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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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PART II - RECRUITMENT

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.

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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.

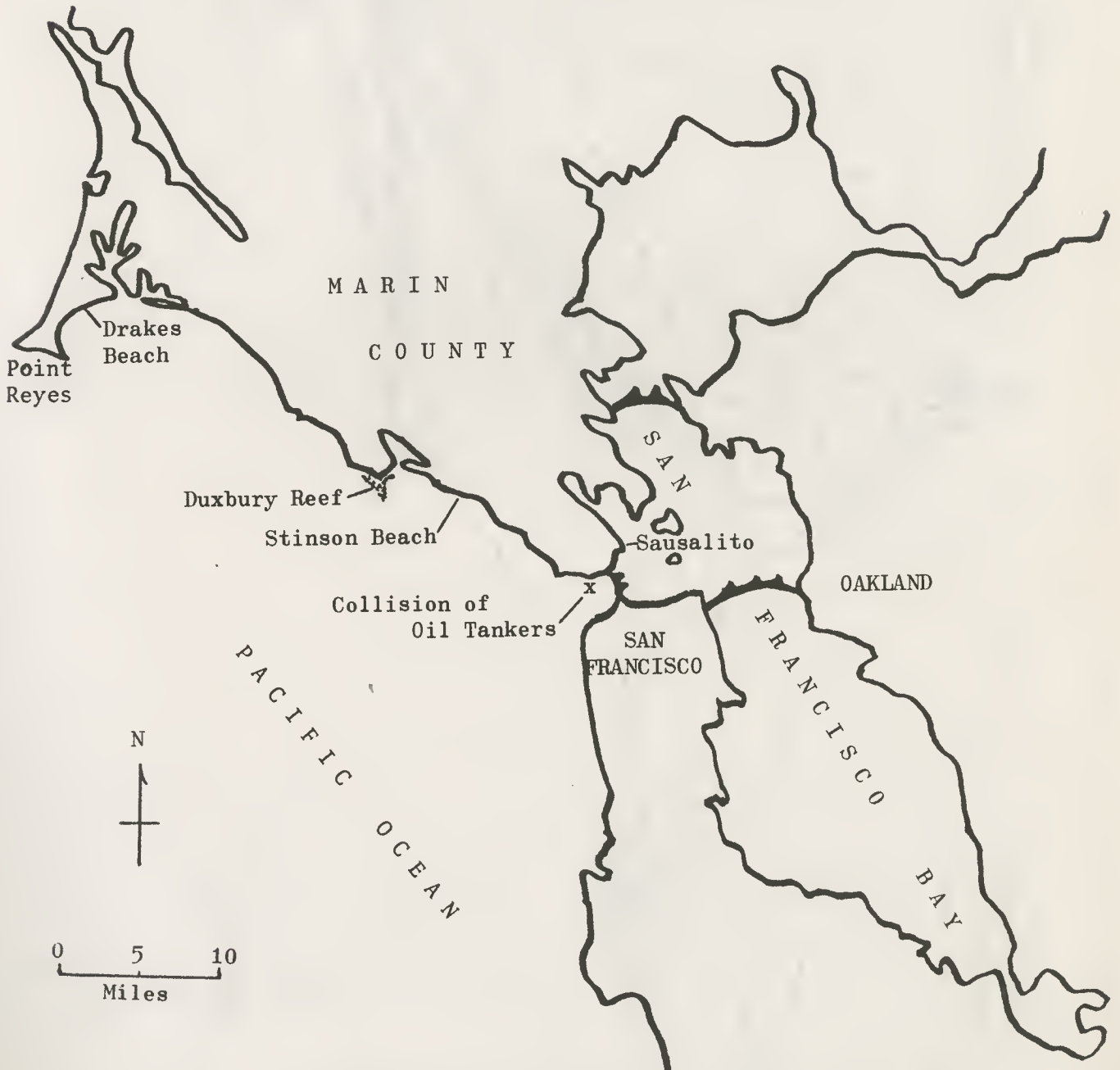


Figure 1. Localities of the 1971 San Francisco Oil Spill in the state of California

P A C I F I C O C E A N

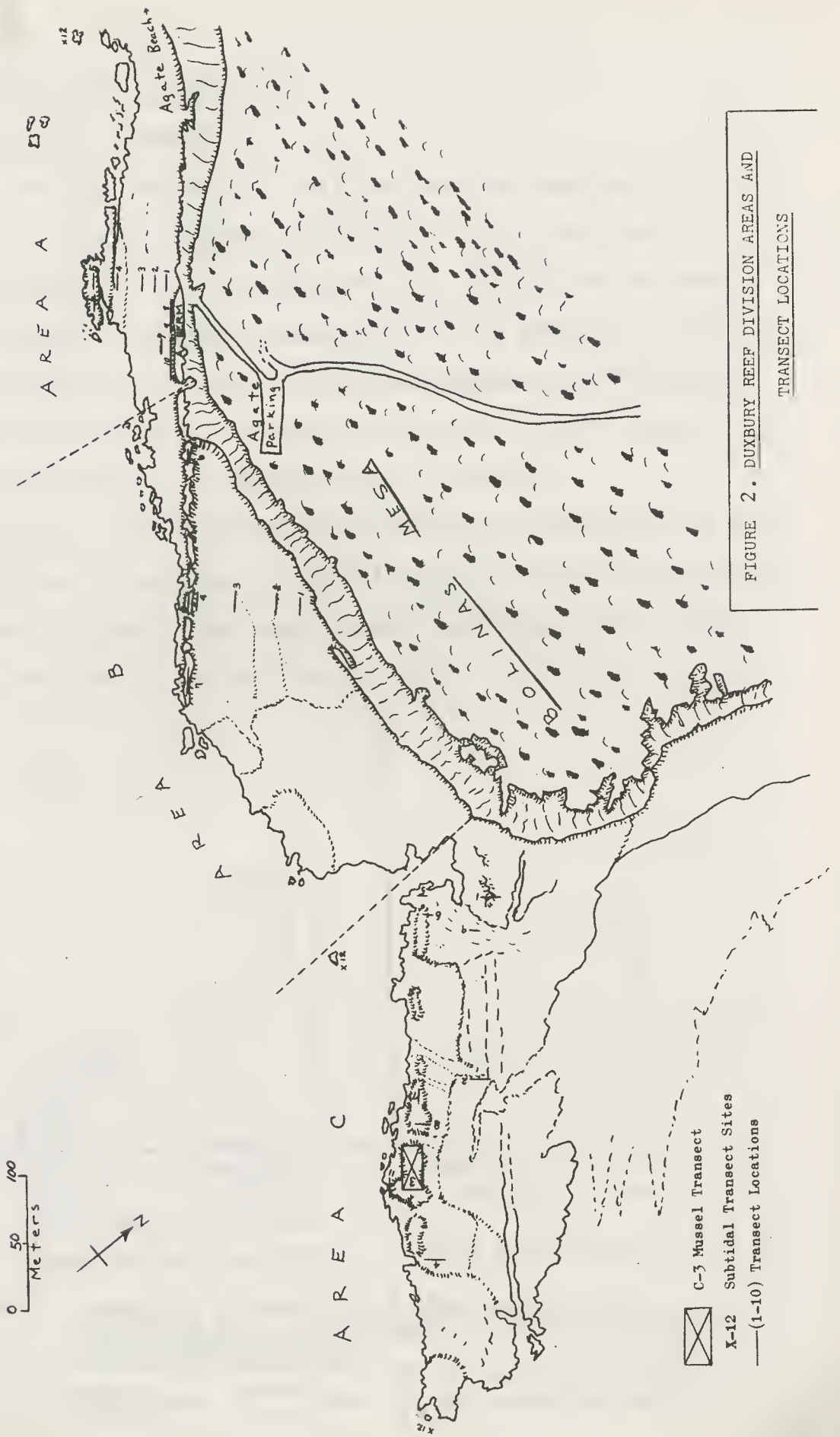





FIGURE 2. DUXBURY REEF DIVISION AREAS AND TRANSECT LOCATIONS

-  C-3 Mussel Transect
-  X-12 Subtidal Transect Sites
-  (1-10) 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.

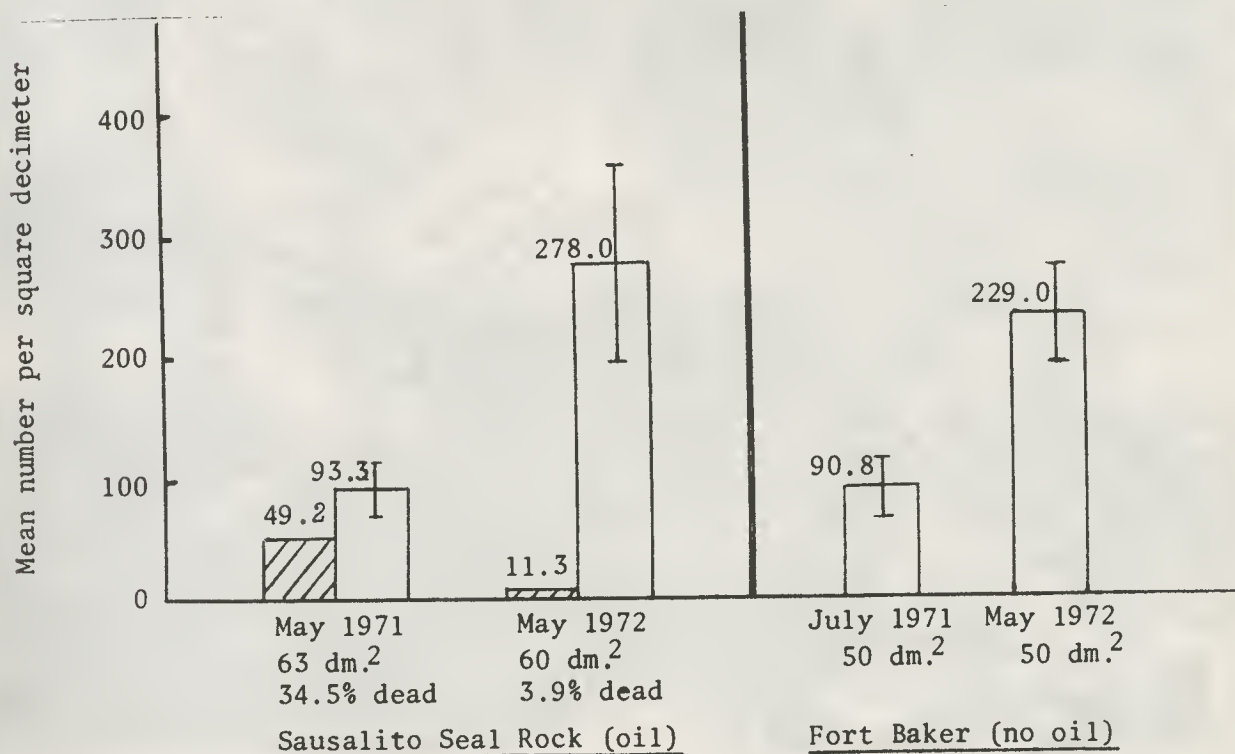


Figure 3. Comparison of barnacles, *Balanus glandula* and *Chthamalus dalli*, for transects in Sausalito (oil) and Ft. Baker (no oil)

 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.

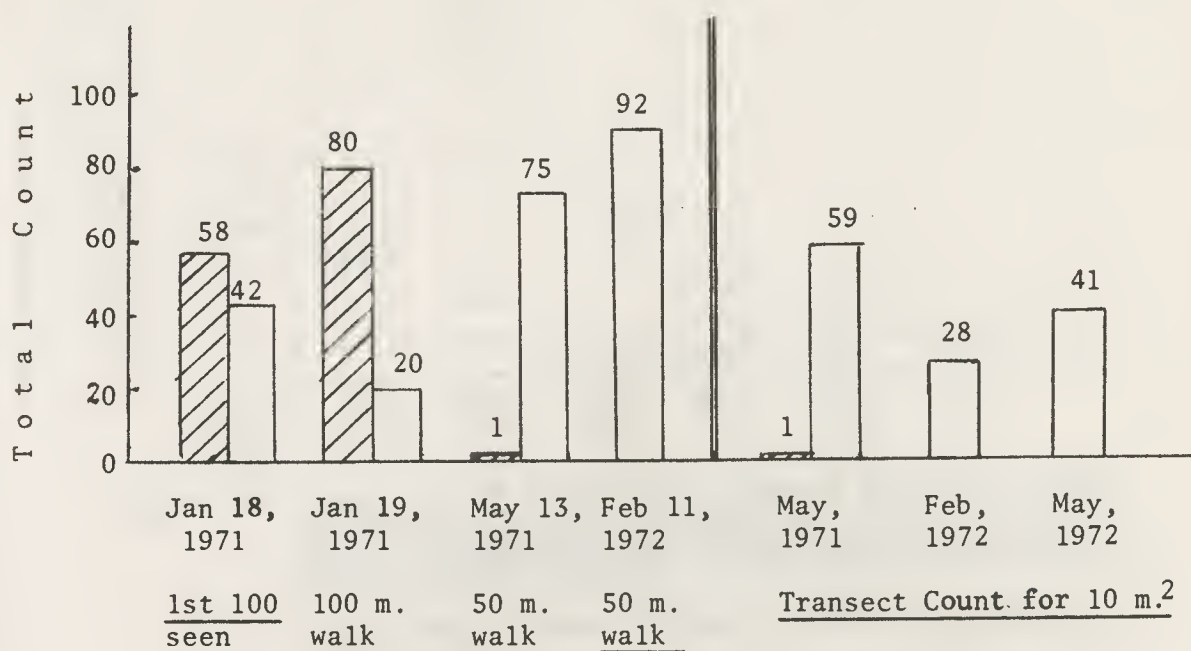


Figure 5. *Pachygrapsus crassipes* and *Hemigrapsus nudus* counts at Sausalito Seal Rock reef area

▨ 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

Nephtys 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.

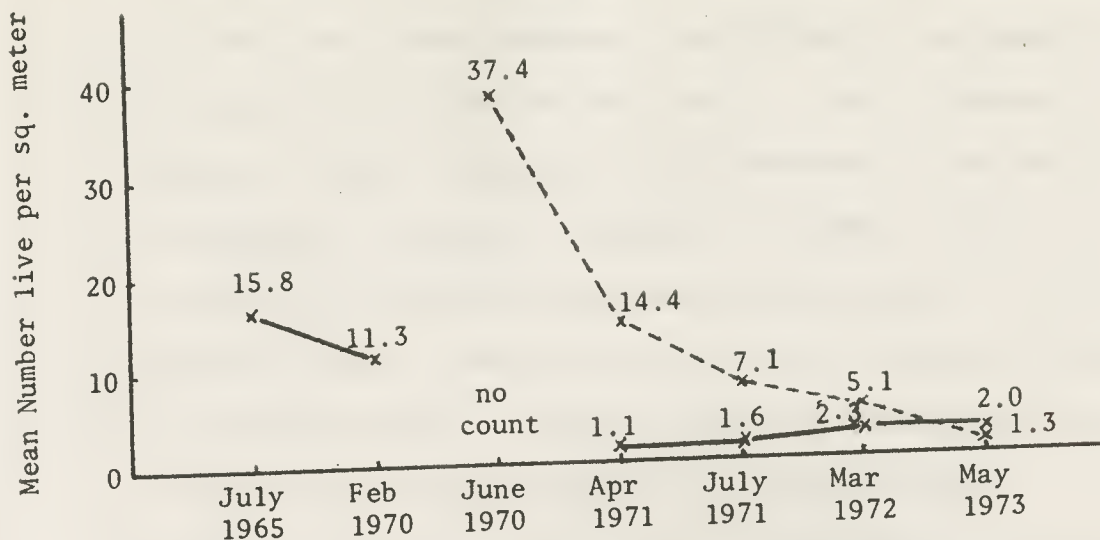


Figure 6. Comparison of transects at Stinson Beach and Drakes Beach for three species combined: *Emerita analoga*, *Neptys californiensis*, and *Orchestoidea californiana*

— 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, *Neptys 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.

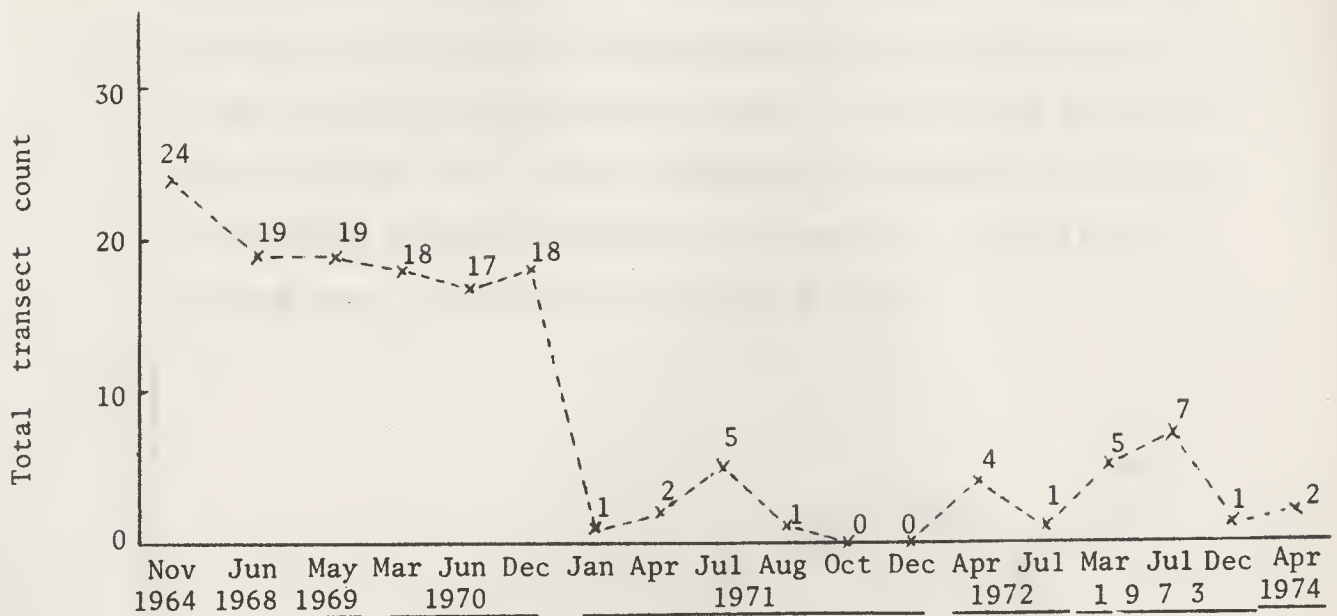


Figure 8. Total transect count of *Littorina planaxis* for Duxbury Reef, Berm A-8,9: 20 square meters

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

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.

