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THE EFFECTS OF THE SAN FRANCISCO OIL SPILL ON MARINE LIFE--PART II

by

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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

The San Francisco oil spill occurred during the early morning hours of January 18, 1971, when two Standard Oil vessels collided under the Golden Gate Bridge in heavy fog, releasing 840,000 gallons of Bunker C fuel. This asphalt-like oil was washed up on intertidal shores throughout the San Francisco Bay area.

From a comparison of pre-oil and post-oil transect data, taken principally on Duxbury Reef, it was estimated that a total of 4.2 to 7.5 million marine invertebrates, chiefly barnacles, may have been smothered by the oil.

The study in 1972 and 1973 of the subsequent recruitment of marine organisms on the reef transects which had been covered by oil showed that the populations of barnacles, mussels, and limpets have returned to and, in some cases, surpassed pre-oil population levels. In particular, the sample counts for barnacles illustrated a threefold increase in density for 1972, as compared to 1971. Marine algae, which had suffered some die-offs after the spill, have also returned to normal density.

Several species of marine organisms have not returned to previous pre-oil population density, notably the elusive shore crab, *Pachygrapsus crassipes*, on the exposed shale of Duxbury Reef; 1973 counts for this crab, however, show an increase over the other post-oil counts of 1971 and 1972.

No lingering effects of the oil spill have been observed in any of the marine species throughout the intertidal transect sites.

TABLE OF CONTENTS

Cover: The striped shore crab, *Pachygrapsus crassipes*, with left chela missing. Faint traces of Bunker C oil can still be observed here on Duxbury Reef.

I. INTRODUCTION--A REVIEW OF PART I CONCLUSIONS

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. The localities are shown below in Figure 1.

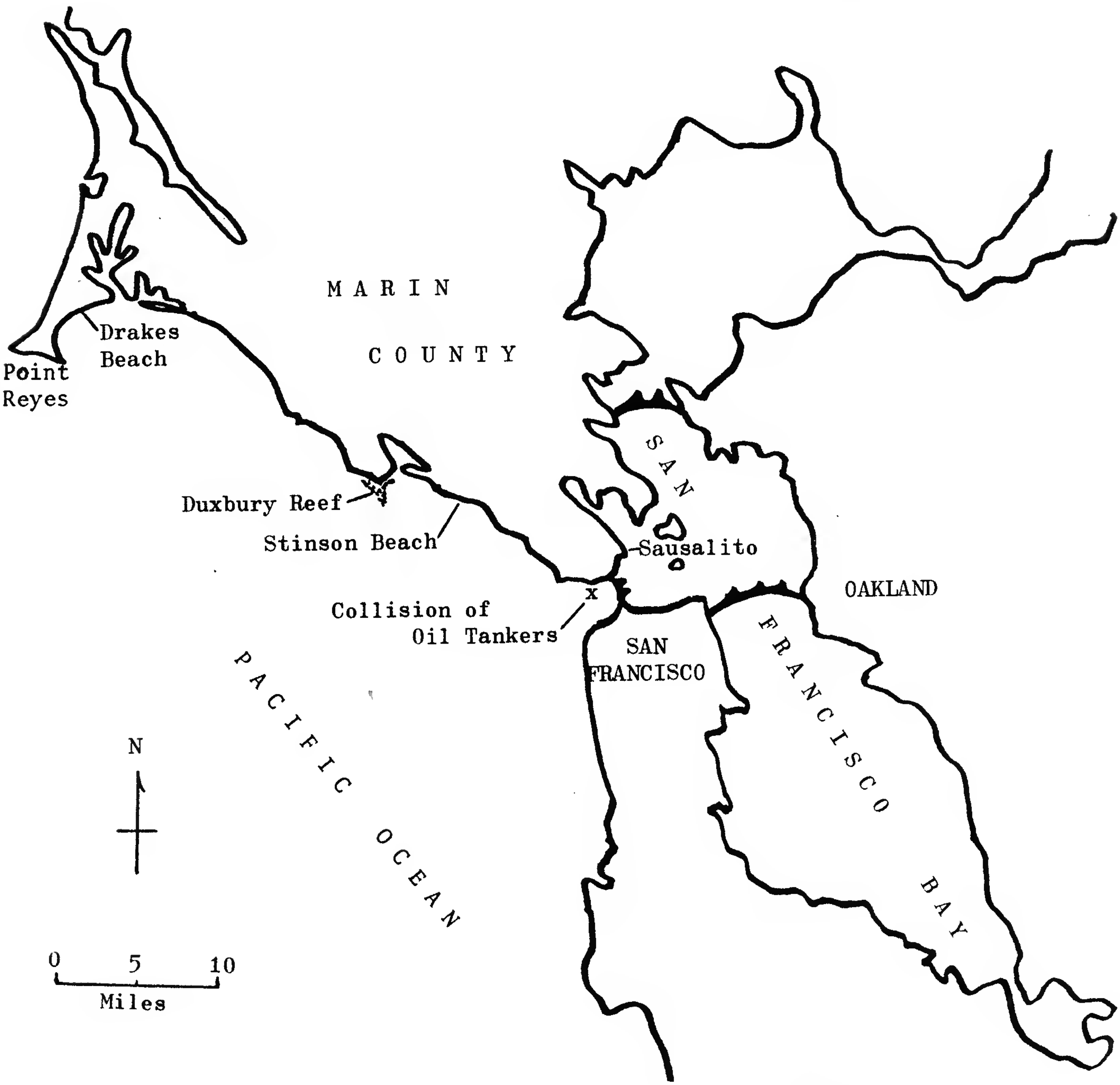

Figure 1. Localities of the 1971 San Francisco Oil Spill in the state of California

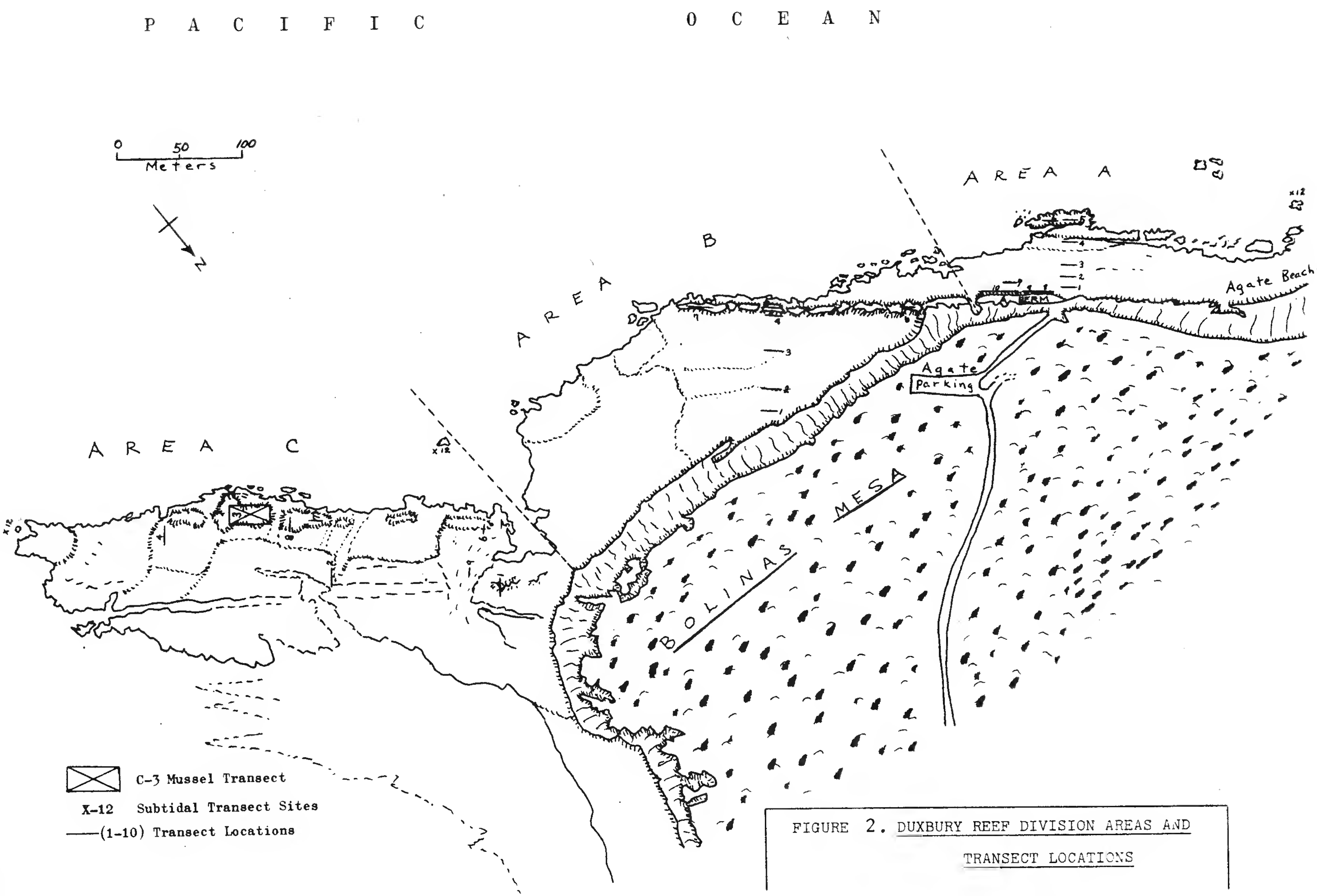

FIGURE 2. DUXBURY REEF DIVISION AREAS AND TRANSECT LOCATIONS

III. OBSERVATIONS AND FINDINGS UP TO 1974

A. SAUSALITO DATA (APPENDIX II)

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.

This same transect in May, 1972, showed solid recruitment of marine life to the study area. Figure 3 shows that these acorn barnacles have nearly tripled in the sample counts, from a mean of 93 live/dm.^{2} in May, 1971, to 278 live/dm.^{2} in May, 1972.

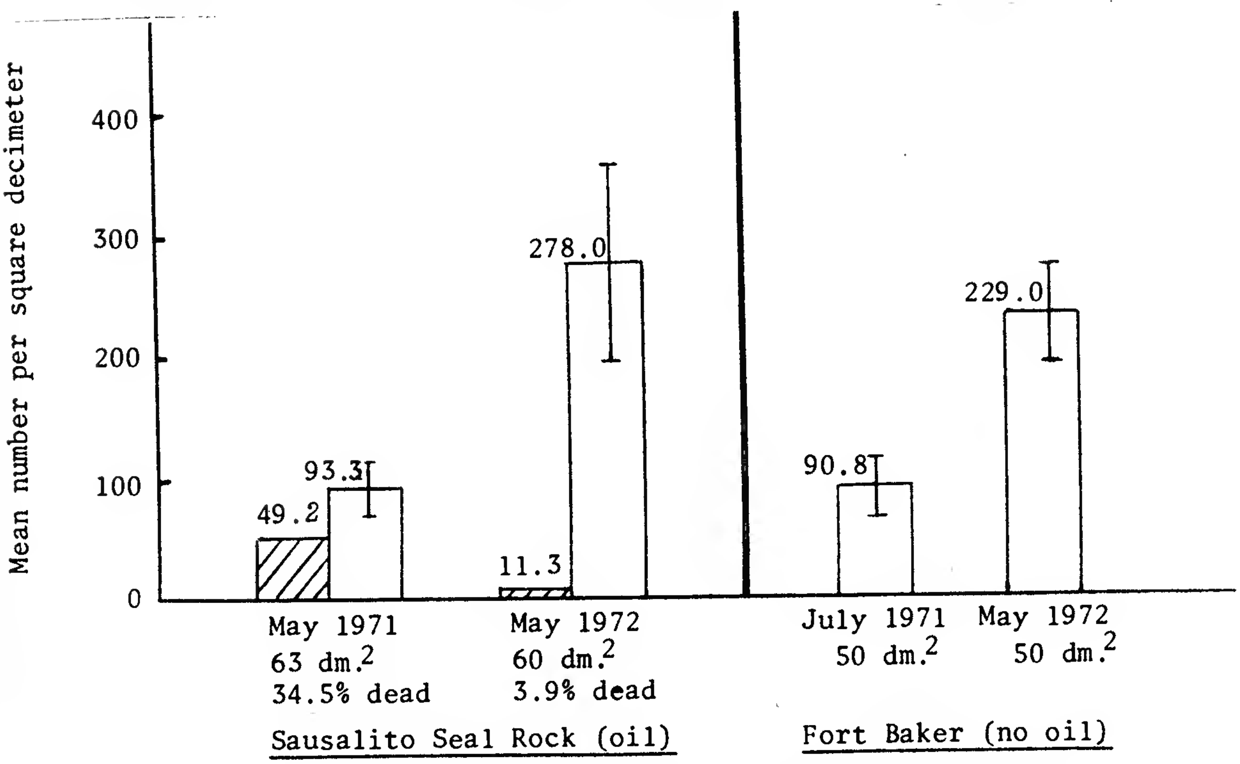

Figure 3. Comparison of barnacles, *Balanus glandula* and *Chthamalus dalli*, for transects in Sausalito (oil) and Ft. Baker (no oil)

dead live 95% confidence interval for population mean

Figure 4. 1972 recruitment of *Chthamalus dalli*, the acorn barnacle, in the Sausalito transect.

a fairly consistent population level through 1972, as shown in Figure 5.

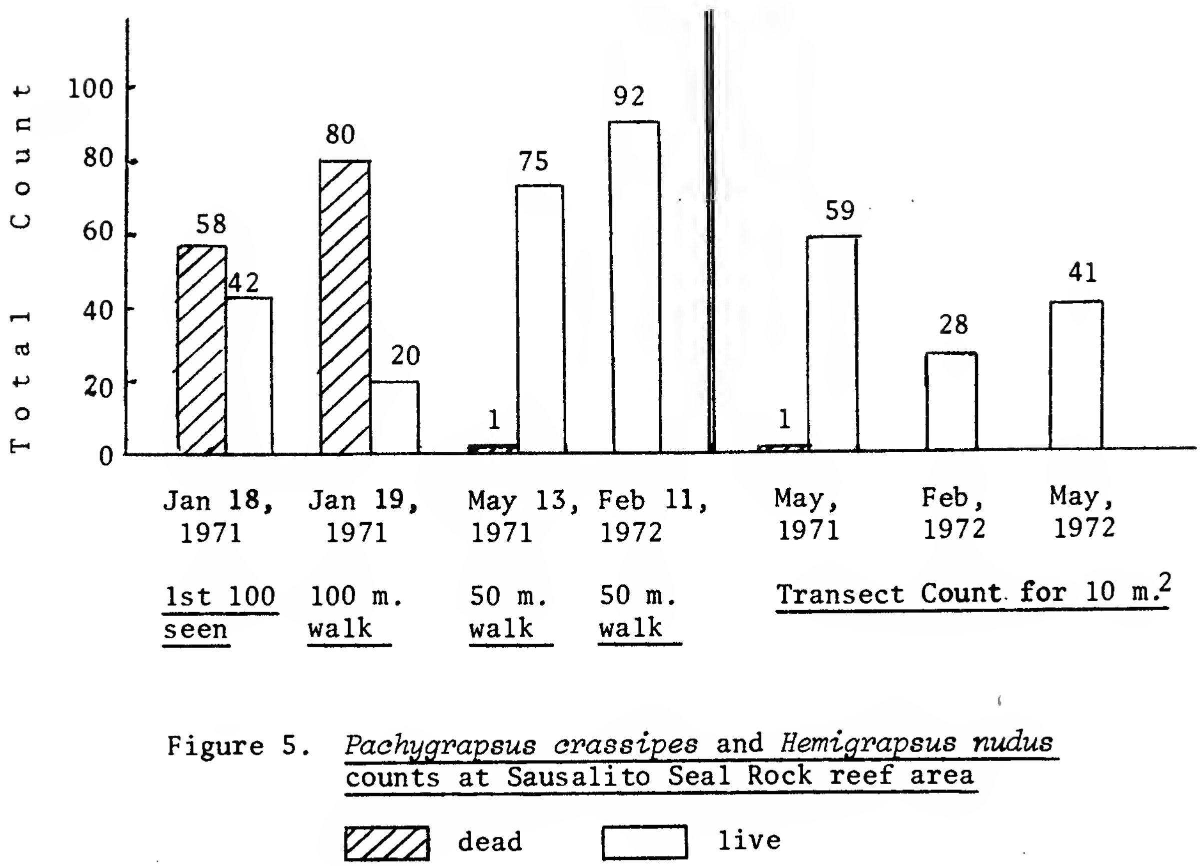

Figure 5. *Pachygrapsus crassipes* and *Hemigrapsus nudus* counts at Sausalito Seal Rock reef area

B. STINSON BEACH DATA (APPENDIX III)

In the initial report on the spill (Chan, 1972), I could not relate the change of marine life density at the Stinson Beach 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

Nepthys californiensis, the sand worm

Orchestoidea californiana, the beach hopper

A comparison of the combined mean number per square meter for all three species since 1965 shows a downward trend in Figure 6.

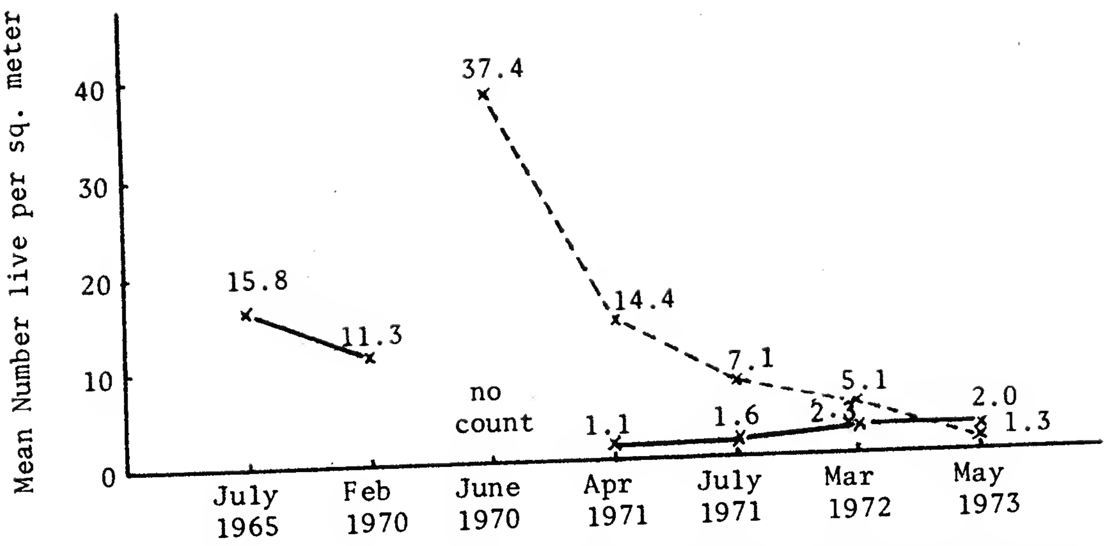

Figure 6. Comparison of transects at Stinson Beach and Drakes Beach for three species combined: *Emerita analoga*, *Nepthys californiensis*, and *Orchestoidea californiana*

——— Stinson Beach Transect (100% oil, graded)

- - - Drakes Beach Transect (non-oil)

Stinson Beach was covered with oil during the early days of the spill. Standard Oil Company reported that its mechanical graders and lifters had disrupted and removed, on the average, the upper six inches of the sand's surfaces. The same species were also counted at Drakes Beach where no oil had been reported. Prior to the spill, the marine polychaete, *Nepthys californiensis*, was quite abundant in the Stinson Beach transect, but since the spill, this worm has not returned in the post-oil counts; on the other hand, the worm has continued to be present at Drakes Beach, the control site. Both areas currently show low densities of marine organisms. Although the oil may have had its smothering effect on the Stinson Beach organisms, perhaps the major contributing reason for the poor recruitment can be directly related to an ecological sand disturbance of winter and summer conditions rather than an effect of the spill and cleanup disruptions.

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 (Silva, 1972), 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, Figure 7 below.

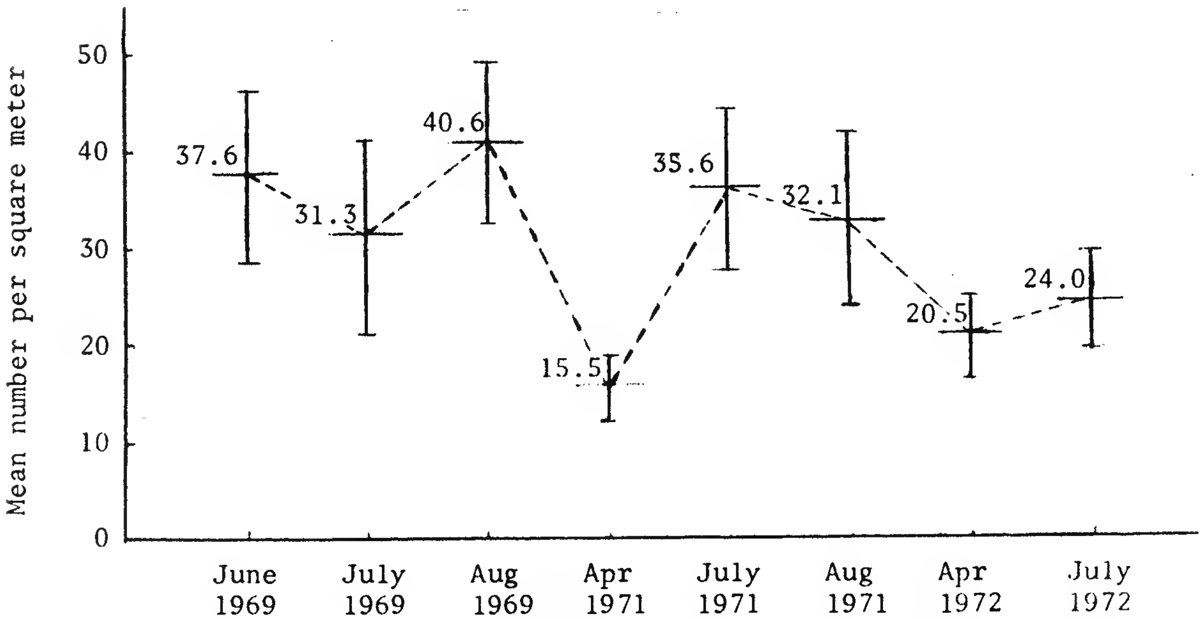

Figure 7. Summary of *Tegula funebralis*, Duxbury Reef, 11 transects

sample mean — 95% confidence interval for population mean

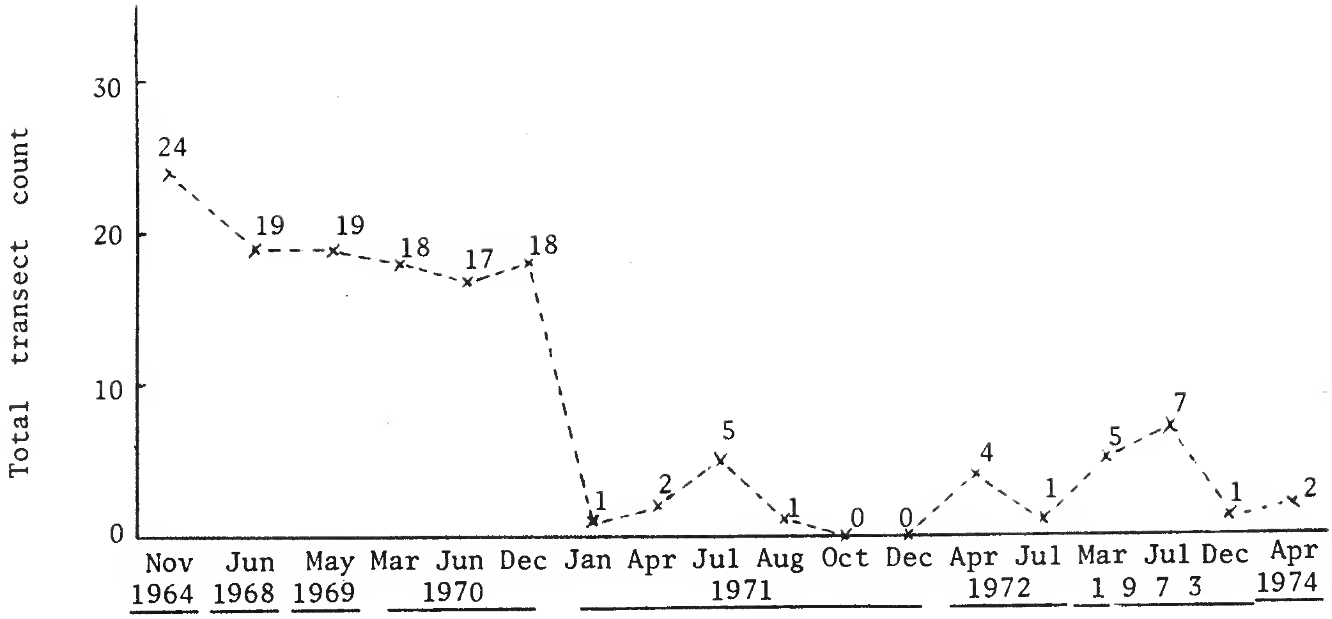

Figure 8. Total transect count of *Littorina planaxis* for Duxbury Reef, Berm A-8,9: 20 square meters

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 (Figure 13A), a high rate of mortality was expected; however, much to my surprise, mussels which were located in the Area C transect beds covering about 1,000 square meters survived the oil with only a loss of 2%, or 12,000 dead. The high survival rate of these mussels, 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* (1974), 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 means when compared to pre-oil data through June, 1971,as shown in Figure 9 below.

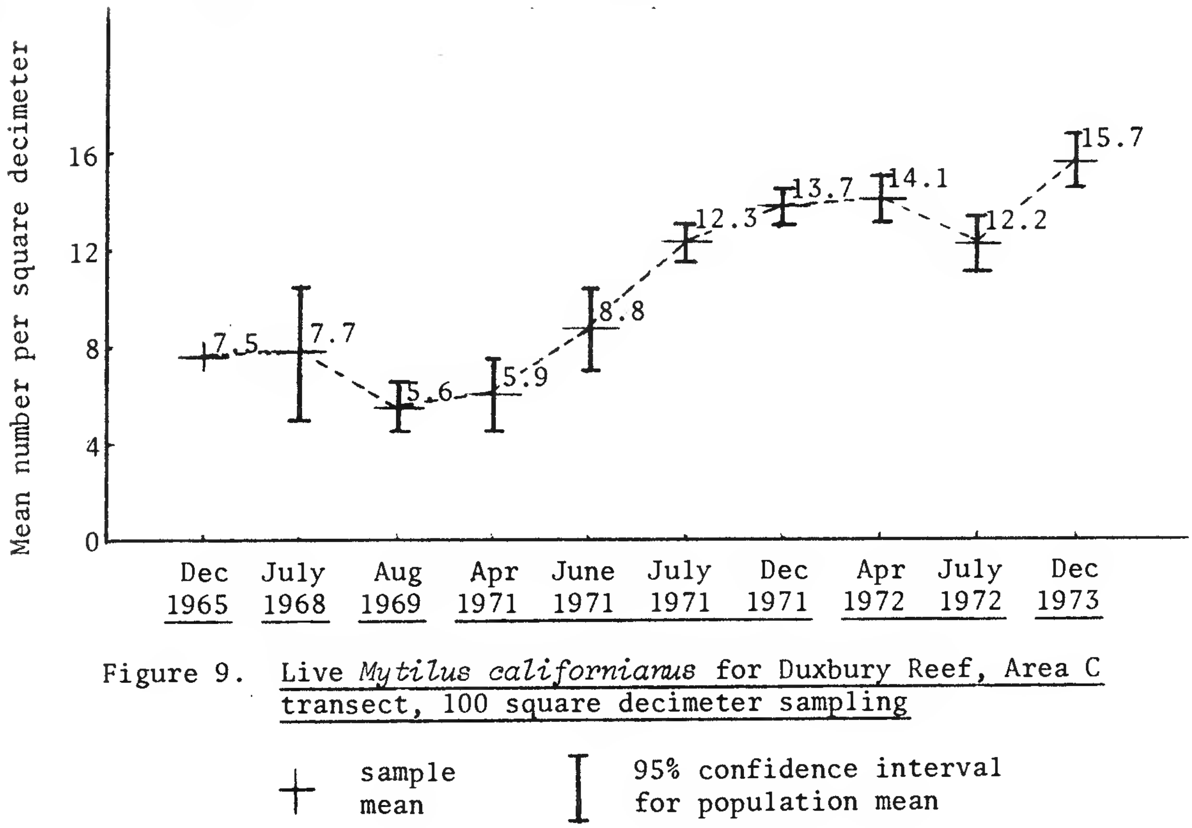

Figure 9. Live *Mytilus californianus* for Duxbury Reef, Area C transect, 100 square decimeter sampling

Like Kanter (1974), 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 10 presents data dating back to 1964.

