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A STUDY OF THE EFFECTS OF THE SAN FRANCISCO OIL SPILL ON MARINE LIFE
PART II: RECRUITMENT

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ABSTRACT

A study of marine organisms on intertidal transects encompassed the central theme of observing the effects of the San Francisco Bunker C oil spill of January 18, 1971. From a comparison of pre-oil and post-oil transect data with computation of 95% confidence intervals for population means, it was estimated that 4.2 to 7.5 million marine invertebrates, chiefly barnacles, were smothered by the oil. In subsequent observations from 1972 to 1974, the sample counts of invertebrates had returned to, and in some cases surpassed, pre-oil transect levels. No lingering effects of the oil spill have been noted in any of the marine species.

INTRODUCTION

On January 18, 1971, during the early morning hours, two Standard Oil tankers collided under the Golden Gate Bridge in thick fog, spilling 840,000 gallons of Bunker C oil into the coastal waters of the San Francisco Bay area of California (figure 1). During the following days, tidal currents carried the oil to nearby reefs in Marin County where my students and I had established various marine life transects, some as early as 1958. Comparisons of the pre-oil and post-oil counts on these transects constituted the analysis of the damage to marine life by this spill. The results of studies conducted through August 1971 were published in the report, A Study of the Effects of the San Francisco Oil Spill on Marine Organisms, Part I [2]. The study on recruitment includes data gathered through April 1974.

Sampling Methods and Procedures

There were 37 transects involved in the study. The transects, usually 10 meters long, were chosen from random numbers. A square-meter quadrat frame, with at least ten square-decimeter sections within the frame, was moved along a ten-meter line, and organisms inside the frame were counted.

The amount of residual oil on each transect was also recorded, rated according to the percentage of square meters with oil:

\[ N = \text{no square meters had oil} \]
\[ + = 1-25\% \text{ with oil} \]
\[ ++ = 26-50\% \text{ with oil} \]
\[ +++ = 51-75\% \text{ with oil} \]
\[ ++++ = 76-100\% \text{ with oil} \]

The statistical 95% confidence interval based on sample data was used consistently to determine the interval within which we may expect the population mean or population proportion. If, on the basis of repeated sampling, 95% confidence intervals for the population mean are set up, then approximately 95% of these confidence intervals will actually contain the true population mean [6]. The hypothesis of significant difference between population means was tested by statistical analysis, comparing data of different sampling dates and transects: \( H_0: \mu_1 = \mu_2; H_1: \mu_1 \neq \mu_2; \alpha = .05 \). Reject \( H_0 \) if test statistic \( Z \) is \( > 1.96 \) or \( < -1.96 \).

Observations and Findings up to 1974

Sausalito Data

In the early days of the spill, the Seal Rock area was blanketed with oil. The transect here had a plus 4 (++++) rating with all of the square meters heavily covered with oil. Based on the 95% confidence interval, an estimated range of 3.6 to 6.2 million barnacles (33.6 to 35.5% of the population), Balanus glandula and Chthamalus dalli, may have died in this transect study area of 1,000 square meters in the general Bridgeway section of Sausalito.
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This same transect in May 1972 showed solid recruitment of marine life to the study area. Figure 2 shows that these acorn barnacles have nearly tripled in the sample counts from a mean of 93 live/dm² in May 1971 to 278 live/dm² in May 1972.

By May 1972 the oil had eroded off to a plus 2 (++) residual oil rating, leaving bare spots and many barnacle scars. Small acorn barnacles, about 1 mm in size, were seen scattered in profuse numbers; much of the new barnacle recruitment has settled on the old barnacle base scars.

The data from this random sampling indicate that the planktonic barnacle larval population in San Francisco Bay appears to be following a sound recruitment pattern, such that the 1972 live population mean is significantly different from that of 1971 by an interval estimate of difference ranging from 191.1 to 268.5 per dm². At Fort Baker, a no-oil transect was established in July 1971 as a control reference of comparison with the Seal Rock oil transect. There was no significant difference between the live population means of the acorn barnacles of these two transects in 1971. A year later, in 1972, there also was no significant difference between the live population means, indicating that the recruitment for the oil transect was on a comparable level with that of the no-oil transect.

The limpet sample count for Calle Del Sierra (formerly Acmaea spp.) increased from a total of 21 in 1971 to 63 random dm² to 90 in 1972 for 60 dm². The movement of these flat gastropods is quite variable, so the higher density count cannot be automatically construed as a recruitment growth pattern.