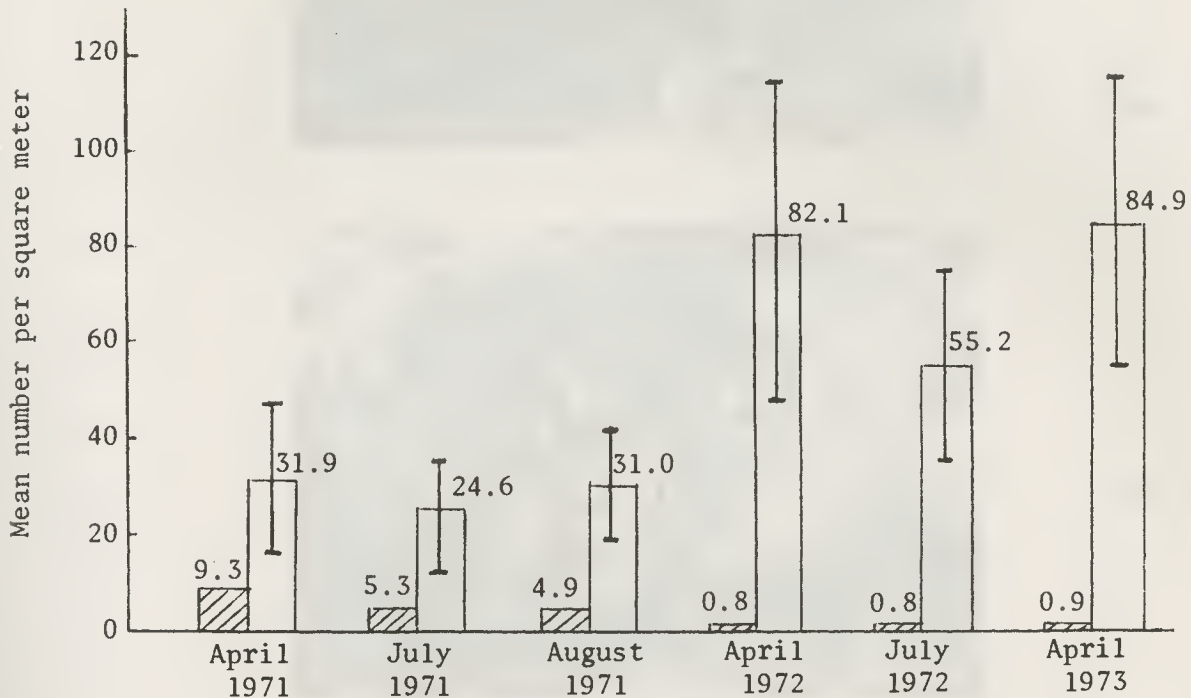


Figure 11. *Collisella spp.* for Duxbury Reef Berm A-8,9,10; 30 square meters

 dead
  live
  95% confidence interval for population mean

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

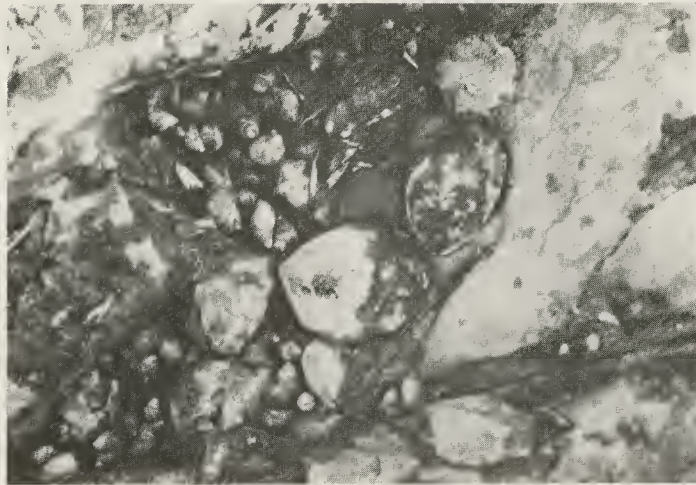


Fig. 11B



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.

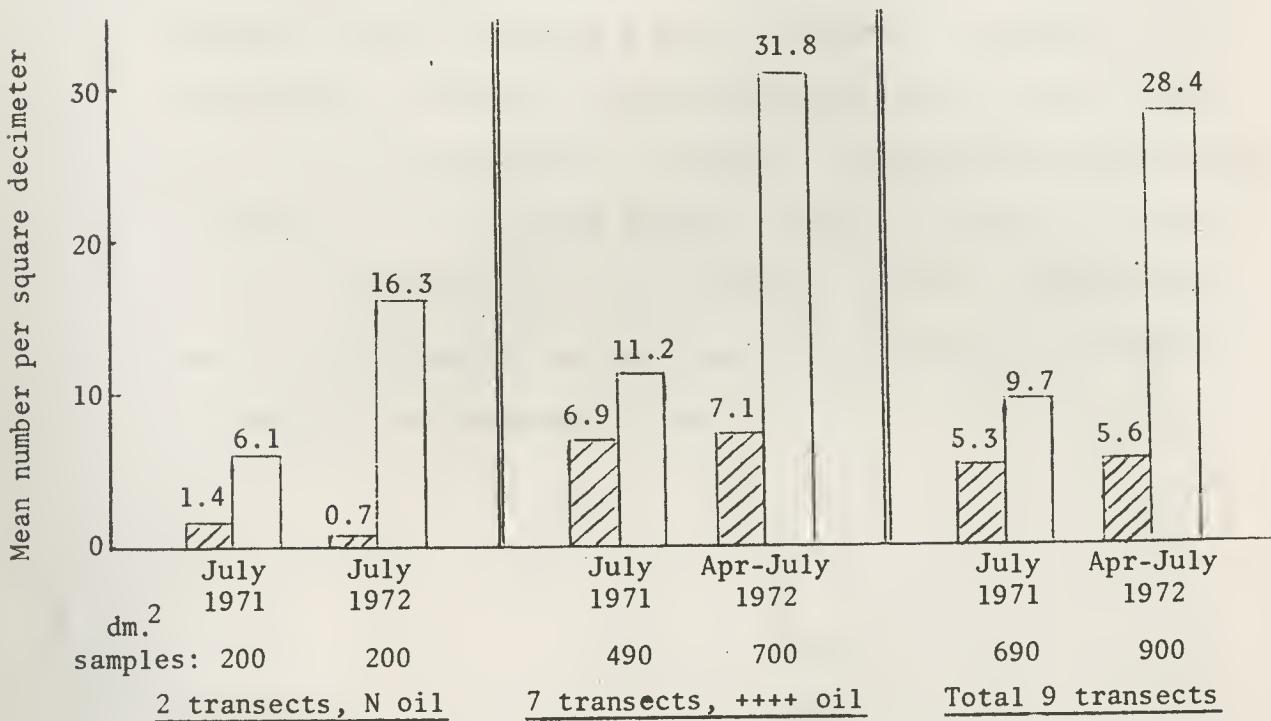


Figure 12. Comparison of *Balanus glandula* and *Chthamalus dalli* for Duxbury Reef, 9 transects



 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.

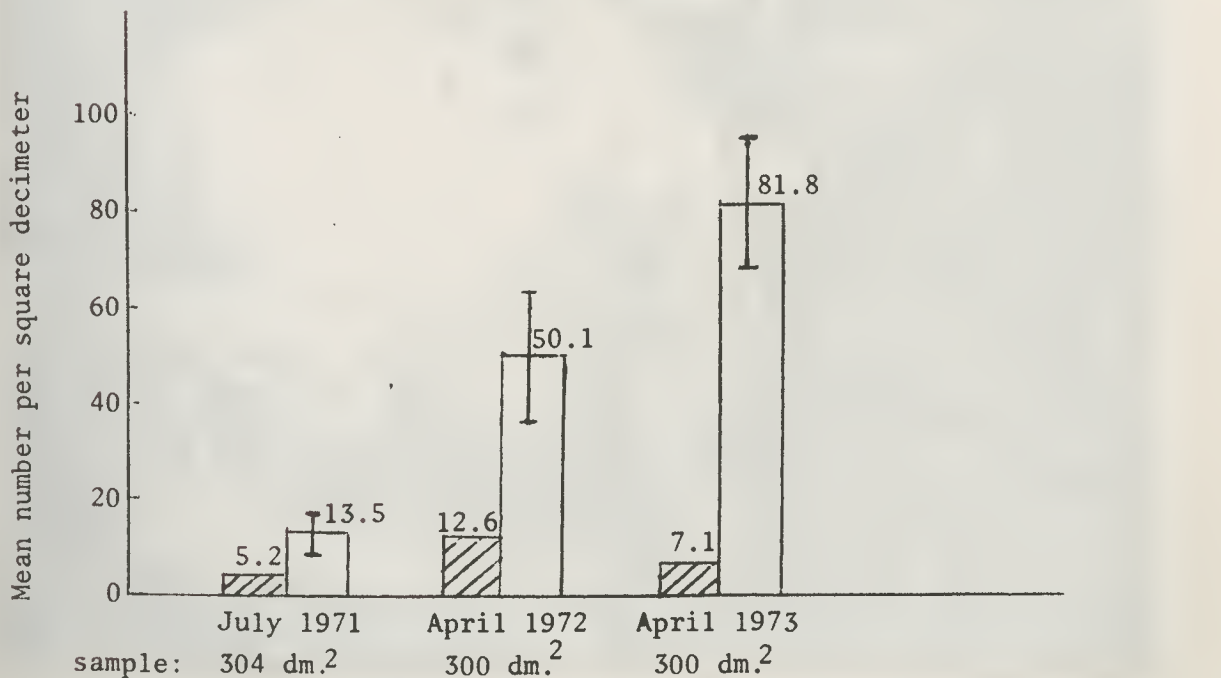


Figure 13. *Balanus glandula* and *Chthamalus dalli* for Duxbury Reef, Berm A-8,9,10

 dead
  live
  95% confidence interval for population mean



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

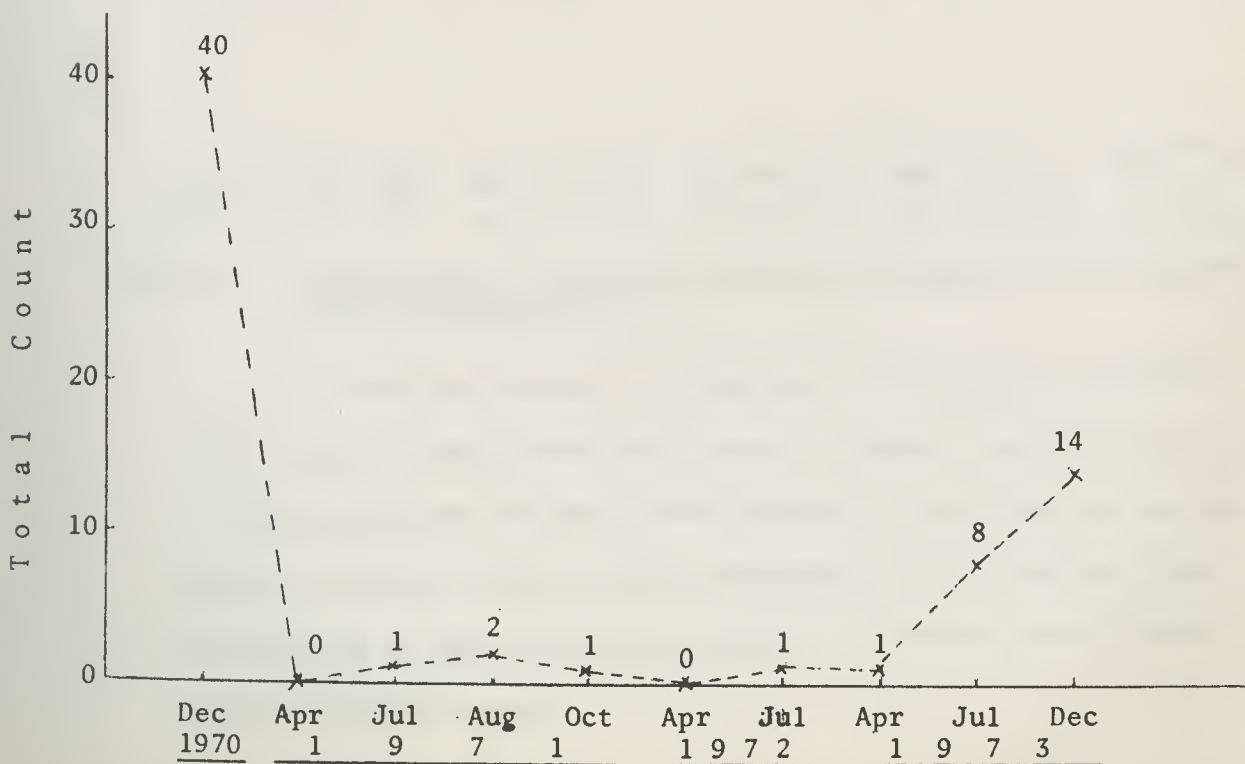


Figure 14. Total count of *Pachygrapsus crassipes* for Duxbury Reef Berm transects, A-8,9; 20 square meters

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.

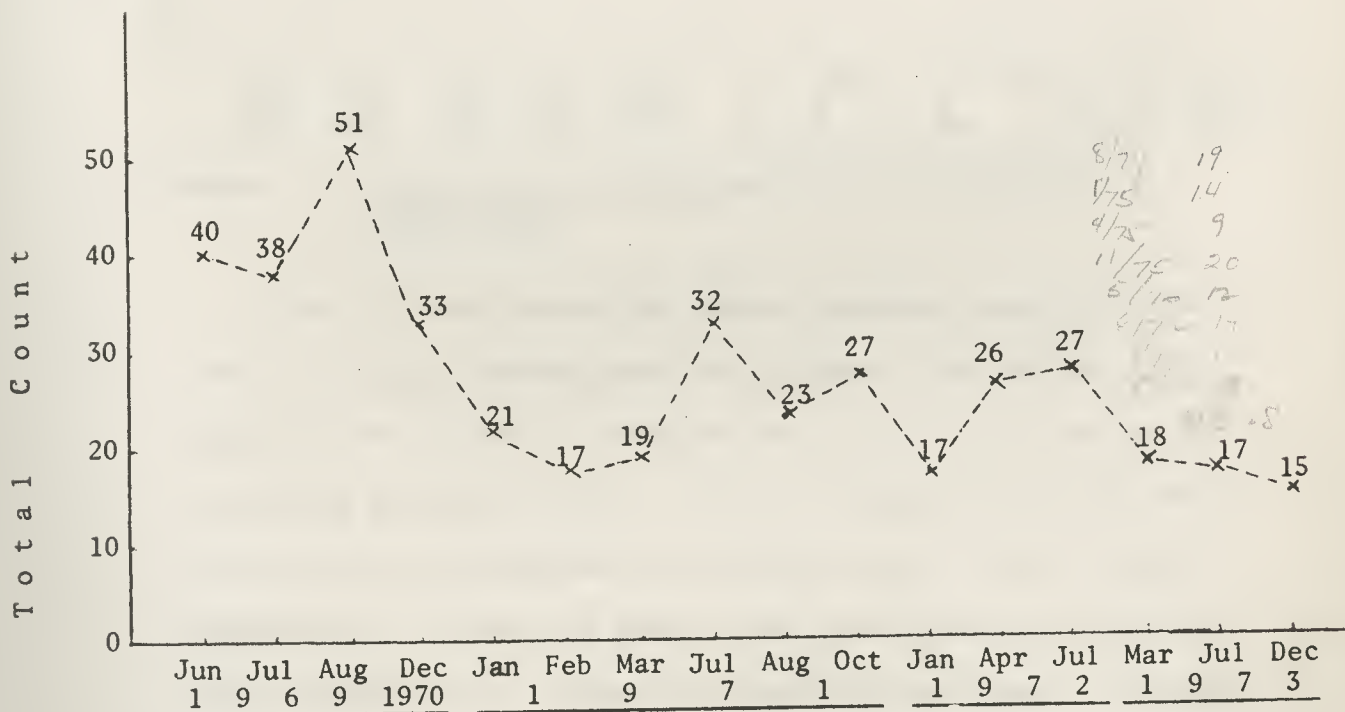


Figure 15. Total transect count for *Pisaster ochraceus* on Duxbury Reef, C-4, 10 square meters

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.

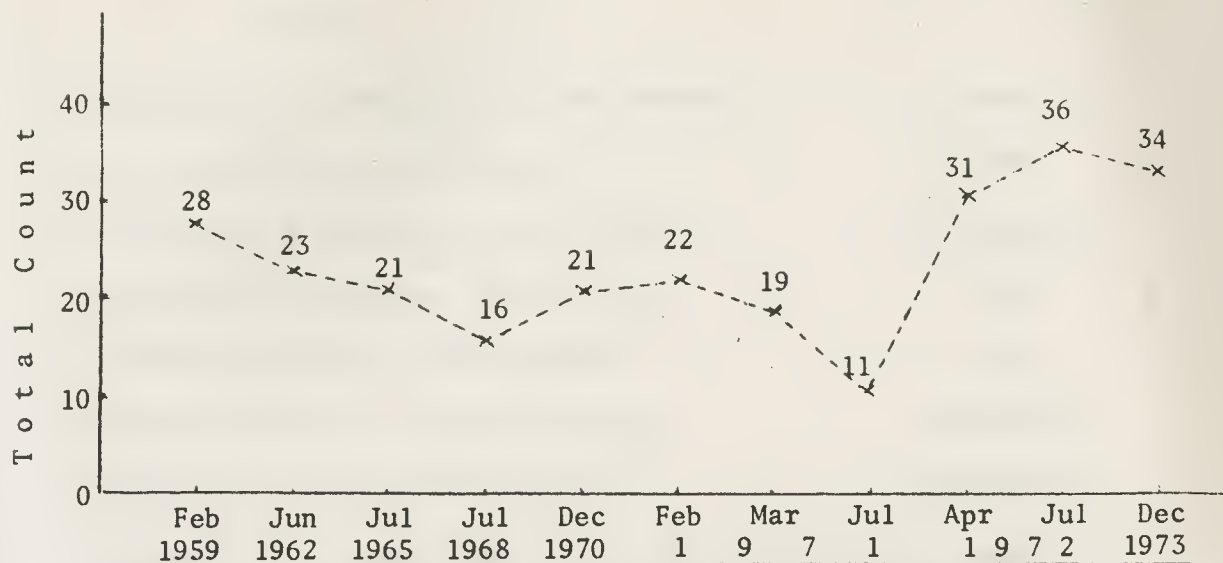


Figure 16. Total counts of *Lottia gigantea* on transect C-7, Duxbury Reef

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:

<u>Species</u>	<u>Post-oil counts</u>
<i>Anthopleura xanthogrammica</i> , sea anemone	increasing
<i>A. elegantissima</i> , sea anemone	same
<i>Pollicipes polymerus</i> , goose barnacle	increasing
<i>Platyodon cancellatus</i> , boring clam	same
<i>Pholadidea penita</i> , boring piddock	same
<i>Hermaeina smithi</i> , black nudibranch	decreasing
<i>Haliotis rufescens</i> , red abalone	decreasing
<i>Pagurus</i> spp., hermit crabs	same
<i>Pugettia</i> sp., kelp crab	same
<i>Hemigrapsus nudus</i> , purple shore crab	same
<i>Cancer antennarius</i> , cancer rock crab	same
<i>Strongylocentrotus purpuratus</i> , 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).