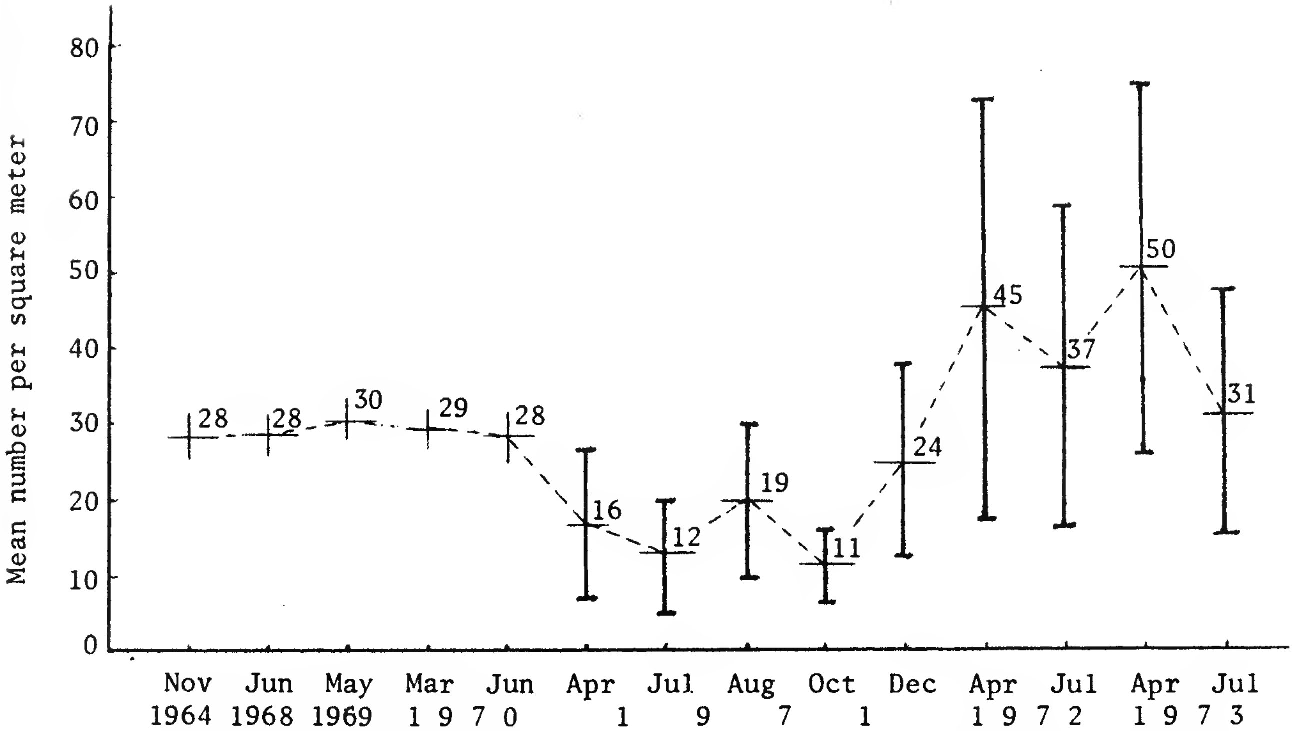

Figure 10. Live *Collisella spp.* for Duxbury Reef Berm A-8,9; 20 square meters

sample mean — 95% confidence interval for population mean

The pre-oil sample means were very consistent, from 28 to 30/m.^{2} , while the sample means during the immediate year following the oil spill varied from 11 to 24/m.^{2} 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.

Conversely, there is a steady decrease in the dead limpets, which are still "glued" to the shale rock by the old oil and straw matrix. Figure 11 includes an added berm transect, A-10.

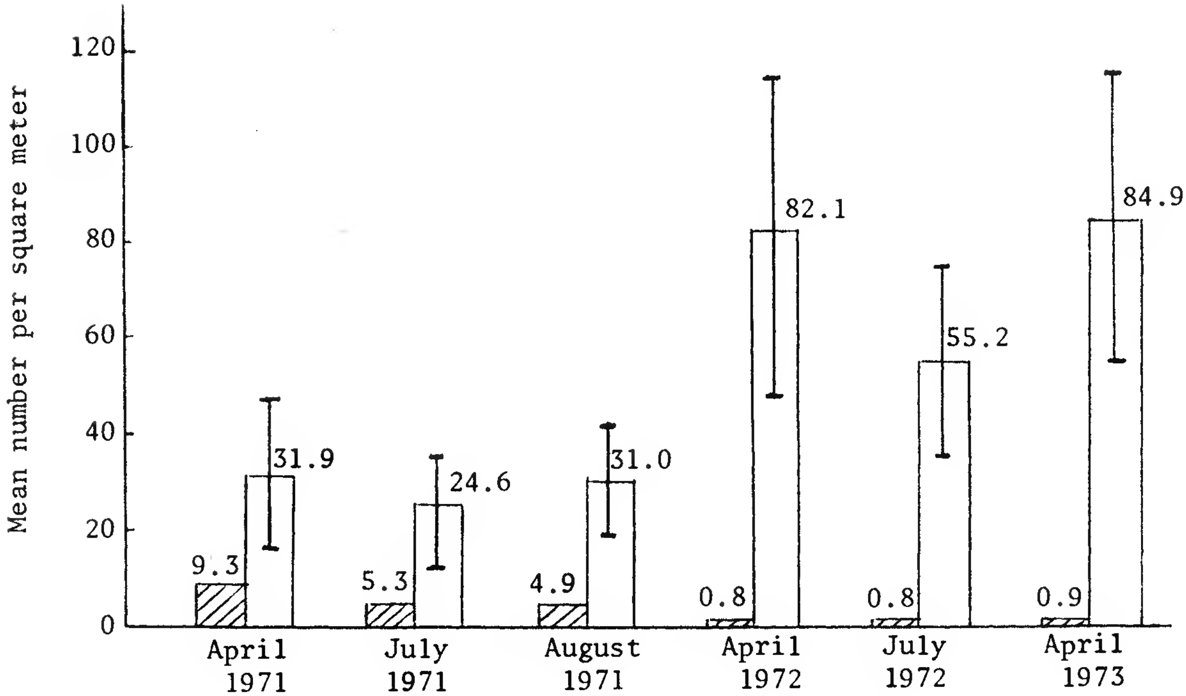

Figure 11. *Collisella spp.* for Duxbury Reef Berm A-8,9,10; 30 square meters

The sample mean of dead limpets has decreased from 9.3/m.^{2} in April, 1971, to 0.9/m.^{2} in April, 1973. The overall recruitment of limpets has caused the sample number live/m.^{2} to climb from a low of 24.6 in July, 1971, to a high of 84.9 in April, 1973. There is also a significant difference between the live population means of April 1971 and April 1973 with an interval estimate of difference ranging from 18.5 to 87.5/m.^{2} The return of large numbers of these limpets to the berm transects is an encouraging ecological sign of recruitment of organisms to these habitats. The recruitment of *C. digitalis* is clearly shown in Figures 11A, 11B, 11C, on page 19.

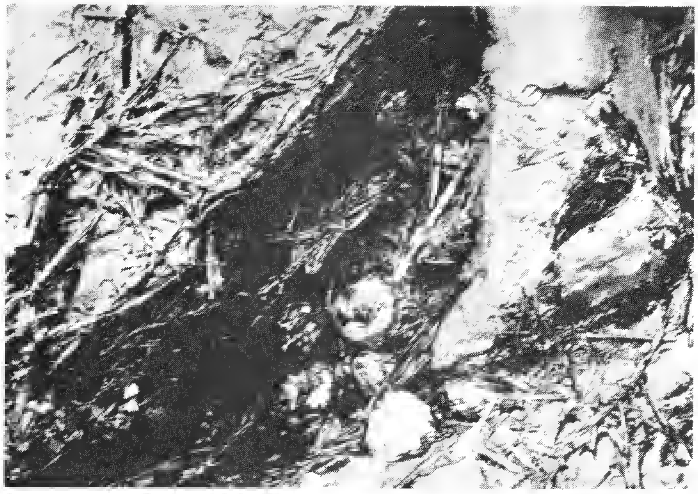

Fig. 11A

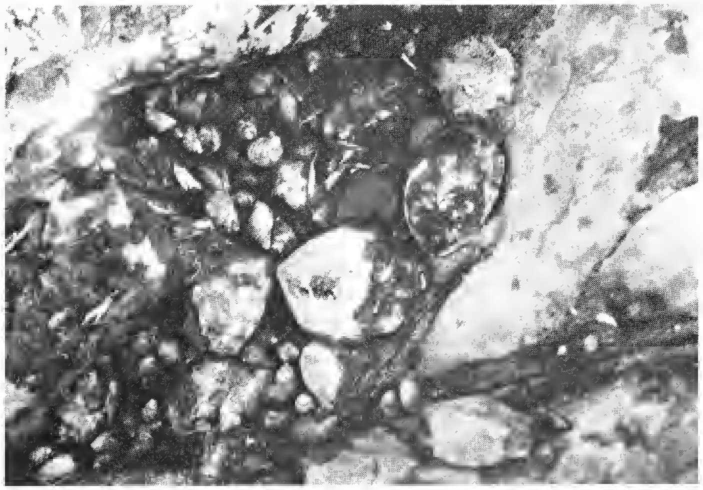

Fig. 11B

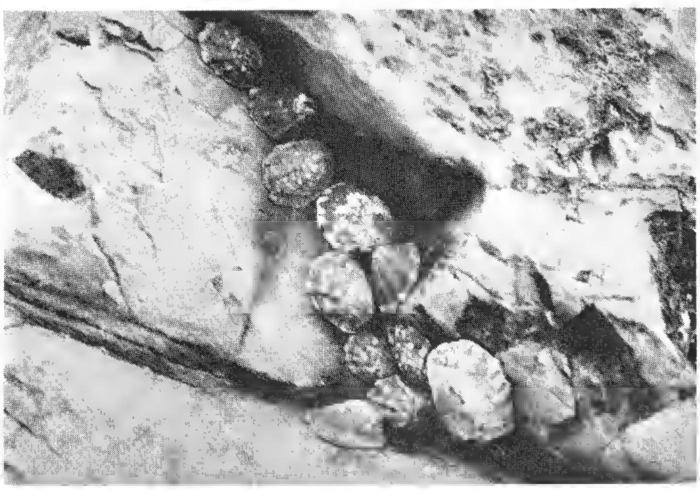

Fig. 11C

Figures 11A, 11B, 11C. Three-year review of a square decimeter on Duxbury Reef Berm Transects A-8 and 9.

A-January, 1971 dead *Collisella digitalis* in $dm.^2$, covered by oil and straw.
B-January, 1972 *Littorina scutulata* occupying the $dm.^2$ with dead *C. digitalis*.
C-January, 1974 live *C. digitalis* reoccupying $dm.^2$ with slight traces of 1971 oil.

5. Barnacles

My initial report stated that some one million barnacles were smothered by oil on Duxbury Reef; however, the subsequent natural recruitment of barnacles, *Balanus glandula*, and *Chthamalus dalli*, to the transect sites, particularly the Area A berm, has been quite successful, as seen in Figure 12.

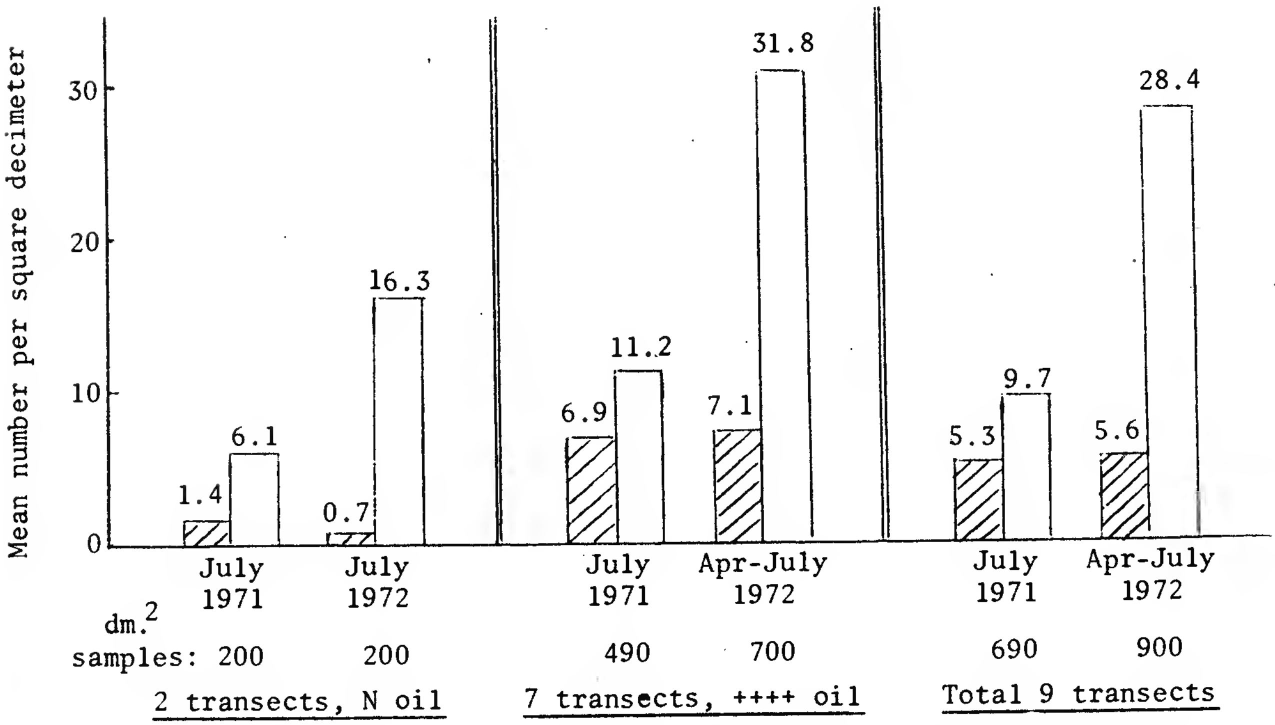

Figure 12. Comparison of *Balanus glandula* and *Chthamalus dalli* for Duxbury Reef, 9 transects

dead   live   No oil = B-5; C-2
++++ oil = A-1,5,6,7,8,9,10;C-3

Figure 12 affords two notable observations, in the comparison of two transects with no residual oil to seven transects with 76-100% coverage of oil, including the berm and mussel bed transects. The no-oil transects had smaller populations of live and dead barnacles than the oil-covered transects. The oil transects, with the higher ratio of dead to live due to the oil, showed an almost threefold increase, a recruitment comparable to that of the no-oil transects. This graph simply illustrates that where wave actions are most concentrated, more oil is splashed on these sites. Likewise, more larval populations settled in these areas of good wave action. The barnacle recruitment here seems to parallel (almost threefold increase) that of Sausalito and Fort Baker.

Where the oil once covered the shale berm, thousands of small barnacles, mostly less than 2 mm. in diameter, now occupy the bare rock surfaces. Figure 13 presents the sample means for the berm transects, 30 square meters. The recruitment in this area has caused the sample mean to increase threefold from 13.5 in 1971 to 50.1/m.^{2} in 1972, or sixfold from 13.5 to 81.8/m.^{2} in 1973. Each successive year since the spill, thus far, has shown a significant difference between the live population means.

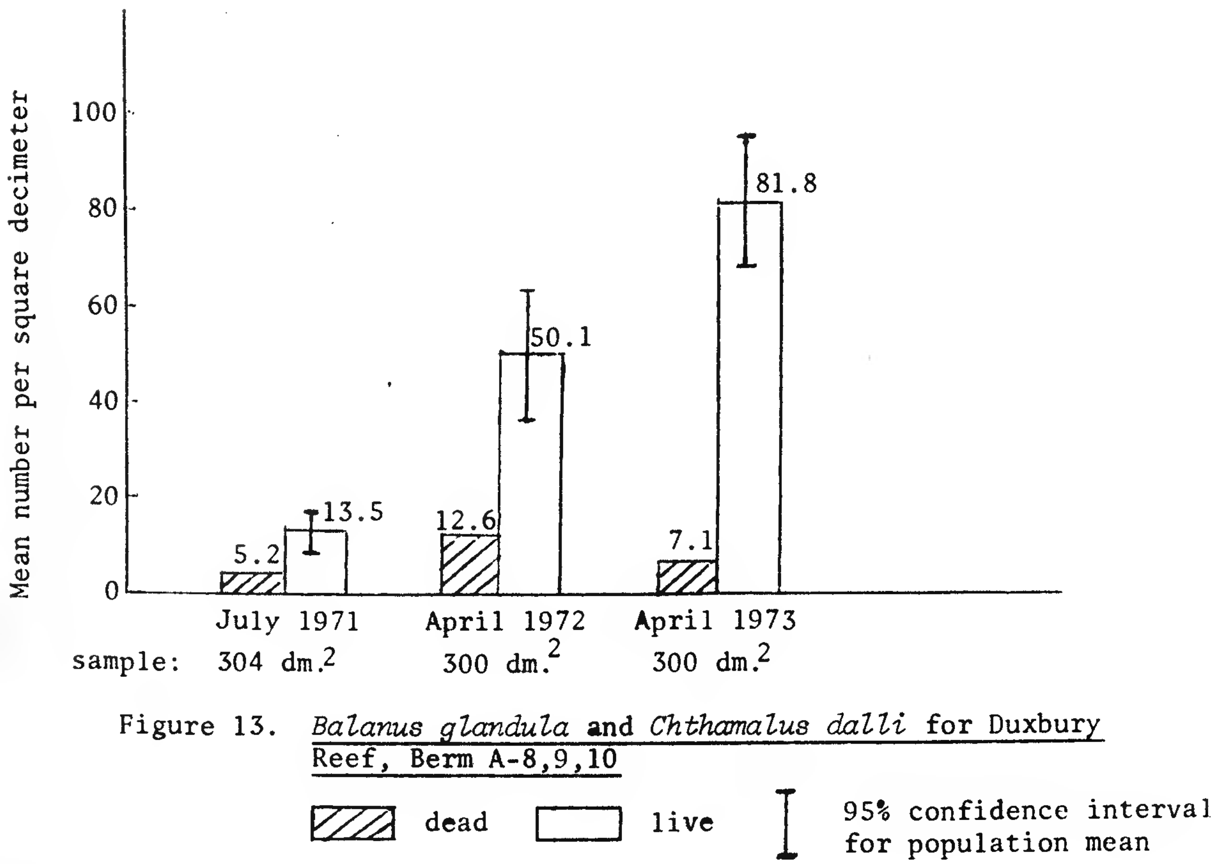

Figure 13. *Balanus glandula* and *Chthamalus dalli* for Duxbury Reef, Berm A-8,9,10

Figure 13A. Duxbury Reef mussel bed marker, a plastic pipe embedded in fresh concrete, March 1971, with some *Urospora penicilliformis* on the pipe.

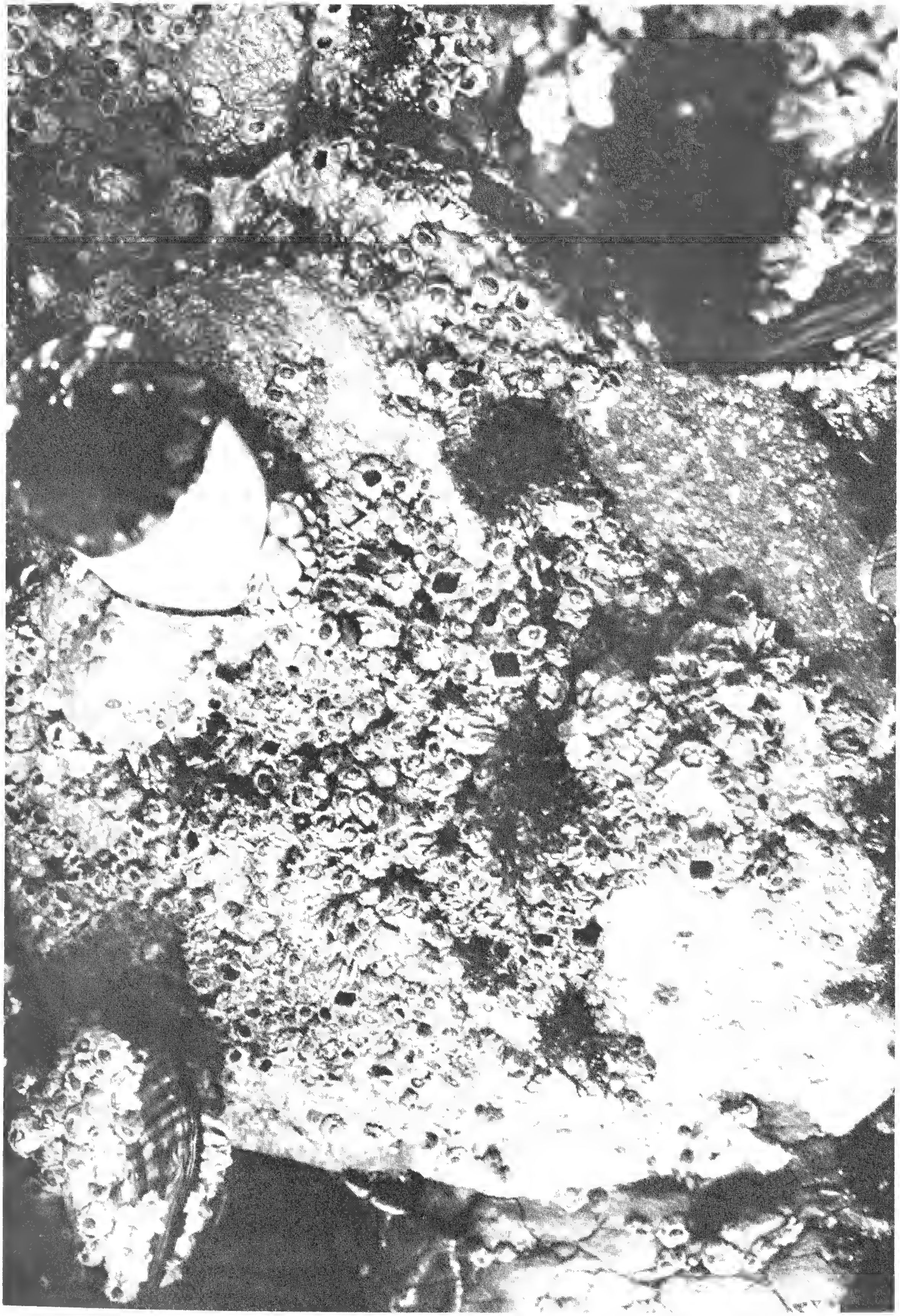

Figure 13B. Dense growth of *Balanus glandula* and *Chthamalus spp*. on the concrete surface, January 1972, one year after the oil spill. Plastic pipe is at the upper left side.

6. Marine Crabs

The shore crab, *Pachygrapsus crassipes*, has not returned to pre-oil densities. Total counts of crabs for the berm transects previous to the oil spill had ranged from 30 to 50. Figure 14 indicates that post-oil total counts for this same area have ranged from 0 to 2 for 1971 and 1972. Total counts in 1973 are higher, 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 of crabs is further harassed by hundreds of school children who come to the reef and pick up and abuse these remnant organisms for a "show and tell" sequence on the reef. Students and general public must be admonished not to touch these organisms in this marine reserve. In area C, *P. crassipes* occupies habitats under the protection of the mussels and appears to be normal in density.

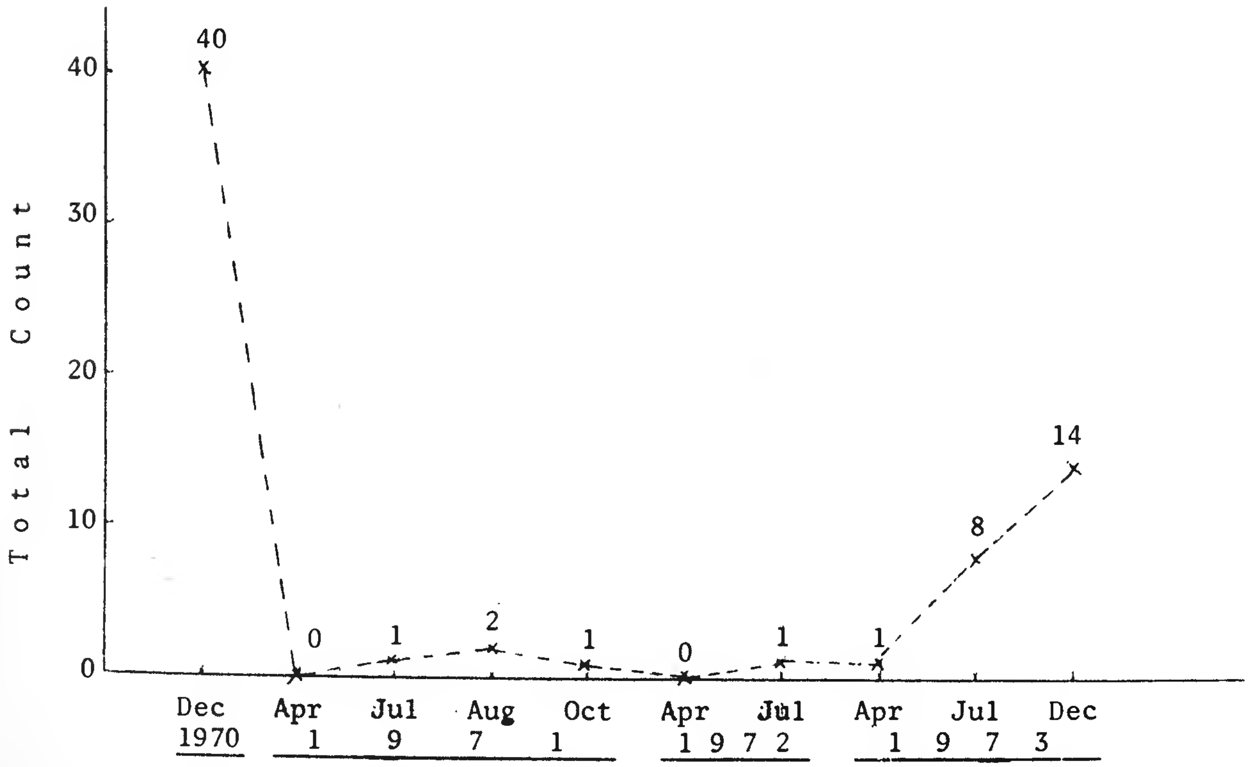

Figure 14. Total count of *Pachygrapsus crassipes* for Duxbury Reef Berm transects, A-8,9; 20 square meters

7. Other Marine Organisms

The starfish population of *Pisaster ochraceus* has declined from pre-oil total counts of 33 to 51 within the transect, Figure 16, with 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.

