster aggregata); Ej, black perch (Embiotoca jacksoni); Gm, striped kelpfish (Gibbonsia metzi); Ha, walleye surfperch (H. argenteum); Hc, rainbow seaperch (Hypsurus caryi); Hr, giant kelpfish (Heterostichus rostratus); Mm, dwarf seaperch (Micrometrus minimus); Pc, kelp bass (Paralabrax clathratus); Pf, white seaperch (Phanerodon furcatus); Pne, sand bass (Paralabrax nebulifer); Rt, rubberlip perch (Rhacochilus toxotes); Rv, pile perch (R. vacca); Sm, cabezon (Scorpaenichthys marmoratus); Sr, grass rockfish (Sebastodes rastrelliger); Sy, pipefish (Syngnathus, sp.). The rarest species are grouped as "others."

the localities of abundant seaperch catches and diverse fish collections. Foster et al. (1969) noted that oil covered the kelp canopy during the period of severe spill. The coincidence of better seaperch catches and surface oil, therefore, may simply mean that oil was often recorded over the best habitat for the Seaperch Community, especially when the ocean surface

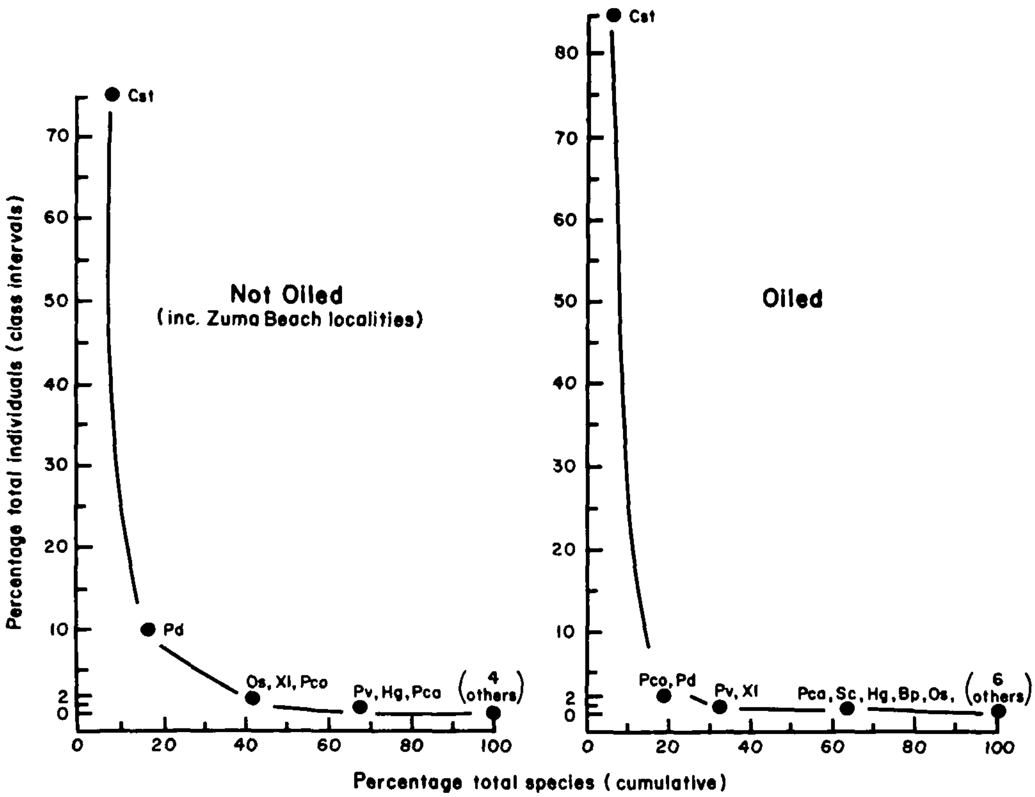

FIGURE 8. ABUNDANCE-DIVERSITY CURVES COMPARING "NOT OILED" AND "OILED" REPRESENTATIONS OF THE SHALLOW FLATFISH COMMUNITY THAT INHABITS SANDY BOTTOMS