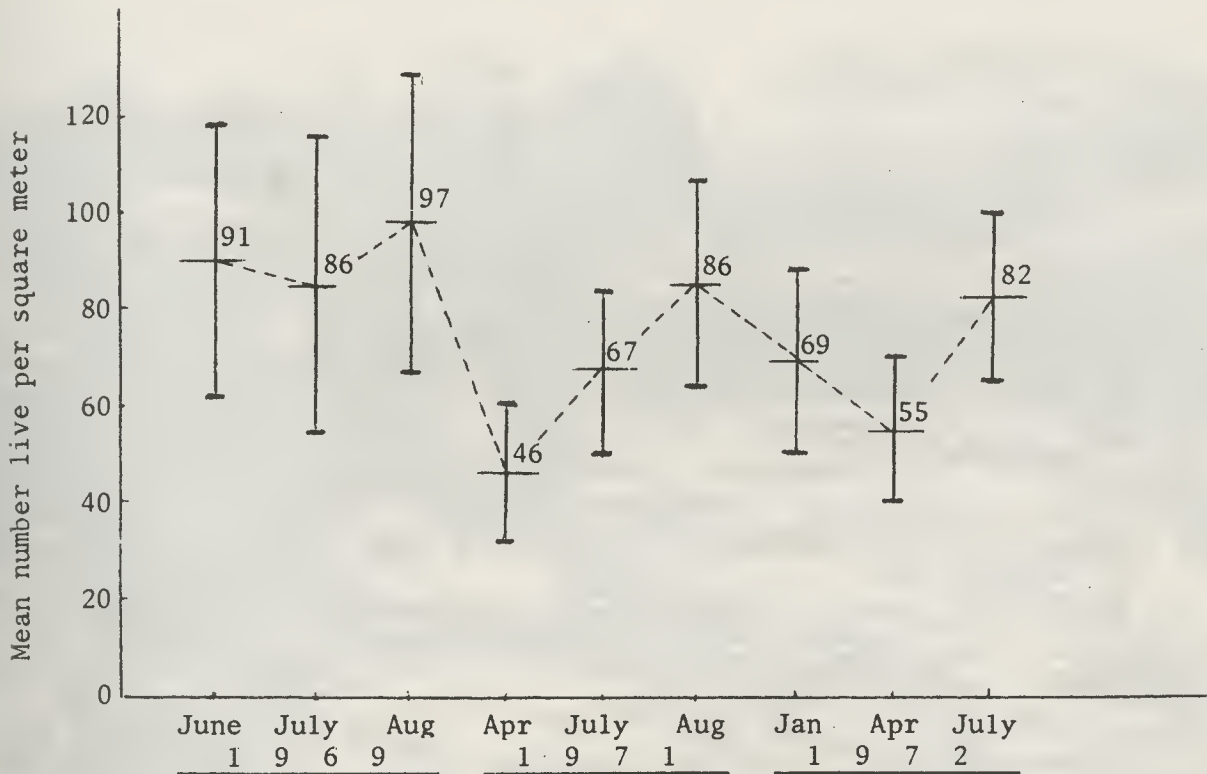


Figure 17. Summary of square meter sampling for all species counted, Duxbury Reef, 13 transects

+ 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

<u>Species</u>	<u>Date and Sample</u>	<u>Sample Mean per dm.²</u>	<u>95% confidence interval for population mean</u>	<u>Interval of Significant Difference</u>
SAUSALITO	May 13, 1971	93.3 live	69.0-117.7	1971 vs. 1972
<u>Barnacles</u>	63 dm. ²	49.2 dead	36.7- 61.8	101.1-268.3 live/dm. ²
<i>Balanus glandula</i>				25.1- 50.7 dead/dm. ²
<i>Chthamalus dalli</i>	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
<u>Barnacles</u>	50 dm. ²			89.1-187.3 live/dm. ²
<i>Balanus glandula</i>	May 18, 1972	229.0 live	187.6-270.3	
<i>Chthamalus dalli</i>	50 dm. ²			

Live Barnacles:	<u>Sausalito vs. Fort Baker</u>			

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.

<u>SAUSALITO</u>	<u>Date</u>		
<u>Limpets</u>			
<i>Collisella</i> spp.	May 13, 1971	21 live for 63 dm. ²	
	May 18, 1972	90 live for 60 dm. ²	
<u>Shore Crabs</u>			<u>Non-transect counts for Shore Crabs</u>
<i>Pachygrapsus</i>	*May 13, 1971	59 live, 1 dead	Jan 18, 1971 42 live
<i>crassipes</i> and	*Feb 11, 1972	28 live, 0 dead	1st 100 seen 58 dead
<i>Hemigrapsus</i>	*May 18, 1972	41 live, 0 dead	
<i>nudus</i>			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

*Total transect count

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

<u>Date</u>	<u>Square Meter Samples</u>	<u><i>Emerita analoga</i></u>	<u><i>Nephtys californi- niensis</i></u>	<u><i>Orchestoidea californiana</i></u>	<u>3 species combined</u>
<u>STINSON BEACH</u>					
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.

<u>DRAKES BEACH</u>					
June 25, 1970	30	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

A. Black Turban Snail, *Tegula funebris*

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

<u>Date</u>	<u>Live Sample Mean per m.²</u>	<u>95% confidence interval for population mean</u>
Nov, 1964	28.7	
June, 1968	28.5	(data not
May, 1969	30.0	
Mar, 1970	29.0	available)
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

<u>Date</u>	<u>Sample mean per m.²</u>	<u>95% confidence interval for population mean</u>
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

APPENDIX IV (continued, page 3) - Duxbury Reef Statistics

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

<u>Date</u>	<u>Square meters sampled</u>	<u>Sample mean</u>	<u>95% confidence interval for population mean</u>	<u><i>T. funebris</i> % of total count</u>
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 $H_0: \mu_1 = \mu_2$

$H_1: \mu_1 \neq \mu_2$

Reject H_0 if test statistic $Z \geq 1.96$ or ≤ -1.96

Comparison μ_1 w μ_2	$ \bar{x}_1 - \bar{x}_2 $	Decision	Interval estimate of difference
4/71 w 6/69	44.5	Reject H_0	13.0 to 76.0
w 7/69	39.9	Reject H_0	7.1 to 72.7
w 8/69	50.6	Reject H_0	17.9 to 83.3
w 7/71	20.7	Reject H_0	0.2 to 41.2
w 8/71	39.4	Reject H_0	13.8 to 65.0
w 1/72	22.1	H_0 true	
w 4/72	8.3	H_0 true	
w 7/72	35.7	Reject H_0	4.6 to 50.2
4/72 w 6/69	36.2	Reject H_0	4.5 to 67.9
w 7/69	31.6	H_0 true	
w 8/69	42.3	Reject H_0	9.4 to 75.2
w 4/71	8.3	H_0 true	
w 7/71	12.4	H_0 true	
w 8/71	31.1	Reject H_0	5.2 to 57.0
w 1/72	13.8	H_0 true	
w 7/72	27.4	Reject H_0	4.6 to 50.2

In tests for significant difference between population means for summer counts, H_0 was true for the following comparisons:

7/69 w 7/71	Test statistic $Z = 1.1148$	$ \bar{x}_1 - \bar{x}_2 = 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	<i>A. xanthogrammica</i>	<i>A. elegantissima</i>	<i>Balanus/Chthamalus</i>	<i>Pollicipes</i> sp.	<i>Pachygrapsus</i> sp.	<i>Cancer</i> sp.	<i>Pugettia</i> sp.	<i>Pagurus</i> spp.	<i>Mopalia</i> sp.	<i>Mytilus</i> sp.	<i>Platydora</i> sp.	<i>Collisella</i> spp.	<i>Haliotis</i> sp.	<i>Littorina</i> sp.	<i>Tegula</i> sp.	<i>Acanthina</i> sp.	<i>Pisaster</i> sp.	<i>Strongylocentrotus</i> sp.	Mean/square meter
June, 1969	1.5	1.6 P/3	1.1 P/3	1.1	P/1	.01 P/1	0.3 P/1	10.9 P/1	0.2 P/1	35.5 P/2	9.2 P/2	31.4	9.2 P/2	31.4	4.7	0.3	0.3	.08	91.3*
July, 1969	1.5	1.6 P/3	0.9 P/3	0.9	P/1	P/1	0.2 P/1	6.3 P/1	0.2 P/1	44.4 P/2	9.2 P/2	26.1	9.2 P/2	26.1	1.8	0.3	0.3	.02	86.7
Aug, 1969	1.5	1.6 P/3	0.9 P/3	0.9	P/1	.02 P/1	0.2 P/1	6.4 P/1	0.2 P/1	44.3 P/2	9.2 P/2	33.8	9.2 P/2	33.8	4.7	0.4	0.4	.06	97.4
Apr, 1971	0.9	3.3 P/2	1.5 P/5	1.5	-0-	.03	0.5	10.8 P/1	0.4	17.2 P/1	-0-	12.8	9.2 P/2	12.8	0.7	0.2	0.2	0.1	46.8
July, 1971 119m ²	0.9	1.1 P/2	2.5 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	4.7 P/1	29.6	1.8	0.3	0.3	0.1	67.5
Aug, 1971	0.9	2.6 P/2	2.5 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	5.0 P/2	26.8	0.9	0.2	0.2	.07	86.2
Jan, 1972 101m ²	0.7	3.1 P/4	0.7 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	1.1 P/2	24.2	.05 P/1	0.1	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	0.2 P/2	17.1	0.6	0.2	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 P/2	20.0	9.6 P/2	20.0	1.1	0.2	0.2	0.3	82.5

IMPORTANT

FOUNDATION CHARTS
(DATA)

Report IV completed

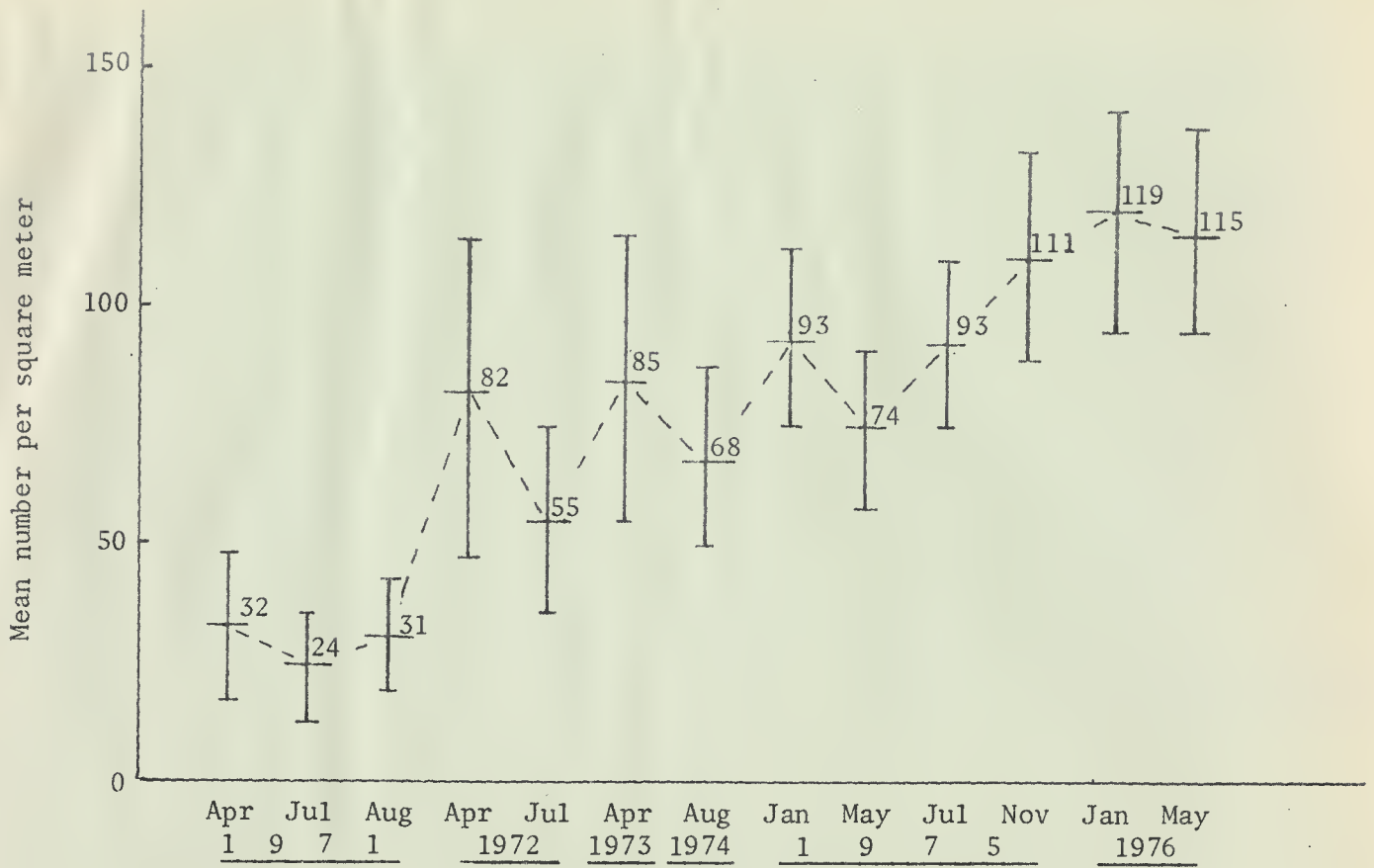


Figure Live *Collisella* spp. for Duxbury Reef Berm A-8,9,10:
30 square meters

—+— sample mean

⌋ 95% confidence interval
for population mean

~~IV~~ 5
III 8

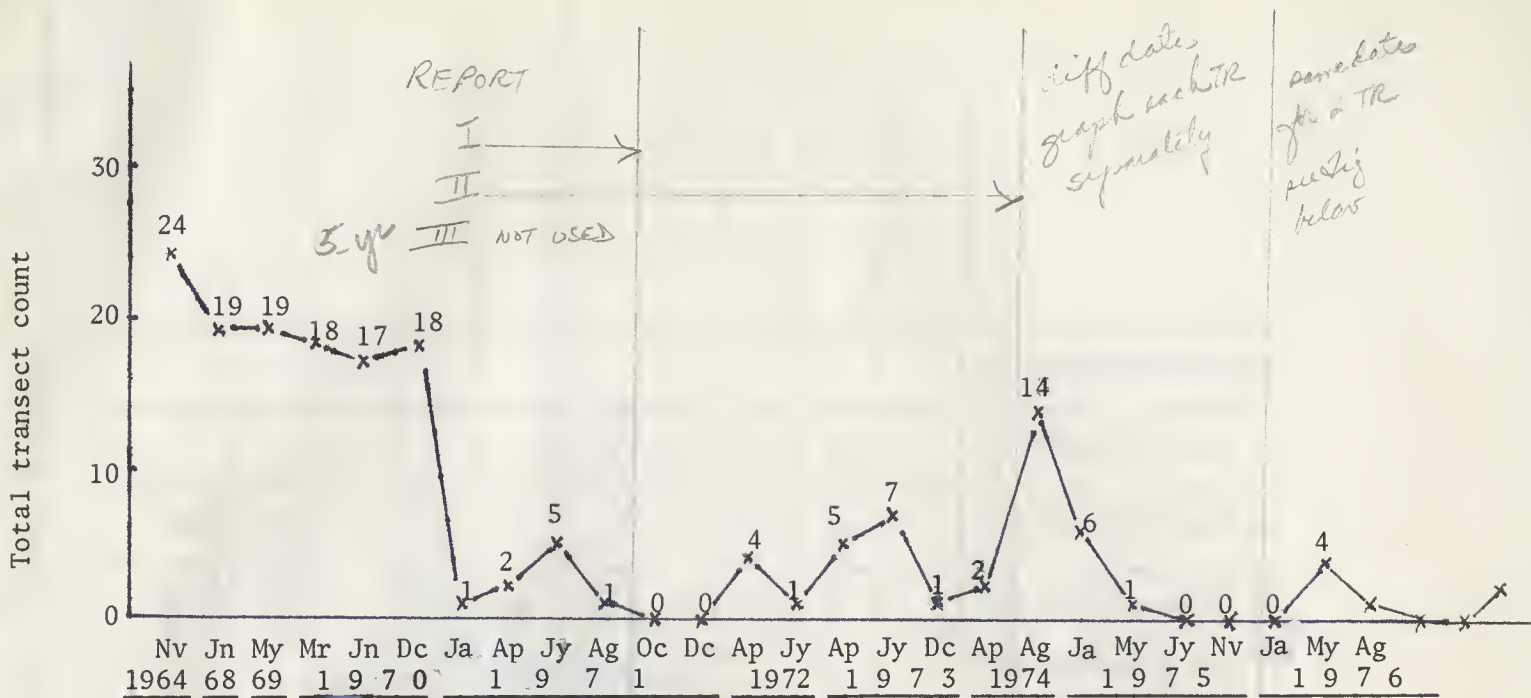


Figure Total transect count of *Littorina planaxis* for Duxbury Reef, Berm A-8,9: 20 square meters

DO NOT USE COMBINED TR in this GRAPH
different sampling dates 1974 until 1976

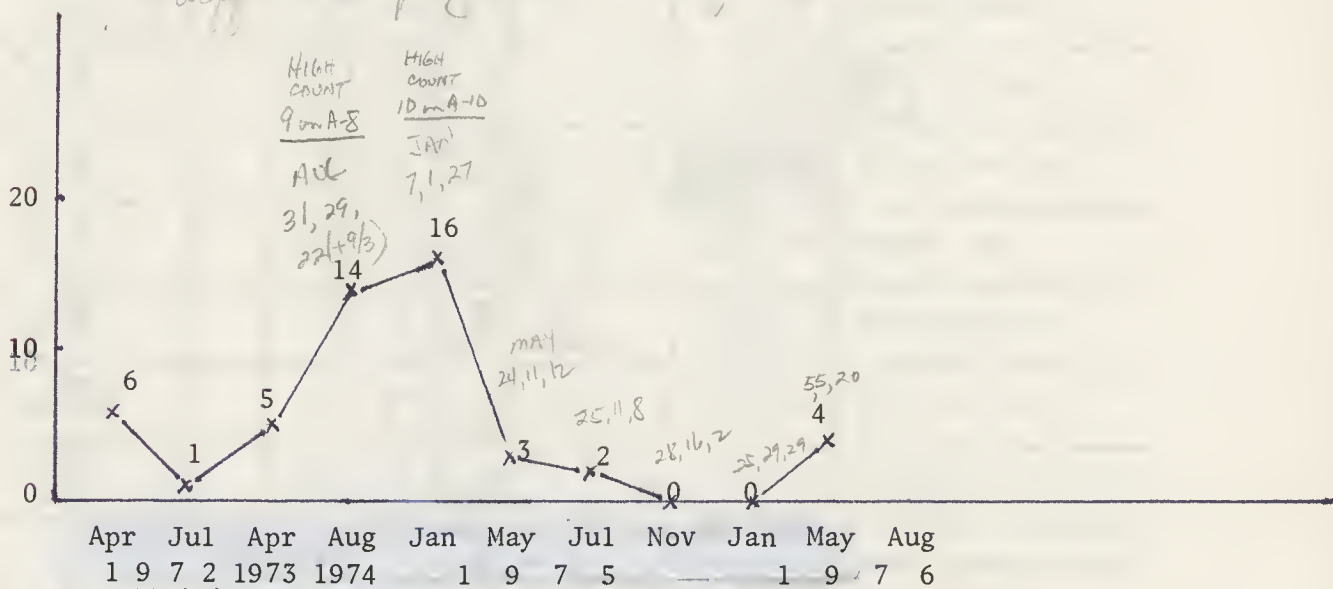


Figure Total transect count of *Littorina planaxis* for Duxbury Reef, Berm A-8,9,10: 30 square meters

