AMCHITKA BIOENVIRONMENTAL PROGRAM
RESEARCH PROGRAM ON MARINE ECOLOGY,
AMCHITKA ISLAND, ALASKA

ANNUAL PROGRESS REPORT

July 1, 1971 - June 30, 1972

by

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RESEARCH PROGRAM ON MARINE ECOLOGY,
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ABSTRACT

Research continued on the marine environment of Amchitka Island for evaluation of the short- and long-term effects of Cannikin (November 6, 1971), as well as some long-term effects of Milrow (October 2, 1969). The principal features studied included marine fish, invertebrates, and algae. Other marine sampling was conducted for the University of Washington Laboratory of Radiation Ecology and the U. S. Geological Survey.

The most obvious effect of Cannikin was localized disruption of intertidal invertebrate and algal communities as a result of permanent uplift of the adjacent intertidal benches. Present information indicates that 6.1 km (alongshore distance) of Bering coastline had detectable algal damage attributable to Cannikin. Offshore studies revealed significant reduction in catches (November) of rock sole after Cannikin. Nearshore studies revealed marked declines in rock greenling catches immediately postevent followed by a stabilization of catches below preevent levels. About 300 dead fish, mostly rock greenling, were recovered postevent but the decrease in catches indicated that many more than this were killed by the Cannikin test. Further sampling offshore and nearshore is planned for determination of any long-term effects on the fish population.

The impact of Cannikin on the entire Island's marine ecology is small because of the localized areas of intertidal bench, offshore waters, and nearshore waters involved. Recovery of uplifted intertidal bench that is still in the intertidal zone is expected with floral and faunal succession. Recovery of fish populations in offshore and nearshore waters to pretest levels is expected by immigration because habitat disruption is localized and not great enough to reduce the carrying capacity of disrupted areas.

Algal recolonization of Milrow-disturbed intertidal areas progresses with replacement of Hedophyllum by Fucus in part of the Duck Cove (IA-1) fault study area and colonization at the Duck Cove rockfall site leading to algal growth comparable to that on nearby undisturbed rocks. Siltation on the intertidal bench below the Square Bay rock slide is reduced in area, compared to 1971 observations.

INTRODUCTION

Background

Since the fall of 1967, Battelle's Columbus Laboratories and its subcontractors have studied the marine, freshwater, and terrestrial ecosystems at Amchitka Island, Alaska. These studies are designed to predict, evaluate, and document the effects on the biota and environment from underground nuclear tests, to recommend measures for minimizing the effects, and to predict and evaluate the potential hazards to man that might result from the accidental release of radionuclides to the environment and their subsequent transport to humans via food chains. These studies are sponsored by the U. S. Atomic Energy Commission's Nevada Operations Office as a part of its supplemental nuclear test-site activities.

The marine ecology phase of the Amchitka Bioenvironmental Program was initiated by the Fisheries Research Institute (FRI) under subcontract to Battelle Memorial Institute, Columbus Laboratories (BCL) in July, 1967. Annual progress reports of research conducted from fiscal year 1968 to the present are included in Burgner and Associates (1968), Burgner et al (1969, 1971), and Burgner and Nakatani (1972). In these prior years, FRI was concerned with the collection of background information about Amchitka's marine environment excluding marine mammals and marine birds which were under study by other organizations. The main mission of FRI was to assess both the short- and long-term effects of underground nuclear testing on Amchitka's marine environment. FRI conducted comparative pre- and postevent investigations related to Milrow (October 2, 1969) and began preevent studies to prepare for Cannikin (November 6, 1971).

Objectives and Activities for FY 1972

During FY 1972, FRI was primarily concerned with continuing preevent marine surveys for Cannikin, planning testtime experiments, and conducting postevent surveys after Cannikin. FRI personnel provided draft reports used in preparation of a report (Kirkwood and Fuller, 1971) predicting the probable bioenvironmental effects of Cannikin. Input for the Cannikin environmental impact statement (U. S. AEC, 1971) was also furnished. After the test, FRI also provided a draft report on the effects observed two months after the test (Kirkwood and Fuller, 1972).