Species are identified, in alphabetical order, as : Bp, shovel-nose guitarfish (Rhinobatus productus); Hg, diamond turbot (Hypsopsetta guttulata); Os, basketweave cusk-eel (Otophidium scrippsae); Pca, California halibut (Paralichthys californicus); Pco, C-O sole (Pleuronichthys coenosus); Pd, curlfin sole (P. decurrens); Pv, English sole (Parophrys vetulus); Cst, speckled sanddab (Citharichthys stigmaeus); Sc, Pacific angel shark (Squatina californica); Xl, fantail sole (Xystreurys liolepis). The rarest species are grouped as "others."

was flat at the edge of the kelp where two communities overlap. The oil itself probably did not affect the catches one way or another. Other physical variables with low communalities were: increasing overcast, phase of moon, and time of day (most trawls were made near midday).

The last factor resolved a series of seasonal events without species correlates (Table 11). Most indicated the concordant changes in local water masses and Channel Island sport fisheries from winter through summer. Environmental and catch-rate variables defining this seasonal sportfish factor were, in order: number of days after February 21, 1969, rising offshore and on-station water temperatures, calming seas, and increasing surface salinity; decreasing catch of rockfish per angler was inversely correlated with increasing catches of kelp bass, halibut, bonito, and barracuda. Coincidentally, the density of small mysid shrimps that live on the kelp canopy increased steadily throughout the spring and summer.

The uneven decrease of total sport-fish catch from winter through summer reflected the usual pattern of decreasing effort to catch the pedestrian but always available deep rockfishes along with increasing effort to catch the preferred surface game fishes during the warmer months (Fig. 9). This trend was evident both before and after the oil spill during the same seasons in 1967 and in 1969. The rising water temperature and salinity reflected the progression of oceanographic periods (see Section IV). Live anchovies became increasingly available for bait. This accounted for larger catches of kelp bass and halibut and contributed to the surface game fishery, which included large migratory fishes like the bonito and barracuda that follow the warming trend. Although rockfish can be caught in relatively large numbers on heavily weighted gang hooks baited with dead bait and fished in deep water, they provide generally less sport than the surface game fish, which are usually caught in fewer numbers on single hooks baited with live anchovies skillfully cast, with little or no extra weight, onto the surface of the water.

The winter rockfishery was erratic following the oil spill (Fig. 9). But a sharp drop in catches immediately after the spill was most likely caused by the combined effects of severe storms and the undesirability of fishing in or near oil slicks. Catches of rockfish were back to previous levels by early April after the storms. As the water warmed abruptly in early May before the late onset of upwelling in June, the first significant catches of halibut, bass, and bonito heralded the surface game fishery.