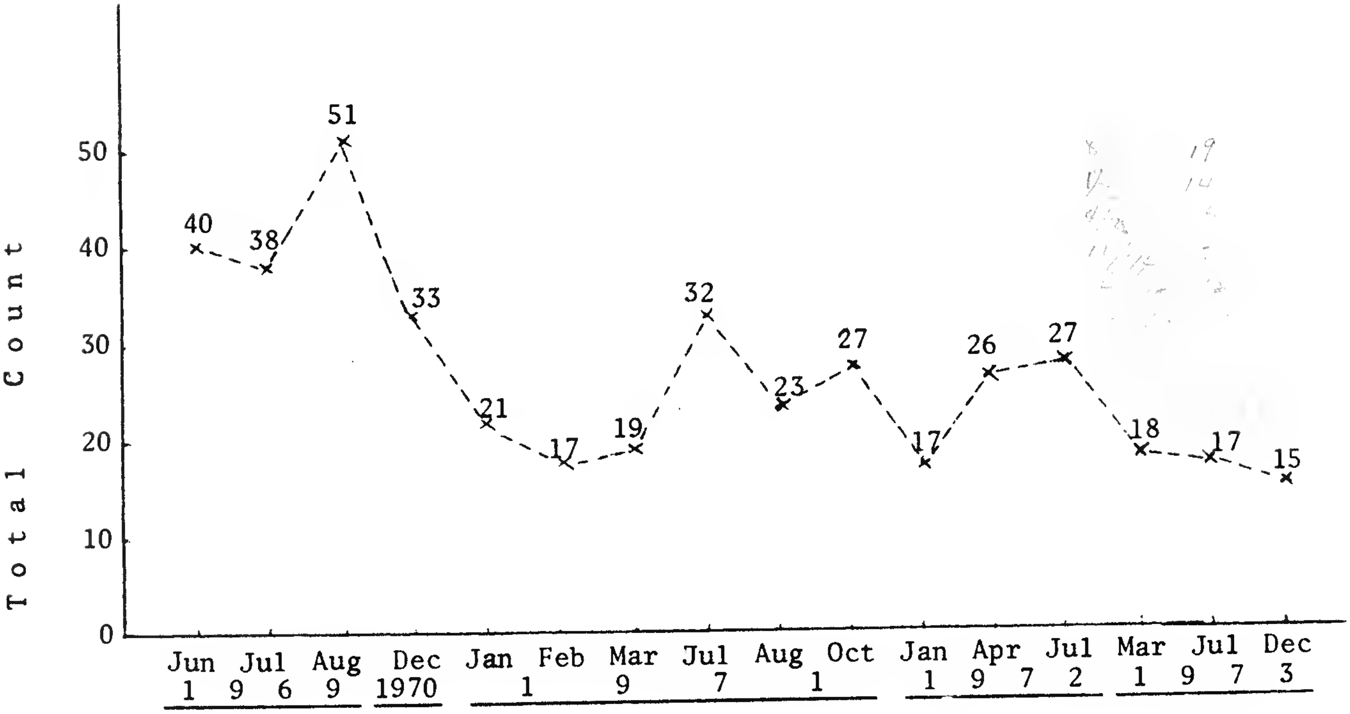

Figure 15. Total transect count for *Pisaster ochraceus* on Duxbury Reef, C-4, 10 square meters

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.

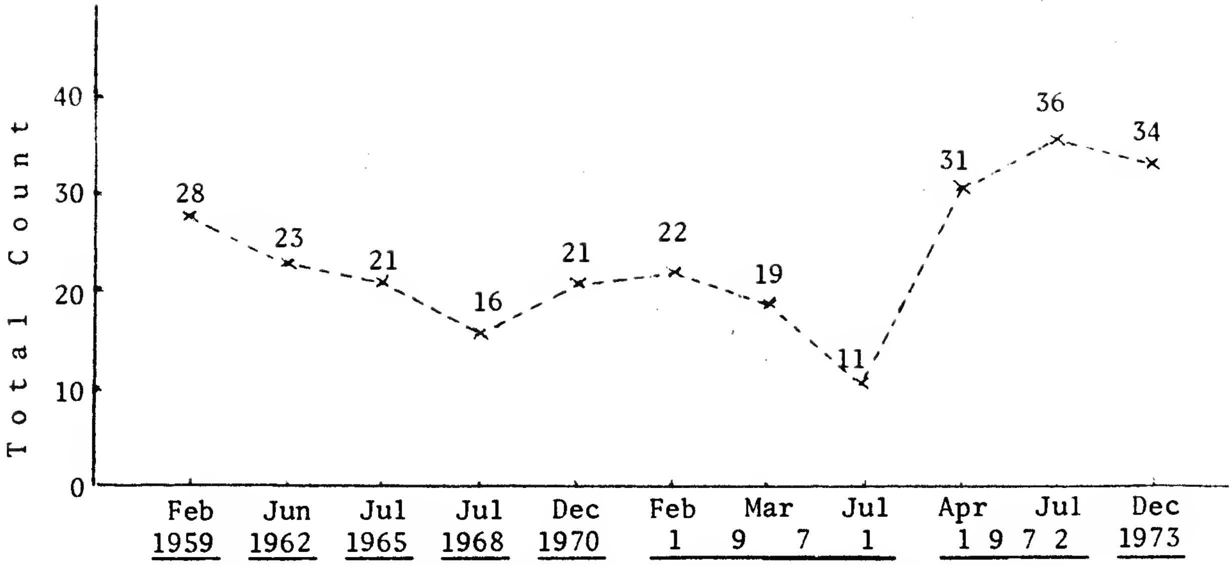

Figure 16. Total counts of *Lottia gigantea* on transect C-7, Duxbury Reef

Total transect counts for *Lottia gigantea*, Figure 16 above, reveal a slight increase over pre-oil years. The decline in the spring of 1971, down to a transect low of 11 in July, may be partially due to the oil spill. Of the 22 limpets counted in February, 1971, all but one had oil on their shells. In the present population of 34, none of these large limpets show any traces of oil on their shells. However, the subtle reason why *L. gigantea* seems to be increasing may perhaps be that the existence of the Duxbury Marine Reserve in 1971 has prohibited collectors and food hunters from removing these organisms from the reef.

Other marine organisms were noted in our transect counts, but the data was inconclusive as regards any relationship to the effects of the oil spill. The status of the post-oil counts are described, in comparison with pre-oil counts:

Species	Post-oil counts
Anthopleura xanthogrammica, sea anemone	increasing
A. elegantissima, sea anemone	same
Pollicipes polymerus, goose barnacle	increasing
Platyodon cancellatus, boring clam	same
Pholadidea penita, boring piddock	same
Hermaeina 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 *Hermaeina 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 sub-tidal 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 17 below presents counts for 13 transects selected because of corresponding investigation dates. The Area A berm transect and Area C mussel bed transect are not included in this summary group. See Appendix IV for the species of organisms counted and their sample means (page 42).

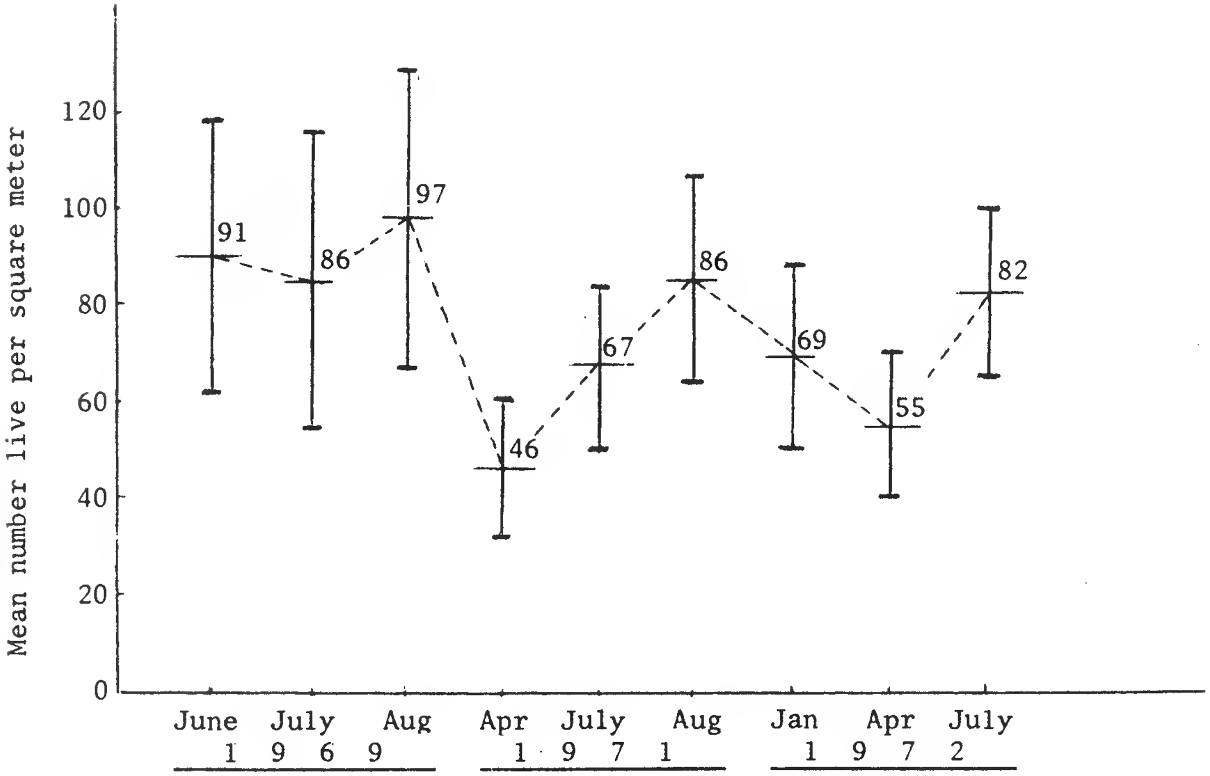

Figure 17. Summary of square meter sampling for all species counted, Duxbury Reef, 13 transects

sample mean — 95% confidence interval for population mean

The graph indicates no significant difference between the summer population means for the species counted, for the months of July--1969, 1971, 1972, and for the months of August--1969, 1971, with July, 1972. However, the April 1971 mean was significantly different from all the pre-oil and post-oil summer means.

APPENDIX I. The author, G. Chan, counting marine organisms in a Duxbury Reef transect.

APPENDIX II SAUSALITO AND FORT BAKER TRANSECT STATISTICS

Sausalito Transect: 1971=100% oil-covered, 10 m.^{2}
Fort Baker Transect: 1971= no oil, 10 m.^{2}

Species	Date and Sample	Sample Mean per dm.^{2}	95% confidence interval for population mean	Interval of Significant Difference
SAUSALITO	May 13, 1971	93.3 live	69.0-117.7	1971 vs. 1972
Barnacles	63 dm.^{2}	49.2 dead	36.7- 61.8	101.1-268.3 live/dm^2
Balanus glandula				25.1- 50.7 dead/dm^2
Chthamalus dalli	May 18, 1972	278.0 live	198.0-358.0	
	60 dm.^{2}	11.3 dead	8.7- 13.9	
FORT BAKER	July 23, 1971	90.8 live	64.3-117.3	1971 vs. 1972
Barnacles	50 dm.^{2}			89.1-187.3 live/dm^2
Balanus glandula	May 18, 1972	229.0 live	187.6-270.3	
Chthamalus dalli	50 dm.^{2}			

Live Barnacles: Sausalito vs. Fort Baker

1971= 2.5 difference between sample means
1972=49.0 difference between sample means
There was no significant difference between live population means for 1971 and for 1972.

SAUSALITO	Date	
Limpets		
Collisella spp.	May 13, 1971	21 live for 63 dm^2
	May 18, 1972	90 live for 60 dm^2
Shore Crabs		
Pachygrapsus crassipes and	*May 13, 1971	59 live, 1 dead
Hemigrapsus nudus	*Feb 11, 1972	28 live, 0 dead
	*May 18, 1972	41 live, 0 dead

*Total transect count

Non-transect counts for Shore Crabs	
Jan 18, 1971	42 live
1st 100 seen	58 dead
Jan 19, 1971	20 live
100 m.	80 dead
May 13, 1971	75 live
50 m.	1 dead
Feb 11, 1972	92 live
50 m.	0 dead

APPENDIX 111 STINSON BEACH and DRAKES BEACH SAMPLE MEAN DATA

Stinson Beach: 1971=100% oil-covered, top 6" graded off
square meter sampling every 10th meter

Drakes Beach: 1971=no oil
square meter sampling every alternate meter

Date	Square Meter Samples	SAMPLE MEAN PER SQUARE METER *Emerita analoga*	*Nepthys californiensis*	*Orchestoidea californiana*	3 species combined
STINSON BEACH					
July 15, 1965	9	7.9	5.2	2.7	15.8
Feb 17, 1970	9	7.6	3.1	0.7	*11.3
Apr 16, 1971	9	1.1	-0-	-0-	* 1.1
July 23, 1971	9	1.6	-0-	-0-	1.6
Mar 10, 1972	8	1.3	-0-	1.0	2.3
May 7, 1973	9	2.0	-0-	-0-	2.0

*Significant difference between population means (95% confidence interval) by an interval estimate of difference, .03 to 20.4.

Date	Square Meter Samples	*Emerita analoga*	*Nepthys californiensis*	*Orchestoidea californiana*	3 species combined
DRAKES BEACH				**	
June 25, 1970	30 consecutive	31.3	6.1	-0-	37.4
Apr 20, 1971	10	13.1	1.3	-0-	14.4
Aug 4, 1971	10	4.0	3.1	-0-	7.1
Mar 14, 1972	12	3.1	2.0	-0-	5.1
May 21, 1973	12	0.67	0.67	-0-	1.3

**this species is present, off the transect site

APPENDIX IV

DUXBURY REEF STATISTICS

A. Black Turban Snail, *Tegula funebralis*

100 square meter sampling for total of 11 transects: A-1,2,3,5,7 B-1,2,3,4 C-1,6

Date	Live Sample mean per m^2	95% confidence interval for population mean	Test statistics for significant difference between population means; interval estimate of difference
June, 1969	37.6	28.6 to 46.6	6/69 w 7/69 0.8997 H_0 true
July, 1969	31.3	20.9 to 41.6	7/69 w 8/69 -1.3991 H_0 true
Aug, 1969	40.6	32.7 to 48.5	8/69 w 4/71 5.7401 Reject H_0; 16.5 to 33.7
			4/71 w 7/71 -4.5781 Reject H_0; 11.5 to 28.7
Apr, 1971	15.5	12.2 to 18.8	7/71 w 8/71 0.5960 H_0 true
July, 1971	35.6	27.6 to 43.5	8/71 w 4/72 2.4698 Reject H_0; 2.4 to 20.8
Aug, 1971	32.1	23.8 to 40.5	4/72 w 7/72 -0.9865 H_0 true
			4/71 w 4/72 -1.9107 H_0 true
Apr, 1972	20.5	16.6 to 24.4	7/69 w 7/71 -0.6457 H_0 true
July, 1972	24.0	18.3 to 29.7	7/71 w 7/72 2.3353 Reject H_0; 1.9 to 21.4
			7/69 w 7/72 1.2150 H_0 true
			8/69 w 8/71 1.4507 H_0 true

B. California sea-mussel, *Mytilus californianus*

100 square decimeter sampling for mussel bed transect C-3

Date	Live Sample mean per dm^2	95% confidence interval for population mean		Dead Sample Mean per square meter
Dec, 1965	7.5	(not available)		
July, 1968	7.7	4.6 to 10.7		
Aug, 1969	5.6	4.4 to 6.7		
Jan, 1971				none (1/23/71)
Apr, 1971	5.9	4.9 to 7.0	(50% S)*	12.6
June, 1971	8.8	6.9 to 10.7		5.0
July, 1971	12.3	11.5 to 13.0	(23.7%S)*	6.4
Dec, 1971	13.7	12.9 to 14.5	(10.1%S)*	no count
Apr, 1972	14.1	13.2 to 15.0	(4.7%S)*	0.3
July, 1972	12.2	11.3 to 13.1		no count
Dec, 1973	15.7	14.6 to 16.7		no count

* = oil-covered shells

APPENDIX IV (continued, page 2) - Duxbury Reef Statistics

C. Limpets, *Collisella spp*.

Berm transects: A-8,9 = 20 square meters

Date	Live Sample Mean per m.^{2}	95% confidence interval for population mean
Nov, 1964	28.7	(data not available)
June, 1968	28.5	
May, 1969	30.0	
Mar, 1970	29.0	
June, 1970	28.6	
Apr, 1971	16.1	6.0 to 26.1
July, 1971	12.4	5.5 to 19.3
Aug, 1971	19.7	9.6 to 29.7
Oct, 1971	11.1	6.6 to 15.5
Dec, 1971	24.8	12.5 to 37.0
Apr, 1972	45.0	17.2 to 72.7
July, 1972	37.6	16.7 to 58.4
Apr, 1973	50.4	26.8 to 74.0
July, 1973	31.5	15.0 to 47.8

Berm transects: A-8,9,10 = 30 square meters   L=live, D=dead

Date	Sample mean per m.^{2}	95% confidence interval for population mean
Apr, 1971	31.9L, 9.3D	16.8 to 47.0L, 2.5 to 16.0D
July, 1971	24.6L, 5.3D	13.5 to 35.7L, 1.8 to 8.9D
Aug, 1971	31.0L, 4.9D	19.0 to 43.0L, 1.3 to 8.6D
Apr, 1972	82.1L, 0.8D	47.4 - 116.9L, 0.3 to 1.4D
July, 1972	55.2L, 0.8D	34.6 - 75.9L, 0.3 to 1.4D
Apr, 1973	84.9L, 0.9D	54.0 - 116.0L, 0.4 to 1.4D

D. Acorn barnacles, *Balanus glandula* and *Chthamalus dalli*

Berm transects: A-8,9,10

Date =	JULY, 1971	APRIL, 1972	APRIL, 1973
number in sample, n =	304 $dm.^2$	300 $dm.^2$	300 $dm.^2$
sample mean/$dm.^2$, $\bar{X}$ =	13.5L, 5.2D	50.1L, 12.6D	81.8L, 7.1D
95% confidence interval, μ =	10.4 to 16.6L 2.8 to 7.6D	37.8 to 62.5L 9.1 to 16.1D	68.4 to 95.1L 5.8 to 8.3D
%Live, %Dead =	72.3%L, 27.7%D	79.9%L, 20.1%D	92.1%L, 7.9%D

E. SUMMARY FOR 13 TRANSECTS (live counts only)

See page 42 for species counted and sample mean for species.

no oil transects = B-3,4,5
+,++ oil transects = A-2,3; C-4,6
+++,++++ oil transects = A-1,5,7; B-1,2; C-1

Date	Square meters sampled	Sample mean	95% confidence interval for population mean	*T. funebralis* % of total count
June, 1969	120	91.3	62.7 to 119.8	34.4%
July, 1969	120	86.7	56.7 to 116.7	30.1%
Aug, 1969	120	97.4	67.6 to 127.3	34.7%
Apr, 1971	120	46.8	33.4 to 60.2	27.4%
July, 1971	119	67.5	52.0 to 83.0	43.8%
Aug, 1971	120	86.2	64.3 to 108.0	31.1%
Jan, 1972	101	68.9	50.1 to 87.7	35.1%
Apr, 1972	120	55.1	41.2 to 69.0	31.0%
July, 1972	120	82.5	64.5 to 100.6	24.2%

Tests for significant difference between population means on the following page.

Tests for significant difference between population mean per square meter for 13 transects noted on previous page.

Test for $H_o: \mu_1 = \mu_2$ $H_1: \mu_1 \neq \mu_2$

Reject H_o if test statistic $Z \geq 1.96$ or ≤ -1.96

Comparison μ_1 w μ_2	$\lvert \bar{X}_1 - \bar{X}_2 \rvert$	Decision	Interval estimate of difference
4/71 w 6/69	44.5	Reject H_o	13.0 to 76.0
w 7/69	39.9	Reject H_o	7.1 to 72.7
w 8/69	50.6	Reject H_o	17.9 to 83.3
w 7/71	20.7	Reject H_o	0.2 to 41.2
w 8/71	39.4	Reject H_o	13.8 to 65.0
w 1/72	22.1	H_o true	
w 4/72	8.3	H_o true	
w 7/72	35.7	Reject H_o	4.6 to 50.2
4/72 w 6/69	36.2	Reject H_o	4.5 to 67.9
w 7/69	31.6	H_o true	
w 8/69	42.3	Reject H_o	9.4 to 75.2
w 4/71	8.3	H_o true	
w 7/71	12.4	H_o true	
w 8/71	31.1	Reject H_o	5.2 to 57.0
w 1/72	13.8	H_o true	
w 7/72	27.4	Reject H_o	4.6 to 50.2

In tests for significant difference between population means for summer counts, H_o was true for the following comparisons:

Comparison	Test statistic Z =	$\lvert \bar{X}_1 - \bar{X}_2 \rvert$ =
7/69 w 7/71	1.1148	19.2
7/71 w 7/72	-1.2363	15.0
7/69 w 7/72	0.2351	4.2
8/69 w 8/71	0.5938	11.2
8/71 w 7/72	0.2560	3.7
8/69 w 7/72	0.8376	14.9

NOTE: The berm and mussel bed transects (A-8,9,10, and C-3) are not included in this group of 13 transects.

APPENDIX IV. SUMMARY FOR 13 TRANSECTS, MEAN NUMBER LIVE PER SQUARE METER
(continued, p.4)

P/number= species present/number of transects (counts available for selected dates only, m^2 are omitted from computation of mean)

13 transects A-1,2,3,5,7 B-1,2,3,4,5 C-1,4,6 120 m^2	A. xanthogrammica	A. elegantissima	Balanus/Chthamalus	Pollicipes sp.	Pachygrapsus sp. Hemigrapsus sp.	Cancer sp. Pugettia sp. Pagurus spp.	Mopalia sp.	Mytilus sp.	Platyodon sp.	Collisella spp.	Haliotis sp.	Littorina sp.	Tegula sp.	Acanthina sp.	Pisaster sp.	Strongylocentrotus sp.	Mean/square meter
June, 1969	1.5	1.6 P/3	P/3	1.1	P/1	.01 P/1	0.3	10.9 P/1	0.2 P/1	35.5 P/2		9.2 P/2	31.4	4.7	0.3	.08	91.3
July, 1969	1.5	1.6 P/3	P/3	0.9	P/1	P/1	0.2	6.3 P/1	0.2 P/1	44.4 P/2		9.2 P/2	26.1	1.8	0.3	.02	86.7
Aug, 1969	1.5	1.6 P/3	P/3	0.9	P/1	.02 P/1	0.2	6.4 P/1	0.2 P/1	44.3 P/2		9.2 P/2	33.8	4.7	0.4	.06	97.4
Apr, 1971	0.9	3.3 P/2	P/5	1.5	-0-	.03	0.5	10.8 P/1	0.4	17.2 P/1		-0- P/2	12.8	0.7	0.2	0.1	46.8
July, 1971 119m^2	0.9	1.1 P/2	P/6	2.5	.03	0.5	0.3	10.9 P/1	0.4 P/1	17.3 P/2		4.7 P/1	29.6	1.8	0.3	0.1	67.5
Aug, 1971	0.9	2.6 P/2	P/6	2.5	.01	.6	0.5	10.6 P/1	0.4 P/1	40.7 P/2		5.0 P/2	26.8	0.9	0.2	.07	86.2
Jan, 1972 101m^2	0.7	3.1 P/4	P/6	.07 P/1	.04	.06	0.2 P/2	10.9 P/1	0.6 P/1	29.9 P/4		1.1 P/2	24.2 P/2	.05 P/1	0.1	0.2	68.9
Apr, 1972	0.4	3.9 P/3	1.5 P/7	2.5	.03	.01	0.5	11.8 P/1	0.6 P/1	20.2 P/2		0.2 P/2	17.1	0.6	0.2	0.3	55.1
July, 1972	0.5	4.2 P/3	3.1 P/7	2.3	.03	0.2	0.6	12.2 P/1	0.6 P/1	37.2 P/2		9.6	20.0	1.1	0.2	0.3	82.5

IMPORTANT

FOUNDATION CHARTS
(DATA)