Specific research tasks proposed by FRI for fiscal year 1972 were as follows:

- Continue exploratory fishing investigations on the Bering Sea side of Cannikin SZ associated with predicted over- and under-pressure areas.
- Conduct live-box experiments during Cannikin in the above areas.
- Collect marine radiological samples within the scope of the proposed program for the Laboratory of Radiation Ecology, University of Washington (LRE). The sampling plan (8 vessel-days on-island) to be implemented by FRI in accordance with agreement among BCL, LRE, and FRI.
- Continue nearshore surveys on the Bering Sea side adjacent to Cannikin SZ.

- Continue intertidal investigations on the fault area in Duck Cove to assess long-term recovery from this Milrow disruption.
- Continue investigations on new materials moved into the intertidal areas by the Milrow event.
- Continue Milrow reference-transect studies to maintain a base line from which to compare Milrow, and possible Cannikin, intertidal disruptions.
- Participate in post-Cannikin searches and surveys to detect habitat changes and initial mortalities of marine organisms.
- Collect seawater samples during two periods, pre- and postevent in accordance with agreement among BCL, FRI, and Isotopes, Incorporated.

While FRI essentially completed* these tasks as proposed, the distribution of effort for the various tasks varied considerably from the original plan for a number of reasons including the delayed time Cannikin and inclement weather.

The diagram in Figure 1 shows the major tasks and their interrelationship to the overall problem of evaluating and assessing the impact of Milrow and Cannikin on the adjacent marine areas under study. Because changes caused by these tests are still occurring, final answers cannot be provided for some questions at present. Future studies are oriented toward continued evaluation in disturbed marine areas.

FIGURE 1. INTERRELATIONS OF THE FRI MARINE ECOLOGY PROGRAM

* Some projects, such as the planned live-box experiments, were drastically reduced because of stormy weather at testtime. Seawater samples were collected for the U. S. Geological Survey (U. S. G. S.) rather than for Isotopes, Incorporated, as proposed.

MARINE BIOLOGICAL STUDIES

Basic data collection in Fisheries Research Institute's biological studies of Amchitka's marine environment was apportioned into three components - marine fish, divided into offshore (>20 f or 37 m) and nearshore ($\geq$ 20 f or 37 m) populations; marine invertebrates; and marine algae.

Offshore Marine Fishes

Objectives and Tasks

- Assess the effects of Cannikin by pre- and postevent fishing with conventional gear in specific areas.
- Continue collecting background information on meristics, diet, etc., of several offshore fishes.
- Provide additional services as requested (water sampling for U.S.G.S., sampling for LRE, etc.).
- Prepare and conduct live-box experiments (see Appendix B for a full discussion).

Materials and Methods

Exploratory fishing was conducted from August 27 through November 21, 1971, on the 81-ft (25 m) purse seiner, M/V Commander. The bottom trawl, midwater trawl, and salmon longline gear described in Burgner and Nakatani (1972) were the main sampling gears used. Locations of 31 bottom trawls used in test comparisons, 40 midwater trawls, and 14 salmon longline sets are shown on Figures 2 and 3. All catches were sorted as to species and counted. Several samples of particular species were examined further for information on their size, age, sex, and diet.

Many of the pelagic fishes and invertebrates taken with the midwater trawl could not be identified in the field. They were preserved in 10 percent formalin and shipped to Seattle where they are being examined.

Thirty-one bottom trawls (16 preevent and 15 postevent) and 10 salmon longline sets (7 preevent and 3 postevent) were chosen on the basis of proximity to SZ and similarity of location, depth, and duration for comparison of their catch per effort to assess the effects of Cannikin on offshore fishes. The catches were converted to a standard catch per unit effort (CPU) of the number of individuals caught per hour. The catch data were further transformed to $\log_{10}(\text{CPU} + 1)$, and the transformed catches were compared using regression analysis, analysis of variance, and Student's t test.

Data from 13 bottom trawls and 4 longline sets were not used because they were made for other programs (e.g., LRE sampling), or the effort was ineffective. Bottom

*Four of the trawls and two of the longline sets were not included in the D+2 Months Report (Kirkwood and Fuller 1972) because of the questionable information in the vessel log which has since been corrected and verified

(a) Pre-Cannikin (September - October) - 16 hauls.

(b) Post-Cannikin (November) - 15 hauls.