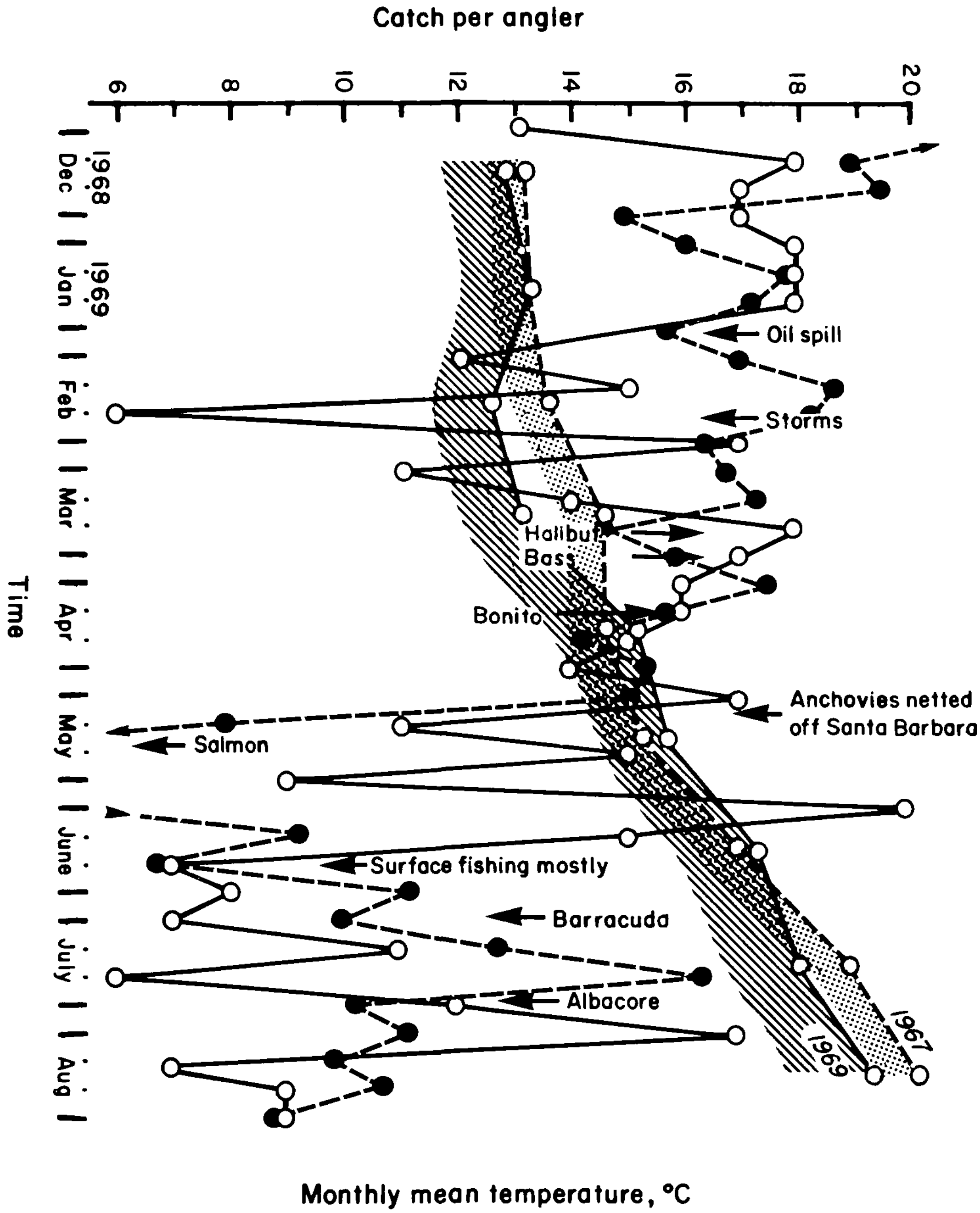

FIGURE 9. SEASONAL CHANGE IN THE CHANNEL ISLAND SPORT FISHERY

The total catch per angler (solid, unshaded line through open circles) and water temperature (hatched line) after the blowout during 1969 are compared with the catch (dashed, unshaded line through solid circles) and water temperature (stippled line) prior to the blowout during the same seasons of 1967. Arrows indicate pertinent events occurring in 1969.

Populations of small mysid shrimps, which showed a progressive resurgence during the present study, may have been initially decimated by the oil that covered the kelp canopy. Dense populations observed in the canopy during the fall of 1968 were undetectable immediately after the spill (Dr. Richard M. Ibara, personal communication). After reappearing in late March, the mysids increased in density through the spring and summer. But the severe storms with heavy rains may have also disturbed their habitat and driven them elsewhere.

Discussion

Sampling bias and environmental heterogeneity probably accounted for most of the surprisingly few conspicuous differences observed between assemblages of bottom fishes trawled from "oiled" and "not oiled" localities near kelp beds. Catches from "oiled" environments were often more productive than catches from "not oiled" environments for reasons probably unrelated to the oil spill. The Deep Sandy-Mud Community, the only community adequately represented by collections made before the spill, showed no significant differences in general composition or diversity. The Seaperch Community was associated with increasing amounts of oil observed on station, but this may simply mean that oil was recorded most often near the kelp beds where the members congregate.