The most mobile of the Sausalito intertidal invertebrates are the shore crabs, Pachygrapsus crassipes and Hemigrapsus nudus. Although the oil spill killed off many crabs, the surviving crustaceans were able to dodge into the crevices and maintain a fairly consistent population level through 1972 (figure 3).

Stinson Beach Data

This long sandy beach was covered with oil during the early days of the spill. Standard Oil Company reported that its mechanical graders and lifters, in the process of removing the oil and debris, had disrupted and removed, on the average, the upper six inches of the sand's surfaces. Since this upper portion of sand contained a large percentage of the transect population, it was not possible to estimate the number of dead organisms. In Part I of this report on the spill [2], I could not relate the drastically reduced marine life density at this transect as a direct result of the oil spill. Three major species have been observed at the Boyle's sand fence transect near Calle Del Sierra: Emerita analoga, the mole or sand crab; Nephtys californiensis, the sand worm; and Orchestoidea californiana, the beach hopper. The same species were also counted at Drakes Beach where no oil had been reported. A comparison of the combined mean number per square meter for all three species since 1965 shows a downward trend in figure 4.

Prior to the spill, the marine polychaete, Nephtys californiensis, was quite abundant in the Stinson Beach transect, but since the spill, this worm has not returned in post-oil counts. On the other hand, the worm has continued to be present at Drakes Beach, the control transect. Both areas currently show low densities of marine organisms. Although the oil may have had its smothering effect, perhaps the major contributing reason for the poor recruitment can be related to an ecological sand disturbance of winter and summer conditions rather than the spill and cleanup disruptions.

Guard and Cobet [3], from their experiments with Bunker fuel oil on beach sand, reported that normal beach conditions quickly returned as a result of effective cleanup combined with the natural processes of evaporation, dissolution, and beach erosion. The sands of Stinson Beach today do not show much effect of the 1971 oil spill.

Duxbury Reef Data

The major locality for the oil spill study was this large 66-acre shale reef in Bolinas, California, about twenty miles north of San Francisco. Quadrat studies have been conducted here since 1958. A total of 33 transects were used for statistical comparison; 26 of these were established before the spill. Data for the most heavily affected areas revealed 20% of all organisms counted were dead. An estimate of over one million organisms had been suffocated by the oil, with the barnacles and limpets suffering the highest mortality in relation to their population densities, 34% and 22% respectively for the samples studied.

By the summer of 1971, the oil was fast disappearing from the reef's rocky surfaces, chipped off by water erosion. The present condition of the reef appears to be quite healthy. About 95% of the oil has eroded away and recruitment of marine life is generally good, with a few exceptions. The reef's status as a state marine reserve since 1971 has generally protected the marine invertebrates from collectors. A chronology of the effects of oil on the marine organisms follows.

1. Marine Plants. Although the surf grass, Phyllospadix scouleri, and other upper-zoned algae, Gigartina spp. and Endocladia muricata, suffered some die-offs at the tips of the plants from the oil, their growth is now as luxurious as ever.

All the marine algae seem to be growing at pre-oil densities. The macroscopic crustose, Ralfsia pacifica, has been growing profusely on all rocky surfaces, including on top of old oil, from the low to the high tide levels. There had been thick growths of the green algae, Urospora penicilliformis, particularly on mussels which had oil on their shells. This filamentous algae, which is common on upper intertidal boulders [5], continued to be present throughout the summer of 1972, but at only 25% of the density observed during the post-oil summer months of 1971. There were small traces of this algae during the summer of 1973. No harmful effect on marine fauna was attributed to this algae growth of U. penicilliformis.
2. Snails. The black turban snail, *Tegula funebralis*, is a dominant species, occurring in large numbers throughout the Duxbury Reef shale flats. In our 11-transect sample of 100 square meters, this snail had a fluctuating sample mean number between 15 and 40 per square meter (see figure 5).

![Figure 4. Comparison of transects at Stinson Beach and Drakes Beach for three species combined: Emerita analoga, Nepthys californiensis, and Orchestoidea californiana](image)

![Figure 5. Summary of Tegula funebralis, Duxbury Reef, 11 transects](image)

With nearly all the oil eroded from the expansive shale reef, *T. funebralis* is grazing in large numbers, and present densities appear to be comparable to pre-oil status except for April of 1971 and 1972 which had shown significant lows. Further monitoring will determine if these are cyclical lows for this species. The April 1971 decrease, however, is probably partially associated with the spill.