Report IV completed

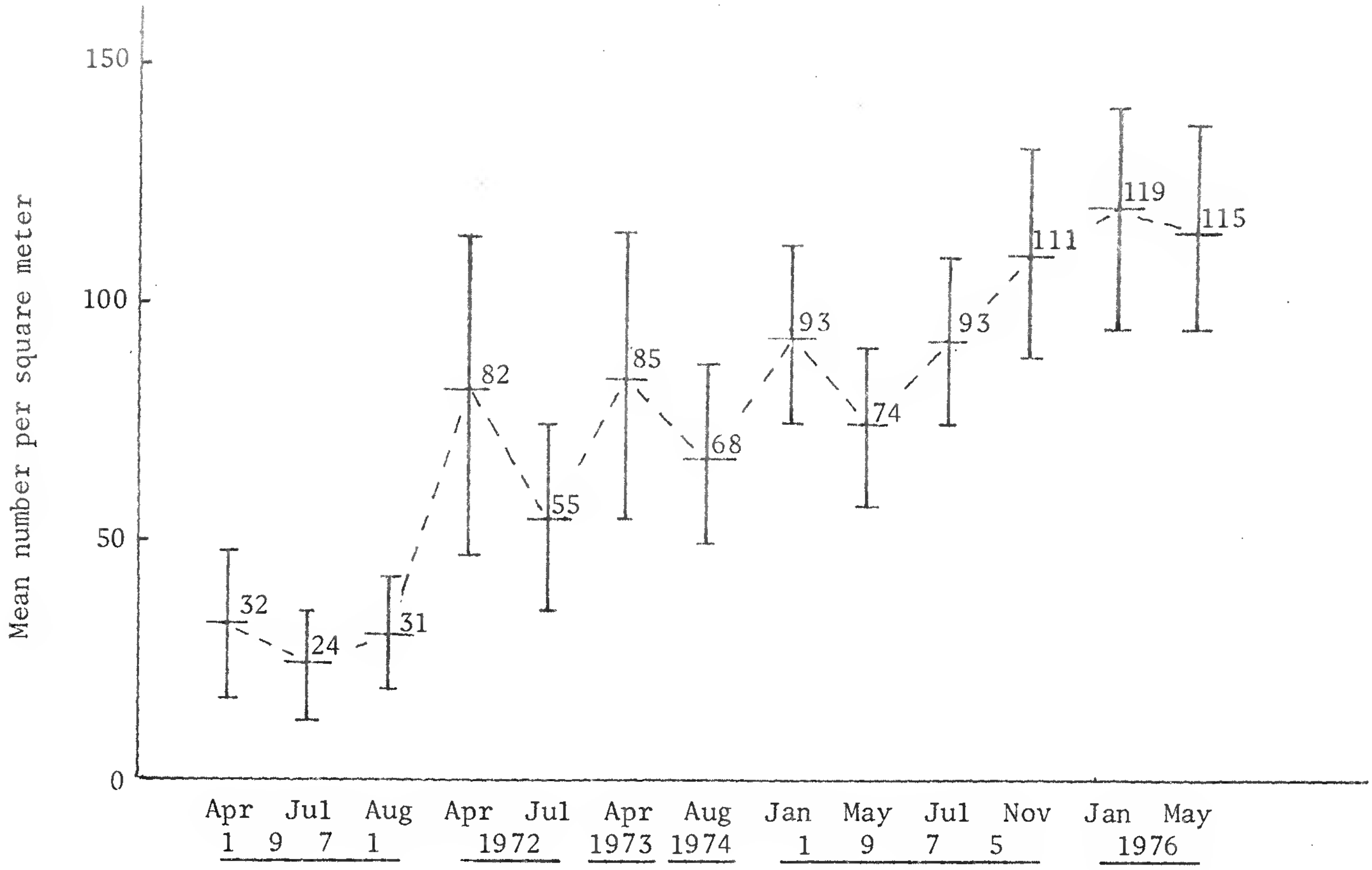

Figure Live *Collisella spp*. for Duxbury Reef Berm A-8,9,10: 30 square meters

—+— sample mean

95% confidence interval for population mean

IV 5
III 8

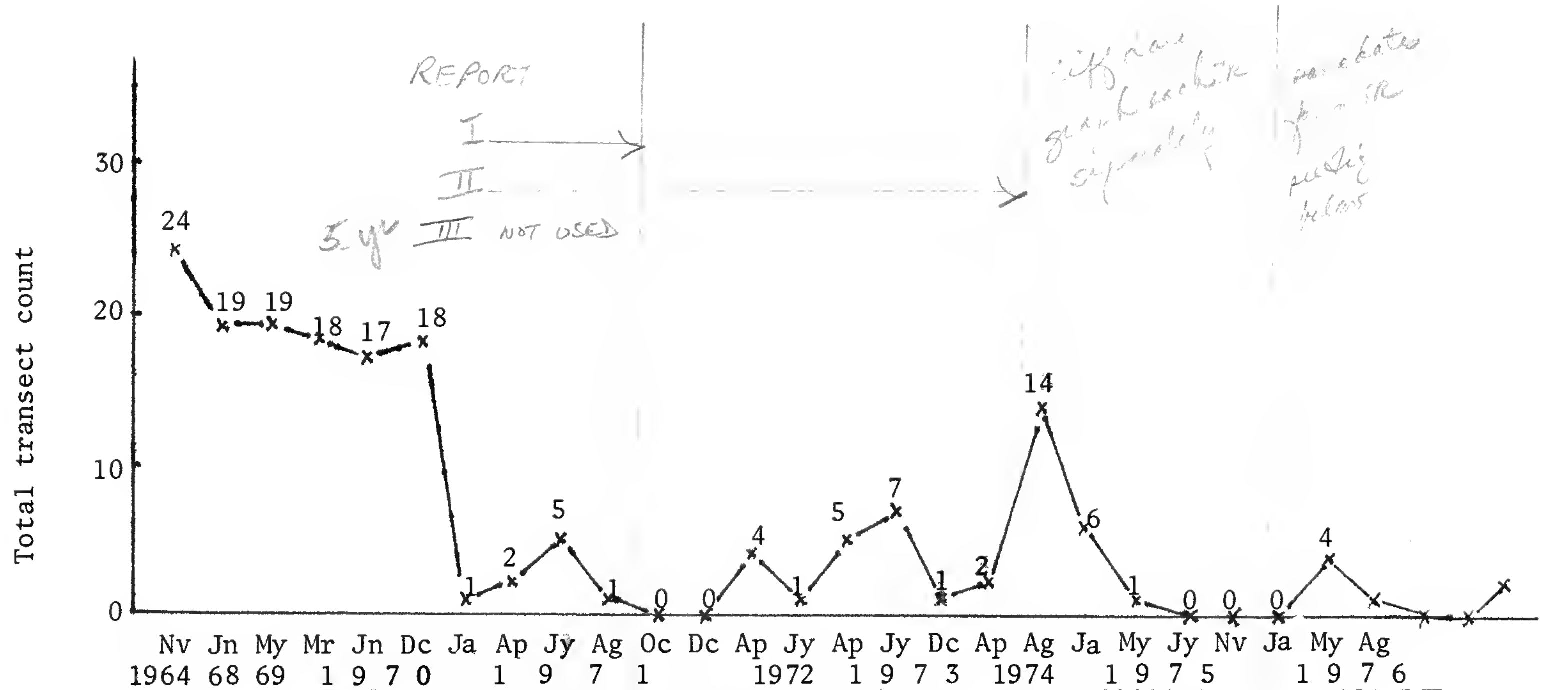

Figure Total transect count of *Littorina planaxis* for Duxbury Reef, Berm A-8,9: 20 square meters

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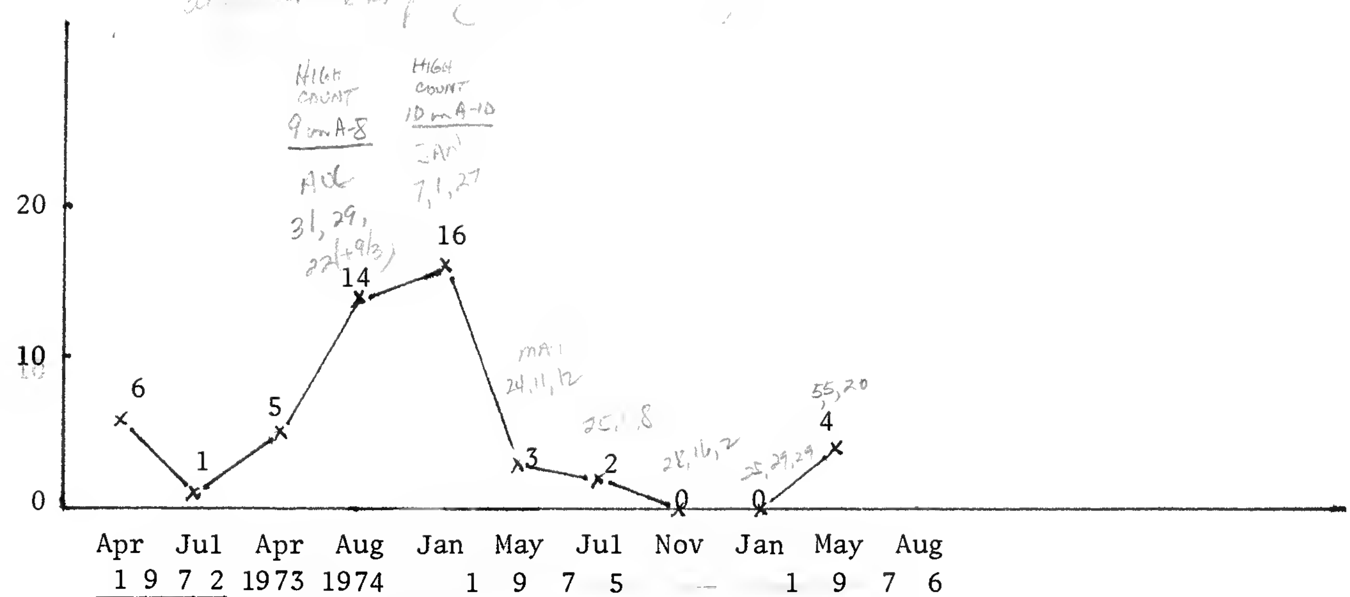


Figure Total transect count of *Littorina planaxis* for Duxbury Reef, Berm A-8,9,10: 30 square meters

IV 6
III 5a

LITTORINA PLANAXIS on DUXBURY REEF BERM

X = different dates
○ = AB-8 + 9 ONLY
✓ = same date

TRANSECT TOTALS	11/64	6/68	5/69	3/70	6/70	12/70	1/71	4/71 (diff dates)	7/71 (diff dates)	8/71 (diff dates)	10/71	12/71	4/72	7/72		
AB-8							I=1	2(15)	1	{ I=1 0	0	0	3(15)	0		
AB-9								0	4	{ 0	0	0	1	1		
AB-10	NC	NC	NC	NC	NC	NC	NC	4	7/22 0	8/7 0	NC	NC	[illegible]	0		
total	(24)	(19)	(19)	(18)	(17)	(18)	(1)	~~6~~	~~5~~	~~X~~	( )	( )	6	1		

	4/73	7/73	12/73	4/74	8/74	1/75	5/75	7/75	11/75	1/76	5/76	8/13/76	12/3/76	2/12/77	4/22/77	
AB-8	1	{ Σ	{ II=1	3/29/74 0	8/29+31 9	1	0	0	{ 11/29=1 0	0	4 ✓	0	0	0	2	
AB-9	4	{ 7	}	2	5	5	1	0	{ 0	0 ✓	0 ✓	1	0	0	0	
AB-10	0	NC	NC	NC	1/16 6	10	2	2	0	0 ✓	0	0	0	0	0	
	5	(7)	(1)	(2)	~~14~~	~~16~~	~~3~~	~~2~~	~~0~~	0	4					
Mean/square meter	Strongylocentrotus sp.	Pisaster sp.	Acanthina sp.	Tegula sp.	Littorina sp.	Haliotis sp. (4/6, 1/7, 1/27)	Acmaea spp.	Platyodon sp.	Mytilus sp.	Mopalia sp.	Cancer sp. Pugettia sp. Pagurus spp.	Pachygrapsus sp. Hemigrapsus sp.	Pollicipes sp.	Balanus/Chthamalus	A. elegantissima	A. xanthogrammica

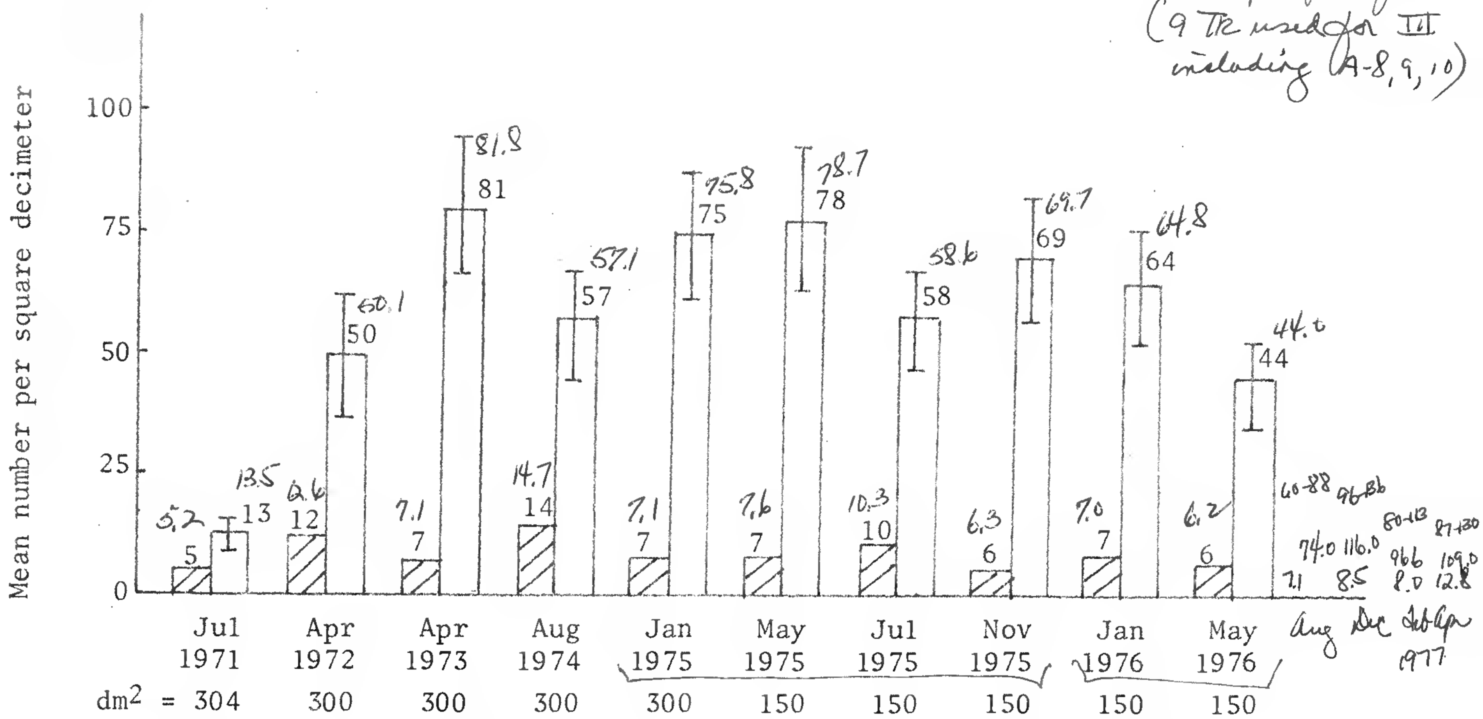


Figure Balanus glandula and Chthamalus dalli for Duxbury Reef, Berm A-8,9,10

dead live 95% confidence interval for population mean

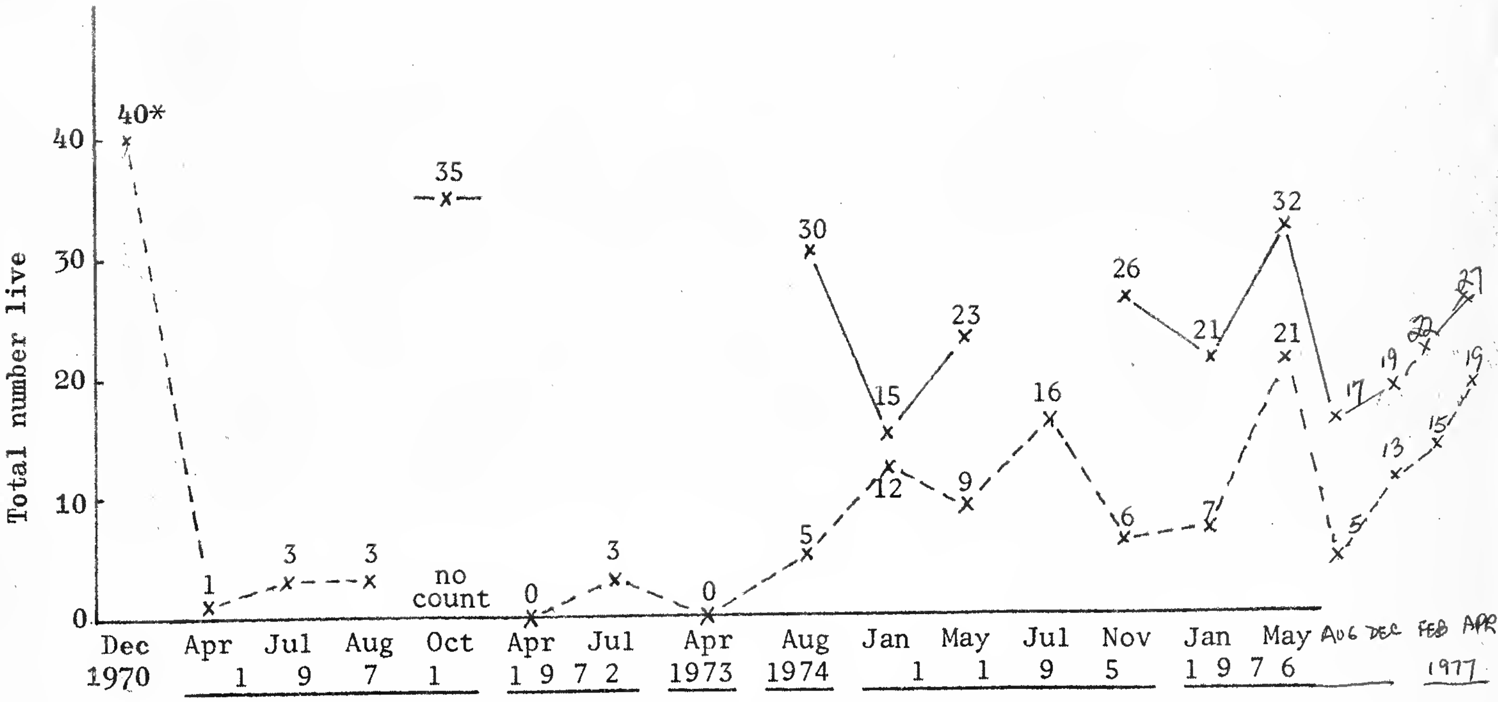


Figure 3. Total counts of *Pachygrapsus crassipes* for Duxbury Reef berm transects and for berm crevices

x— — — transact counts for A-8,9,10 = 30 m.^{2} x——— berm crevice counts

* pre-oil spill count for A-8,9

IV 8

Gordon L. Chan:

The Five-Year Recruitment of Marine Life after the 1971 San Francisco Oil Spill

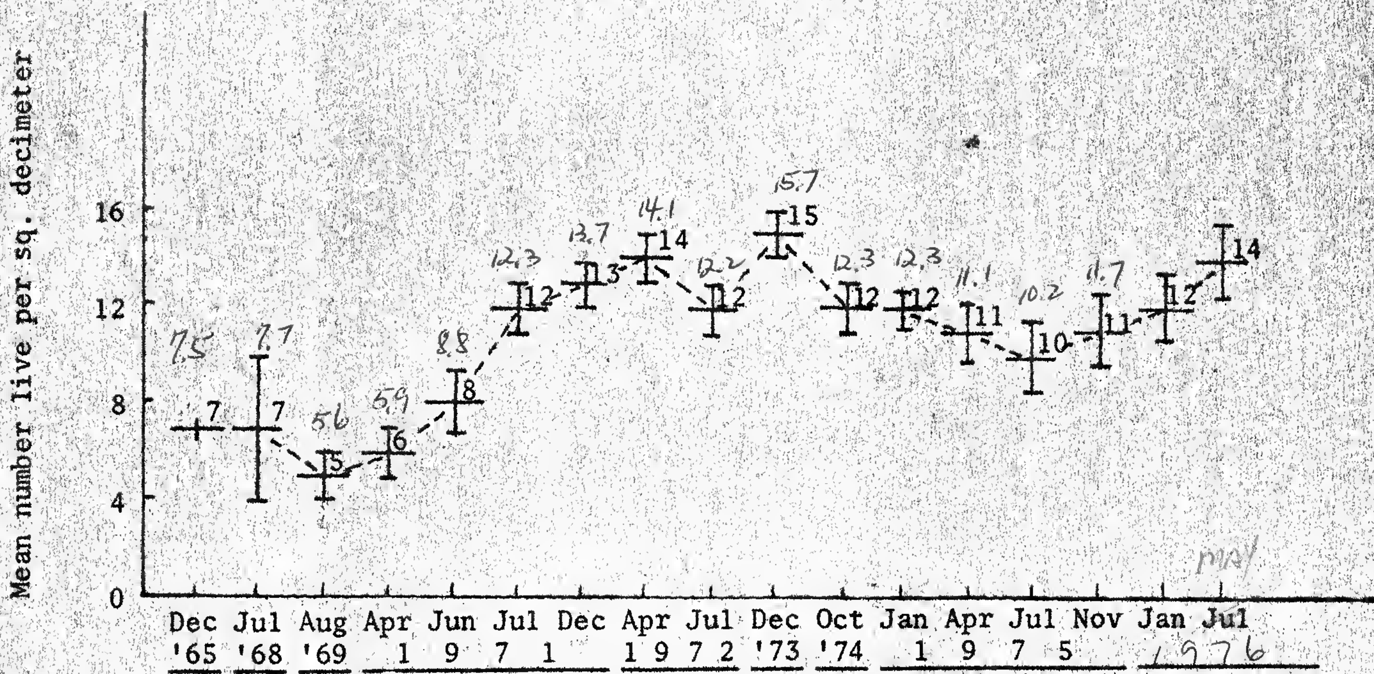


Figure Live *Mytilus californianus* for Duxbury Reef, Area C transect, square decimeter sampling

—+— sample mean

I 95% confidence interval for population mean

MAY = 14.0 (12.2-15.7)
JUL = 12.2 (10.8-13.7)
NOV = 13.4 (11.8-15)
1977 JAN = 12.3 (11-14.7) 13.7
MAY = 11.5 (10-12.8)

III 11(b)

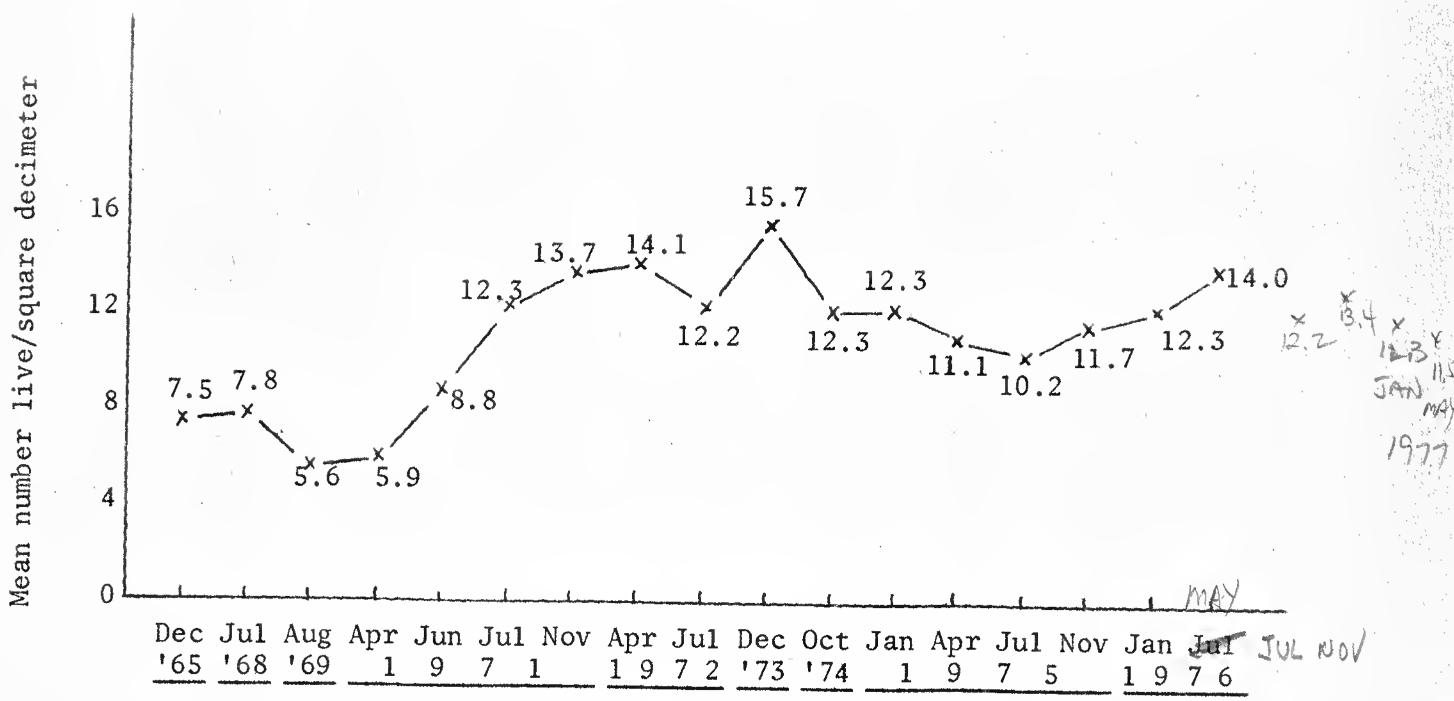
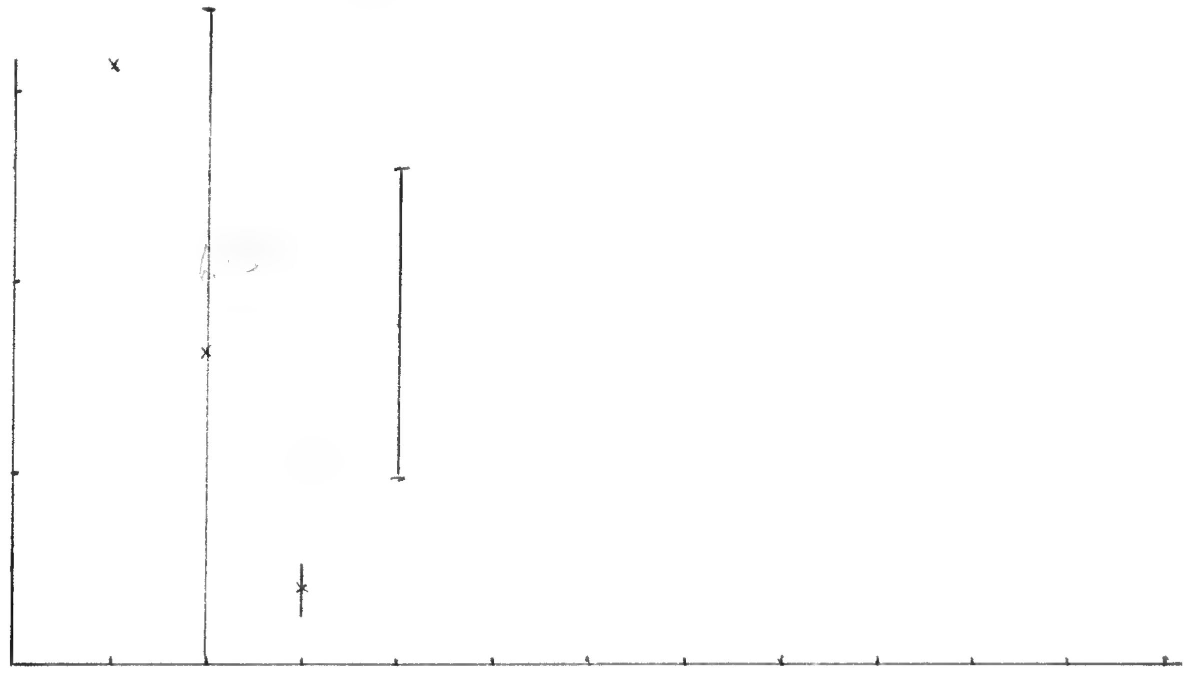


Figure 6. Live *Mytilus californianus* for Duxbury Reef, Area C transect, square decimeter sampling

12.2 13.4

1977= 12.3, 11.5



7/72   1/75   4/75   7/75   11/75   1/76   5/76   7/76   11/76 | 1/77   5/77

95% CI   -6 to 32   ~~-6 to 32~~ -1 to 13.8 | ~~1 to~~ ~~1 to~~ 1 to 2   3.9 to 10.3   6.6 to 11.2   4.6 to 8.6   2.2 to 8.0   6.5 to 12.3   4.5 - 7.7   4.0 - 6.7   2.0 - 9.8   3.1 to 7.7 | 3.8 - 7.6   2.7 - 6.1