FIGURE 2. LOCATIONS OF BOTTOM TRAWLS USED IN PRE- AND POSTTEST COMPARISONS

FIGURE 3. SALMON LONGLINE (●) AND MIDWATER TRAWL (→) STATIONS, AUGUST - NOVEMBER, 1971
(Midwater trawl sets 9-12 and 23-33 are in the shaded area.)

trawls were considered ineffective if the gear malfunctioned (e.g., crossed doors, broken cable) or if the trawl snagged an obstruction shortly after being set.

Results and Discussion

Longline Sampling. The catch data are presented in Table A-1.

Sixty-four salmon were caught on the 14 longline sets, chum salmon being the most abundant (81 percent). The catch was less than in previous years [$F=9.06 > 7.60$ (1, 29 df.), significant at the 0.01 level]* but the low catches of immature salmon were expected and they corresponded with index fishing by FRI at Adak Island during July and August (Rogers, 1972; INPFC, in press).

The preevent and post event salmon-catch data were not statistically comparable since the species composition changed. Sockeye salmon were not caught before the test but only sockeye salmon were caught after the test. The likelihood of any Cannikin effect on the salmon was remote because of their small numbers off Amchitka in the fall, and their tendency to stay far offshore. Only two salmon were taken within 9.6 km (6 miles) of Cannikin SZ, and the largest catches were made 18-20 km (11-12 miles)

*Analysis of variance tables and other information on analyses for offshore catch data are given in Appendix A

away. A similar catch distribution in relation to the island was noted in all the previous years of sampling.

Midwater Trawling. The purpose of the midwater trawling was to collect information on distribution and diversity of the small midwater fishes and invertebrates around Amchitka. These animals are important as food for the pelagic predators such as salmon. Many of the fish species collected were new to the project and some are yet to be identified. Those identified are the California headlightfish, Diaphus theta; two lanternfishes, Hierops thompsoni and Lampanyctus regalis, stout blacksmelt, Bathylagus milleri; and the roughscale rattail, Coryphaenoides acrolepis. A complete presentation of the midwater trawl catches will be given in the FY 1973 annual report.

Bottom Trawling. The catch data are presented in Table A-2.

Flatfish was the major group in bottom trawl catches (51 percent), followed by cods (30 percent) and sculpins (13 percent). Rock sole was the preponderant species - 41 percent of all fish caught. Pre- and postevent comparisons for rock sole and halibut catches were made separately because they were the most abundant and consistent, being present in nearly all the trawl hauls.

Analysis and interpretation of the data are made difficult by the large variance and paucity of replicates. In addition, the depth distributions of the fishing efforts are not the same for pre- and postevent hauls. The mean sampling depths were 70.5 m and 56.8 m, respectively. This difference was not a flaw in the sampling design but resulted from difficulty in repeating with precision the sampling at preevent sites after the test, and an inability to locate trawlable transects in the shallower areas before the test. The analysis is further complicated by a positive relationship between catch and depth in the postevent samples for rock sole [$F=16.42 > 9.07$ (1, 13 d.f.), significant at the 0.01 level] and total catch [$F=8.83 > 4.67$ (1, 13 d.f.), significant at 0.05 level] (Appendix Table A-5). The increase of total catch with depth is still significant if the rock sole are not included ($F=5.97 > 4.67$ (1, 13 d.f.), significant at the 0.05 level]. There was no such relationship for the preevent samples [$F=0.45$ (rock sole) and $F=1.84$ (total catch) < 4.60 (1, 14 d.f.) N.S.].

The disparity of sampling depths and the difference of relationship of catch and depth between pre- and postevent samples negates a direct comparison of the data from the two time periods. However, the mean preevent catch (the best estimate of preevent catch at any depth) can be compared with the expected postevent catch at 70.5 meters, the mean preevent sampling depth, thus correcting for the difference in sampling depths (see Appendix Figure A-1). The expected catches are estimated from the postevent relationships calculated from the transformed data, i. e., $\hat{Y} = -1.34993 + 0.04033 (70.5)$ for rock sole and $\hat{Y} = -0.57383 + 0.03574 (70.5)$ for total catch. This gives a t statistic with

$$\frac{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}} - 2$$

$$\frac{n_1}{n_1 + 1} + \frac{n_2}{n_2 + 1}$$

degrees of freedom where S_i^2 and n_i are variance and sample size of group i (Table 1).