The small periwinkle snail, *Littorina scutulata*, is in a very healthy state of recruitment. Some of the square meters in the berm transects contain thousands of these snails. They were the first marine organisms observed crawling on top of encrusted oil as early as three months after the initial deposit of oil on the reef.

The only snail which appears to be on the verge of extinction is a very small population of *Littorina planaxis*, found in a small section of the Area A berm. Although it is very common on other reefs throughout central California, this grey periwinkle snail has never been abundant in our counts; pre-oil counts yielded total transect numbers ranging from 18 to 24, while counts in 1971 to 1973 ranged from 0 to 7. The 1971 oil spill was a major factor in reducing the total counts, with only two observed in a recent April 1974 count.

3. Mussels. This reef is blessed with a large population of approximately 1,200,000 mussels, *Mytilus californianus*. The mussel beds form a large chenille-like rug on top of this reef, covering about 2,000 square meters. Since about 50% of the beds had been covered with oil, a high rate of mortality was expected; however, mussels in the Area C transect beds, covering about 1,000 square meters, survived the oil with only a 2% loss, or 12,000 dead. The high survival rate, despite the blanket of Bunker C oil, is probably due to their effectiveness in keeping their shells closed during the time of oil coverage. Kanter, in his study of the effects of crude oil on *M. californianus* [4], also found that this avoidance behavior was very significant for survival. The present condition of mussels indicates a healthy state of recruitment; many mussels measure 2 to 5 cm, a sign of new population growths. Statistical analysis of data for July 1971 through December 1973 showed significant differences in population mean when compared to pre-oil data through June 1971 as shown in figure 6.

![Figure 6. Live Mytilus californianus for Duxbury Reef, Area C transect, 100 square decimeter sampling](image)

![Figure 7. Live Collisella spp. for Duxbury Reef Berm A-8, 9; 20 square meters](image)

The pre-oil sample means were very consistent, from 28/m² to 30/m², while the sample means during the immediate year following the oil spill varied from 11/m² to 24/m². The years 1972 and 1973 showed a large influx of limpets to the transect sites. Many of these limpets were less than 1 cm in length, indicating young populations, an encouraging ecological sign of recruitment. Conversely, there has been a steady decrease in dead limpets, which are still "glued" to the shale rock by the old oil and straw matrix. For berm transects totaling 30 square meters, dead limpets have decreased from a mean of 9.3/m² in April 1971 to 0.9/m² in April 1973.

Like Kanter [4], I also have concluded that the survival of the sea-mussel, *M. californianus*, is probably due to a combination of factors: intraspecies variations, size, age, geographical location, tolerances to natural oil seeps, seasonal influences, and tidal-current conditions at the time of oil contamination.

4. Limpets. Several species of limpets, *Collisella* spp., together form a solid picture of density recruitment on the Duxbury Reef berm area. Figure 7 presents data dating back to 1964.
5. Barnacles. My initial report stated that some one million barnacles were smothered by oil; however, the subsequent natural recruitment of barnacles, Balanus glandula and Chthamalus dalli, to transect sites has been successful. Where the oil once covered the shell berm, for instance, thousands of small barnacles, mostly less than 2 mm in diameter, now occupy the bare rock surfaces. The sample mean for three berm transects, 30 square meters, has increased from 13.5/m² in 1971 to 50.1/m² in 1972 to 81.8/m² in 1973. Each successive year since the spill has shown a significant difference between the live population means for these transects.

Figure 8 affords two notable observations in the comparison of two transects with no residual oil to seven transects with 76-100% oil coverage, including the berm and mussel bed transects. The oil transects, with higher ratio of dead to live due to oil, showed an almost threefold increase, a recruitment comparable to that of the no-oil transects and similar to that of Sausalito and Fort Baker. Where wave actions were more vigorous on the exposed outer coast reefs, more oil was splashed on these sites; likewise, more larvae settled on sites of good wave action, a major factor in the healthy recruitment.

6. Marine Crabs. The shore crab, Pachygrapsus crassipes, has not returned to pre-oil densities. Total counts of crabs for area A berm transects previous to the oil spill had ranged from 30 to 50. Post-oil total counts for this same area ranged from 0 to 2 for 1971 and 1972, and from 1 to 14 for 1973, with some young crabs noted in the July count. The decrease in the crab population is mainly attributable to the oil spill. The present low number is further harassed by hundreds of school children who visit the reef, pick up, and abuse these remnant organisms for a "show and tell" session on the reef. Visitors to this marine reserve must be admonished not to touch these organisms. In area C, P. crassipes occupies habitats under the protection of the mussels and appears to be normal in density for this section of the reef.