$\bar{X}$ =   12.6   6.4 (5) | 1.5   7.1   8.9   6.6   5.1   9.4   6.1   5.4   5.9   5.4 | 5.7   4.4

32 to 23.9
14.6
Undershells counted

Dead Mytilus / sq meter

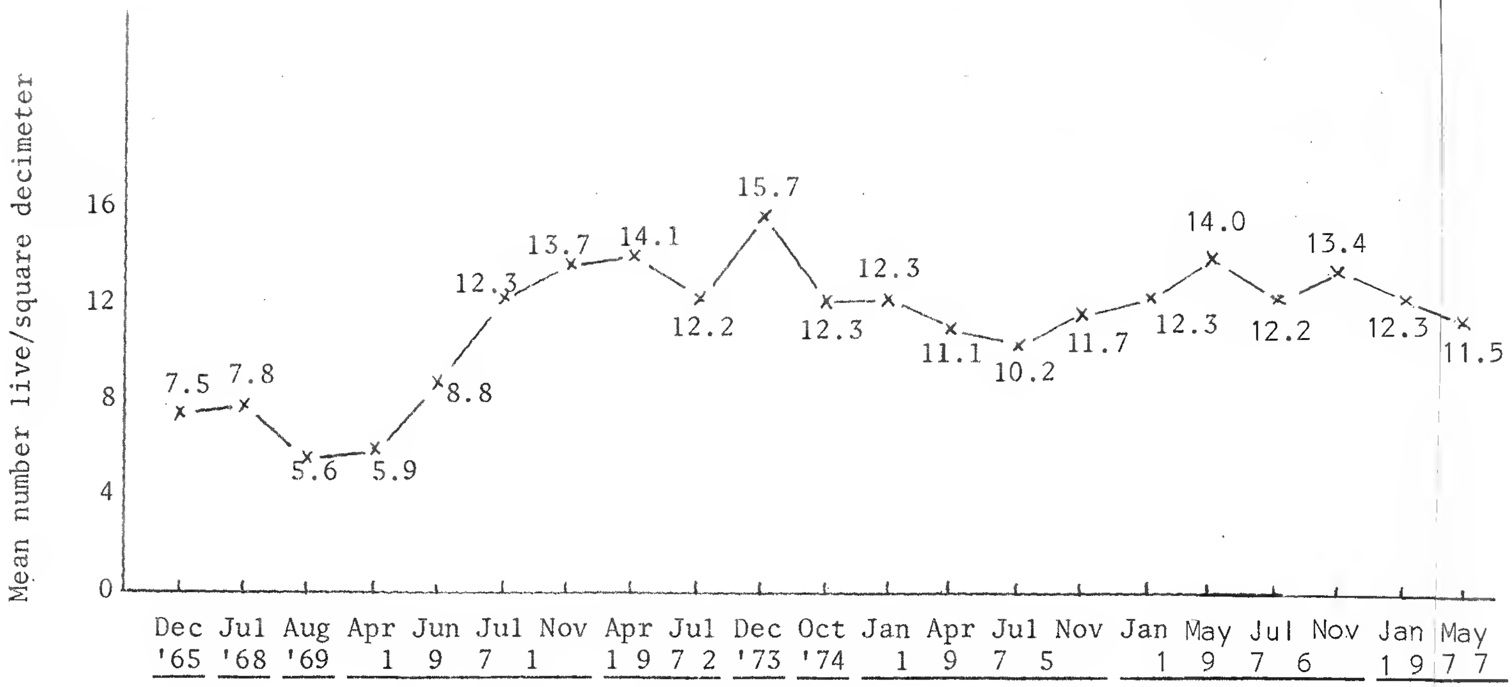


Figure Live *Mytilus californianus* for Duxbury Reef, Area C transect, square decimeter sampling

TI 9a

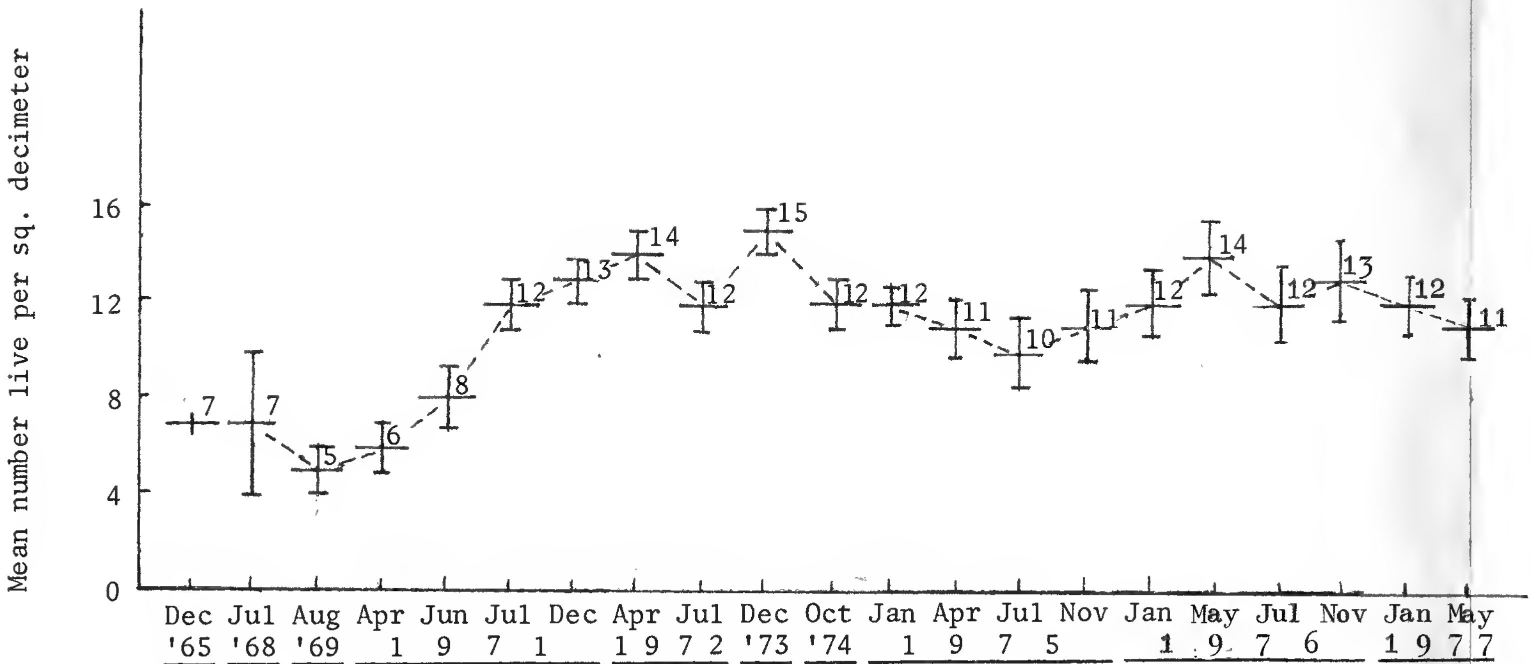


Figure Live *Mytilus californianus* for Duxbury Reef, Area C transect, square decimeter sampling

—+— sample mean

I 95% confidence interval for population mean

IV 9b

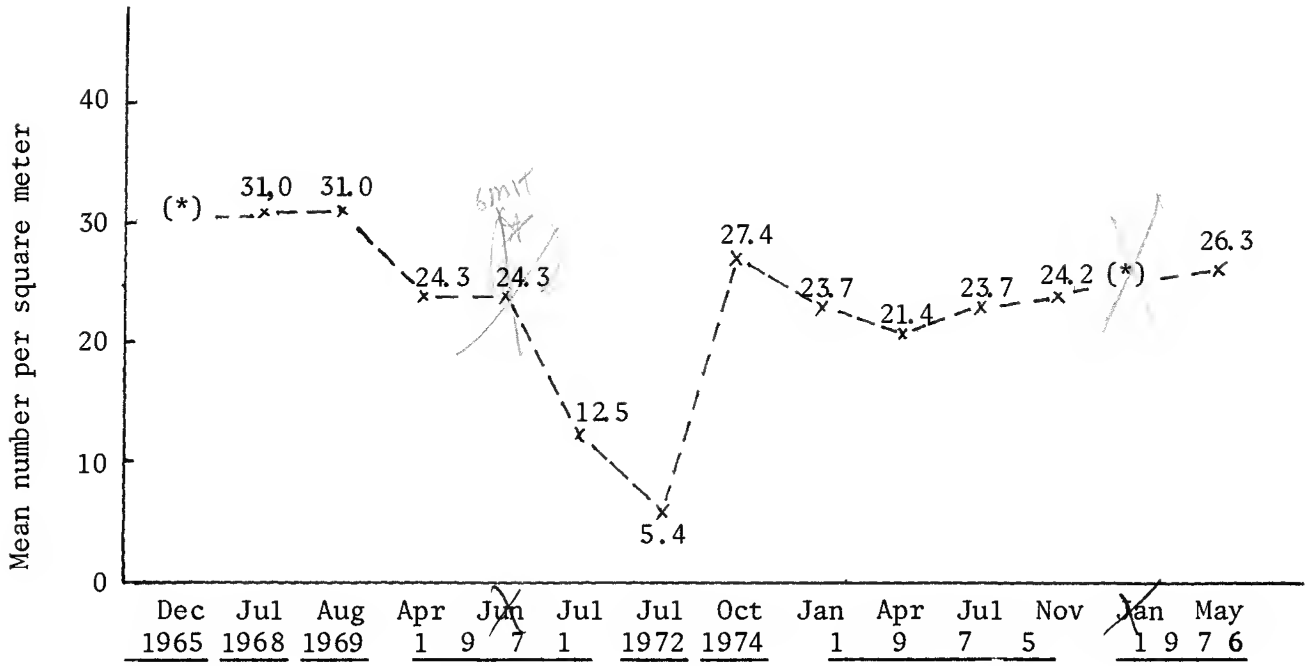


Figure Sample means of *Pollicipes polymerus* on Duxbury Reef, transect C-3 mussel bed: 10 square meters
(*) = present, no count

1976 Jul 26.4
1976 Nov 30.6
19 30.1
31.4

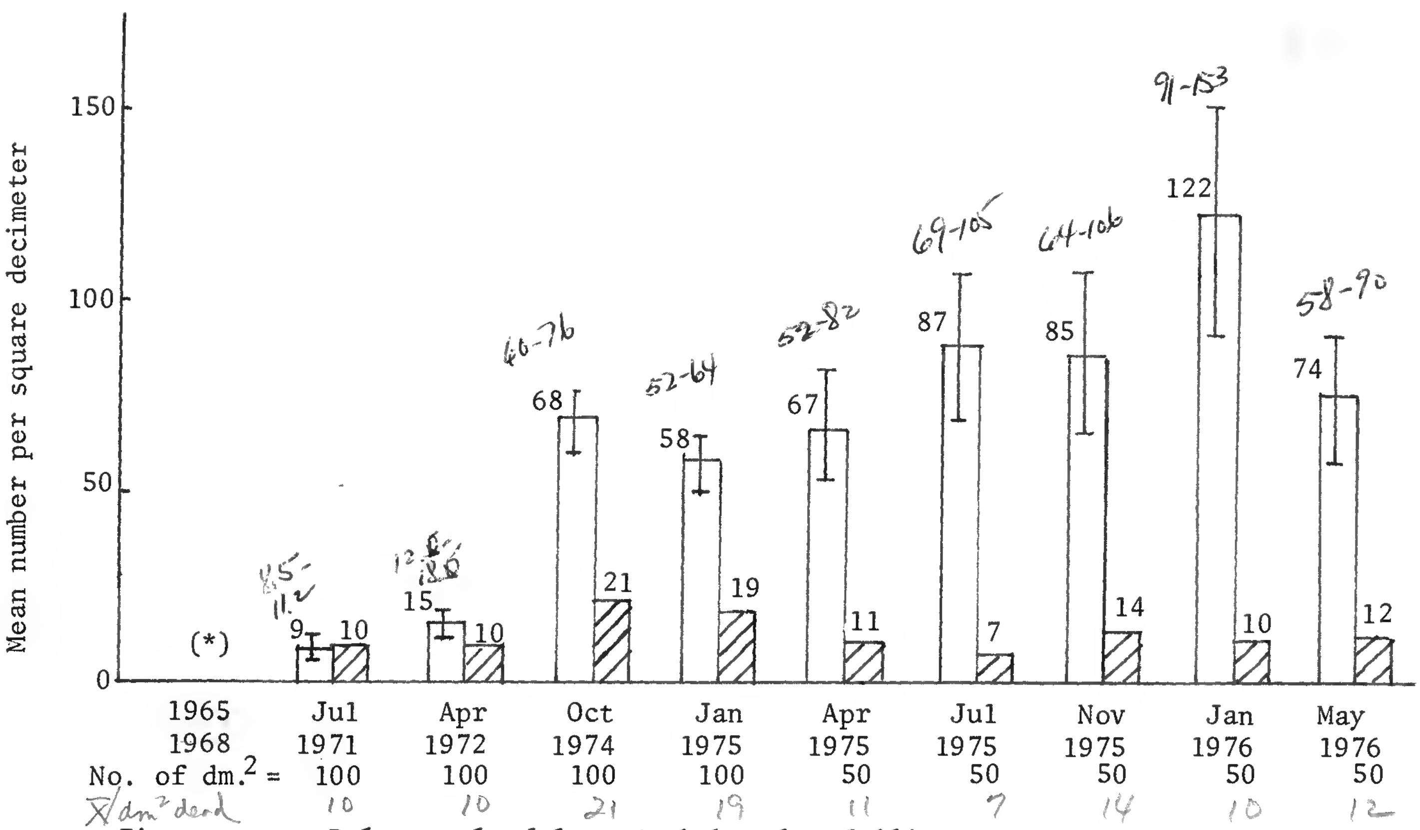


Figure *Balanus glandula* and *Chthamalus dalli* for Duxbury Reef, Mussel bed transect C-4: square decimeter sampling

(*) = present, no count

live dead

95% confidence interval for population mean

July 1976 158 L, (119–197) 14 D

Nov 1976 304 L (242–367) 16 D

Jan 1977 263 L (214–312) 23

May 1977 225 (176–274) 36

Reprint from Proceedings of

1977 Oil Spill Conference
(Prevention, Behavior, Control, Cleanup)
March 8-10, 1977, New Orleans, Louisiana

American Petroleum Institute
2101 L Street, N.W.
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THE FIVE-YEAR RECRUITMENT OF MARINE LIFE AFTER THE 1971 SAN FRANCISCO OIL SPILL

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ABSTRACT

On January 18, 1971, two Standard Oil tankers collided underneath the Golden Gate Bridge, releasing about 840,000 gallons of Bunker C fuel. An estimated 4.2 million to 7.5 million intertidal invertebrates, chiefly barnacles, were smothered by the oil. Five-year observations of marine life recruitment following the spill indicate that population densities of some marine species have significantly increased in the San Francisco Bay area intertidal zones at Sausalito and Duxbury Reef. With some fluctuations, the barnacles ***Balanus glandula*** *and* ***Chthamalus dalli*** *have increased from July 1971 to May 1976—from 93 to 189 barnacles per* dm^2 *at Sausalito and from nine to 34 per* dm^2 *at Duxbury Reef. The large bed of mussels,* ***Mytilus californianus****, showed a steady rise from 5.9/*m^2 *in April 1971 to 14.0/*dm^2 *in July 1976. The density of mobile organisms, such as limpets, snails, crabs, and starfish, all show cyclical variations; some show an overall increase. The limpets,* ***Collisella spp****., which suffered high mortality during the spill have increased threefold over pre-oil counts.*

In 1975, some significantly low sample means were recorded for barnacles in Sausalito and for 18 composite species at Duxbury Reef, probably due to natural ecological forces. The five-year recruitment (1971–76), however, shows no evidence of lasting detrimental effects of Bunker C oil on the populations of marine life within the transect sites.

INTRODUCTION

Following the 1971 San Francisco oil spill when two Standard Oil tankers collided under the Golden Gate Bridge releasing about 840,000 gallons of Bunker C oil, studies were conducted on the marine life in selected affected sites. Some major conclusions from my previous reports of these studies[1, 2] were:

1. A range of 4.2 million to 7.5 million organisms, primarily barnacles, were smothered in 37 marine transects; an estimated 25% were dead immediately following the spill
2. In the three years after the spill, recruitment of marine populations in the transects had doubled in sample mean for limpets, barnacles, mussels, and periwinkles; only the population of the striped shore crab, *Pachygrapsus crassipes*, remained low
3. By 1974, only small traces of oil remained and no lingering effects of Bunker C fuel on marine life were observed.

In the period 1971–76, the marine populations within the transects have been studied and monitored to determine the cyclical nature of these organisms. Continuing studies are expected to show that these marine intertidal populations will survive without any effects from the 1971 oil spill.

Sampling methods and procedures

The populations of marine organisms were observed in 37 randomly selected transects, usually 10 meters long, some established prior to the oil spill. Square-meter quadrat frames with at least 10 square-decimeter sections were used to count the intertidal organisms.

Statistical sample means and 95% confidence intervals for population means were computed. Statistical analysis using the .05 level was applied to test significant difference between population means of different sampling dates and different transects or groups of transects.

Observations and findings to date

Sausalito in the Sausalito intertidal transect, the five-year study showed a remarkable cyclical variation in barnacle densities. In Figure 1, the density of barnacles at Sausalito, a locality with heavy oil coverage in 1971, is compared to that of Ft. Baker, an adjacent intertidal site where no oil was deposited. The two areas were similar in density immediately after the spill—93/dm^2 and 89/dm^2, respectively. The curve for both sites climbed in 1972 and then dropped in 1975 to 72/dm^2 at Sausalito in July and 37/dm^2 at Ft. Baker in February. By 1976, there was no significant difference between the population means of 1971 and 1976 for Ft. Baker. However, for Sausalito, there was a significant difference between the 1971 and 1976 populations means; the May 1976 live sample mean of 189/dm^2 at Sausalito also is more than double Ft. Baker's 76/dm^2.

The cyclical variation in density emphasizes the point that drastic population declines may occur without a major catastrophe such as an oil spill. The 1975 barnacle declines may have been caused by severe storm-wave action during the early part of the year. At any rate, there is no evidence that these declines were caused by major pollution factors. The intertidal zone is subjected to many variables, some of which may be natural ecological forces (large waves, etc.) capable of detrimental effects. Recovery appears to have taken place in 1976.

Likewise, transect counts of mobile crabs at Sausalito show great fluctuations. The Seal Rock transect count, Figure 2, was zero in July of 1975, while the adjacent 50-meter transect had a high total count of 74. The variability of these counts often can mask the actual damage this species suffered from an oil spill.

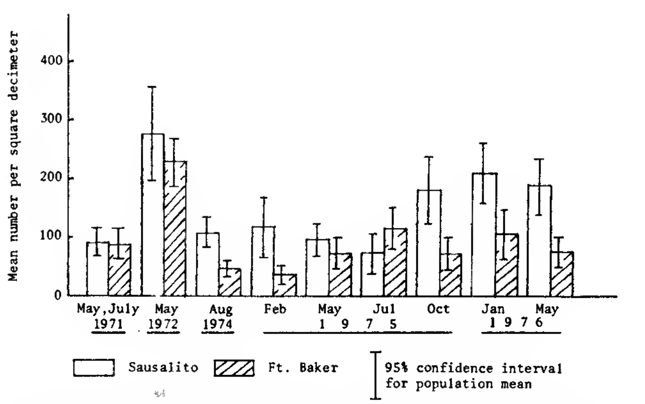

Figure 1. Comparison of live barnacles, *Balanus glandula* and *Chthamalus dalli*, for transects in Sausalito (oil) and Ft. Banker (no oil)

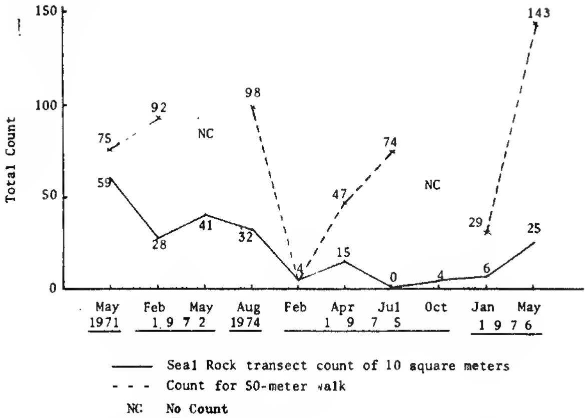

Figure 2. Total counts for crabs, *Pachygrapsus crassipes* and *Hemigrapsus nudus*, at Sausalito

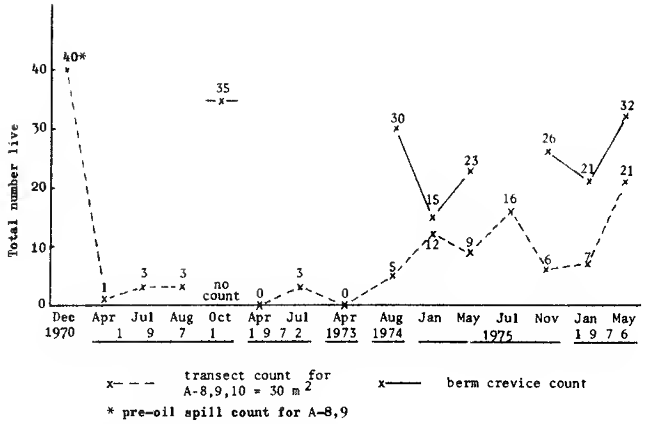

Figure 3. Total counts of *Pachygrapsus crassipes* for Duxbury Reef berm transects and for berm crevices

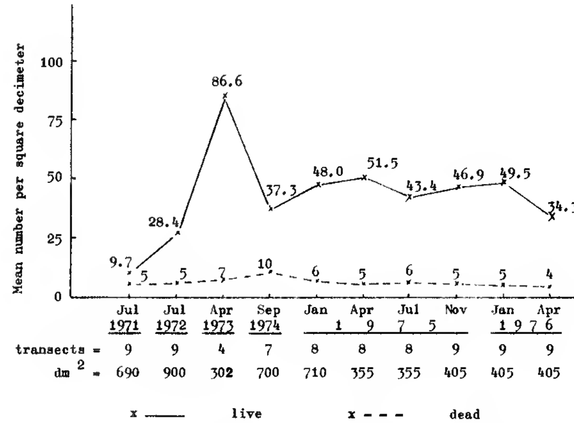

Figure 4. Square decimeter sampling for *Balanus glandula* and *Chthamalus dalli* for Duxbury Reef; nine transects, including the berm and the mussel bed

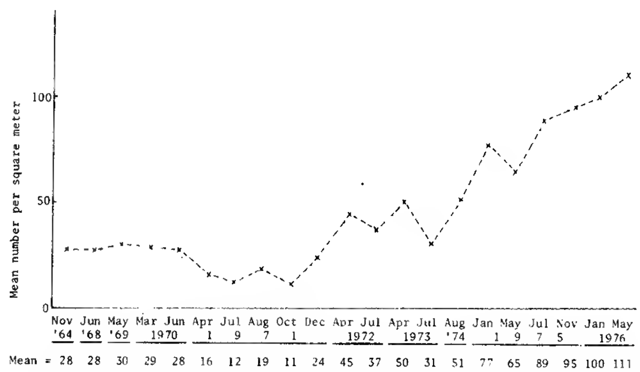

Figure 5. Sample means for live *Collisella spp.* for Duxbury Reef Berm A-8,9; 20 square meters

Duxbury Reef. At Duxbury Reef, the exposed outer coast shale reef, the shore crab population was seriously low in transect counts immediately after the spill[1,2](Figure 3). The total live counts for the berm had dropped to levels ranging from three to zero for 1971 and 1972, as compared to the pre-oil spill count of 40. Recently Guard, Hunter, and DiSalvo[3] reported that such crab disappearances may have been partially due to the adverse effects of the water-soluble components (Acetophenone) in the water. Kittredge (1973) showed that the water-soluble components of fuel oils seriously impaired feeding and sexual behavior of crab species at parts per billion concentrations. After direct observations at Duxbury Reef, I had reported that suffocation by oil appeared to be the main contributing cause of death for these crabs immediately after the spill. Nevertheless, Figure 3 shows that recent counts have risen significantly over the 1971-72 counts.

Other major Duxbury Reef species development:

1. The barnacle population had suffered the highest mortality during the spill. Square decimeter sampling in 1971 yielded 27% dead for the berm and 51% dead for the mussel bed. Figure 4 is a composite of available data for nine transects, beginning with summer of 1971, with 9.7/dm² live and 5/dm² dead. April 1973 sampling of four transects, primarily on the berm, shot up to 86.6/dm² live barnacles and subsequently steadied out between 34 and 51 from 1974 to 1976 for the total transects. Dead barnacles remained fairly consistent, ranging from 4.7 to 10.2/dm². In general, the cyclical recruitment of barnacles on the reef is quite satisfactory.
2. The limpets, *Collisella spp.*, continue to increase in the berm transects, (Figure 5) with the most recent sample mean of 111/m² in 1976. Data for seven other Duxbury transects of 60 m² also indicate overall increase.
3. The vast mussel beds, *Mytilus californianus*, show steady, higher sample means as compared to the oil spill months of 1971, (Figure 6) with the most recent sampling of July 1976 at 14.0/dm² live mussels.
4. Other marine species:
   a. The small population of the periwinkle, *Littorina planaxis*, is stable; the counts are low, but the species survives.
   b. The seastar, *Pisaster ochraceous*, shows some decline in the established transect, but is abundant in adjacent crevices.
   c. The goose barnacle, *Pollicipes polymerus*, is a stable population, from 21 to 27/m² over the past five years on the mussel bed transect.
   d. The owl limpet, *Lottia gigantea*, also illustrates stable transect counts with the recent 1976 total 19/10 m²
   e. The black turban snail, *Tegula funebralis*, generally has maintained a population comparable to pre-oil spill density, ranging between 24 and 41/m² for 1971-76 in 11 transects of 100m.² The exceptions are the April 1971 mean of 15.5/m² soon after the oil spill, and the April 1972 mean of 20.5/m²; each of these population means was significantly lower than all other counts of the five-year period and pre-oil spill period. Counts for 1974-76 have stayed within the pre-oil spill range of 31-40/m².

Excluding the recruitment of barnacles, the overall curve for 18 other species on Duxbury Reef shows a leveling off of invertebrates, with the sample mean fluctuating since the oil spill between 46 and 86/m² for 13 transects (Figure 7). The low of 46/m² was observed just after the oil spill, and a similar low of 47/m² was recorded in April 1975; this latter figure probably was a result of natural forces. The present number live per square meter is holding steady at the 52 to 60 range and has not returned to the higher 86 to 91/m² range of the pre-oil spill year, 1969.