TABLE 1. COMPARISONS OF PREEVENT AND POSTEVENT BOTTOM TRAWL CATCHES
(Transformed to the number of individuals caught per hour of trawling)

	Mean ^(a) $\pm$ Std. Dev.		Estimated Postevent Catch At 70.5-m Depth	Degrees of Freedom	t
	Preevent	Postevent			
Rock sole	100.70 $\pm$ 86.14		31.15	23	2.52 $p < 0.05$
Pacific halibut	8.32 $\pm$ 15.39	10.23 $\pm$ 26.11		29	0.40 N.S.
Total catch (bottom trawl)	143.20 $\pm$ 93.63		88.29	18	1.07 N.S.

(a) Geometric means

The analyses indicate a significant decline of rock sole catches after Cannikin. The reason for this is uncertain; however, a direct effect of Cannikin or a seasonal offshore movement are the most reasonable explanations.

There is some evidence that rock sole move offshore where they spawn during winter months (Fedeev, 1965). This movement appears to depend on the approach of the spawning season between February and April. The offshore movement in the south-eastern Bering Sea was found to be from a depth of approximately 50 m to a depth of 90 m. In the Bering Sea adjacent to Cannikin SZ such change would necessitate a horizontal movement of less than 1 nautical mile (1,853 m) away from the Bering Sea shoreline. It is therefore doubtful that such a spawning migration would take place as early as October.

The rock sole catch data within the two time periods (preevent and postevent) give no indication of an offshore movement [$F=0.004$ (1, 13) d.f. and $F=0.002$ (1, 12) d.f.]. That is, the 29 days of preevent and 15 days of postevent trawling indicate no statistical correlation between date and catch.

Some of the statistics and several statements appearing in this report differ from those submitted by FRI and included in the D+2 Months Report (Kirkwood and Fuller, 1972). With the additional time available to compile this report the data were treated more rigorously and some new information became available through literature searches. At the time of the D+2 Months Report no information had been found to indicate that a winter offshore migration could be expected and it was necessary to assume that the reduction in catch of rock sole was most probably a result of fish kill resulting from Cannikin. The statement "...the investigators believe a reasonable estimate would be

thousands of fish" (killed) was therefore made. However, there is no really satisfactory way to compute an estimate based on change in catch per unit of effort. The statements and statistics presented in this report pre-empt those in the D+2 Months Report but, as indicated below, the basic conclusion is unchanged.

The decline in catch of rock sole is interpreted as an effect of Cannikin, i. e. , the result of a large localized mortality; however, there is no direct evidence for this mortality and it is not proven by the catch statistics. Although dead rock sole were recovered in the postevent trawls, many are killed by the fishing gear itself and there was no objective method to recognize fish that may have been dead before they were caught. The conclusion is simply the authors' opinion based on all the information available to us.

Recovery of the rock sole populations will depend upon how the area around Cannikin SZ is repopulated. If the repopulation is by immigration, it could be quite rapid (one or a few years), but if it is mostly by reproduction, the recovery could be slow since rock sole take 5-7 years to reach maturity (Shubnikov and Lisovenko, 1964).

Nearshore Marine Fishes

Objectives and Tasks

- Determine the occurrence and relative abundance of nearshore fishes in the Bering Sea adjacent to Cannikin SZ.
- Determine the effects of Cannikin on nearshore fishes by comparing pre- and post-Cannikin trammel net catches.
- Determine the effects of the test-produced water shock wave and associated pressure changes on representative marine fishes by conducting testtime live-box experiments.
- Estimate magnitude of any fish kill by collection of any dead or injured fish during postevent surveys and determine the mechanism of the test-induced damage.
- Collect nearshore fish from the exposed (open to swell and sea action) near-shore region of the Bering Sea coastline for analysis of stomach contents.

Materials and Methods

Sampling in 1971 was conducted nearshore from May 11 to September 6 and September 29 to November 25, and, in 1972, from April 14 to 30. Test-fishing effort designed to evaluate the effects of Cannikin was concentrated in the Bering Sea waters adjacent to Cannikin SZ from Sand Beach Cove to Banjo Point. Considerable sampling effort was also carried out in Constantine Harbor for procurement of fish for the live-box studies. Ichthyoplankton sampling was conducted at several locations in the Bering Sea.