IV 6
III 5a

LITTORINA PLANAXIS on DUXBURY REEF BERM

X = different date
 O = AB-8 & 9 only
 ✓ = same date

TRANSECT TOTALS	11/64	6/68	5/69	3/70	6/70	12/70	1/71	4/71	7/71	8/71	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	0	0	NC	NC	2	0					
Total	24	19	19	18	17	18	1	X	X	X	O	O	6	1					
	4/73	7/73	12/73	4/74	8/74	1/75	5/75	7/75	11/75	1/76	5/76	8/76	12/76	2/77	4/77				
AB-8	1	5	I=1	0	9	1	0	0	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	10	10	2	0	0	0	0	0	0	0	0				
	5	7	1	2	X	X	X	X	X	0	4								
Mean/square meter	Strongylocentrotus sp.	Pisaster sp.	Acanthina sp.	Tegula sp.	Littorina sp.	Maliotis sp.	Acmaea spp.	Platyodon sp.	Mytilus sp.	Mopalia sp.	Pagurus spp.	Cancer sp.	Pugettia sp.	Hemigrapsus sp.	Pachygrapsus sp.	Pollicipes sp.	Balanus/Chthamalus	A. elegantissima	A. xanthogrammica

IV

was not used for III,
preparation IV
(9 TR used for III
including A-8, 9, 10)

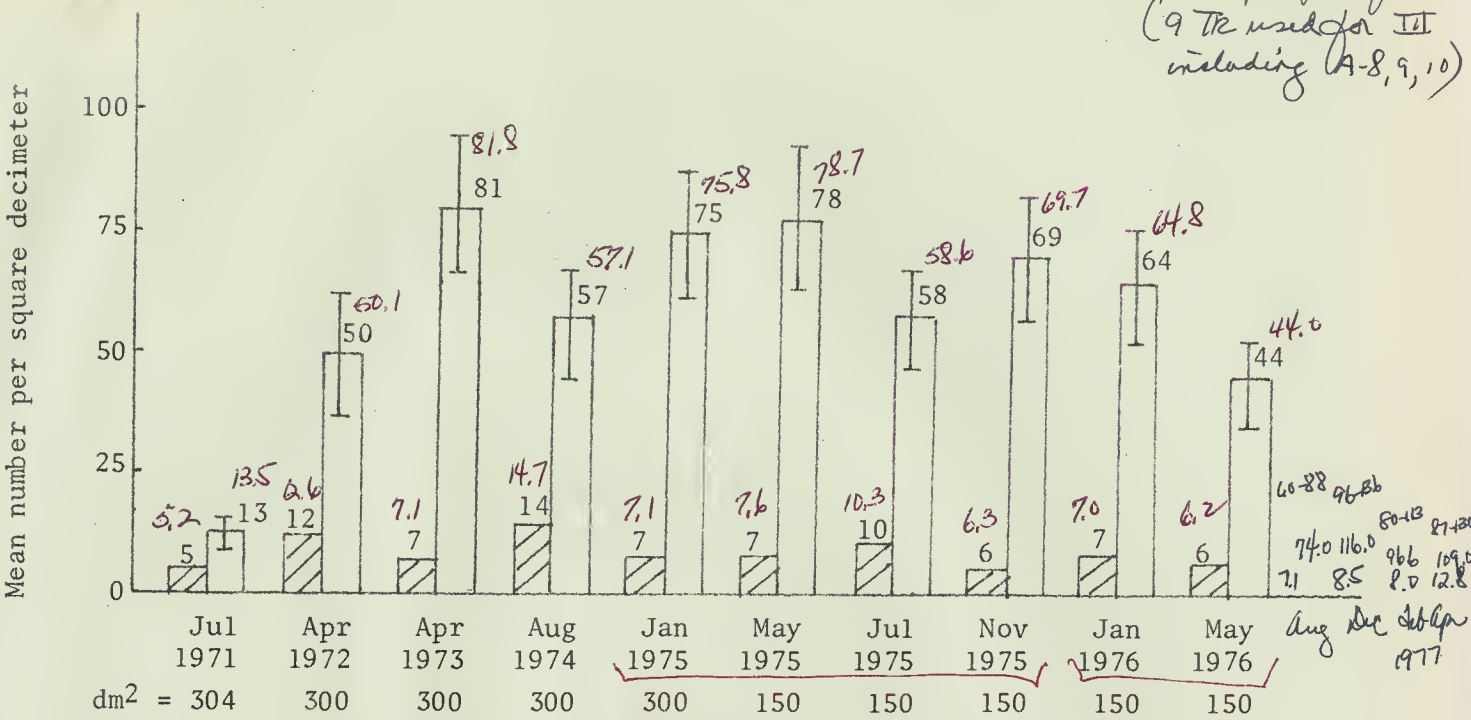


Figure *Balanus glandula* and *Chthamalus dalli* for Duxbury Reef, Berm A-8,9,10

dead
 live

 |
 | 95% confidence interval
 | for population mean

III 9
IV 7

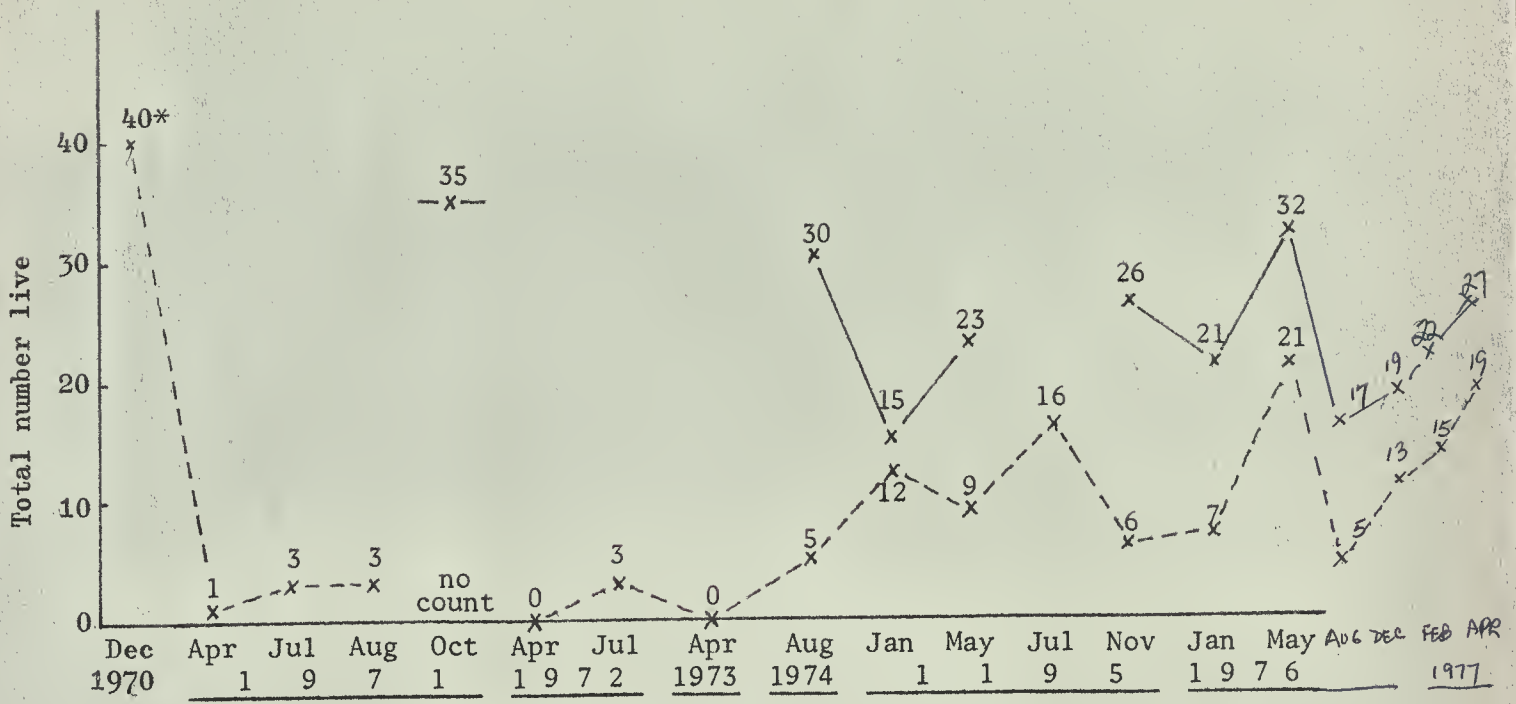


Figure 3. Total counts of *Pachygrapsus crassipes* for Duxbury Reef berm transects and for berm crevices

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

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

Gordon L. Chan:

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

JK 8

Mean number live per sq. decimeter

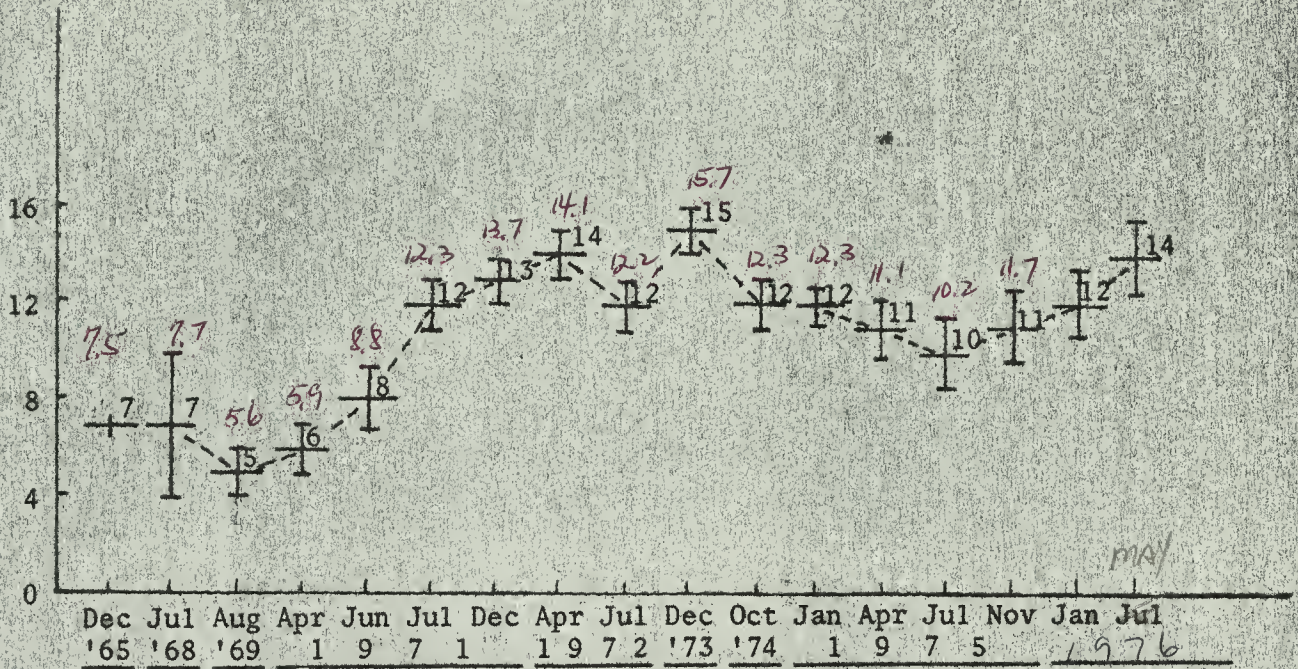


Figure Live *Mytilus californianus* for Duxbury Reef, Area C transect, square decimeter sampling

—+— sample mean

| 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)

JUL 11(6)
 JUL 14(8)

Mean number live/square decimeter

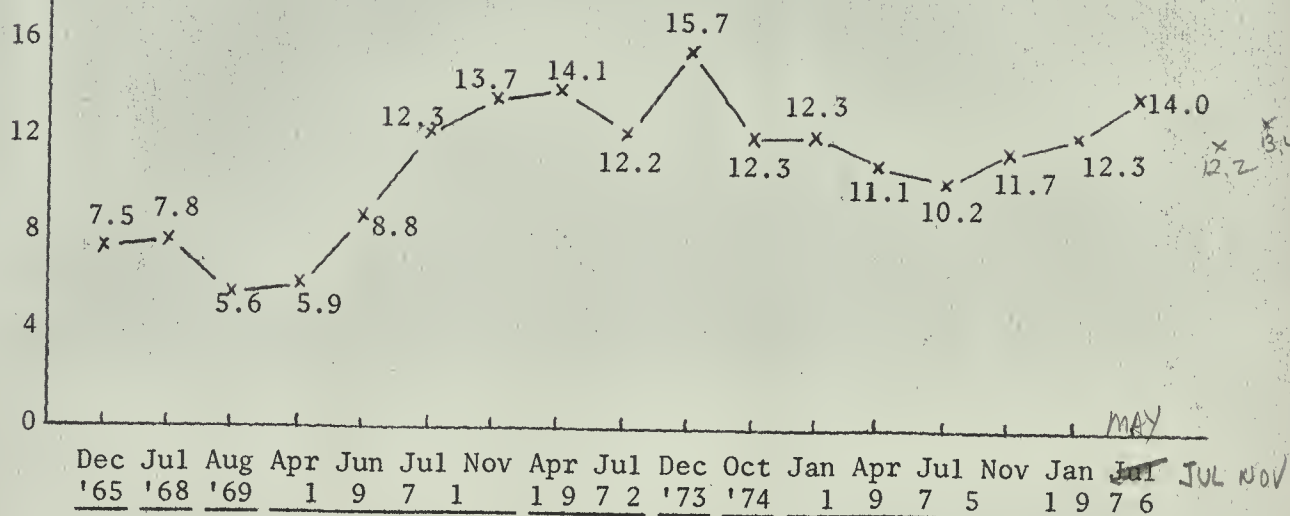
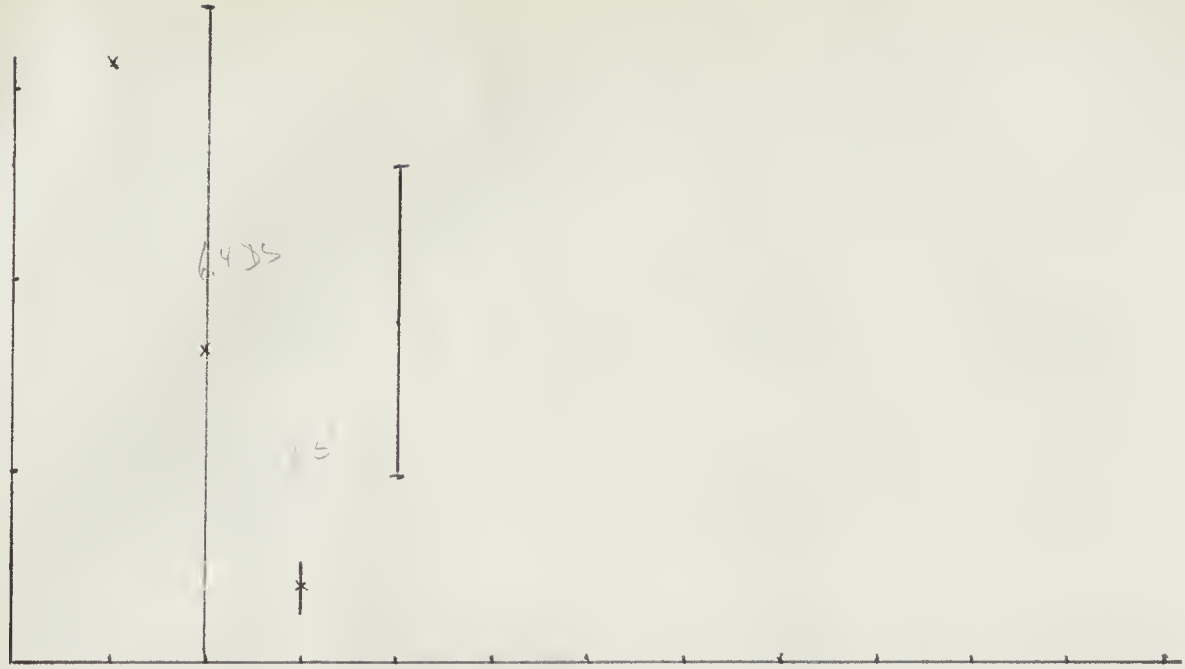


Figure 6. Live *Mytilus californianus* for Duxbury Reef, Area C transect, square decimeter sampling

Gordon L. Chan

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



	1/22	2/23	3/24	4/25	5/25	6/25	7/25	8/26	9/26	10/26	11/26	12/27	13/27	
95% C.F.	6 to 32	6 to 32	16 to 2	16 to 2	6.6 to 11.2	4.6 to 8.6	2.5 to 8.0	6.5 to 12.3	4.5 to 7.7	4.0 to 6.7	2.0 to 9.8	3.1 to 7.7	3.8 to 7.6	2.7 to 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	Under shell	counted									

Dead Nystalus / 29 meter

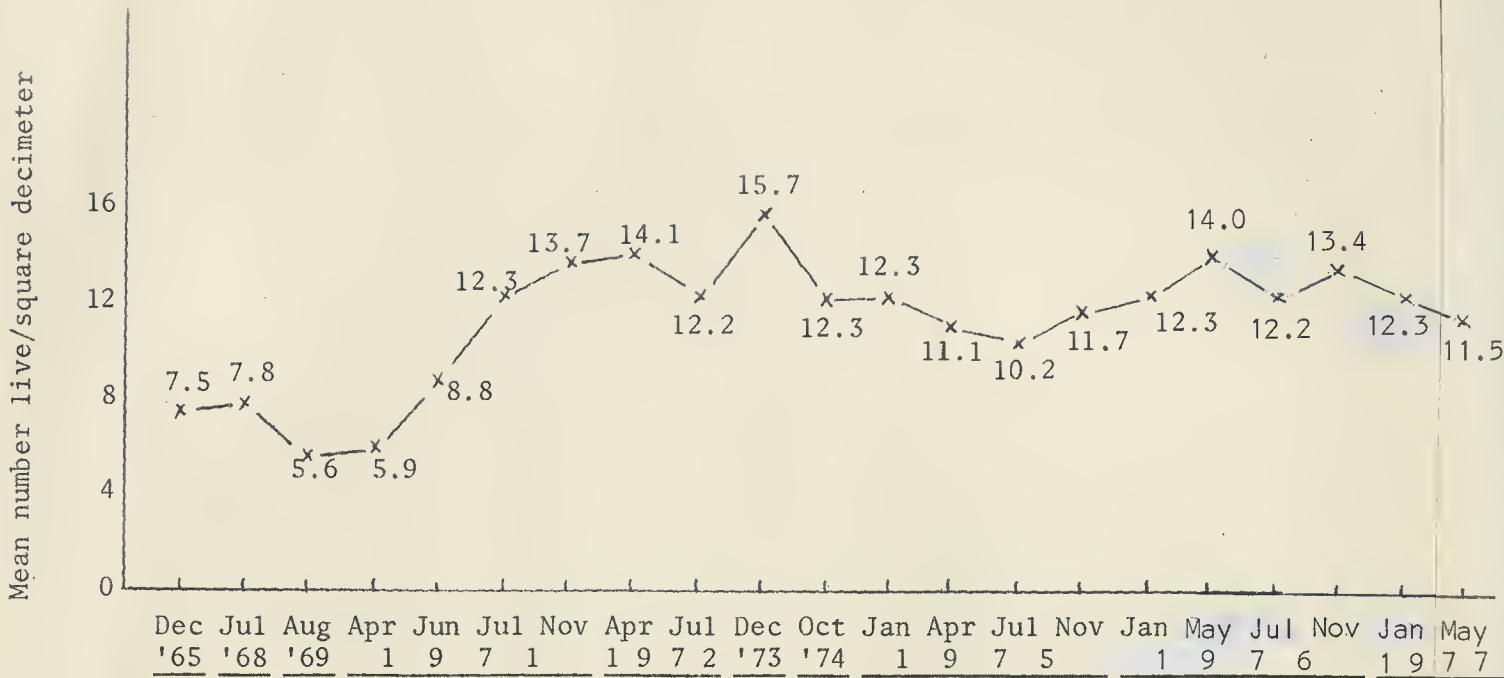


Figure Live *Mytilus californianus* for Duxbury Reef, Area C transect, square decimeter sampling