Stinson Beach. The open beach transects at Stinson Beach and Drakes Beach show very slight overall gains in density of *Emerita analoga*, the

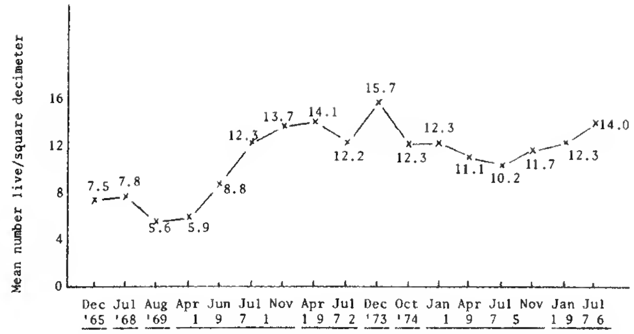

Figure 6. *Live Mytilus californianus* for Duxbury Reef, Area C Transect, square decimeter sampling

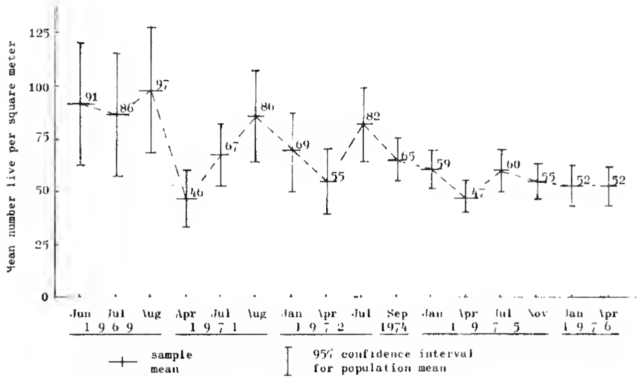

Figure 7. Summary of square meter sampling for all species counted, Duxbury Reef, 13 transects; 120 square meters

mole crab, and *Nepthys californiensis*, the beach worm. However, the present densities have not approached the pre-oil status for this area.

CONCLUSION

During five years of direct observation of marine organisms in transects which had been covered by the 1971 San Francisco oil spill, I have detected some unusual population lows for a few intertidal species. At Sausalito, the 1974-75 drastic population decline in barnacle species paralleled the same low range for population mean in April 1971 immediately after the oil spill (Figure 1). Likewise, at Duxbury Reef, the overall curve for 18 marine species, excluding barnacles, declined to 47/m² in April 1975, similar to the April 1971 low of 46/m² after the suffocation of marine life occurred (Figure 7). In both cases, there was no observable major catastrophe attributable to man-made pollutions for the 1975 declines. I have concluded that such lows were the result of natural ecological forces such as large waves.

The intertidal zone is an area of dynamic ecological forces; evaluating marine life density by grouping all species into a single population curve is not totally accurate. The overall picture does indicate that the marine life in the study transects are in a general state of good health. In practical terms, each individual species must be studied as a single unit because each faces different ecological problems within an intertidal marine niche. In that light, my study has revealed that barnacles, limpets, mussels, periwinkles, starfish, turban snails, and the shore crabs all have shown steady population recruitment in the five years after the 1971 San Francisco oil spill.

ACKNOWLEDGEMENTS

This research is supported by the Board of Trustees of the College of Marin. Special thanks are extended to my assistants Carl Zeigler and my wife Maxine.

REFERENCES

1. Chan, G., 1973. A study of the effects of the San Francisco oil spill on marine organisms. *Proceedings of the Joint Conference on Prevention and Control of Oil Spills*. American Petroleum Institute, Washington, D.C.
2. Chan, G., 1975. A study of the effects of the San Francisco Oil Spill on marine life, Part II: recruitment. *Proceedings of the Joint Conference on Prevention and Control of Oil Pollution*. American Petroleum Institute, Washington, D.C.
3. Guard, H. E., L. Hunter, and L. H. DiSalvo, 1975. Identification and potential biological effects of the major components in the sea water extract of a bunker fuel. *Bulletin of Environmental Contamination and Toxicology*. 14:4, p400. Springer-Verlag, New York
4. Takahashi, F. T. and J. S. Kittredge, 1973. in *The Microbial Degradation of Oil Pollutants*,D. G. Ahearn and S. P. Meyers, eds. Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana

OIL REPORT III

original graphs

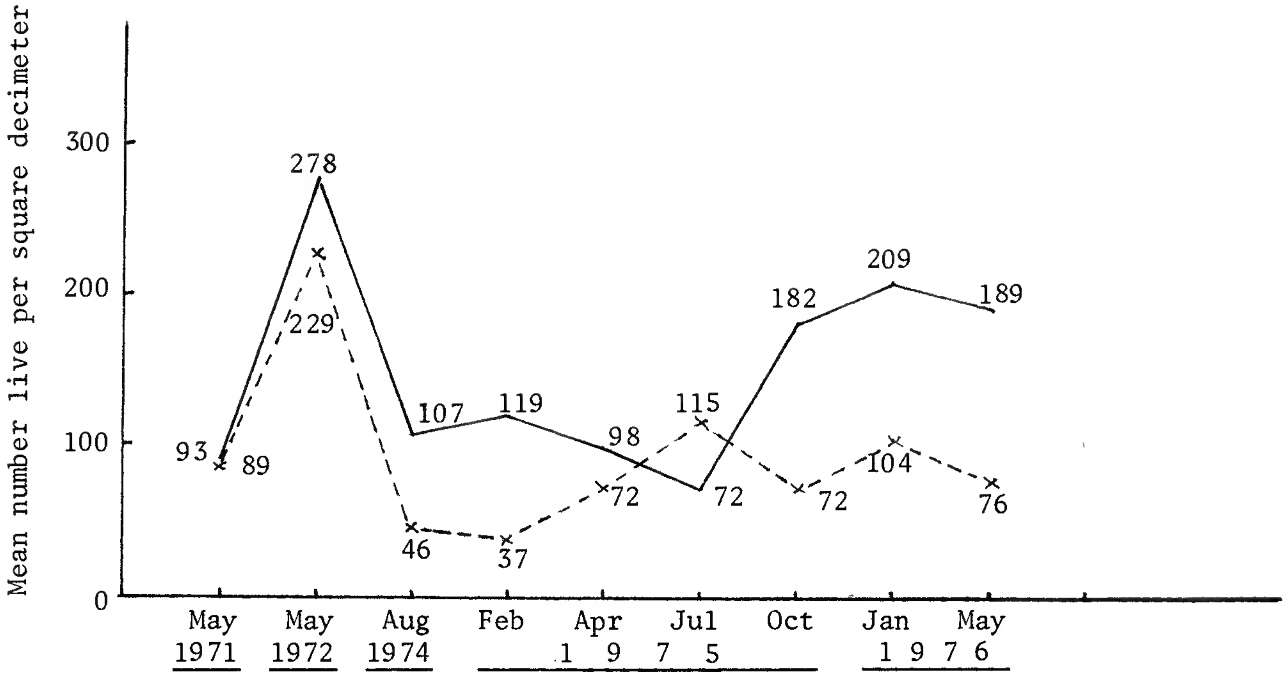

Figure Comparison of barnacles, *Balanus glandula* and *Chthamalus dalli*, for transects in Sausalito (oil) and Fort Baker (no oil); sampling of 50 square decimeters in each transect.

——— Sausalito - - - Fort Baker

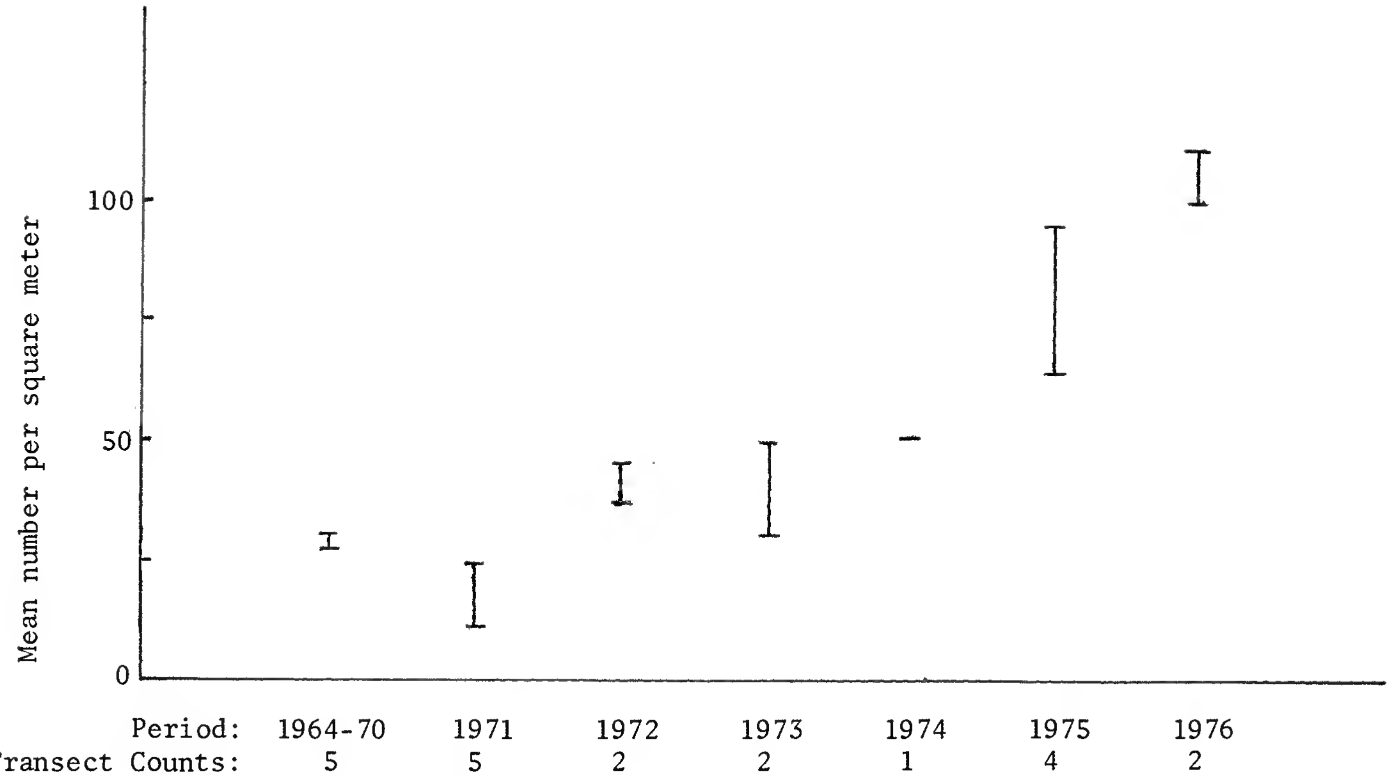

Figure Live *Collisella spp*. for Duxbury Reef Berm A-8,9:
Range of sample means for transect count of 20 square meters

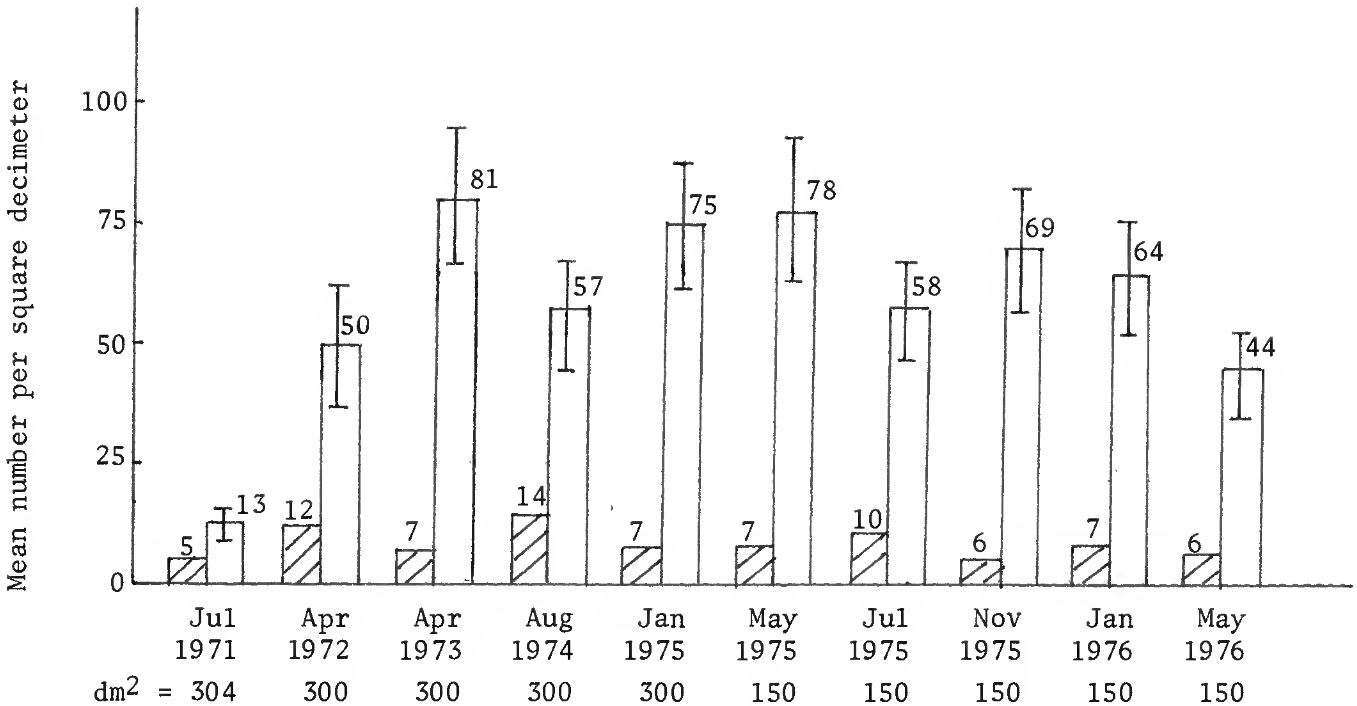

Figure *Balanus glandula* and *Chthamalus dalli* for Duxbury Reef, Berm A-8,9,10

dead live 95% confidence interval for population mean

Analysis
* WORKSHEET
[illegible]

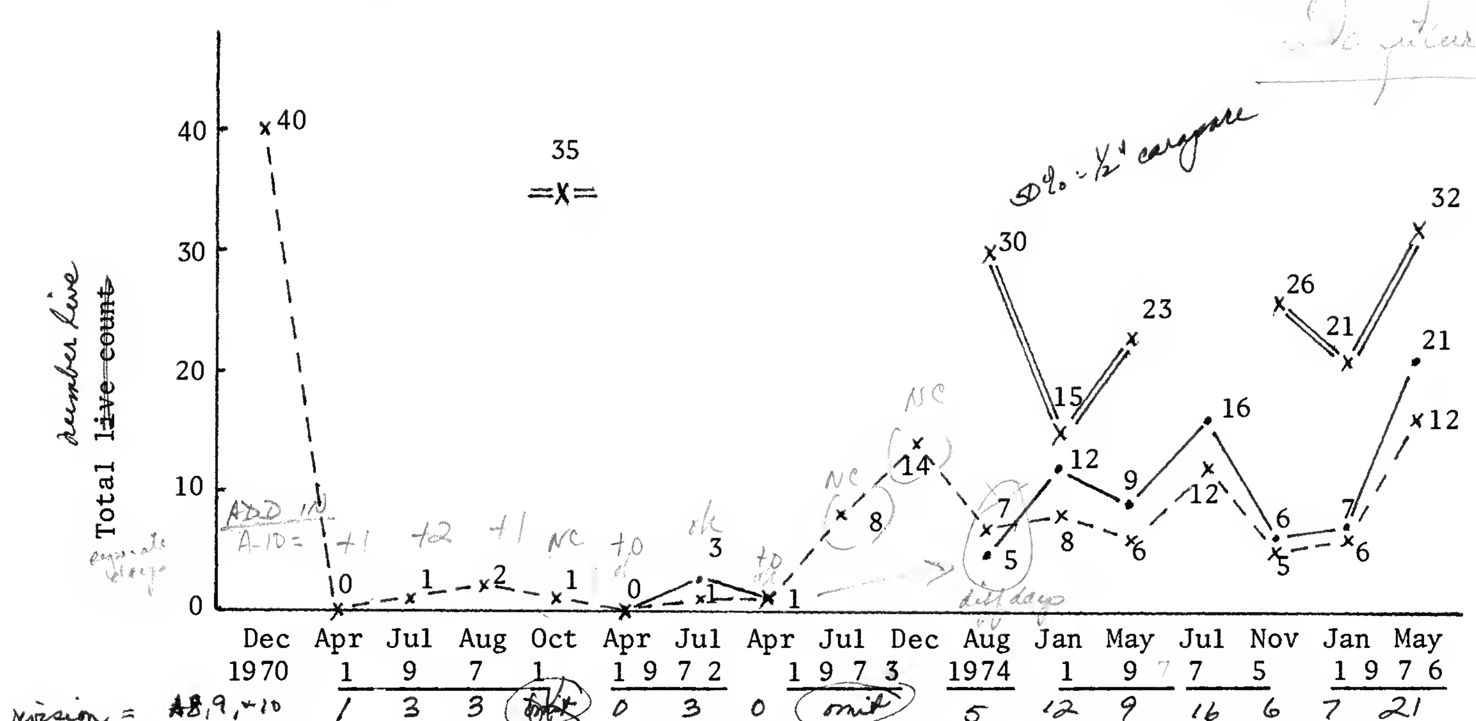

Figure Total count of *Pachygrapsus crassipes* for Duxbury Reef Berm transects

- - x - - A-8,9: 20 square meters (prior to 8/74 = SAME DAY COUNTS) (8/74 thru 1/76 = diff days)

—•— A-8,9,10: 30 square meters 1972 = same days. Aug 1974 etc = diff days

═x═ Berm crevice count

RANGE of total counts [A-8,9 20 m²] Dec 1970 = 40 since then count has ranged

1970 (Dec)	40
1971	0 to 2
1972	0 to 1
1973	1 to 14
1974	7
1975	5 to 12
1976	6 to 12

REVISE omit A-8,9

support for III, 10

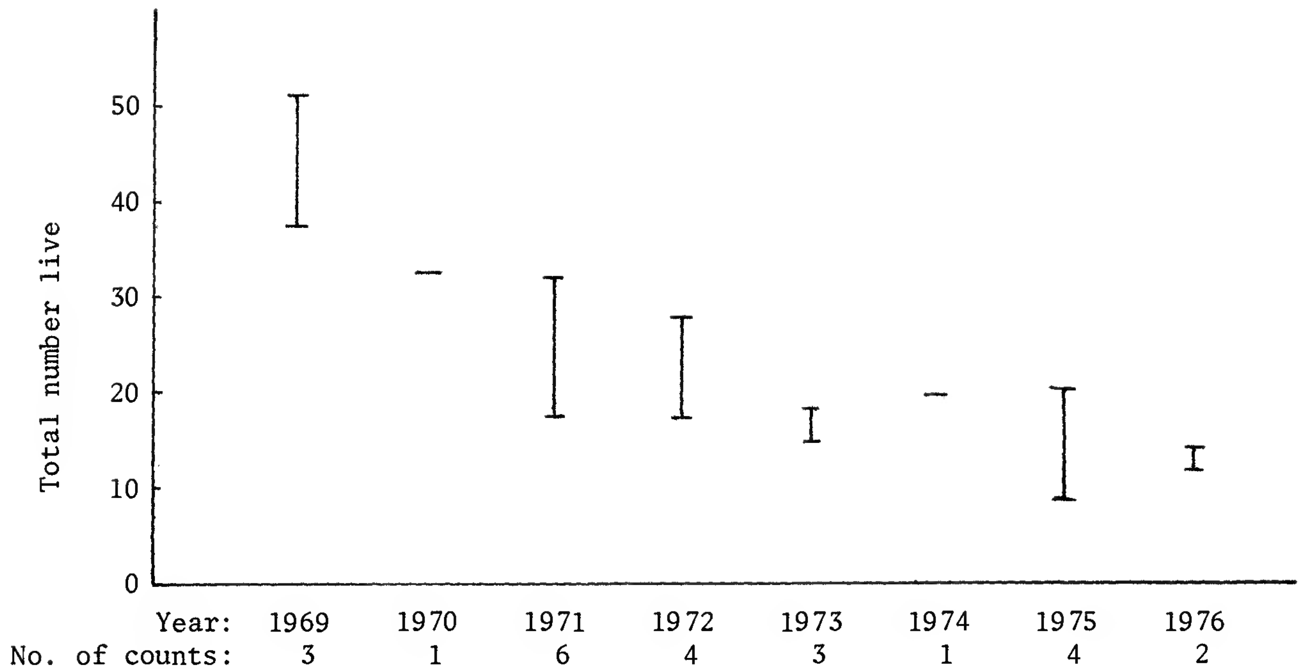

Figure Range of total transect counts of live *Pisaster ochraceus* on Duxbury Reef, trasnect C-4: 10 square meters

III WORK CHARTS

FINAL III
page 2

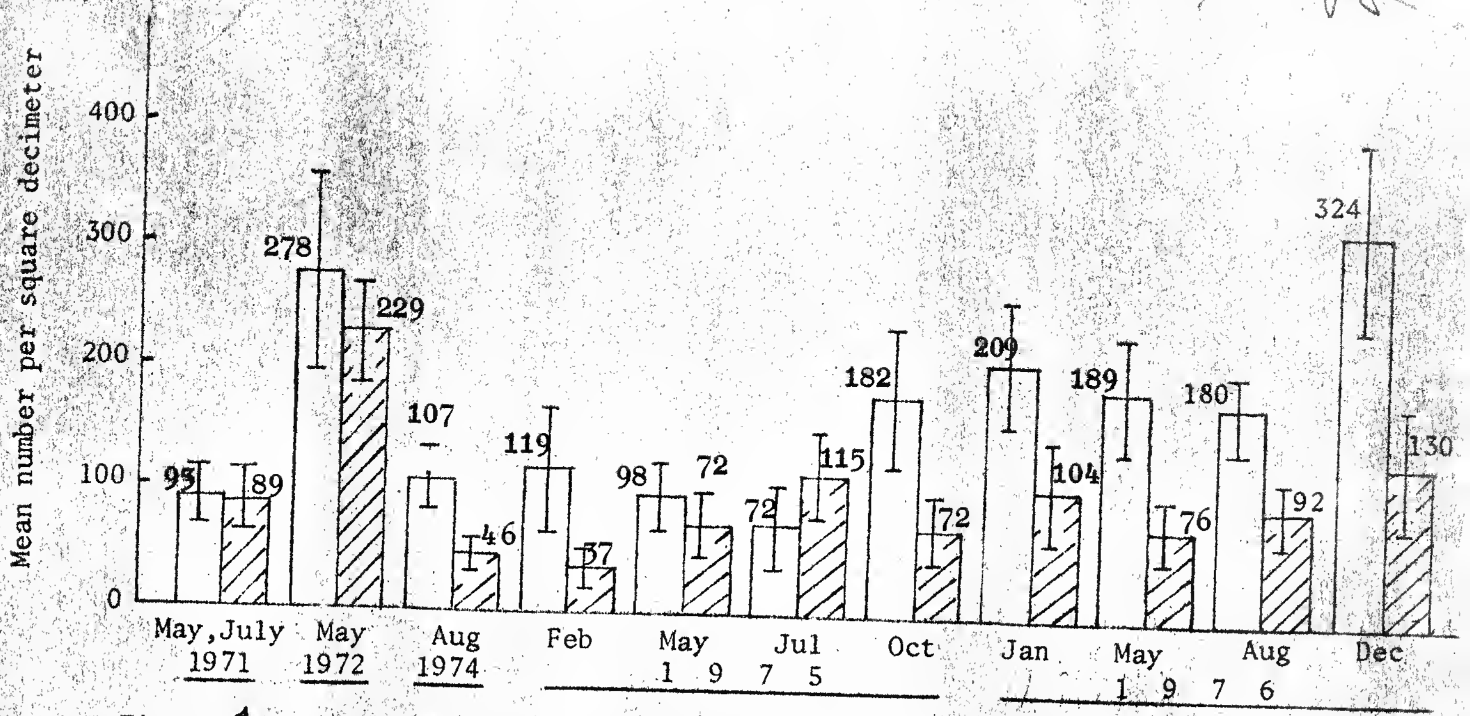

Figure 1 Comparison of live barnacles, *Balanus glandula* and *Chthamalus dalli*, for transects in Sausalito (oil) and Ft. Baker (no oil)

Sausalito   Ft. Baker   95% confidence interval for population mean

Reference - sample means not numbered in original

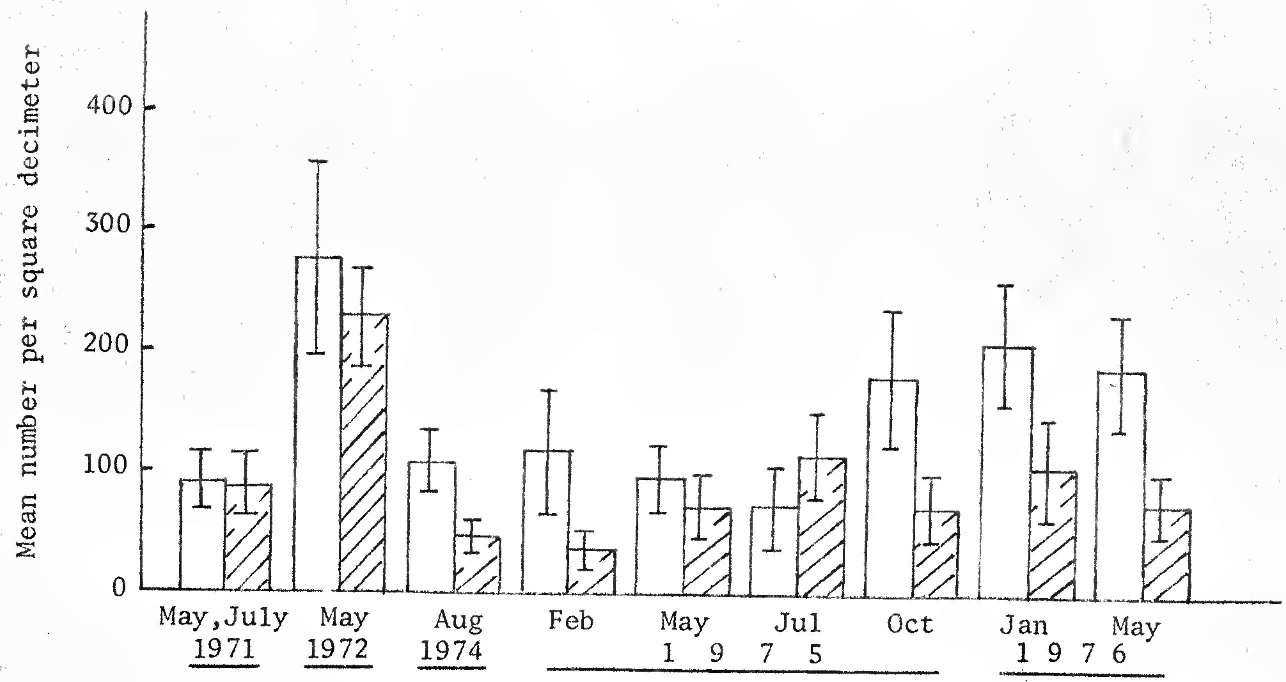

Figure 1. Comparison of live barnacles, *Balanus glandula* and *Chthamalus dalli*, for transects in Sausalito (oil) and Ft. Baker (no oil)

Sausalito | Ft. Baker | 95% confidence interval for population mean

Gordon L. Chan:

The Five-Year Recruitment of Marine Life After the 1971 San Francisco Oil Spill

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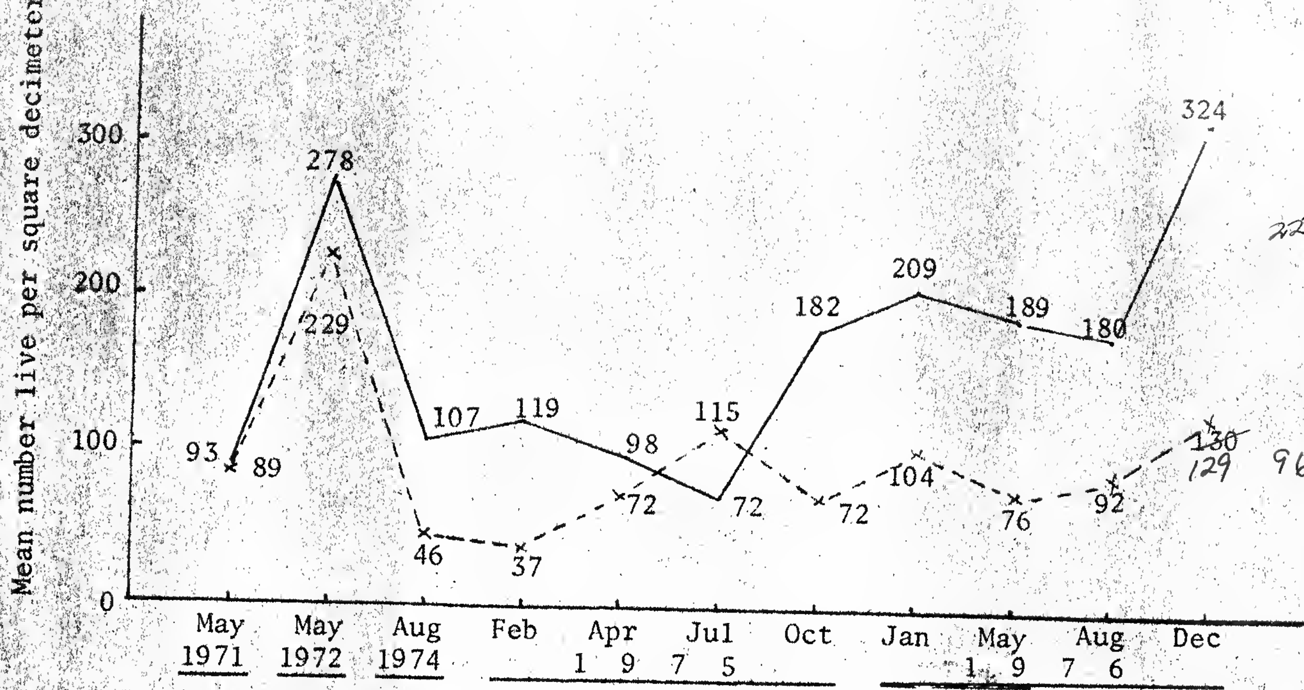

Figure 1 Comparison of barnacles, *Balanus glandula* and *Chthamalus dalli*, for transects in Sausalito (oil) and Fort Baker (no oil); sampling of 50 square decimeters in each transect.