Climatic anomalies may have caused the few remaining differences. Northern and southern species react differently to warming or cooling trends (Hubbs, 1948, 1960; Radovich, 1961). Such trends exert their greatest effects on a fishery at the margins of several fish populations, such as occur in the Channel. But, wide fluctuations in catches between climatically dissimilar years may be obscured by artificial disruptions like overfishing and pollution (Radovich, 1961). In 1969, nearshore temperatures rose sharply in April after a prolonged period of winter mixing (Flittner, 1969a; Fig. 9). Then sporadic upwelling occurred from late June to August, so that summer warming lagged behind normal (Flittner, 1969b). Large migratory fishes that prefer warm water arrived relatively late. For example, the albacore, which prefers temperatures between 60 and 66°F, arrived in the California fishery some two or three weeks later than in 1968 (Flittner, 1969c).

The relatively greater 1969 abundance of pink seaperch at Locality I may have reflected the prolonged mixing period. We noticed that this fish is very sensitive to slight warming and soon dies of heat stress in an aquarium at only 14°C. Some deep-water rockfishes, however, persisted in the same aquarium and may be less temperature sensitive. By summer, rockfishes had become proportionately more abundant in the collections. Normally, depths exceeding 100 feet are coldest during May and June of the upwelling period (Quast, 1968a).

Most of the seasonal variables explained the evolution of the Channel Island sport fishery from winter through summer. Catches from boats berthed at Oxnard and Port Hueneme changed as surface temperatures and salinities rose after the winter mixing period. The erratic trend of decrease in catch per angler reflected the usual change-over from a deep bottom fishery for rockfish and lingcod during the winter and spring to a preferred surface game fishery during the summer. The collapse of the Santa Barbara sport fishery following the initial heavy spill, therefore, may have been caused by factors other than a lack of fish to catch near the Channel Islands. The harbor was closed during the worst part of the spill after the blowout. Then, the undesirability of fishing in oil slicks, the general opinion that fishing would be poor, the fear that oil may have tainted the fish, and the effects of various management problems probably discouraged later effort.

The shoreward accumulation of oil along with the concurrent storms may have decimated populations of mysid shrimps that live in the kelp canopy. Perhaps as oil periodically covered the canopy, the mysids either died or left their preferred habitat on the surface kelp fronds. But, the mysids returned and they now seem to be as dense as they were prior to the blowout.

SECTION VI

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The Fisheries Oceanography Center of the U. S. Marine Fisheries Service in La Jolla furnished monthly reports, summaries, and bulletins, relating seasonal trends to west coast fisheries. Margaret K. Robinson of the Scripps Institution of Oceanography provided reports of ocean temperatures and salinities, which were supplemented by personnel at the Ventura Marina and at the Tiburon Marine Laboratory. Dail W. Brown and Richard M. Ibara completed much of the statistical analyses at the UCSB computer center.

SECTION VII

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SECTION VIII

APPENDICES

Appendix I. Captures of deep and shallow macroplankton, listed by species in order of abundance: fishes, then invertebrates. All captures (numbers of individuals), made by midwater trawl from the General Motors Research Vessel SWAN in 10 February-March hauls during the 1969 oil spill, are pooled for both the Santa Barbara Channel and the Santa Cruz Basin. Fishes are designated by scientific name, followed by general common name and family; invertebrates by scientific name and group only.