The sampling methods were the same as those used previously (Burgner and Associates, 1969; Burgner and Nakatani, 1972), except that the trammel nets were

dyed green. Trammel nets were utilized in the standardized preevent and postevent nearshore studies because they are highly efficient and tend to be less harmful to the fish than the gill net.

Results and Discussion

Catches. A total of 2,407 fish was collected (Table 2). Statistics on catch and effort are detailed in Appendix Table A-3. Of the total fish caught, 459 were retained for analysis of stomach contents, 19 for fecundity estimates, 500 for otolith sampling for age determination, and 1,163 were held for future reference and study or for radiological analysis. General ecology studies of the rock greenling and collection of assorted fishes for the planned in vivo Cannikin live-box experiments accounted for 266 fish tagged with anchor tags and eventually released into Amchitka's waters.

TABLE 2. FISH CAUGHT NEARSHORE FROM MAY 1, 1971
TO MAY 1, 1972, BY SPECIES OR GROUPS

Species/Group	Number Caught
Rock greenling	1,276
Sculpins	693
Pacific cod	89
Walleye pollock	69
Atka mackerel	65
Ronquils	14
Rockfishes	12
Rock sole	28
Pacific halibut	53
Dolly Varden	16
Liparids/Lumpsuckers	22
Pacific sandfish	12
Pricklebacks/Gunnels	18
Poachers	15
Unknown/Larvae/Unidentified	25
Total	2,407

Effects of Cannikin. The nearshore fish sampling in the waters adjacent to Cannikin SZ (the Banjo Point-Sand Beach Cove region) has contributed to the general concept of the area's fish communities. Understanding of the structure of these communities contributes to the evaluation of the effects of Cannikin. The rock/algae and sand/gravel habitats (Isakson et al., 1971) are intermingled in the Bering Sea nearshore environment adjacent to Cannikin SZ. Because of a reduced submarine shelf on this side of the Island as compared to the Pacific Ocean side, the rock/algae (Alaria forest) habitat is much narrower, usually 35 to 55 m wide. Accordingly, fish are less abundant. Rock greenling, sculpins (mostly red Irish lord), Pacific cod, ronquils, and rock sole all appeared in the catches, but rock greenling predominated. Dusky rockfish appeared infrequently. The occurrence of cod is the major difference noted between these communities and those in the rock/algae habitat on the Pacific Ocean side.

The sand/gravel habitat appears quite extensive and extends into offshore regions. As in the other sand/gravel habitats sampled previously, the common species found were armorhead sculpin, Pacific halibut, rock sole, Pacific cod, and rock greenling. Atka mackerel and walleye pollock are also captured. Since these fish are commonly found in the pelagic and offshore/bottom habitats, their occurrence reflects the proximity of these habitats. Preliminary evaluations of the effects of Cannikin on nearshore fishes are included in the D+2 Months Cannikin Report (Kirkwood and Fuller, 1972). In this section new information is given, and the effects of Cannikin are discussed as they are understood at present.

As discussed in the D+2 Months Report the planned live-box experiments could not be implemented because of the storm at testtime. A summary discussion of the proposed live-box experiments (and the experiment conducted at testtime is appended (Appendix B). Fish kills observed in postevent beach surveys are also covered in the D+2 Months Cannikin Report, and no new information is available. Beach surveys (Figure 5, Kirkwood and Fuller, 1972) yielded 277 rock greenling, 7 Pacific sandfish, and one great sculpin on the Bering Sea coast and 8 Pacific cod and 1 rockfish (*Sebastes*) on the Pacific coast. These fish were all thought to have been killed by Cannikin.

Catches from two preevent and six postevent trammel net sets (Figure 4) were compared for evaluation of the effects of the test on nearshore fish. These eight sets,

FIGURE 4. TRAMMEL NET COLLECTIONS, BY SET NUMBER, MADE IN THE VICINITY OF CANNIKIN SZ PREEVENT (●) AND POST-EVENT (⊕) USED IN EVALUATION OF EFFECTS

Depth contours in fathoms.

in nearshore locations of highest predicted water pressure changes, included those taken as late as April 1972 (Table A-3). Trammel net catches prior to October, being of long duration (16-43 hr), cannot be compared to those of October 21 and postevent, which were of short duration (2-6 hr) as necessitated by worsening weather conditions. As these nets are used they "fill" with fish, and avoidance by other fish upon seeing these earlier victims begins to limit the catch proportional to fishing time (gear saturation). This effect and the escape of fish and predation upon those captured produce a decline in catch per unit effort as a net is fished continuously for a long duration.