IV 9a

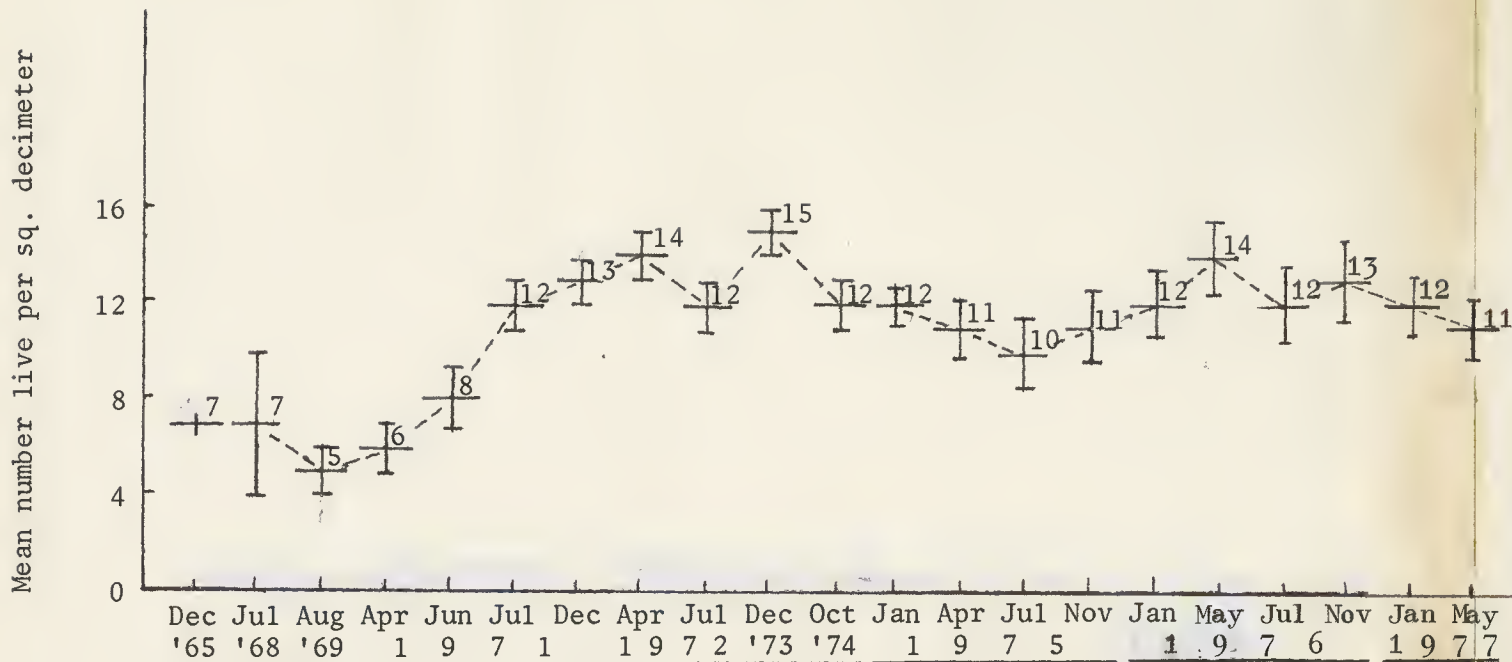


Figure Live *Mytilus californianus* for Duxbury Reef, Area C transect, square decimeter sampling

—+— sample mean

⌈ 95% confidence interval for population mean

IV 9.6

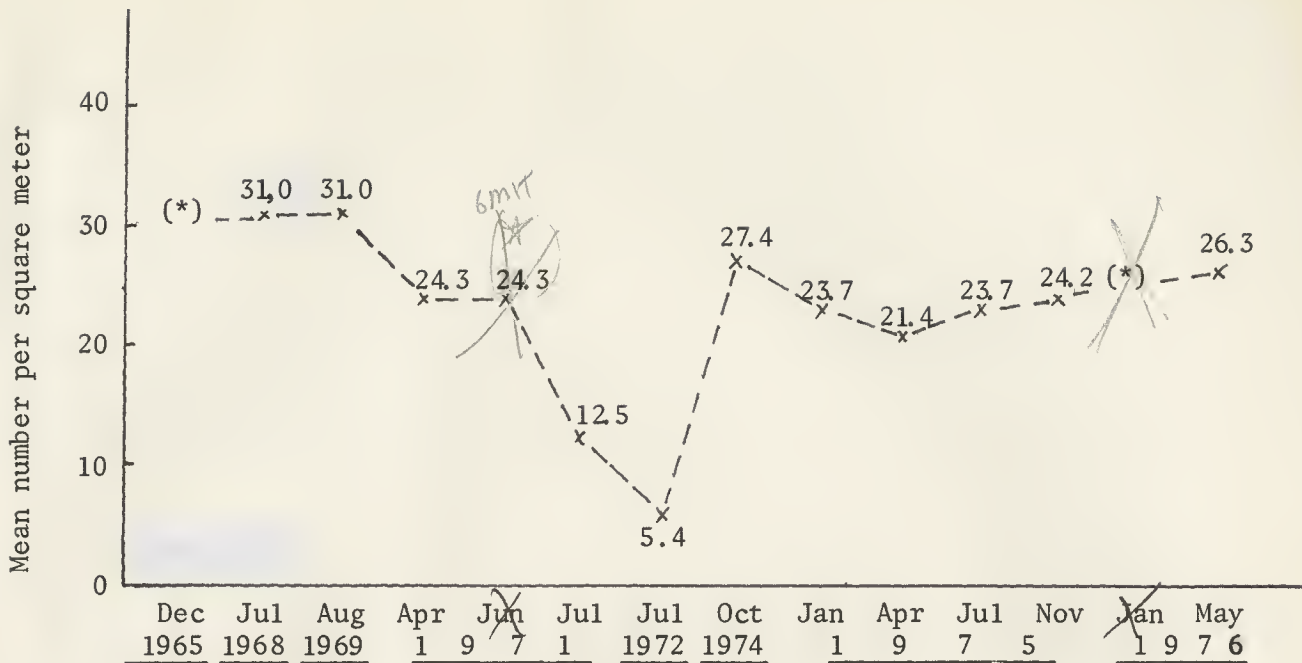


Figure Sample means of *Pollicipes polymerus* on Duxbury Reef, transect C-3 mussel bed: 10 square meters
 (*) = present, no count

1976 Jul 26.4
 1976 Nov 30.6
 1977 { 30.1
 { 21.4

Mean number per square decimeter



Date	Live (Mean)	Dead (Mean)
1965	(*)	(*)
1968 Jul 1971	9	10
1972 Apr	15	10
1974 Oct	68	21
1975 Jan	58	19
1975 Apr	67	11
1975 Jul	87	7
1975 Nov	85	14
1976 Jan	122	10
1976 May	74	12

No. of dm.² =

\bar{x}/dm^2 dead

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, 14 D
(119-197)

Nov 1976 304 L, 16 D
(242-367)

Jan 1977 263 L, 23 D
(214-312)

May 1977 225 L, 36 D
(176-274)

II (1)
III (13)

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

American Petroleum Institute
2101 L Street, N.W.
Washington, D.C. 20037

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 population 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.

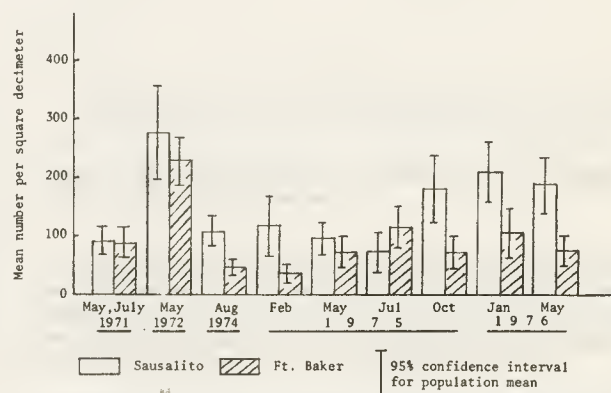


Figure 1. Comparison of live barnacles, *Balanus glandula* and *Chthamalus dalli*, for transects in Sausalito (oil) and Ft. Baker (no oil)

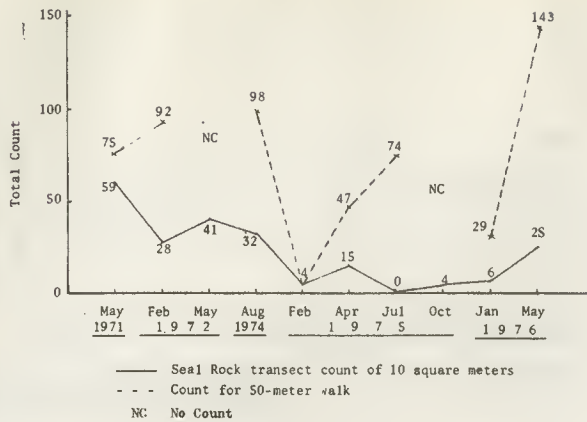


Figure 2. Total counts for crabs, *Pachygrapsus crassipes* and *Hemigrapsus nudus*, at Sausalito

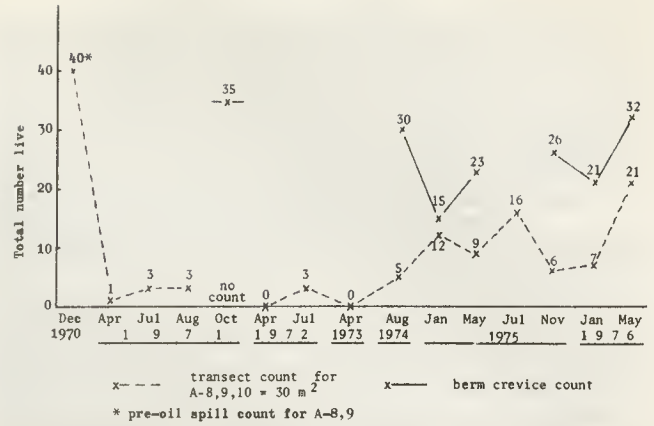


Figure 3. Total counts of *Pachygrapsus crassipes* for Duxbury Reef berm transects and for berm crevices

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 DiSalvo³ 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 funebris*, 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

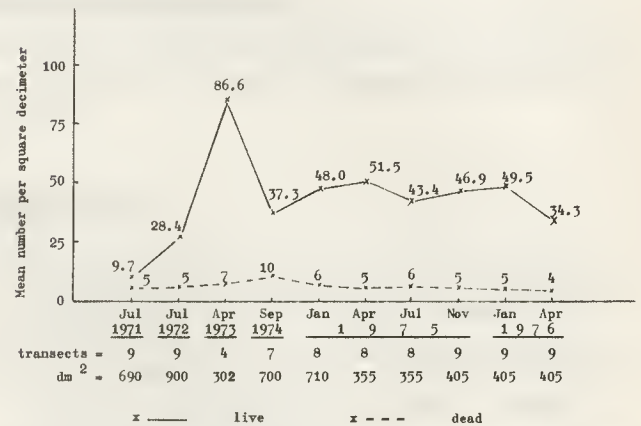


Figure 4. Square decimeter sampling for *Balanus glandula* and *Chthamalus dalli* for Duxbury Reef; nine transects, including the berm and the mussel bed

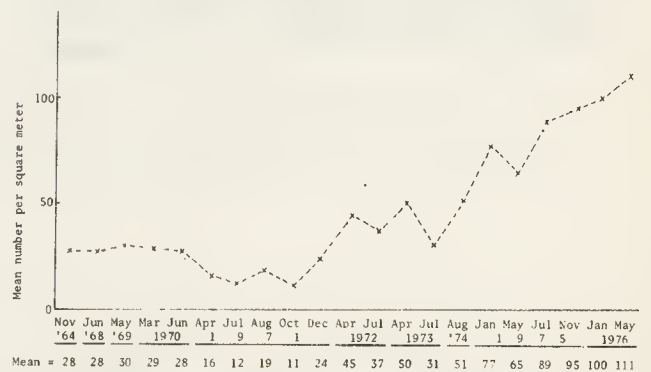


Figure 5. Sample means for live *Collisella spp.* for Duxbury Reef Berm A-8,9; 20 square meters

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

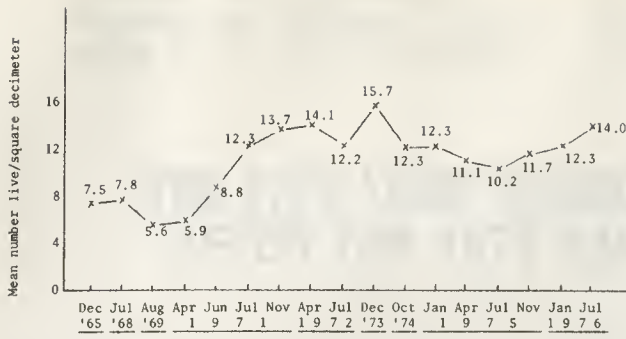


Figure 6. Live *Mytilus californianus* for Duxbury Reef, Area C Transect, square decimeter sampling

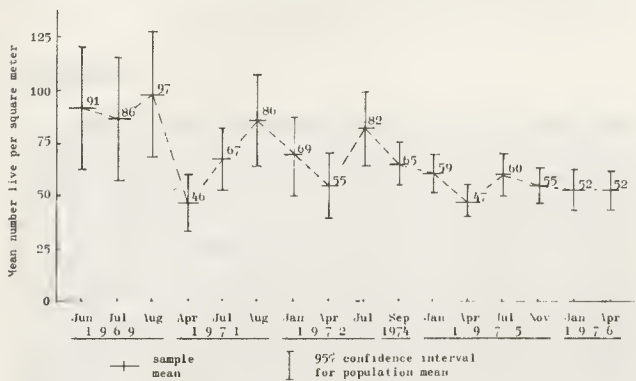


Figure 7. Summary of square meter sampling for all species counted, Duxbury Reef, 13 transects; 120 square meters

mole crab, and *Nephtys 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.

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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

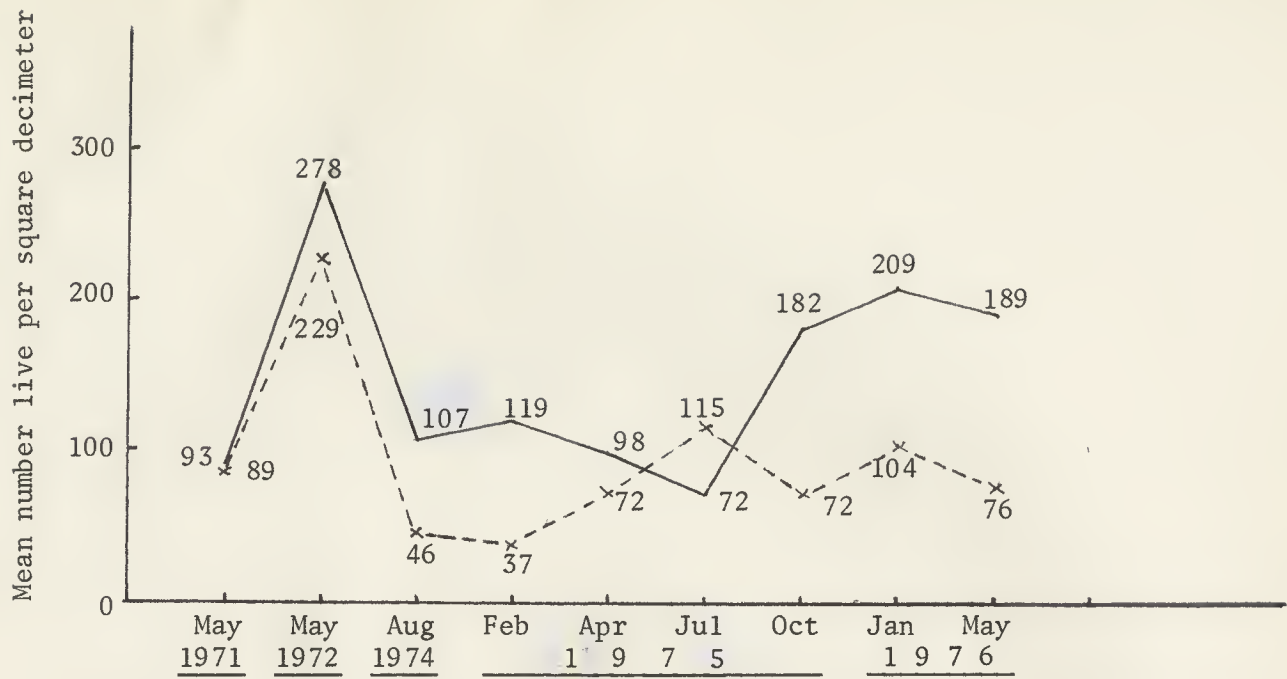


Figure Comparison of barnacles, *Balanus glandula* and *Chthamalus dalli*, for transects in Sausalito (oil) and Fort Baker (no oil); sampling of 50 square decimeters in each transect.