FISHES

Species	Common Name	Family	Captures
Stenobrachius leucopsarus	Lanternfish	Myctophidae	508
Cyclothone acclinidens	Bristlemouth	Gonostomatidae	168
C. signata	Bristlemouth	Gonostomatidae	132
Leuroglossus stilbius	Deep-sea smelt	Bathylagidae	116
Triphoturus mexicanus	Lanternfish	Myctophidae	58
Sebastodes sp. (larvae only)	Rockfish	Scorpaenidae	41
Merluccius productus (larvae only)	Pacific hake	Gadidae	31
Engraulis mordax (larvae only)	Northern anchovy	Engraulidae	16
Diaphus theta	Lanternfish	Myctophidae	11
Lampanyctus ritteri	Lanternfish	Myctophidae	9
Melanostigma pammelas (young)	Eelpout	Zoarcidae	7
Argyropelecus lychnus	Hatchetfish	Sternoptychidae	6
Parmaturus xaniurus	Filetail catshark	Scyliorhinidae	6
Citharichthys stigmaeus (larvae only)	Speckled sanddab	Bothidae	5
Danaphos oculatus	Bigeye lightfish	Gonostomatidae	4
Bathylagus wesethi	Deep-sea smelt	Bathylagidae	3
Scorpaenichthys marmoratus? (larvae only)	Cabezon	Cottidae	2
Sagamichthys abei	Shining tubeshoulder	Searsiidae	1
Bathylagus milleri	Deep-sea smelt	Bathylagidae	1
Argyropelecus pacificus	Hatchetfish	Sternoptychidae	1
Idiacanthus antrostomus	Blackdragon	Idiacanthidae	1
Stomias atriventer	Dragonfish	Stomiatidae	1
Chauliodus macouni	Viperfish	Chauliodontidae	1
Protomyctophum crockeri	Lanternfish	Myctophidae	1
Sebastolobus altivelis (young only)	Longspine channel rockfish	Scorpaenidae	1
Microstomus pacificus (larvae only)	Dover sole	Pleuronectidae	1
Citharichthys sordidus (larvae only)	Pacific sanddab	Bothidae	1
Zaniolepis frenata (larvae only)	Shortspine combfish	Zaniolepidae	1

INVERTEBRATES

Species	Group	Captures
Euphausia pacifica	Euphausiid (krill) shrimp	2607
"Pointed siphonophores"	Siphonophore	1299
Pasiphaea emarginata	Decapod shrimp	930
Euplokamis californiensis	Ctenophore	270
Emerita analoga (larvae only)	Sand crab	233
Sergestes similis	Decapod shrimp	233
Nematocilis difficilis	Euphausiid (krill) shrimp	205
Thysanoessa spinifera	Euphausiid (krill) shrimp	192
Sagitta sp.	Chaetognaths (arrow-worm)	190
Hymenodora frontalis	Decapod shrimp	160
Salpa fusiformis	Salp	58
Blepharipoda occidentalis? (larvae only)	Sand crab	39
Aegina sp.	Medusa (jellyfish)	34
Paracallisoma coesus	Amphipod crustacean	34
Hyperia galba	Amphipod crustacean	28
Pasiphaea pacifica	Decapod shrimp	25
Vibilia sp.	Amphipod crustacean	23
"Megalops larvae"	Crab larvae	23
Paraphronima crassipes	Amphipod crustacean	20
"Zoea larvae"	crab larvae	18
Euphausia hemigibba	Euphausiid (krill) shrimp	17
Atolla wyvillei	Medusa (jellyfish)	13
Colobonema sp.	Medusa (jellyfish)	13
Pasiphaea chacei	Decapod shrimp	4
Pleuroncodes sp (larvae only)	Galatheid shrimp (decapod)	4
Praya dubia	Siphonophore	4
"Zoea larvae"	Crab larvae	3
Phronima sedentaria	Amphipod crustacean	3
Conchoecia sp.	Ostracod crustacean	3
Gennadas propinquus	Decapod shrimp	2
Lepidopa myops (larvae only)	Sand crab	2
Crossota rufobrunnea	Medusa (jellyfish)	2
Sergestes phorcus	Decapod shrimp	2
Doliolum gegenbauri	"Doliolid salp"	1

Appendix II.

Captures of shallow bottom fishes and selected invertebrates, listed by species (or invertebrate group) in order of abundance: fishes, then invertebrates. All captures (numbers of individuals), made by semi-balloon trawl from the Boston Whaler skiff in 56 February-August hauls during the 1969 oil spill, are pooled for all three localities (I-III, deep, intermediate, and shallow) around kelp beds in the "oiled" nearshore area off Santa Barbara and the "not oiled" area off Zuma Beach and Paradise Cove to the south. Fishes are designated by scientific name, followed by common name and family; invertebrates by kind only.