——— Sausalito - - - Fort Baker

dm²
Saus 63 60 50
FtB 50

III
III (59)

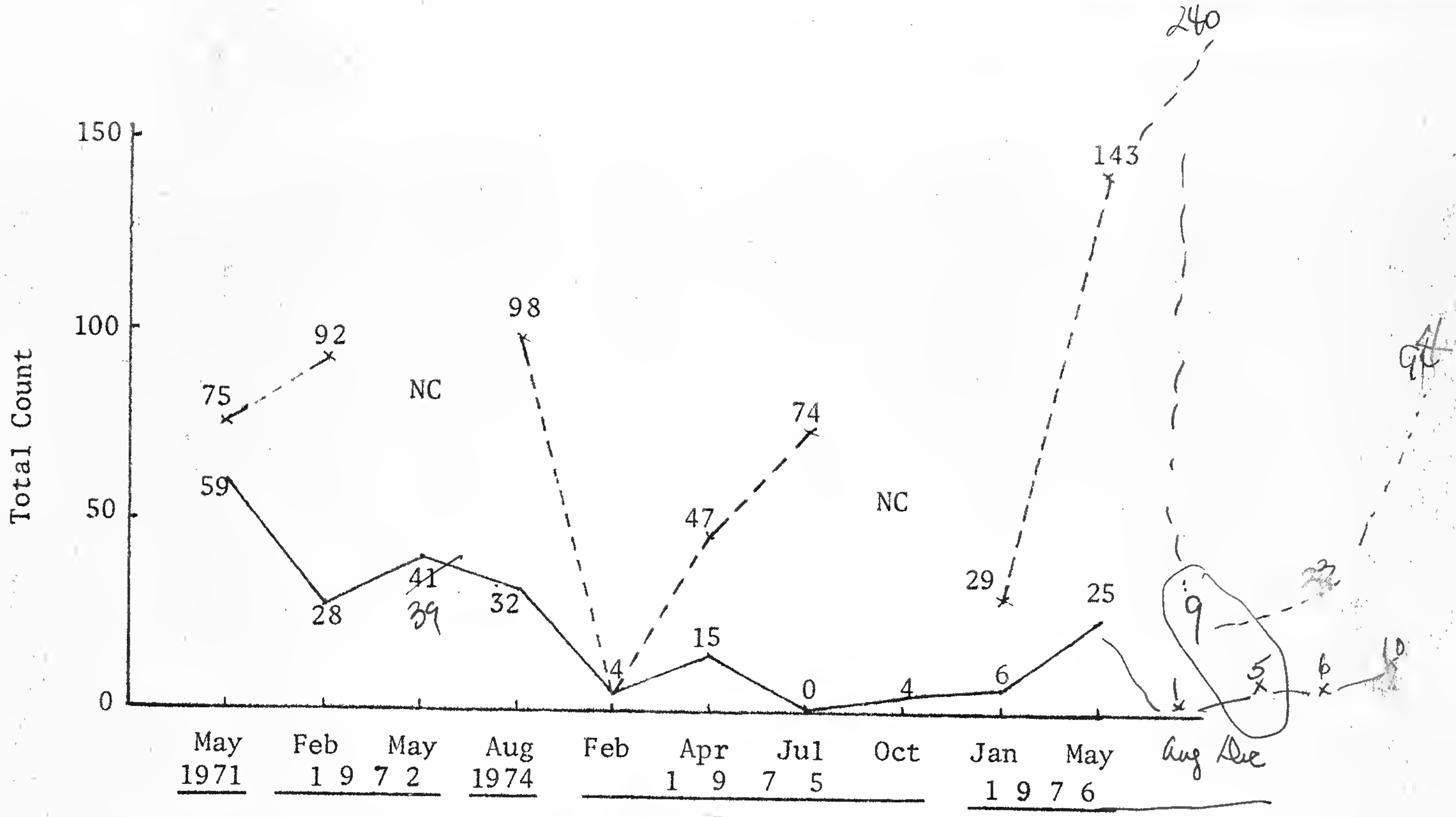

Figure 2. Total counts for ~~crabs~~, *Pachygrapsus crassipes* ~~and *Hemigrapsus nudus*~~, at Sausalito ONLY (May 1972)

—— Seal Rock transect count of ~~20~~ 10 square meters

- - - Count for 50 meter-walk

NC No Count

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The Five-Year Recruitment of Marine Life After the 1971 San Francisco Oil Spill

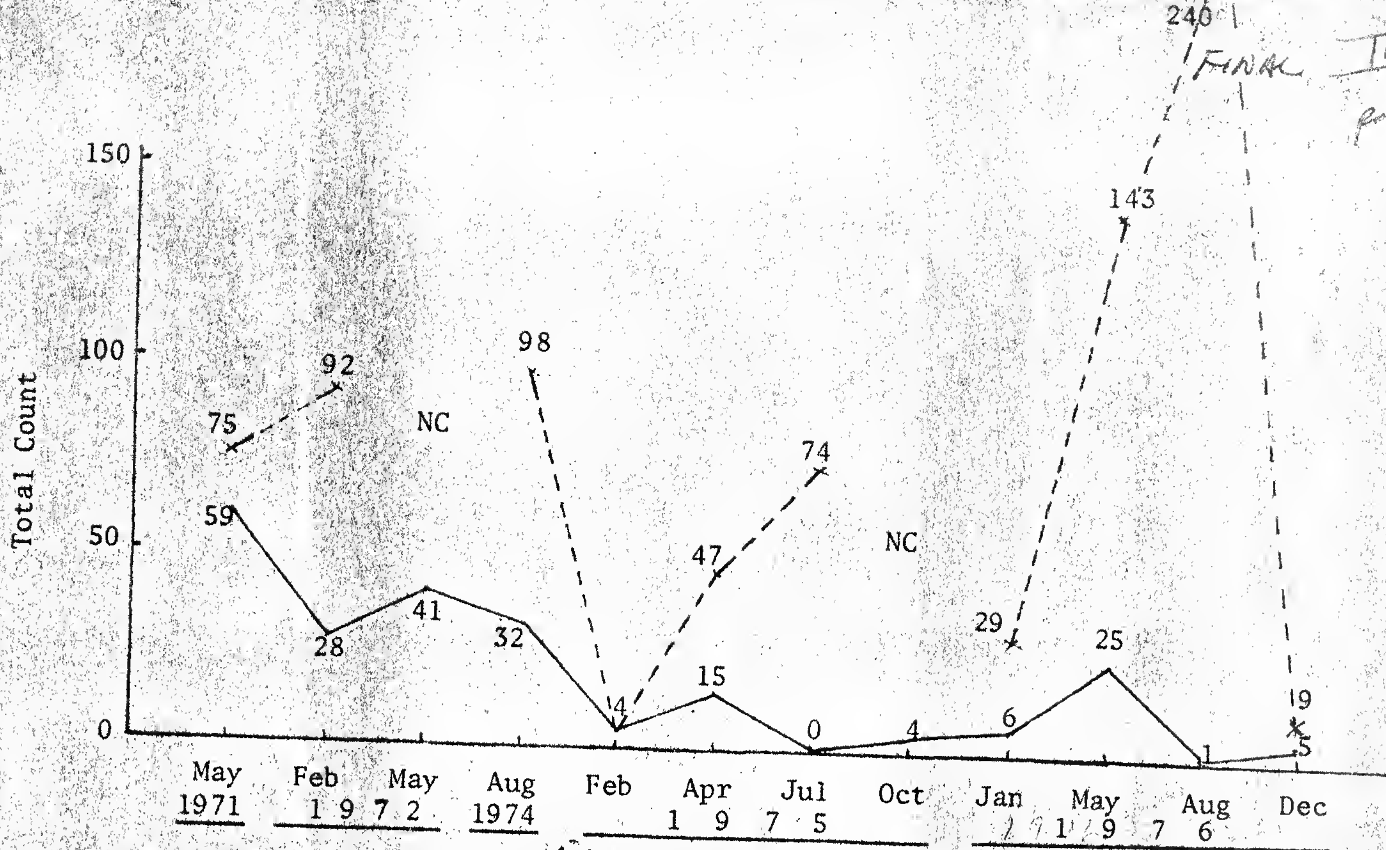


Figure 2 Total counts for live crabs, *Pachygrapsus crassipes* and *Hemigrapsus nudus*, at Sausalito

——— Seal Rock transect count of 20 square meters

- - - Count for 50 meter-walk

NC = no count

FINAL

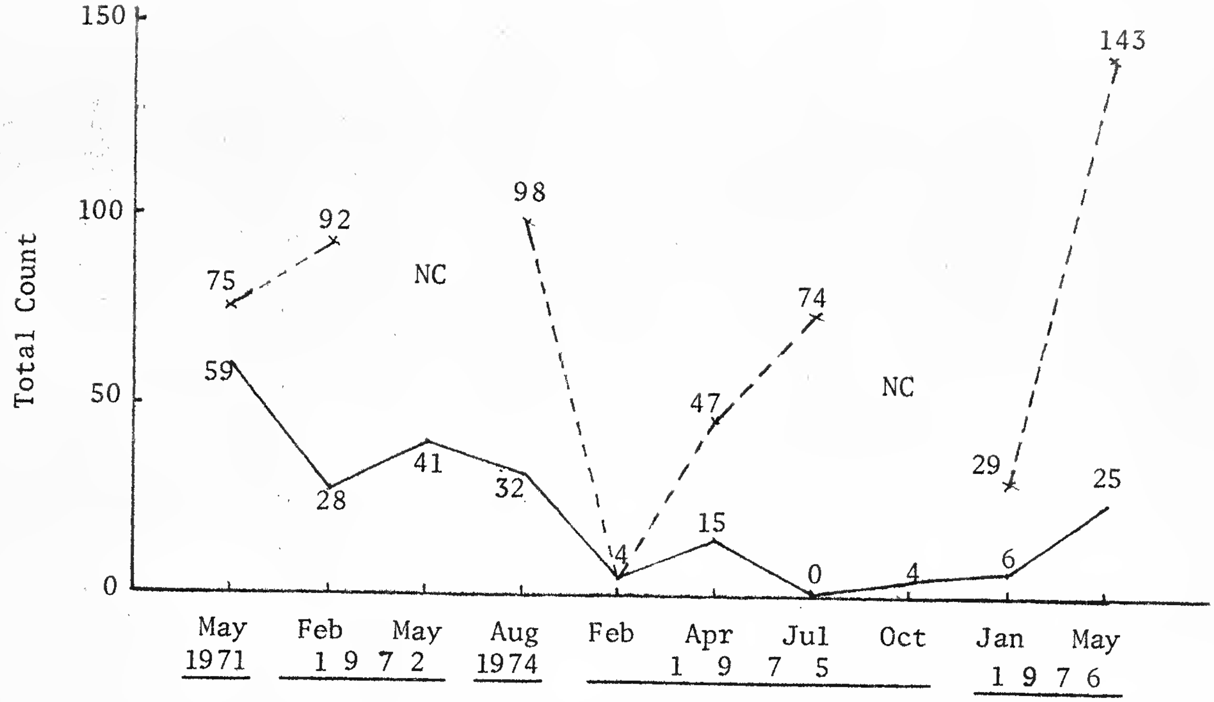
II.1

page

IV use Pachy only

III 3

IV 3



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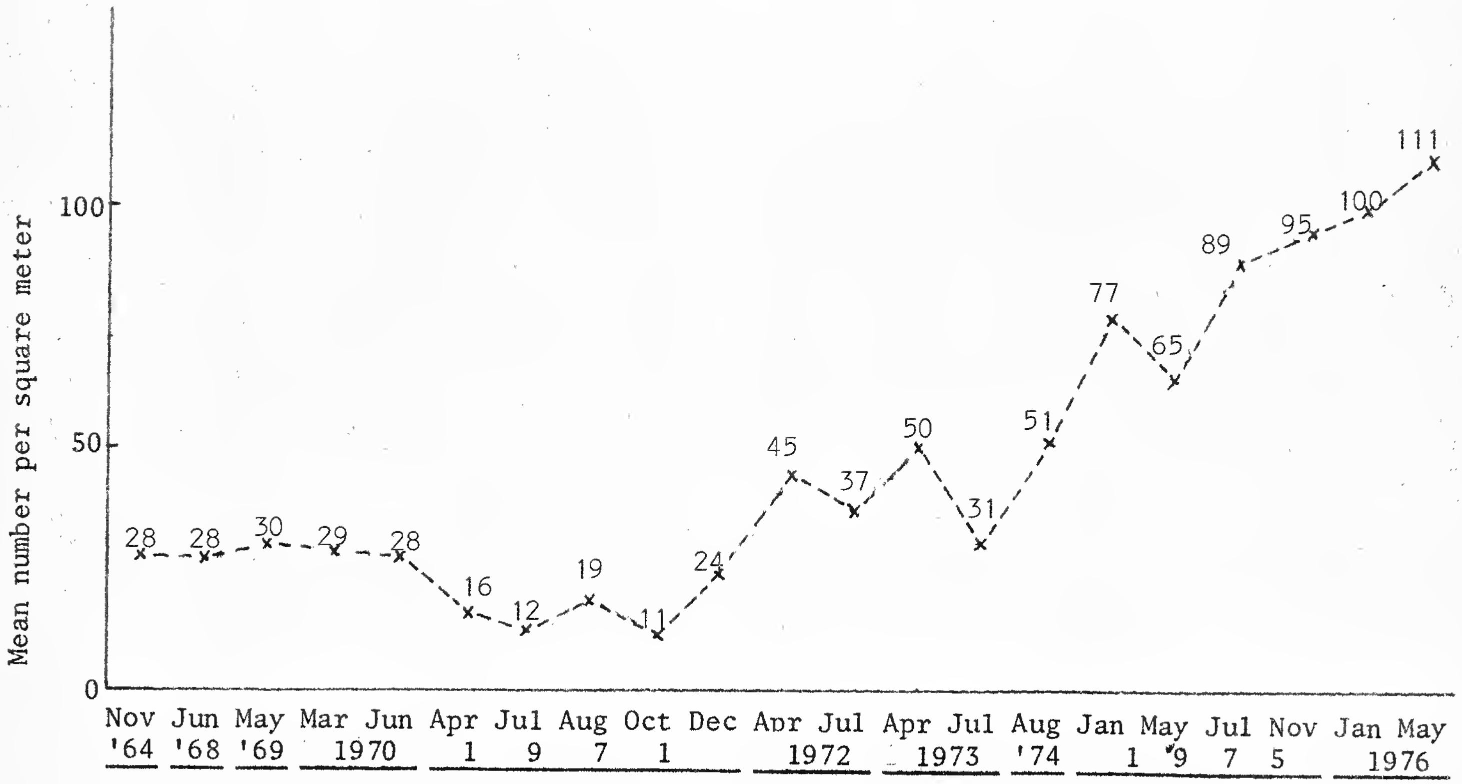
——— Seal Rock transcect count of 20 square meters
- - - Count for 50 meter-walk
NC No Count

IV uses Pachy only



Mean = 28 28 30 29 28 16 12 19 11 24 45 37 50 31 51 77 65 89 95 100 111

Figure 5. Sample means for live *Collisella spp*. for Duxbury Reef Berm A-8,9; twenty square meters.

AUG 1976	DEC 1976	FEB 1977	APR 1977
104	101	93	83

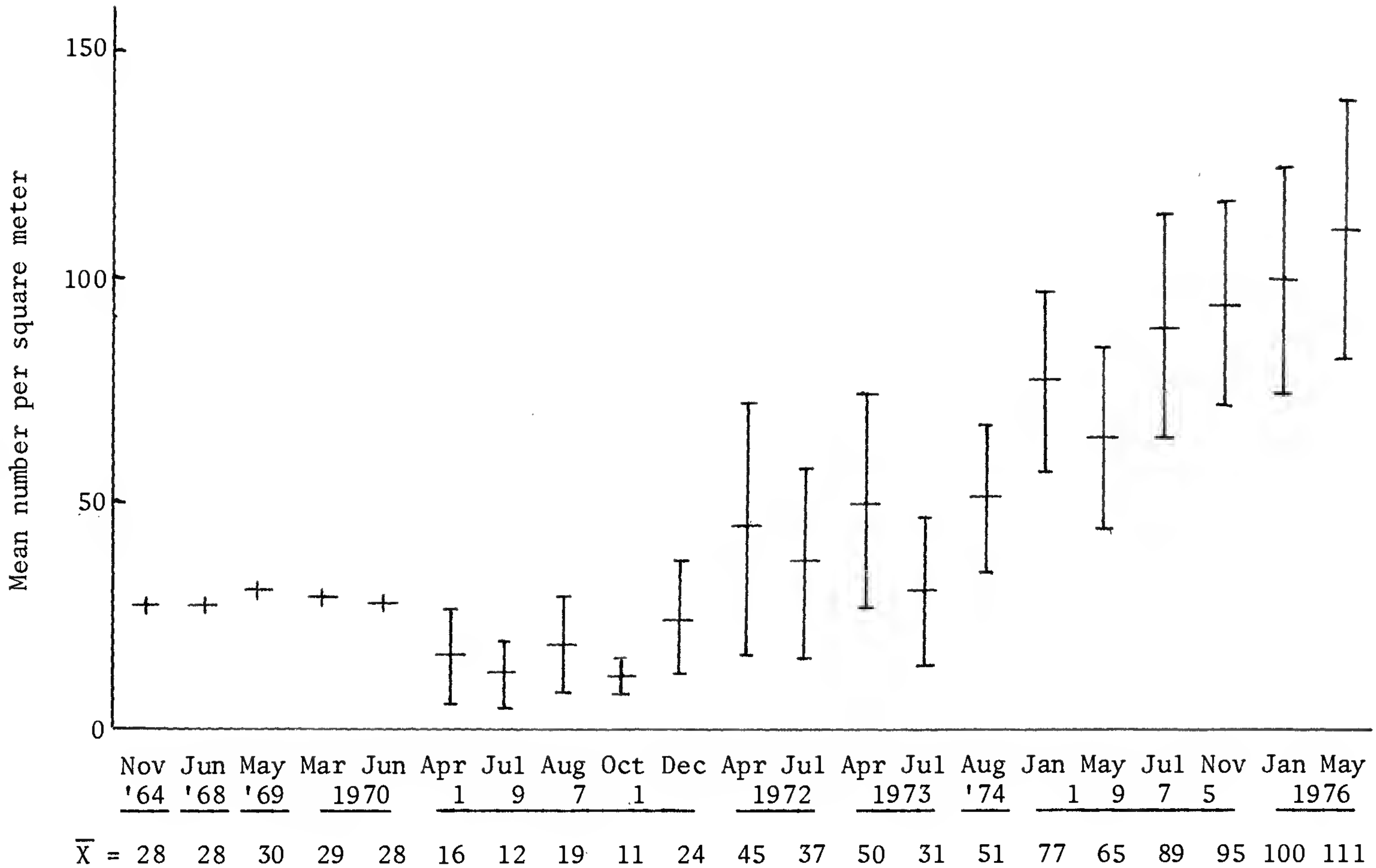


Figure 5 Live *Collisella spp.* for Duxbury Reef Berm A-8,9: twenty square meters

+ Sample mean

I 95% confidence interval for population mean

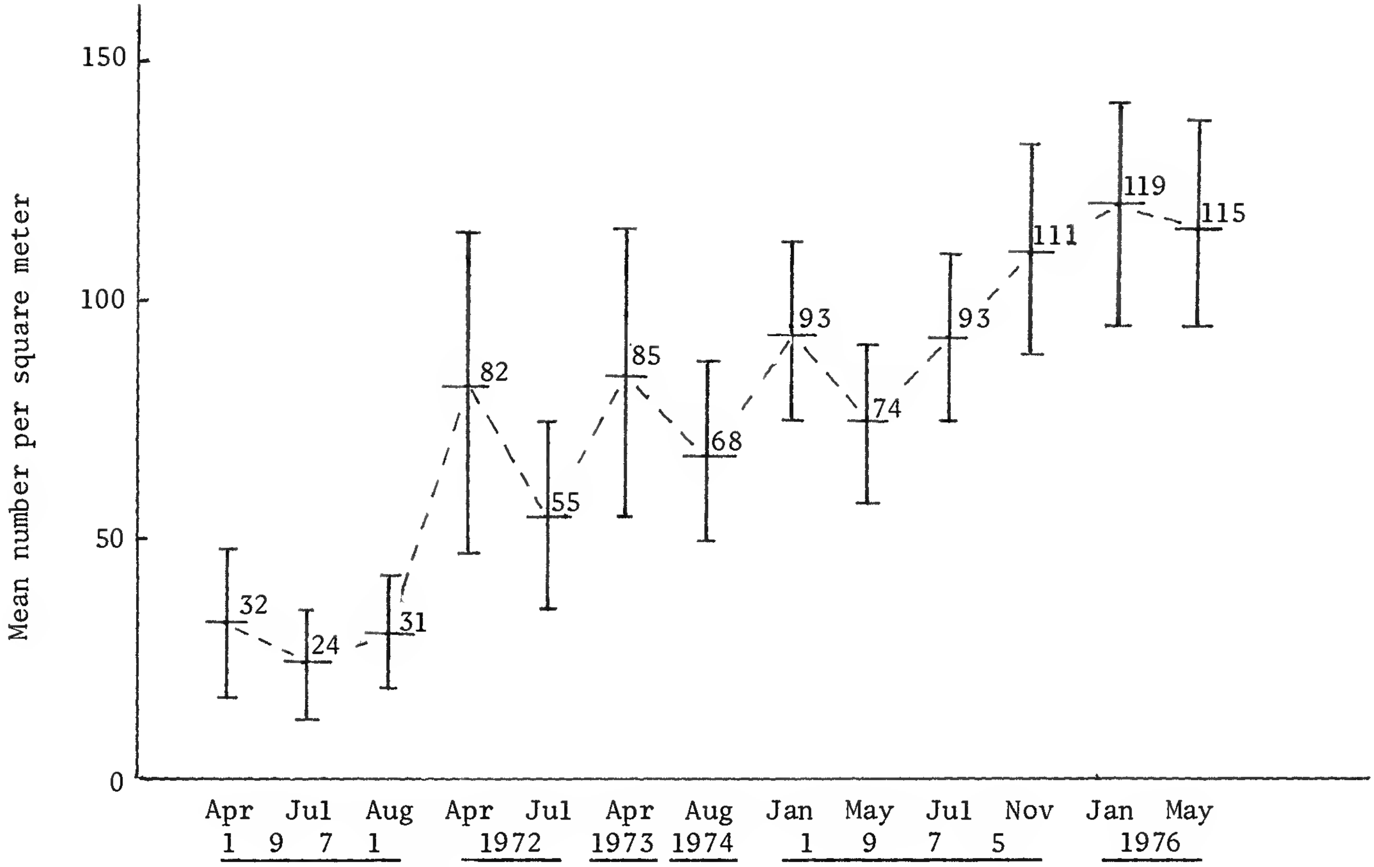


Figure Live *Collisella spp*. for Duxbury Reef Berm A-8,9,10: 30 square meters

sample mean

95% confidence interval for population mean

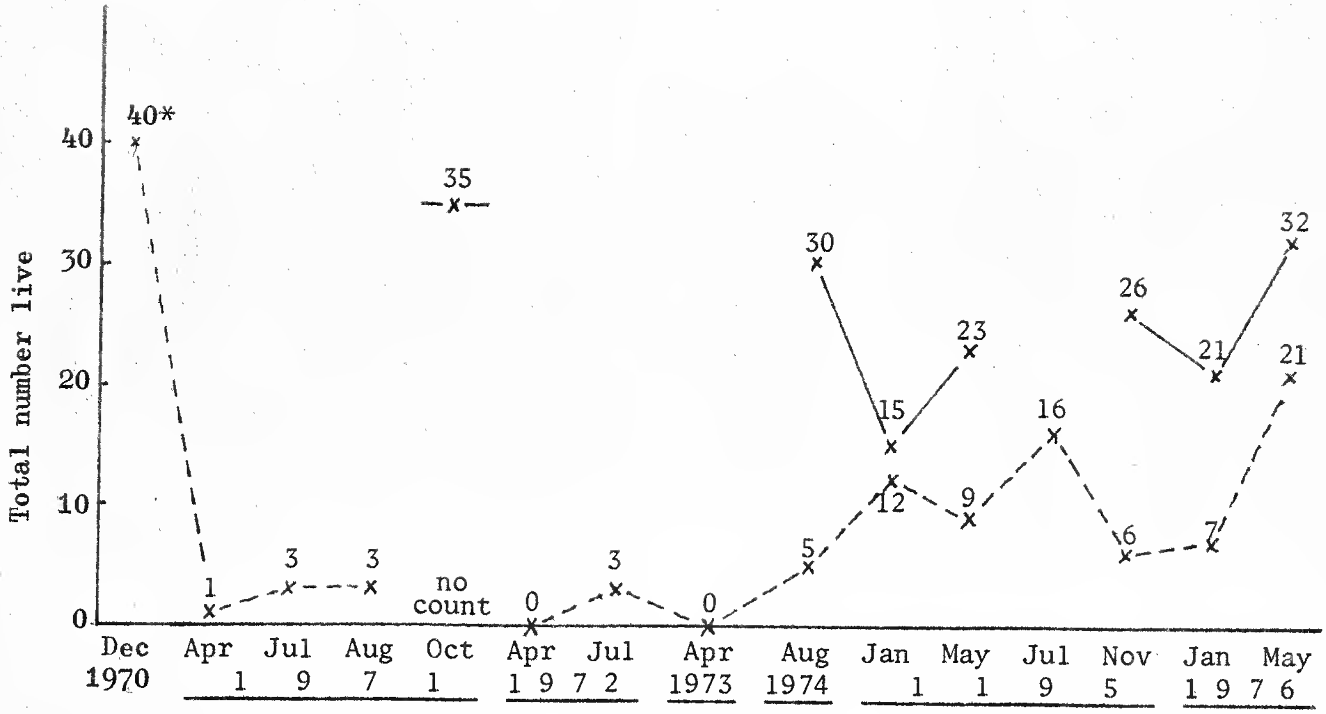


Figure 3. Total counts of *Pachygrapsus crassipes* for Duxbury Reef berm transects and for berm crevices