— 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

7/7/76

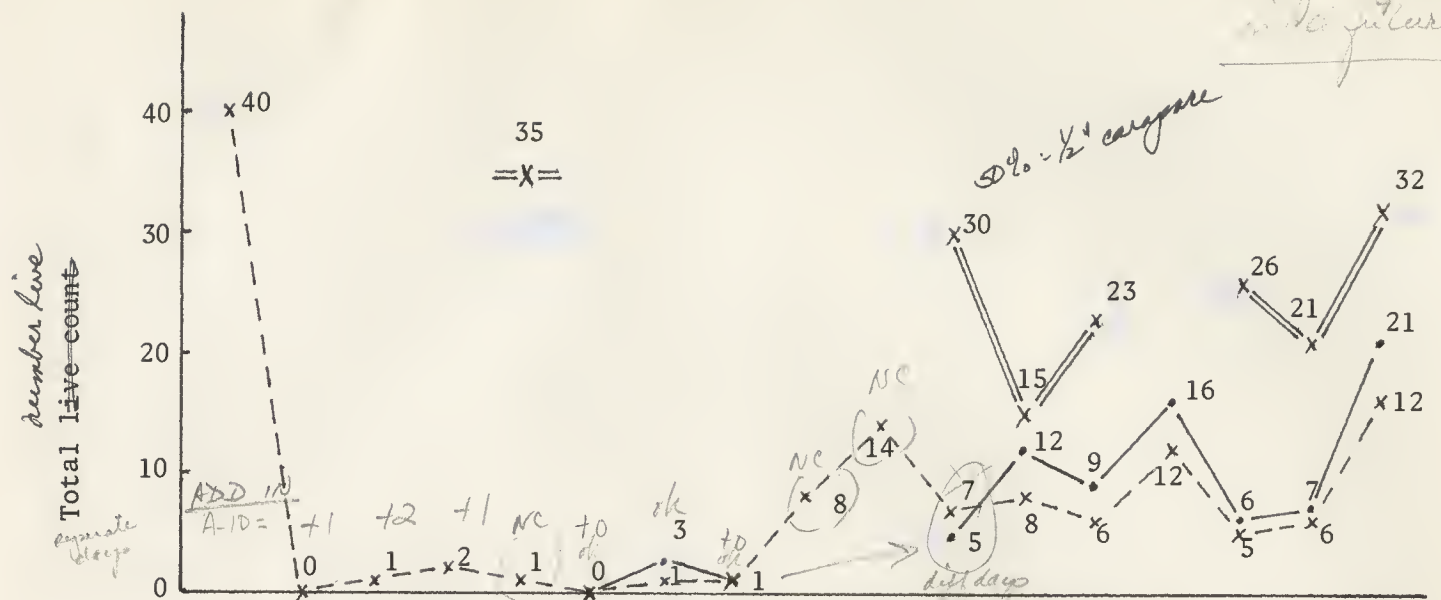


Figure *Balanus glandula* and *Chthamalus dalli* for Duxbury Reef, Berm A-8,9,10

▨ dead □ live

┆ 95% confidence interval
┆ for population mean

Analysis
 * WORKSHEET
 keep a log of
 in the future graphs



revision = A-8,9,10
 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
 11, 10



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

Typical in the range?

III WORK
CHARTS

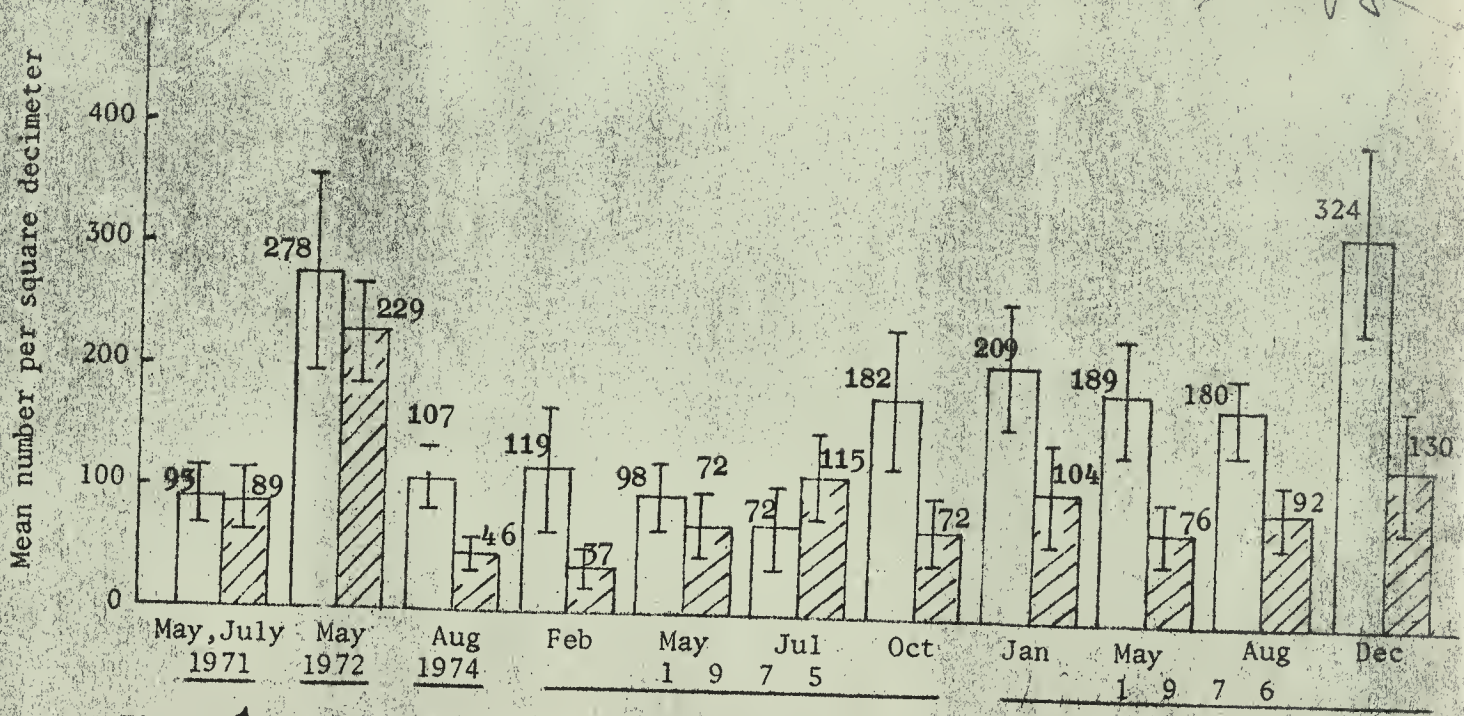


Figure 7 Comparison of live barnacles, *Balanus glandula* and *Chthamalus dalli*, for transects in Sausalito (oil) and Ft. Baker (no oil)

Sausalito
 Ft. Baker
 95% confidence interval for population mean

Reference - sample means not numbered in original

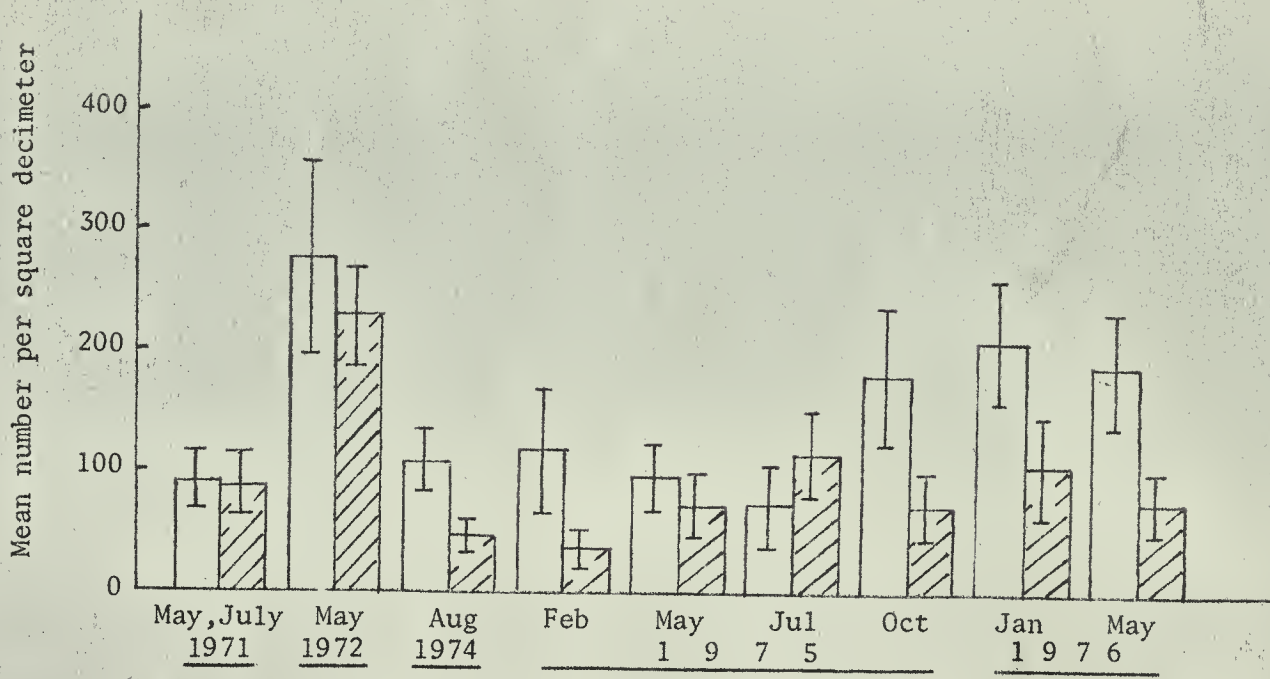


Figure 1. Comparison of live barnacles, *Balanus glandula* and *Chthamalus dalli*, for transects in Sausalito (oil) and Ft. Baker (no oil)

Sausalito
 Ft. Baker
 95% confidence interval for population mean

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not used in III

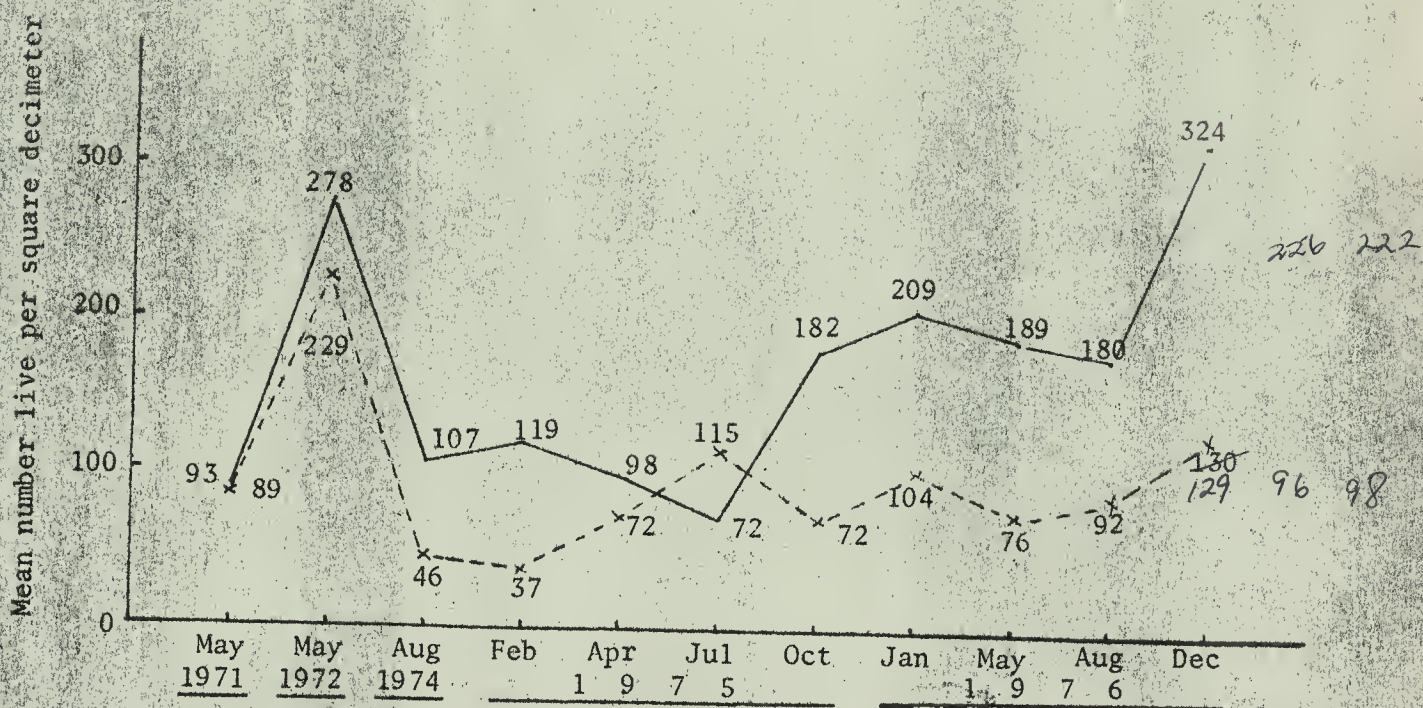


Figure 1. Comparison of barnacles, *Balanus glandula* and *Chthamalus dalli*, for transects in Sausalito (oil) and Fort Baker (no oil); sampling of 50 square decimeters in each transect.

— Sausalito - - - Fort Baker

	Sausalito		Fort Baker	
Jan	63	60	50	
Feb	50			

226 222
96 98

III
III (2)

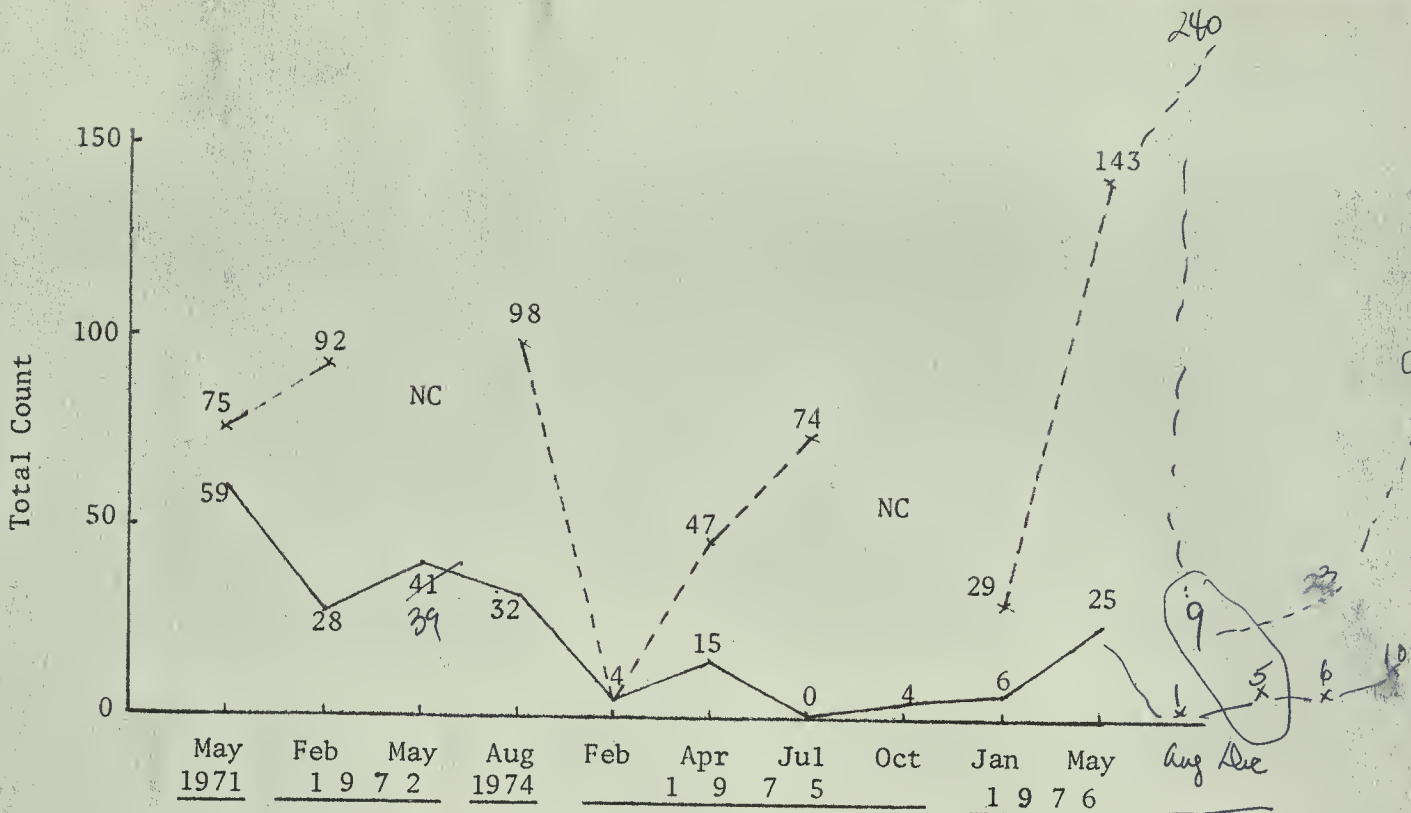


Figure 2. Total counts for ~~crabs~~, *Pachygrapsus crassipes* and *Hemigrapsus nudus*, at Sausalito

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

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 After the 1971 San Francisco Oil Spill

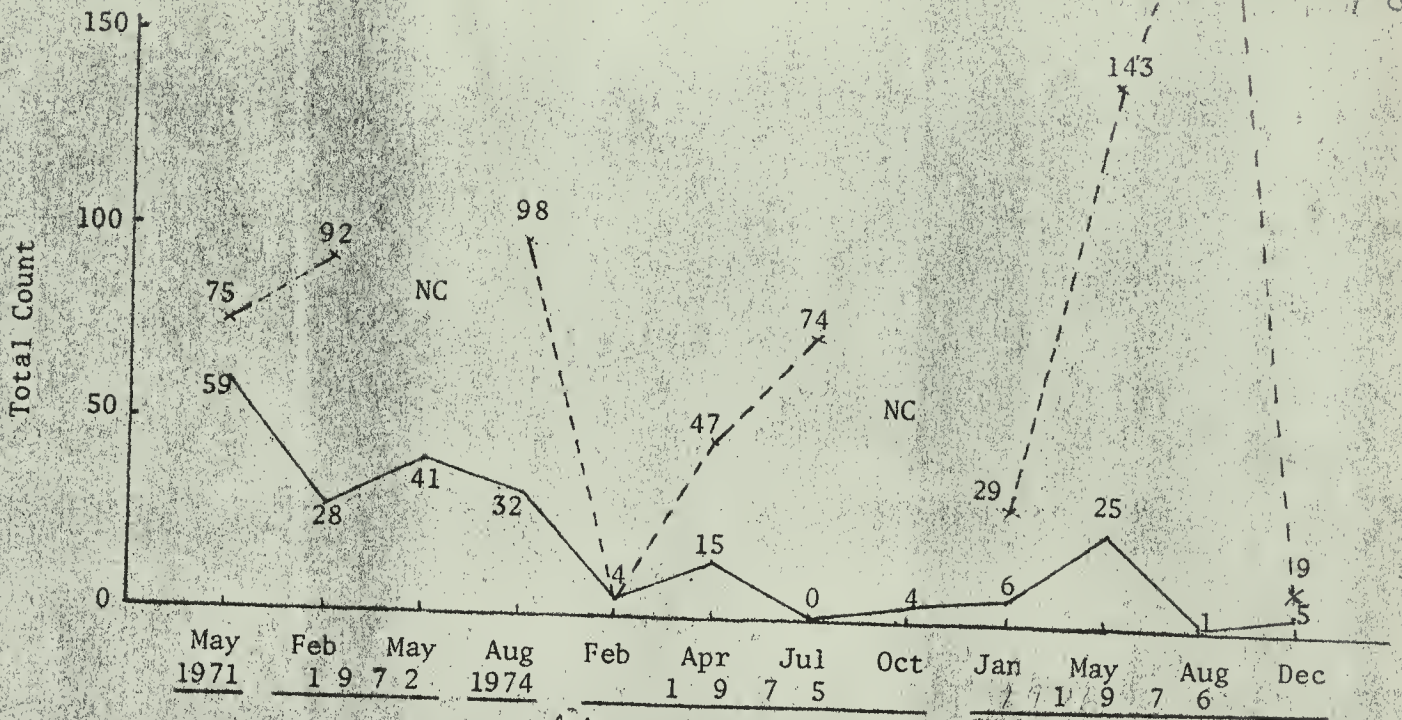


Figure 2 Total counts for crabs, *Pachygrapsus crassipes* and *Hemigrapsus nudus*, at Sausalito