FISHES

Species	Common Name	Family	Captures
Citharichthys stigmaeus	Speckled sanddab	Bothidae	1421
Sebastodes semicinctus	Halfbanded rockfish	Scorpaenidae	615
Zalembius rosaceus	Pink seaperch	Embiotocidae	478
Citharichthys sordidus	Pacific sanddab	Bothidae	442
Porichthys notatus	Northern midshipman	Batrachoididae	410
Microstomus pacificus	Dover sole	Pleuronectidae	295
Genyonemus lineatus	White croaker	Sciaenidae	232
Seriphus politus	Queenfish	Sciaenidae	201
Zaniolepis latipinnis	Longspine combfish	Zaniolepidae	190
Icelinus quadriseriatus	Yellowchin sculpin	Cottidae	177
Phanerodon furcatus	White seaperch	Embiotocidae	163
Citharichthys xanthostigma	Longfin sanddab	Bothidae	147
Symphurus atricauda	California tonguefish	Cynoglossidae	139
Embiotoca jacksoni	Black perch	Embiotocidae	117
Hypsurus caryi	Rainbow seaperch	Embiotocidae	112
Micrometrus minimus	Dwarf seaperch	Embiotocidae	58
Syngnathus sp.	Pipefish	Syngnathidae	53
Hyperprosopon argenteum	Walleye surfperch	Embiotocidae	45
Pleuronichthys coenosus	C-O sole	Pleuronectidae	39
P. decurrens	Curlfin sole	Pleuronectidae	36
Cymatogaster aggregata	Shiner perch	Embiotocidae	34
Hippoglossina stomata	Bigmouth sole	Bothidae	34
Porichthys myriaster	Slim midshipman	Bathrachoididae	25
Heterostichus rostratus	Giant kelpfish	Clinidae	21
Parophrys vetulus	English sole	Pleuronectidae	21
Sebastodes vexillaris	Whitebelly rockfish	Scorpaenidae	20
Pleuronichthys verticalis	Hornyhead turbot	Pleuronectidae	18
Xystreurys liolepis	Fantail sole	Bothidae	17
Odontopyxis trispinosa	Pygmy poacher	Agonidae	15
Hypsopsetta guttulata	Diamond turbot	Pleuronectidae	11
Rhinobatos productus	Shovelnose guitarfish	Rhinobatidae	10
Otophidium scrippsae	Basketweave cusk-eel	Ophidiidae	10
Lepidogobius lepidus	Bay goby	Gobiidae	9
Zaniolepis frenata	Shortspine combfish	Zaniolepidae	9
Paralichthys californicus	California halibut	Bothidae	8
Squatina californica	Pacific angel shark	Squatinidae	8
Lyopsetta exilis	Slender sole	Pleuronectidae	8
Gibbonsia metzi	Striped kelpfish	Clinidae	8
Sebastodes levis	Cow rockfish	Scorpaenidae	7
Hyperprosopon anale	Spotfin surfperch	Embiotocidae	7
Leptocottus armatus	Pacific staghorn sculpin	Cottidae	7
Cephaloscyllium uter	Swell shark	Scyliorhinidae	6
Xeneretmus triacanthus	Bluespotted poacher	Agonidae	6
Scorpaenichthys marmoratus	Cabezon	Cottidae	6
Platyrhinoides triseriata	Thornback	Rhinobatidae	5
Synodus lucioceps	California lizardfish	Synodontidae	5
Sebastodes rastrelliger	Grass rockfish	Scorpaenidae	5
Sebastodes mineatus	Vermilion rockfish	Scorpaenidae	5
Xeneretmus ritteri	Spiny poacher	Agonidae	5
Pleuronichthys ritteri	Spotted turbot	Pleuronectidae	5
Amphistichus argenteus	Barred surfperch	Embiotocidae	4
Sebastodes rubrivinctus	Flag rockfish	Scorpaenidae	4
Paralabrax clathratus	Kelp bass	Serranidae	3
Sebastodes dalli	Calico rockfish	Scorpaenidae	3
Psettichthys melanostictus	Sand sole	Pleuronectidae	3
Stellerina xyosterna	Pricklebreast poacher	Agonidae	3
Aulorhynchus flavidus	Tube-snout	Aulorhynchidae	3
Neoclinus blanchardi	Sarcastic fringehead	Clinidae	3
Triakis semifasciata	Leopard shark	Carcharhinidae	2