x— — — transect counts for A-8,9,10 = 30 m.^{2} x——— berm crevice counts

* pre-oil spill count for A-8,9

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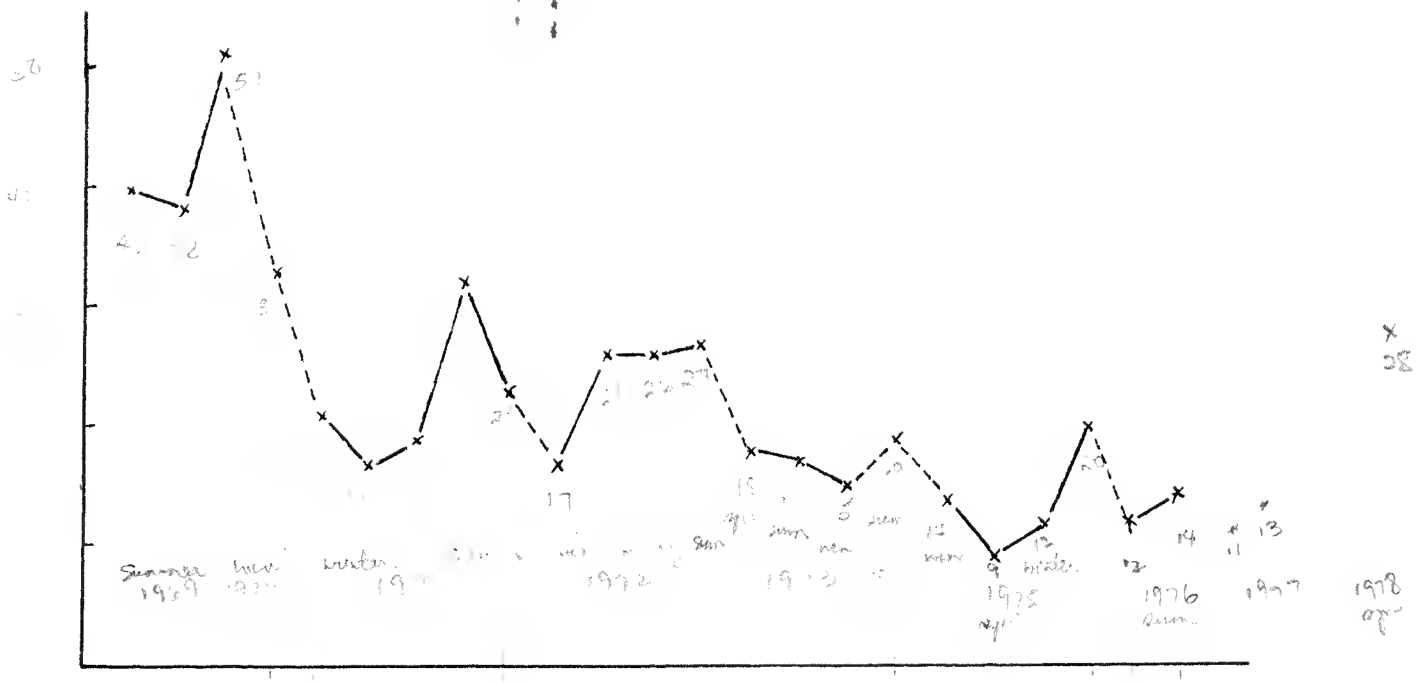
51
17
1972
1975
1976
1978
28
TOTAL

SAUSALITO
FORT BAKER

dead Balanus

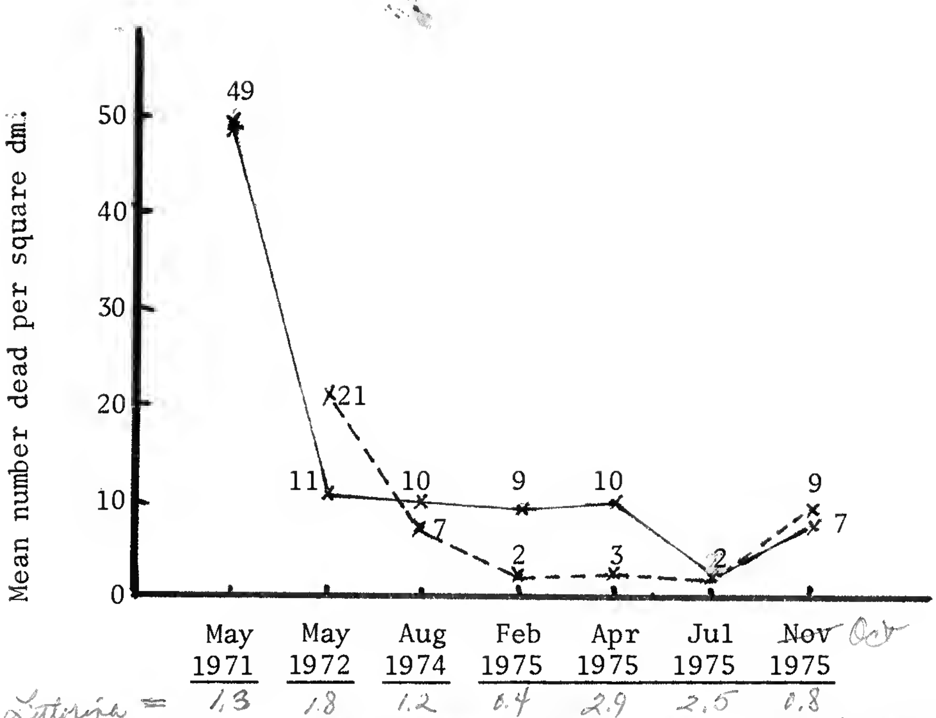

Figure Comparison of dead barnacles, *Balanus glandula* and *Cht hamalus dalli*, for transects in Sausalito (oil) and Fort Baker (no oil): sampling of 50 square decimeters.

Figure Comparison of dead barnacles, *Balanus glandula* and *Chthamalus dalli*, for transects in Sausalito (oil) and Fort Baker (no oil): sampling of 50 square decimeters.

——— Sausalito - - - Fort Baker

1971 - dead barnacles present at Fort Baker, no count

II, fig 3, p7

III
6/76

a fairly consistent population level through 1972, as shown in Figure 5.

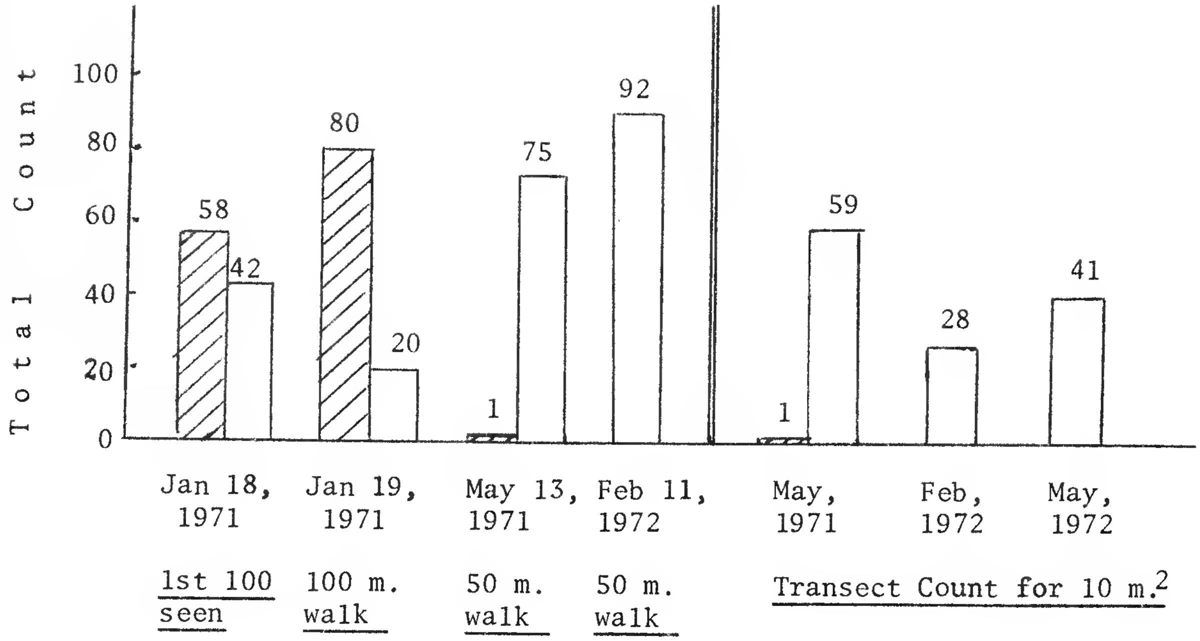

Figure 5. *Pachygrapsus crassipes* and *Hemigrapsus nudus* counts at Sausalito Seal Rock reef area

dead   live

B. STINSON BEACH DATA (APPENDIX III)

In the initial report on the spill (Chan, 1972), I could not relate the change of marine life density at the Stinson Beach 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

Nepthys californiensis, the sand worm

Orchestoidea californiana, the beach hopper

A comparison of the combined mean number per square meter for all three species since 1965 shows a downward trend in Figure 6.

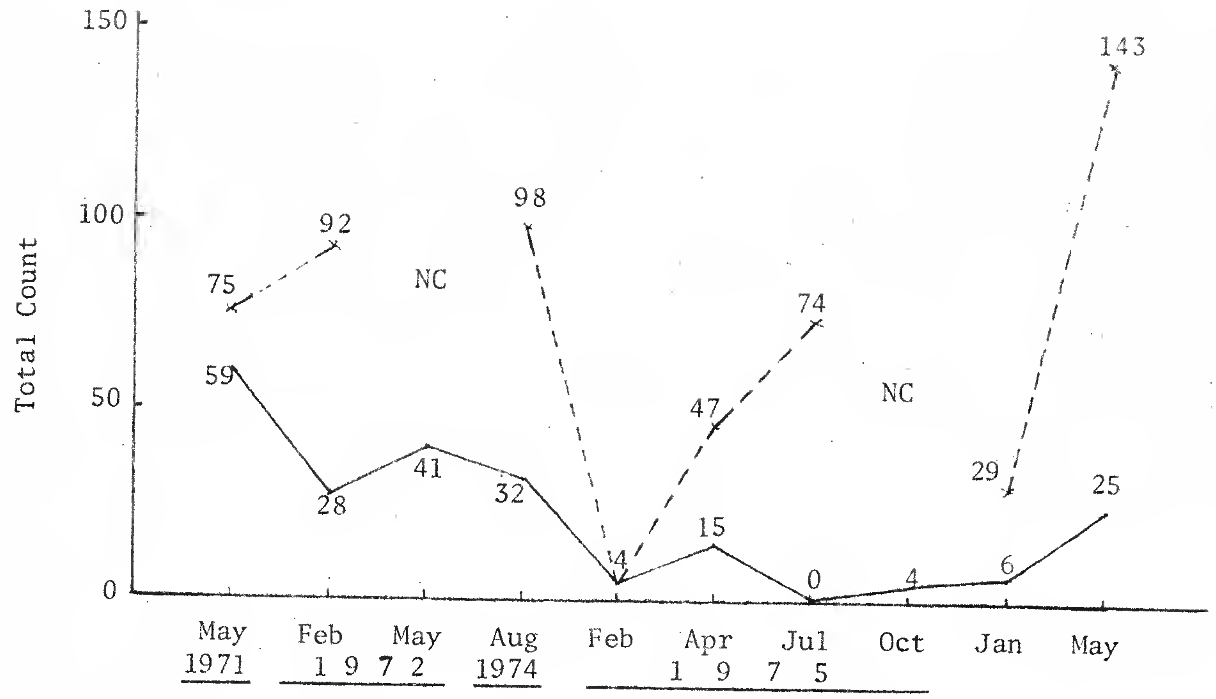

Figure Total counts for crabs, *Pachygrapsus crassipes* and *Hemigrapsus nudus*, at Sausalito

——— Seal Rock transect count of 20 square meters

\- - - Count for 50 meter-walk

not used in III

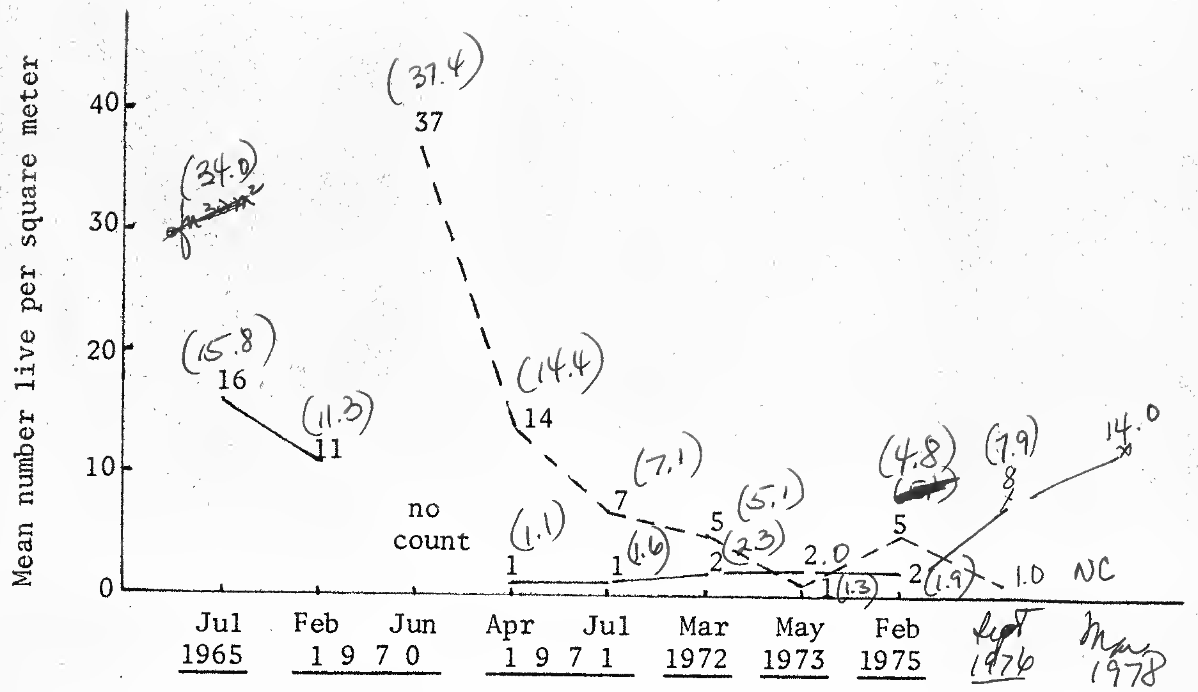

Figure Comparison of transects at Stinson Beach and Drakes Beach for three species combined: *Emerita analoga*, *Nepthys californiensis*, and *Orchestoidea californiana*

——— Stinson Beach (oil, graded surface)

- - - Drakes Beach (non-oil)

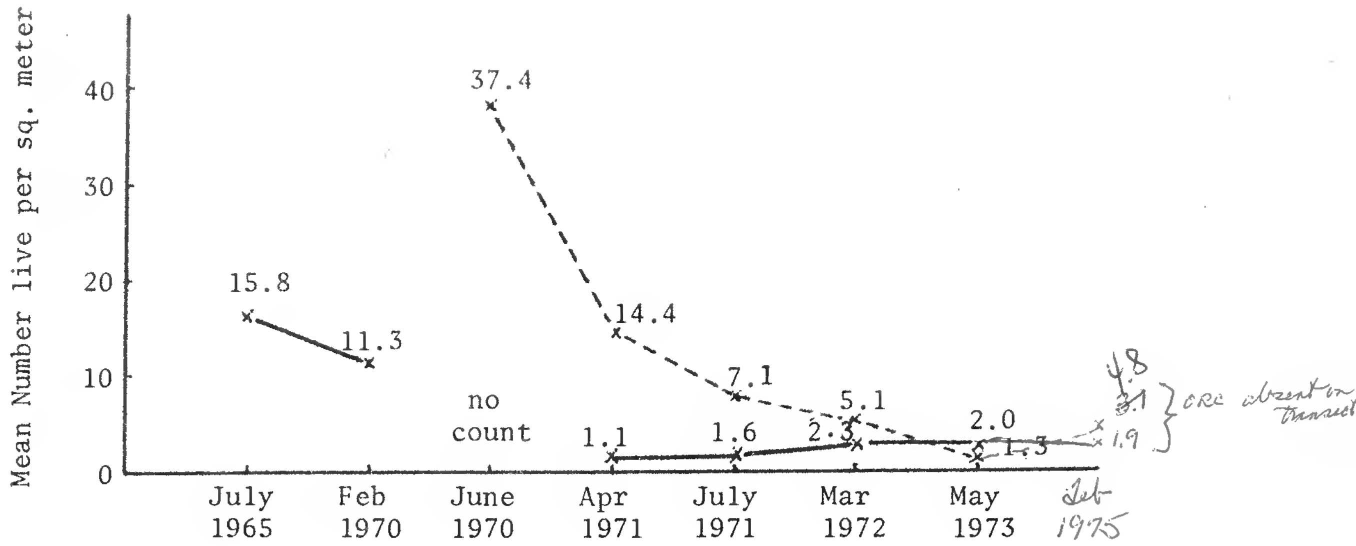

Figure 6. Comparison of transects at Stinson Beach and Drakes Beach for three species combined: *Emerita analoga, Nepthys californiensis,* and *Orchestoidea californiana*

——— Stinson Beach Transect (100% oil, graded) 9 m²

- - - Drakes Beach Transect (non-oil) mostly 20 m²

Stinson Beach was covered with oil during the early days of the spill. Standard Oil Company reported that its mechanical graders and lifters had disrupted and removed, on the average, the upper six inches of the sand's surfaces. The same species were also counted at Drakes Beach where no oil had been reported. Prior to the spill, the marine polychaete, *Nepthys californiensis*, was quite abundant in the Stinson Beach transect, but since the spill, this worm has not returned in the post-oil counts; on the other hand, the worm has continued to be present at Drakes Beach, the control site. Both areas currently show low densities of marine organisms. Although the oil may have had its smothering effect on the Stinson Beach organisms, perhaps the major contributing reason for the poor recruitment can be directly related to an ecological sand disturbance of winter and summer conditions rather than an effect of the spill and cleanup disruptions.

III
6/76

II

draft appendices
for III or IV

redo for III

APPENDIX 1I SAUSALITO AND FORT BAKER TRANSECT STATISTICS

Sausalito Transect: 1971=100% oil-covered, 10 m^2
Fort Baker Transect: 1971= no oil, 10 m^2

Species	Date and Sample	Sample Mean per dm^2	95% confidence interval for population mean	Interval of Significant Difference
SAUSALITO Barnacles *Balanus glandula* *Chthamalus dalli*	May 13, 1971 63 dm^2	93.3 live 49.2 dead	69.0-117.7 36.7- 61.8	1971 vs. 1972 101.1-268.3 live/dm^2 25.1- 50.7 dead/dm^2
	May 18, 1972 60 dm^2	278.0 live 11.3 dead	198.0-358.0 8.7- 13.9	
FORT BAKER Barnacles *Balanus glandula* *Chthamalus dalli*	July 23, 1971 50 dm^2	90.8 live	64.3-117.3	1971 vs. 1972 89.1-187.3 live/dm^2
	May 18, 1972 50 dm^2	229.0 live	187.6-270.3	

Live Barnacles: Sausalito vs. Fort Baker

1971= 2.5 difference between sample means
1972=49.0 difference between sample means
There was no significant difference between live population means for 1971 and for 1972.

	Date		
SAUSALITO Limpets *Collisella spp.*	May 13, 1971 May 18, 1972	21 live for 63 dm^2 90 live for 60 dm^2	
Shore Crabs *Pachygrapsus crassipes* and *Hemigrapsus nudus*	*May 13, 1971 *Feb 11, 1972 *May 18, 1972	59 live, 1 dead 28 live, 0 dead 41 live, 0 dead	

*Total transect count

Non-transect counts for Shore Crabs	
Jan 18, 1971 1st 100 seen	42 live 58 dead
Jan 19, 1971 100 m.	20 live 80 dead
May 13, 1971 50 m.	75 live 1 dead
Feb 11, 1972 50 m.	92 live 0 dead

redo for III

APPENDIX III STINSON BEACH and DRAKES BEACH SAMPLE MEAN DATA

Stinson Beach: 1971=100% oil-covered, top 6" graded off
square meter sampling every 10th meter

Drakes Beach: 1971=no oil
square meter sampling every alternate meter

		SAMPLE MEAN PER SQUARE METER			
Date	Square Meter Samples	*Emerita analoga*	*Nepthys californiensis*	*Orchestoidea californiana*	3 species combined
STINSON BEACH					
July 15, 1965	9	7.9	5.2	2.7	15.8
Feb 17, 1970	9	7.6	3.1	0.7	*11.3
Apr 16, 1971	9	1.1	-0-	-0-	* 1.1
July 23, 1971	9	1.6	**-0-	-0-	1.6
Mar 10, 1972	8	1.3	-0-	1.0	2.3
May 7, 1973	9	2.0	-0-	-0-	2.0
Oct 22, 1975	9	1.8	0.1	**-0-	1.9

*Significant difference between population means (95% confidence interval) by an interval estimate of difference, .03 to 20.4.

see STAT CARD see notes

STAT CARD see [illegible]

- -

DRAKES BEACH					
June 25, 1970	30 consecutive	31.3	6.1	? **-0-	37.4
Apr 20, 1971	10	13.1	1.3	-0-	14.4
Aug 4, 1971	10	4.0	3.1	-0-	7.1
Mar 14, 1972	12	3.1	2.0	-0-	5.1
May 21, 1973	12	0.67	0.67	** -0-	1.3
Oct 22, 1975	12	4.6	0.2	**-0-	4.8

**this species is present, off the transect site

APPENDIX IV

DUXBURY REEF STATISTICS

A. Black Turban Snail, *Tegula funebralis*

100 square meter sampling for total of 11 transects: A-1,2,3,5,7
B-1,2,3,4
C-1,6

Date	Live Sample mean per m.^{2}	95% confidence interval for population mean
June, 1969	37.6	28.6 to 46.6
July, 1969	31.3	20.9 to 41.6
Aug, 1969	40.6	32.7 to 48.5
Apr, 1971	15.5	12.2 to 18.8
July, 1971	35.6	27.6 to 43.5
Aug, 1971	32.1	23.8 to 40.5
Apr, 1972	20.5	16.6 to 24.4
July, 1972	24.0	18.3 to 29.7

Test statistics for significant difference between population means			interval estimate of difference
6/69 w 7/69	0.8997	H_0 true	
7/69 w 8/69	-1.3991	H_0 true	
8/69 w 4/71	5.7401	Reject H_0;	16.5 to 33.7
4/71 w 7/71	-4.5781	Reject H_0;	11.5 to 28.7
7/71 w 8/71	0.5960	H_0 true	
8/71 w 4/72	2.4698	Reject H_0;	2.4 to 20.8
4/72 w 7/72	-0.9865	H_0 true	
4/71 w 4/72	-1.9107	H_0 true	
7/69 w 7/71	-0.6457	H_0 true	
7/71 w 7/72	2.3353	Reject H_0;	1.9 to 21.4
7/69 w 7/72	1.2150	H_0 true	
8/69 w 8/71	1.4507	H_0 true	

B. California sea-mussel, *Mytilus californianus*

100 square decimeter sampling for mussel bed transect C-3

Date	Live Sample mean per dm.^{2}	95% confidence interval for population mean		Dead Sample Mean per square meter
Dec, 1965	7.5	(not available)		
July, 1968	7.7	4.6 to 10.7		
Aug, 1969	5.6	4.4 to 6.7		
Jan, 1971				none (1/23/71)
Apr, 1971	5.9	4.9 to 7.0	(50% S)*	12.6
June, 1971	8.8	6.9 to 10.7		5.0
July, 1971	12.3	11.5 to 13.0	(23.7%S)*	6.4
Dec, 1971	13.7	12.9 to 14.5	(10.1%S)*	no count
Apr, 1972	14.1	13.2 to 15.0	(4.7%S)*	0.3
July, 1972	12.2	11.3 to 13.1		no count
Dec, 1973	15.7	14.6 to 16.7		no count

* = oil-covered shells

APPENDIX IV (continued, page 2) - Duxbury Reef Statistics

C. Limpets, *Collisella spp*.

Berm transects: A-8,9 = 20 square meters

Date	Live Sample Mean per m^2	95% confidence interval for population mean
Nov, 1964	28.7	(data not available)
June, 1968	28.5	
May, 1969	30.0	
Mar, 1970	29.0	
June, 1970	28.6	
Apr, 1971	16.1	6.0 to 26.1
July, 1971	12.4	5.5 to 19.3
Aug, 1971	19.7	9.6 to 29.7
Oct, 1971	11.1	6.6 to 15.5
Dec, 1971	24.8	12.5 to 37.0
Apr, 1972	45.0	17.2 to 72.7
July, 1972	37.6	16.7 to 58.4
Apr, 1973	50.4	26.8 to 74.0
July, 1973	31.5	15.0 to 47.8

Berm transects: A-8,9,10 = 30 square meters L=live, D=dead

Date	Sample mean per m^2	95% confidence interval for population mean
Apr, 1971	31.9L, 9.3D	16.8 to 47.0L, 2.5 to 16.0D
July, 1971	24.6L, 5.3D	13.5 to 35.7L, 1.8 to 8.9D
Aug, 1971	31.0L, 4.9D	19.0 to 43.0L, 1.3 to 8.6D
Apr, 1972	82.1L, 0.8D	47.4 - 116.9L, 0.3 to 1.4D
July, 1972	55.2L, 0.8D	34.6 - 75.9L, 0.3 to 1.4D
Apr, 1973	84.9L, 0.9D	54.0 - 116.0L, 0.4 to 1.4D