— Seal Rock transect count of 20 square meters
 - - - Count for 50 meter-walk
 NC = no count

use pachy only

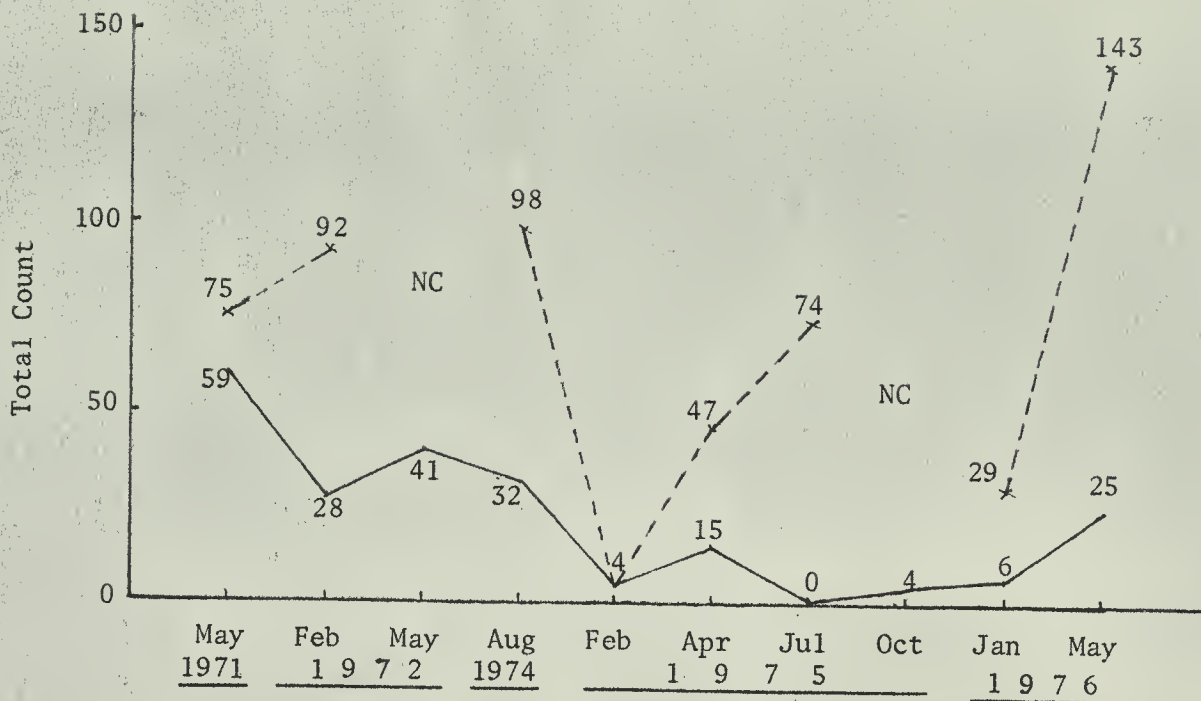


Figure 2. Total counts for crabs, *Pachygrapsus crassipes* and *Hemigrapsus nudus*, at Sausalito

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

IV uses *Pachy* only

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After the 1971 San Francisco Oil Spill

III(3)

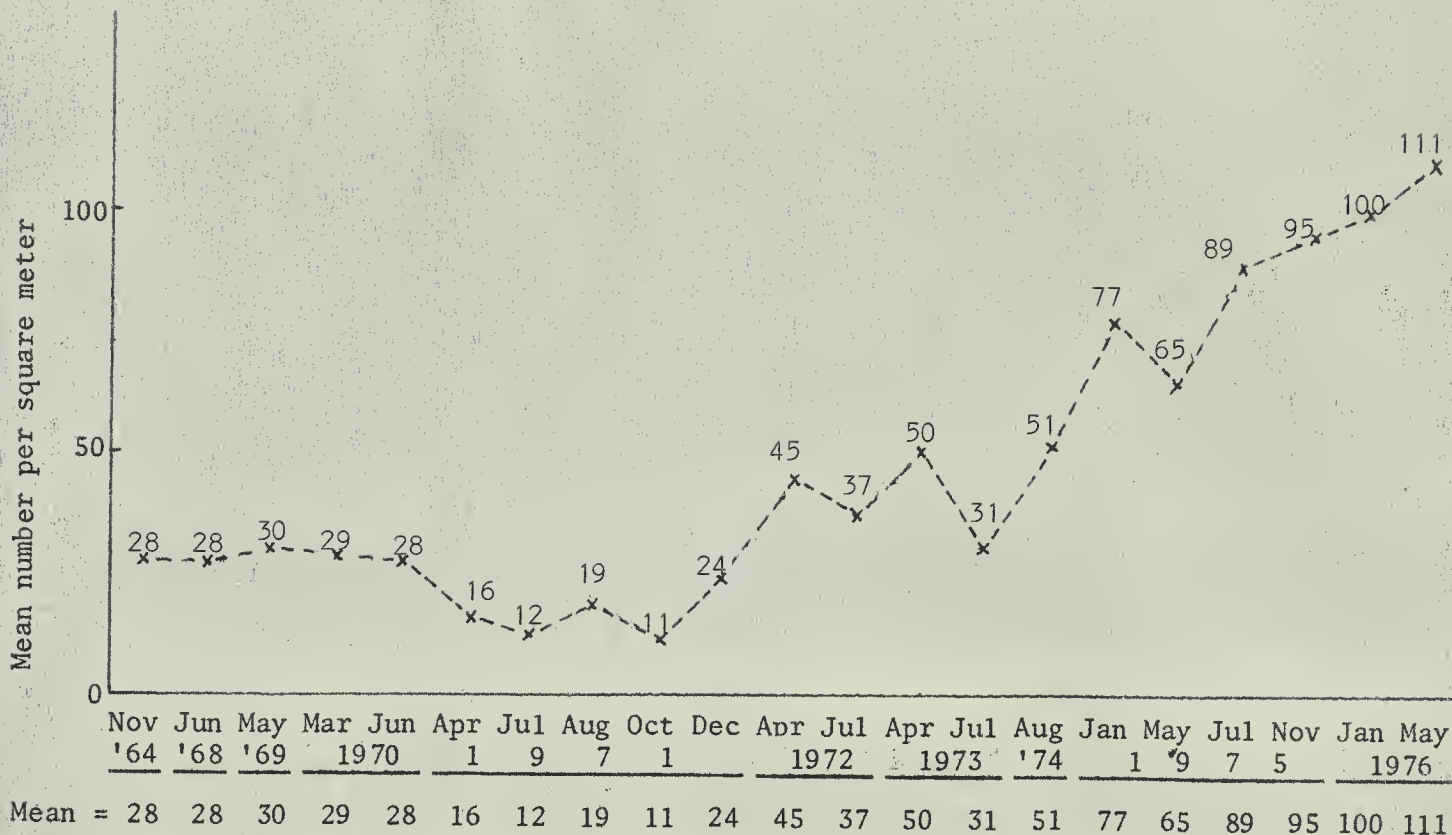


Figure 5. Sample means for live *Collisella* spp. for Duxbury Reef Berm A-8,9; twenty square meters.

<u>AUG</u>	<u>DEC</u>	<u>FEB</u>	<u>APR</u>
<u>1976</u>	<u>1976</u>	<u>1977</u>	<u>1977</u>
104	101	93	83

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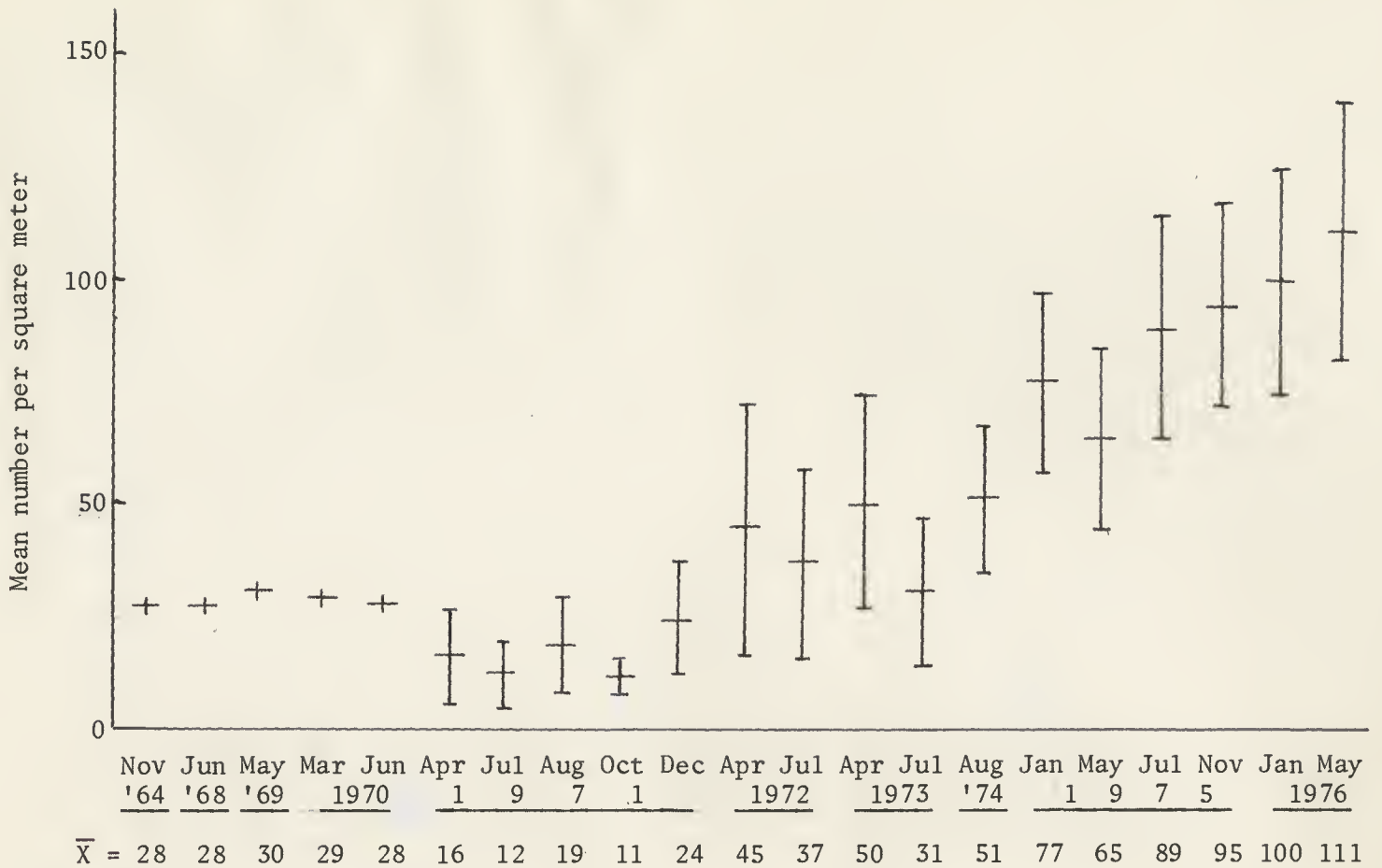


Figure 5 Live *Collisella* spp. for Duxbury Reef Berm A-8,9: twenty square meters

+ Sample mean

| 95% confidence interval
for population mean

707(a)

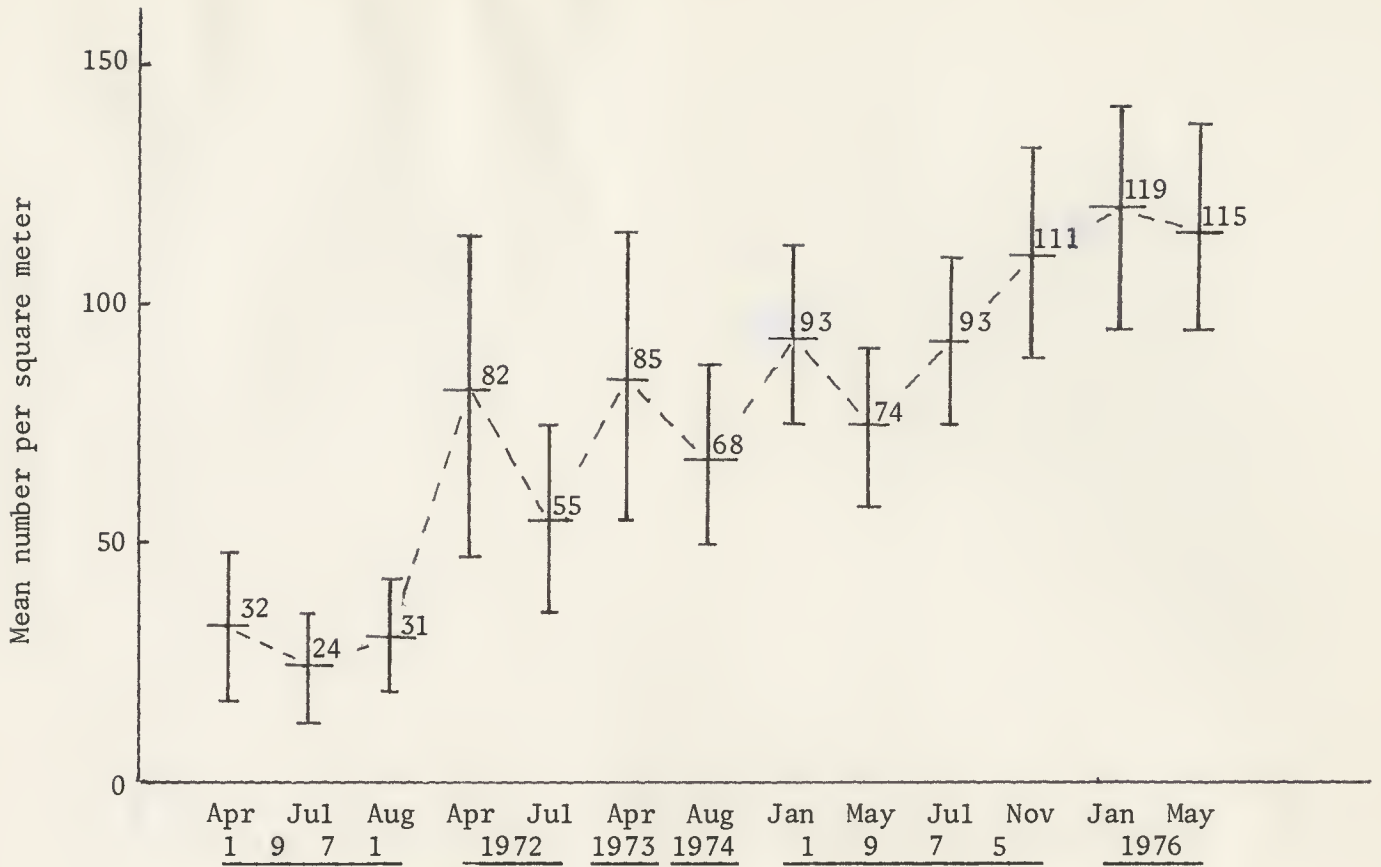


Figure Live *Collisella* spp. for Duxbury Reef Berm A-8,9,10:
30 square meters

—+— sample mean | 95% confidence interval
for population mean

1975 corrected values
approximate days
for 8, 9, & 10
1118

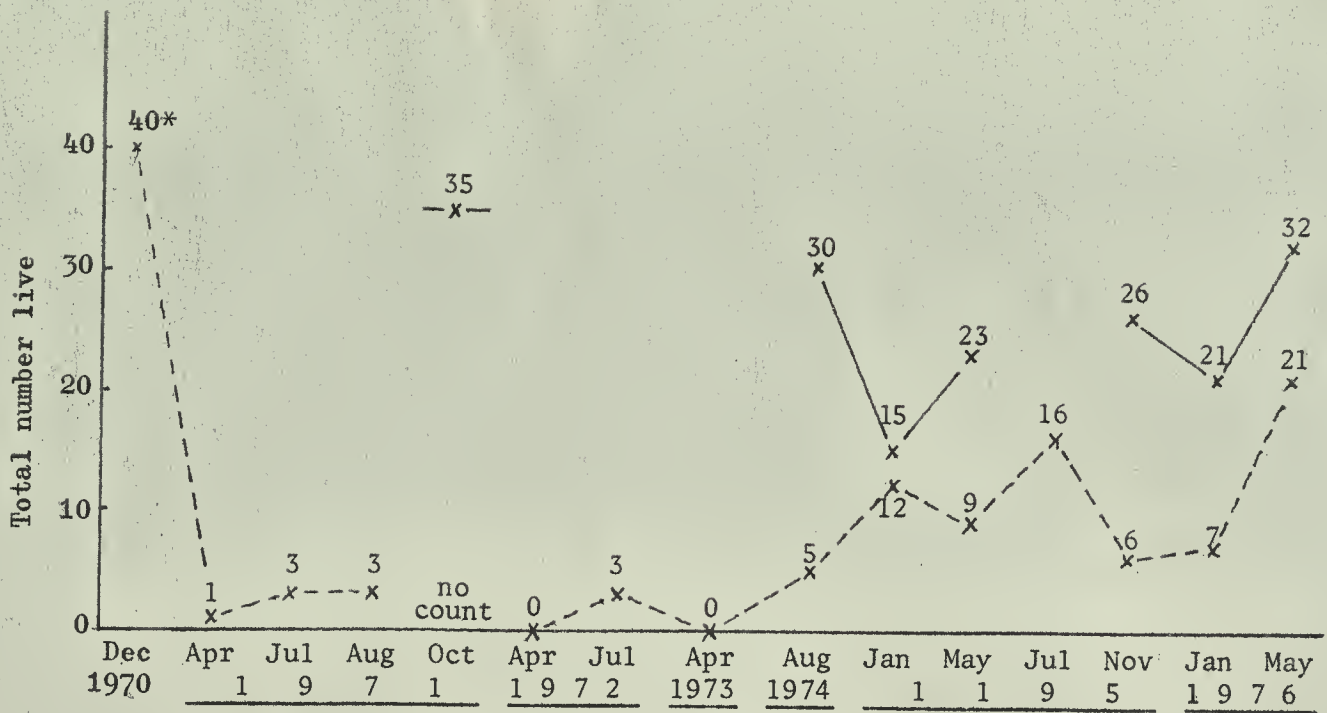


Figure 3. Total counts of *Pachygrapsus crassipes* for Duxbury Reef berm transects and for berm crevices