Appendix II. (Continued)

Species	Common Name	Family	Captures
Agonopsis sterletus	Southern spearnose poacher	Agonidae	2
Otophidium taylori	Spotted cusk-eel	Ophidiidae	2
Paralabrax nebulifer	Sand bass	Serranidae	1
Menticirrhus undulatus	California corbina	Sciaenidae	1
Artedius harringtoni	Scalyhead sculpin	Cottidae	1
Ulvicola sanctaerosae	Kelp gunnel	Pholidae	1
Sebastodes chlorostictus	Greenspotted rockfish	Scorpaenidae	1
Phanerodon atripes	Sharpnose seaperch	Embiotocidae	1
Torpedo californica	Pacific electric ray	Torpedinidae	1
Hyperprosopon ellipticum	Silver surfperch	Embiotocidae	1
Gibbonsia elegans	Spotted kelpfish	Clinidae	1
Apodichthys flavidus	Penpoint gunnel	Pholidae	1
Hippoglossus stenolepis	Pacific halibut	Pleuronectidae	1

INVERTEBRATES

Kind	Captures
Stichopus (sea cucumber)	1930
Eusicyonia ingentis (deep seasquirt)	831
Astropecten (starfish)	305
Sea urchins	(Numerous)
Brittle stars	(Numerous)
Crango	242
Cancer crabs	106
Other crabs	91
Kelletia (kelp whelk)	7
Pateria (starfish)	2
Gorgonians	(not compiled)
Luidia (starfish)	" "

Kind	Captures
Loxorhynchus (spider crab)	(Not compiled)
Pugettia (kelp crab)	" "
Styatula (sea pen)	" "
Octopus	" "
Pleurobranchia (tectibranch)	" "
Clams	" "
Hermit crabs	" "
Dendraster (sand dollar)	" "
Nudibranchs	" "
(Several other shrimps, etc., including the mysid shrimps of the kelp canopy	" "

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6 Title

SANTA BARBARA OIL SPILL: SHORT-TERM ANALYSIS OF MACROPLANKTON AND FISH

10 Author(s)

Ebeling, A.W.
Werner, W.
DeWitt, Jr., F.A.
Gailliet, G.M.

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27 Abstract: Collections of deep and shallow macroplankton from the Santa Barbara Channel area of the 1969 oil spill and from the Santa Cruz Basin further offshore were compared with others from previous years for possible oil damage. Spring and summer collections from nearshore bottom communities of fishes and large invertebrates around kelp beds near the blowout area were compared with collections made either prior to the spill or from an extrinsic area. Because no noticeable fish kills followed the blowout, less obvious criter of possible damage to the macroplankton and bottom communities were investigated: decreased species diversity, numerical evenness, and abundance; increased patchiness of species distributions; changes in community composition favoring the more tolerant species and correlations with amounts of oil and tar estimated on station.

Most observed changes, apparently unrelated to the spill, corresponded with various climati anomalies during March through August, 1969. The bottom-fish communities resembled their counterparts in "not oiled" environments; sampling bias and environmental heterogenity probably caused the observed minor differences in community structure. Larvae of common fishes and invertebrates were abundant in the offshore plankton.

After the blowout, the composition and mode of the Channel Island sport fishery changed wit seasonal trends and probably not as a direct effect of the spill. Of all subtidal events examined during the present short-term study, only the temporary disappearance of tiny mysi shrimps inhabiting the kelp canopy was a likely direct effect.

Abstractor: A. W. Ebeling

Institution: California University, Santa Barbara