The catch per unit of effort for comparable sets for the most abundant fish, the rock greenling, are shown in Figure 5. The data indicate an immediate reduction followed by a stabilization in catch per unit of effort, but still at a lower level than that of the two preevent (October 21) hauls. However, it must be noted that the lower stable abundance may be a seasonal phenomenon in that all postevent sets were in the late fall and winter. Additional sets planned for August-October, 1972 are to be reported.

FIGURE 5. PREEVENT AND POSTEVENT TRAMMEL NET CATCHES IN THE BERING SEA ADJACENT TO CANNIKIN SZ

Ranges are shown for duplicate sets on three sampling days. This figure has been modified from that in the D+2 Months Report on the basis of new information.

Sex, length, and weight compositions of rock greenling in preevent catches, postevent Bering Sea beach surveys (Kirkwood and Fuller, 1972), and postevent trammel net catches were examined for differences (Table 3). Such information could indicate either (1) a selective effect of the Cannikin-induced mortality among greenling or (2) the presence of a different greenling population structure in the fish community recovering from

TABLE 3. STATISTICS FOR GREENLING PREEVENT, CANNIKIN KILL,
AND POSTEVENT FROM NEARSHORE AREA ADJACENT TO
CANNIKIN SZ

Collection	Location	Date	Male/ Female Sex	Sample Size(a)	Mean Length, mm	Mean Weight, m
<u>Preevent</u>						
71BG3	IA-2/IA-3	5/15/71	♂	2	316.00	428.50
			♂	10	273.30	329.30
71BG6	Sand Beach Cove	7/23/71	♂	29	304.55	392.93
			♂	14	422.60	392.71
71TR2	Sand Beach Cove	8/9/71	♂	3	314.67	411.67
			♂	1	280.00	270.00
71TR3	IA-2	8/11/71	♂	6	273.67	270.50
71TR6	Sand Beach Cove	8/23/71	♂	2	322.50	399.50
			♂	4	292.25	345.25
71TR7	Sand Beach Cove	8/26/71	♂	6	321.67	447.00
71TR8	IA-3	8/28/71	♂	25	290.28	363.08
			♂	9	269.89	287.78
<u>Cannikin Kill</u>						
71H7	Sand Beach Cove/IA-2	11/7/71	♂	36	286.92	
			♂	6	294.38	
			Immature	1	125.00	
71H8	Sand Beach Cove/IA-2	11/7/71	♂	29	316.13	
			♂	5	269.33	
71H10	IA-2/IA-3	11/7/71	♂	67	286.38	
			♂	10	299.50	
71H11	Banjo Point	11/7/71	♂	72	284.64	
			♂	22	301.36	
71H12	Sand Beach Cove	11/7/71	♂	1	324.00	
<u>Postevent</u>						
71TR30	IA-2/IA-3	11/11/71	♂	5	267.40	216.75
			♂	5	303.00	329.33
71TR32	IA-2	11/15/71	♂	10	269.70	325.30
			♂	10	290.40	373.70
71TR33	Sand Beach Cove	11/15/71	♂	1	263.00	231.00
71TR34	IA-3	11/21/71	♂	7	339.57	553.71
			♂	9	281.67	352.22
71TR35	IA-2	11/21/71	♂	7	311.00	274.27
			♂	11	300.50	311.27
71TR36	Sand Beach Cove	11/21/71	♂	1	280.00	287.00
71TR37	IA-2	4/19/72	♂	7	332.57	468.43
			♂	9	310.67	434.78
71TR38	IA-2	4/19/72	♂	10	327.00	540.10
			♂	3	290.67	370.00
71TR40	Sand Beach Cove	4/25/72	♂	1	360.00	530.00
71TR41	Sand Beach Cove	4/25/72	♂	1	330.00	432.00

(a) Fish not included in these statistics were immature, eaten by amphipods, etc.

Cannikin, attributable to differential immigration. The sex ratios of the greenling involved were too variable to provide any information, and the natural changes in sex ratio in the spring caused by approaching spawning season could not be separated from any possible changes attributable to the test. The length frequency distributions for all greenling from preevent, killed, and postevent collections, as well as the length distribution common to the general Amchitka greenling population are compared in Figure 6. No significant difference in this size composition appears among the four groups of fish. This fact implies that a nonselective mechanism killed a portion of the greenling population adjacent to Cannikin SZ, and that greenling immigration from adjacent areas were of the same general size distribution.