7. Other Marine Organisms. The starfish population of Pisaster ochraceus has declined from pre-oil total counts of 33 to 51 within the transect to post-oil totals ranging from 15 to 32. The July summer counts showed 32 for 1971, 27 for 1972, and 17 for 1973. The drop in number may be due to ecological factors other than the oil spill. Our starfish transect is adjacent to the mussel bed population, which is their chief food source. Perhaps these mobile echinoderms had migrated to areas where mussels did not have oil on the shells. However, in my general assessment of the starfish, the populations do appear normal throughout the Duxbury Reef intertidal and subtidal areas.

Total transect counts for Lottia gigantea since 1959 ranged from 16 to 28. In February 1971 all but one of the 22 limpets counted had oil on their shells. A low of 11 in July 1971 may be partially due to the spill. December 1973 showed a high of 54, none of which had oil. The subtle reason why this limpet seems to be increasing may perhaps be its protection from collectors and food hunters due to the marine reserve status of the reef.

Data for other marine species noted in our transect were inconclusive as regards any relationship to the oil spill. The status of post-oil counts is described as compared to pre-oil counts:

- **Species** Post-oil counts
- Anthopleura xanthogrammica, sea anemone increasing
- A. elegantissima, sea anemone increasing
- Pollicipes polymerus, goose barnacle increasing
- Platystomum cancellatum, boring clam increasing
- Pholadidea pensa, boring piddock same
- Hermaea smithi, black nudibranch decreasing
- Haliotis rufescens, red abalone decreasing
- Pagurus spp., hermit crabs same
- Pugettia sp., kelp crab same
- Hemigrapsus nudus, purple shore crab same
- Cancer antennarius, cancer rock crab same
- Strongylocentrotus purpuratus, purple sea urchin decreasing

The establishment of a marine reserve at Duxbury Reef in 1971 has definitely enhanced the population of marine life on the reef. The populations of sea anemones, boring clams, limpets, and snails have escaped the predatory hands of the hunter-collector, man. The decreasing populations of the red abalone Haliotis rufescens, the black nudibranch Hermaea smithi, and the purple sea urchin Strongylocentrotus purpuratus are all probably attributable to ecological variables surrounding the reef habitat.

We have continued our underwater surveillance of subtidal transects and have concluded that the missing abalones, H. rufescens, from these transects have migrated elsewhere to find a more favorable niche. I have not observed any human abalone hunter on this reef for the past three years.

8. Summary Transects. Figure 9 presents data for 13 transects selected because of corresponding investigation dates. The berm and mussel bed transects are not included in this summary group. Species counted and noted in these summary transects included:

- Anthopleura xanthogrammica and A. elegantissima, sea anemone
- Balanus glandula and Chthamalus dalli, acorn barnacle
- Pollicipes polymerus, goose barnacle
- Pachygrapsus crassipes, striped shore crab
- Hemigrapsus nudus, purple shore crab
- Cancer antennarius, cancer rock crab
- Pugettia sp., kelp crab
- Pagurus spp., hermit crab
- Mopalia muscosa, chiton
- Mytilus californianus, sea mussel
- Platystomum cancellatum, boring clam

![Figure 8](http://meridian.allenpress.com/iosc/article-pdf/1975/1/457/1738683/2169-3358-1975-1-457.pdf)

![Figure 9](http://meridian.allenpress.com/iosc/article-pdf/1975/1/457/1738683/2169-3358-1975-1-457.pdf)
Collisella digitalis and C. scalaris, limpet
Littorina scutulata, periwinkle snail
Tegula funebralis, black turban snail
Acanthina spirata, tooth snail
Pisaster ochraceus, seastar
Strongylocentrotus purpuratus, sea urchin

There was no significant difference between the population means for the species counted of July 1972 as compared to all other summer months for 1969 and 1971 shown in figure 9. There was also no significant difference between the April population means of 1971 and 1972, indicating possible seasonal spring lows attributable to the high mobility of T. funebralis, the black turban snail, and to low counts of Collisella spp., limpets, and Acanthina spirata, marine snail. However, the April 1971 mean was significantly different from all the pre-oil and post-oil summer means, while the April 1972 mean was so for only 3 of the 5 summer means. For this reason, I suspect the April 1971 decline was partially due to suffocation of marine life from the oil spill. April counts should be continually monitored in future years.