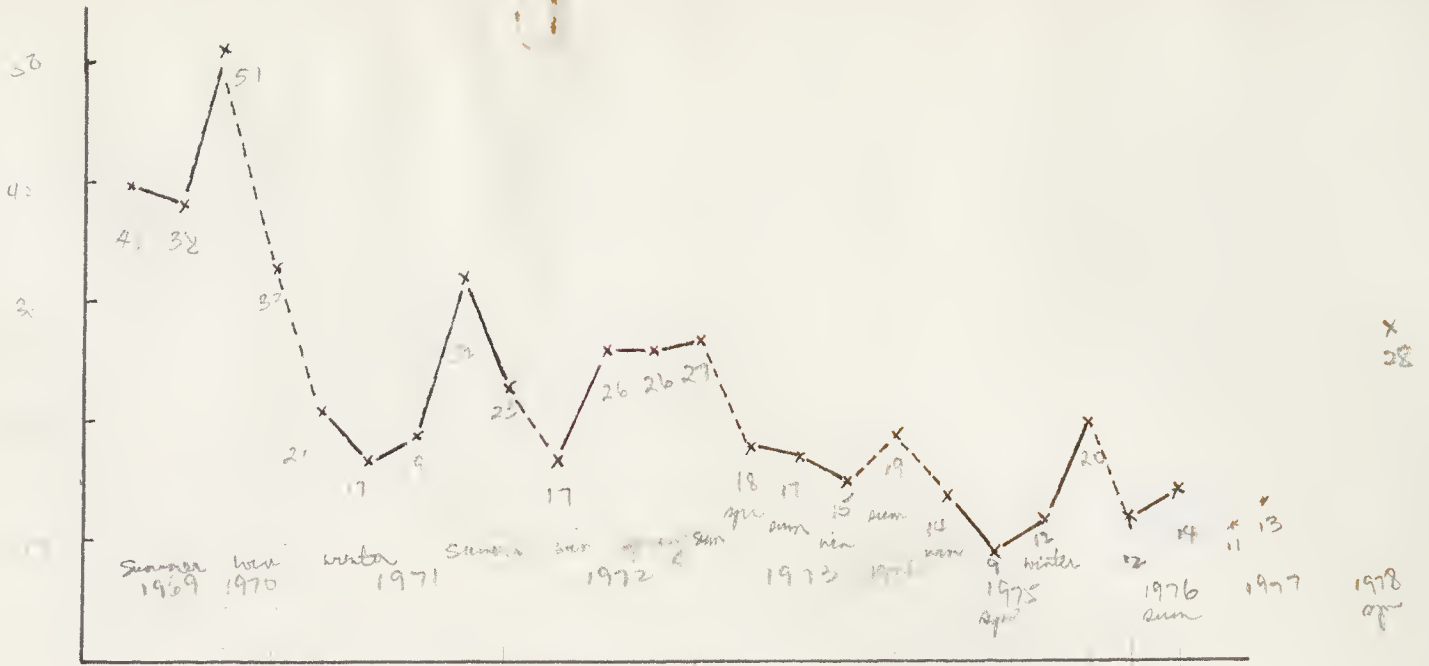
x--- transect counts for A-8,9,10 = 30 m.²

x—— berm crevice counts

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

Gordon L. Chan:

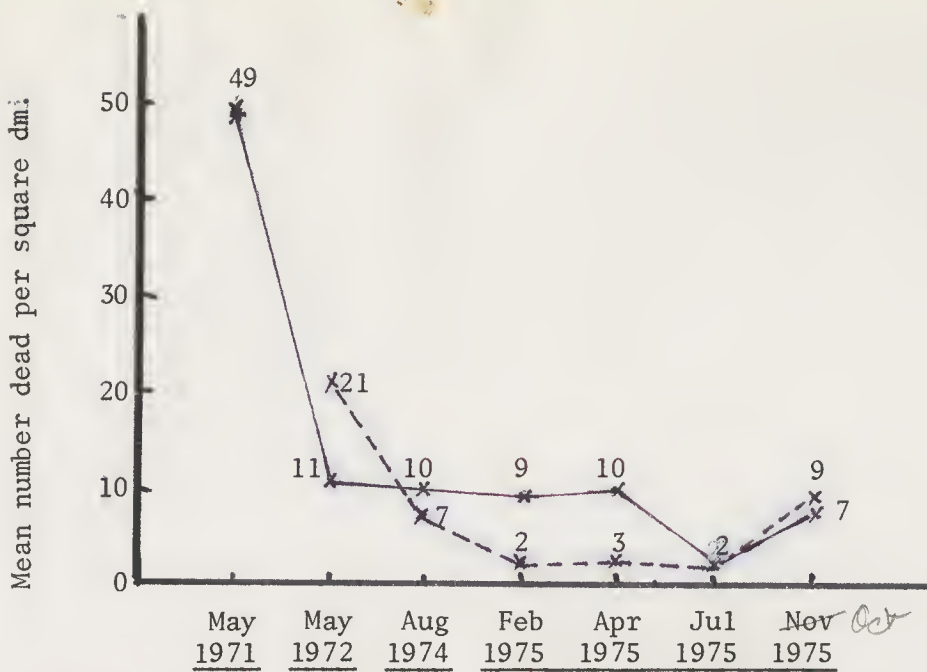
The Five-Year Recruitment of Marine Life after the 1971 San Francisco Oil Spill



TOTAL count of PISA over the period 1969-1978

1978

SAUSALITO
 FORT BAKER
 dead *Balanus*



Littorina = 1.3
scutellata

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.

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, p 7

III
 6/76

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

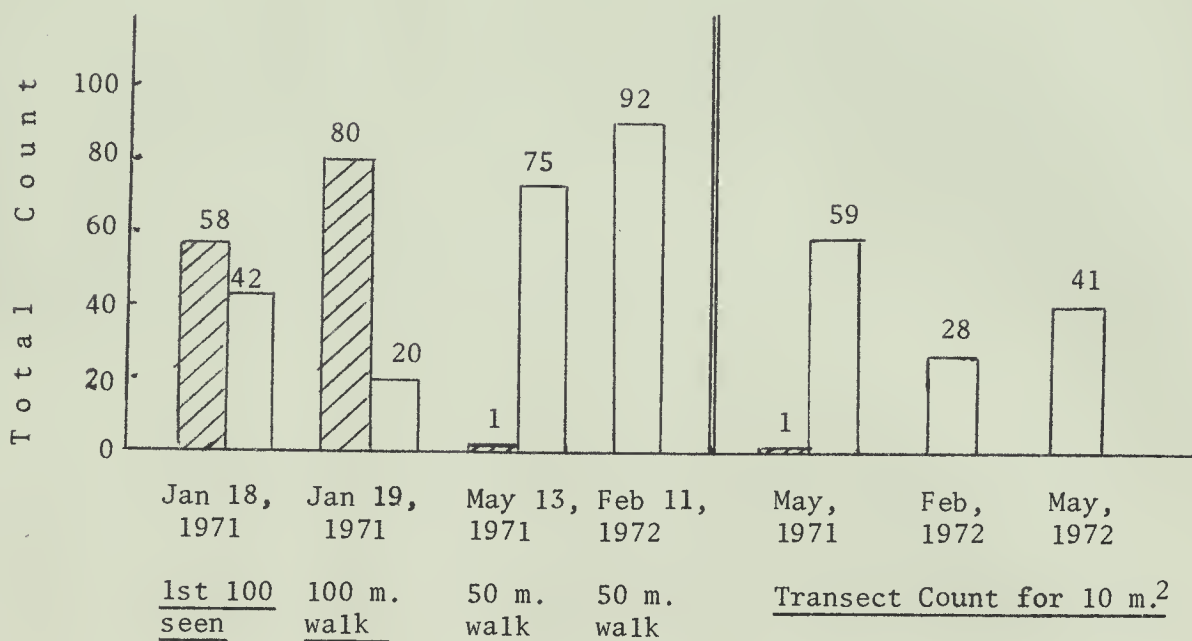


Figure 5. *Pachygrapsus crassipes* and *Hemigrapsus nudus* counts at Sausalito Seal Rock reef area

▨ 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

Nephtys 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.

III Live only
6/16
me

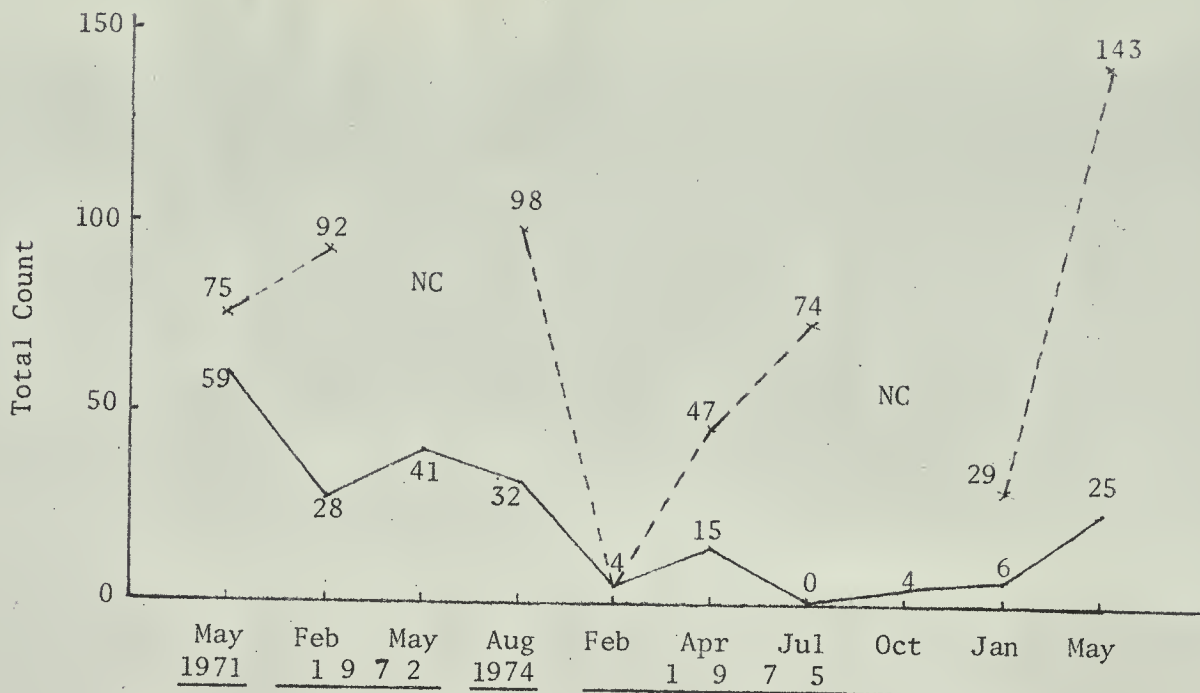


Figure Total counts for crabs, *Pachygrapsus crassipes* and *Hemigrapsus nudus*, at Sausalito

— Seal Rock transect count of 20 square meters
 - - - Count for 50 meter-walk

III (3)

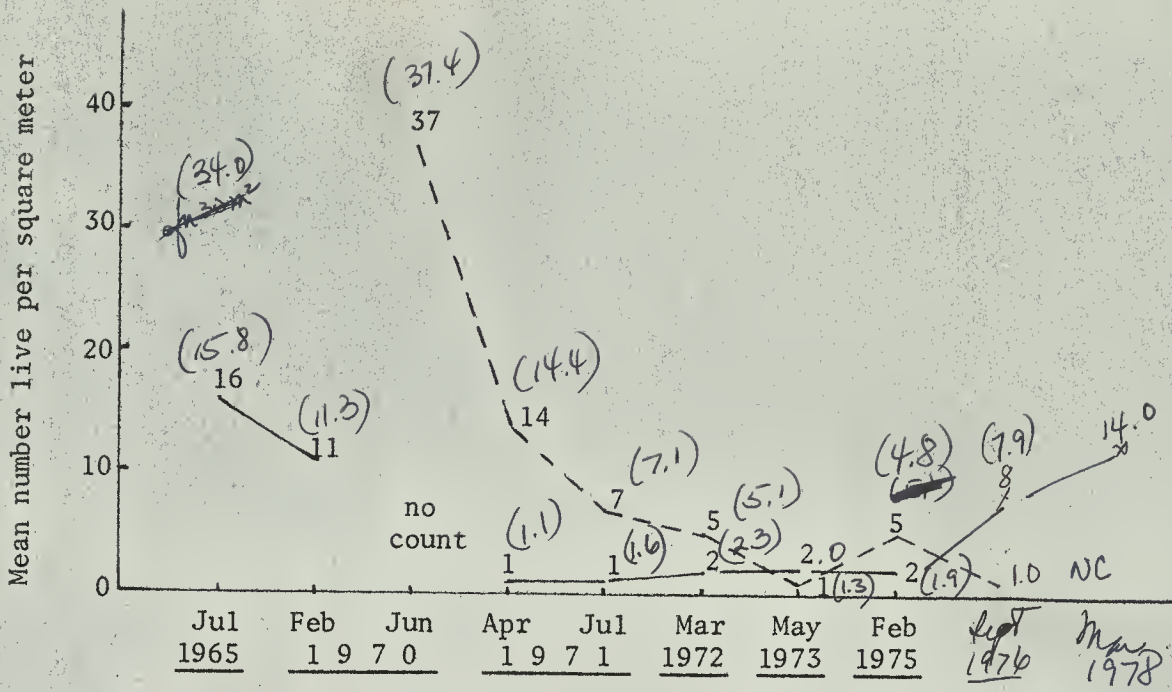


Figure Comparison of transects at Stinson Beach and Drakes Beach for three species combined: *Emerita analoga*, *Nephtys californiensis*, and *Orchestoidea californiana*

— Stinson Beach (oil, graded surface)

- - - Drakes Beach (non-oil)

STINSON
DRAKES

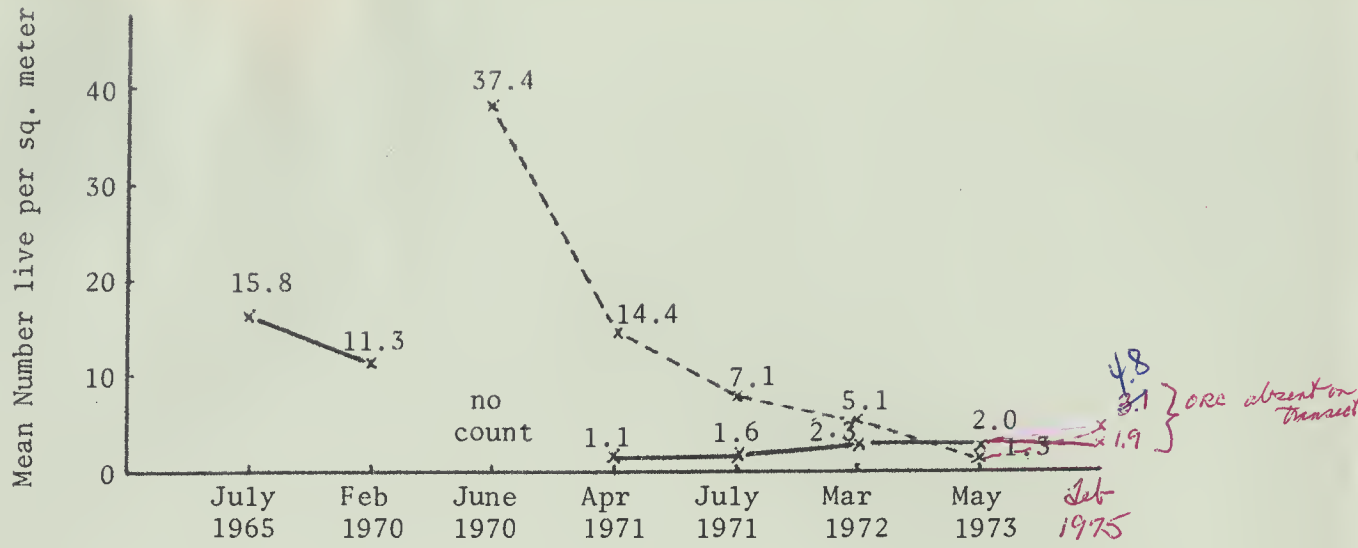


Figure 6. Comparison of transects at Stinson Beach and Drakes Beach for three species combined: *Emerita analoga*, *Neptlys californiensis*, and *Orchestoidea californiana*

— 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, *Neptlys 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

redlog III

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

<u>Species</u>	<u>Date and Sample</u>	<u>Sample Mean per dm.²</u>	<u>95% confidence interval for population mean</u>	<u>Interval of Significant Difference</u>
SAUSALITO	May 13, 1971	93.3 live	69.0-117.7	1971 vs. 1972 101.1-268.3 live/dm ² 25.1- 50.7 dead/dm ²
<u>Barnacles</u>	63 dm. ²	49.2 dead	36.7- 61.8	
<i>Balanus glandula</i>	May 18, 1972	278.0 live	198.0-358.0	
<i>Chthamalus dalli</i>		60 dm. ²	11.3 dead	

FORT BAKER	July 23, 1971	90.8 live	64.3-117.3	1971 vs. 1972 89.1-187.3 live/dm ²
<u>Barnacles</u>	50 dm. ²			
<i>Balanus glandula</i>	May 18, 1972	229.0 live	187.6-270.3	
<i>Chthamalus dalli</i>		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.

<u>SAUSALITO</u>	<u>Date</u>		
<u>Limpets</u>			
<i>Collisella</i> spp.	May 13, 1971	21 live for 63 dm ²	
	May 18, 1972	90 live for 60 dm ²	
<u>Shore Crabs</u>			<u>Non-transect counts for Shore Crabs</u>
<i>Pachygrapsus</i>	*May 13, 1971	59 live, 1 dead	Jan 18, 1971 42 live
<i>crassipes</i> and	*Feb 11, 1972	28 live, 0 dead	1st 100 seen 58 dead
<i>Hemigrapsus</i>	*May 18, 1972	41 live, 0 dead	
<i>rudus</i>			Jan 19, 1971 20 live
	*Total transect count		100 m. 80 dead
			May 13, 1971 75 live
			50 m. 1 dead
			Feb 11, 1972 92 live
			50 m. 0 dead

radio 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

<u>Date</u>	<u>Square Meter Samples</u>	<u>Emerita analoga</u>	<u>Nephtys californi- niensis</u>	<u>Orchestoidea californiana</u>	<u>3 species combined</u>
<u>STINSON BEACH</u>					
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 Emerita

DRAKES BEACH

June 25, 1970	30	31.3	6.1	? ** **0-	37.4
	consecutive				
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



A. Black Turban Snail, *Tegula funebris*

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

<u>Date</u>	<u>Live Sample Mean per m.²</u>	<u>95% confidence interval for population mean</u>
Nov, 1964	28.7	
June, 1968	28.5	(data not
May, 1969	30.0	
Mar, 1970	29.0	available)
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

<u>Date</u>	<u>Sample mean per m.²</u>	<u>95% confidence interval for population mean</u>
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