CONCLUSIONS

Suffocation by the Bunker C oil was the primary cause of death among marine organisms due to the collision of two Standard Oil tankers on January 18, 1971, which resulted in a 840,000-gallon oil spill in San Francisco Bay. Based on my marine transect studies in several localities, an estimate of 4.2 to 7.5 million organisms, mostly barnacles, had been smothered by the oil, based on an overall 25% dead in the most heavily oil-affected sites. For Duxbury Reef’s berm and mussel bed transects, 20% of the sampled organisms were dead, with an extrapolation of some 643,000 to 1,375,000 dead, based on 95% confidence intervals [2]. Now, in April 1974, less than 5% of the oil remains on the rocky surfaces as wave erosion continues to chip away at remnant tar deposits.

The recruitment of marine organisms in the transects has been outstanding for barnacles, mussels, periwinkles, and limpets. In the intertidal areas of Sausalito and Duxbury Reef, the barnacles, Balanus spp. and Chthamalus spp., and periwinkles, Littorina scutulata, have doubled in sample density. Several species of limpets, Collisella spp., on the berm of Duxbury Reef, have more than doubled in sample mean, with young limpets less than 1 cm in length to indicate healthy recruitment. The sea-mussel, Mytilus californianus, has also nearly doubled in sample counts, and the present population mean is significantly different from pre-oil means. In fact, many small mussels, 2 to 5 cm, can be observed in all my Duxbury transect sites—a good sign of the reproducing capabilities of this mollusk.

The good recruitment of barnacles to the transects simply indicates that planktonic production for these barnacle species has been equal to or higher than that of pre-oil years. Although my study did not deal with the effects of Bunker C on plankton production, the good replacement of barnacles in these study sites leads me to conclude that the Bunker C fuel had little lasting effect on these larval crustaceans. Guard and Cobet [3] also concluded in their study of Bunker C fuel that the biologically active hydrocarbons from such spills were removed very quickly in the weathering processes. The remaining oil is simply a very viscous tar, the suffocating agent on the marine life of the intertidal reefs.

Moreover, another reason for good barnacle and limpet replacement may be simply an ecological succession phenomenon. When the eroded oil was chipped off the rocky surfaces, this left much exposed surface for the succession of algae, barnacle larvae, snails and limpets to occupy these open spaces.

On the minus side, there were some decreases in reef organisms. The striped shore crab, Pachygrapsus crassipes, which roams on the flat shale of Duxbury Reef, is still below pre-oil counts. My assumption is that many of these crabs were suffocated by the oil. However, the low number may also be attributed to the relentless overhandling by hundreds of students who visit the reefs. Such abuse has been observed many times, despite the enactment of the 1971 marine reserve on Duxbury Reef. The grey periwinkle, Littorina planaxis, on the berm of Duxbury Reef seems to be on the verge of extinction. This very small population of about 20 snails was blanketed by oil, and a recent count in April 1974 revealed a seasonal low of two snails remaining.

The summary review of 13 transects (excluding the berm and mussel bed transects) on Duxbury Reef showed a significant decrease of live organisms in the spring of 1971. This drop in marine life density is partially attributed to the mobility of the black turban snail, Tegula funebralis, but also reflects the loss of organisms which died from the oil spill. Comparisons of all summer counts for 1969, 1971, and 1972 revealed no significant difference between population means.

The study of marine organisms and the possible relationship of their cyclical patterns to oil suffocation is a very difficult and tenuous task. There are so many ecological variables, such as species differentiation, geological and geographical locations, seasonal, biotic and abiotic changes, contaminants from other water sources, and even the differences in the oil morphology, that one may wonder how valid my evaluations are concerning the effects of the 1971 Bunker C oil spill on the marine life within my study transects. By and large, I am confident that my observational studies have been accurate and that they give supportive evidence that large numbers, particularly of the sessile organisms (barnacles), were smothered by the oil residue. The more mobile organisms, such as limpets, snails, and crabs, were afflicted to a lesser extent.

The apparent large overall recruitment of marine organisms to the transects, which includes a healthy replacement of the marine sessile and algal organisms, leads me to conclude that, at this present time, I can see no lingering effects of this Bunker C fuel. Time and the replacement of marine life will restore these intertidal shores to their lush diversity of fauna and flora, providing there is not another catastrophic pollution of one form or another.

REFERENCES