FIGURE 6. LENGTH DISTRIBUTIONS OF GREENLING COLLECTIONS AND NORMAL DISTRIBUTION

The actual mechanism(s) of the fish mortalities resulting from Cannikin, indicated by the fish recovered on the Bering and Pacific coastline surveys and the decline in trammel net catches of rock greenling, cannot be determined from the data we have.

The dead rock greenling, recovered primarily on intertidal benches, indicate that they were probably stranded due to the bench uplift. However, some individuals located on sand or cobble beaches apparently were not stranded by bench uplift. Autopsy on 23 rock greenling indicated that about half had hemorrhaging or other damage in the brain cavity and/or viscera. This probably resulted from water-pressure changes or sea floor (or bench) impact with these fish which habitually lay on the bottom. The others

autopsied exhibited no noticeable injury. Some rock greenling, therefore, were possibly killed by stranding (no observable injury), while other individuals were killed by physical impact with the sea floor (or bench) or water pressure changes (both possible causes of the observed injuries).

The Pacific sandfish were found stranded both in uplifted sandy beach and in drift zones of the same beach. They were thought to have been stranded as this fish commonly burrows upright in sand of the intertidal zone.

The Pacific cod and rockfish (Sebastes) found on the Pacific coastline both have closed air bladders (physoclistous) and were probably killed by water-pressure changes and then drifted with winds to the coastline. The over- and underpressure regime was much greater in the Bering Sea (both in greater magnitude and areas of pressure changes) due to the proximity of Cannikin SZ to the Bering coastline. Similar species should have been recovered on the Bering coastline; but, possibly as a result of prevailing winds, they were not.

In conclusion, stranding, physical impact with the bottom, and water-pressure changes were all possible mechanisms of fish mortality depending on the location of individual fish and on the physiological structure of some species of fish.

Analysis of Stomach Contents of Marine Fishes

The practical need to examine the stomach contents of marine fishes arises from the concern about potential disruption of the food web by nuclear tests and the need to understand potential pathways for the movement and transfer of radionuclides through the food web in the unlikely event of release of radionuclides to the marine environment. To date, the results on the stomach analyses are negative, i. e. , no stomach analysis data indicate food-web disruption and no radionuclides were identified in the marine environment as released from the underground tests (Held, 1972). Nevertheless, work continues and stomach contents of fish from 12 offshore and 25 nearshore species were analyzed. Percentage composition by weight and percentage occurrence of food items, mean indices of stomach fullness and digestion, and data on samples are summarized in Appendix Table A-4. Previous analyses referred to are reported in Burgner, et al. (1969, 1971) and Burgner and Nakatani (1972).

The data obtained contribute significantly to understanding the structure of the Amchitka marine food web. Amphipods were again found to be of vital importance, but other crustaceans (mysids, euphausiids, copepods), molluscs, echinoderms (brittlestars), and fish (Pacific sand lance and several sculpins) were also significant. Differences in diet were noted between fish taken from protected coastal waters (harbors, bays, and coves) and those of the same species taken from exposed coastal waters. The influence of closely adjacent deep-water offshore communities was also apparent.

Offshore Fishes. The offshore-fish diets included:

Chum salmon, Oncorhynchus keta – Empty stomachs found in 67 percent of the chum salmon captured suggest either periodic feeding or loss of stomach contents in captivity. The other stomachs contained the remains of fish, hyperiid amphipods, and copepods.

Sockeye salmon, O. nerka – contained amphipods and unidentifiable fish but no copepods.

Pacific halibut, Hippoglossus stenolepis – fed offshore as much as nearshore, fish (armorhead and unidentifiable sculpins) and hairy crab (Erimacrus isenbeckii), made up most of the stomach contents instead of the cephalopod molluscs found in specimens examined earlier. (Previous analyses of the stomach contents of nearshore halibut had also indicated significant utilization of this crab.)

Great sculpin, Myoxocephalus polyacanthocephalus – contained only the hairy crab.

Red Irish lord, Hemilepidotus hemilepidotus – fed predominantly hairy crab, but also frequent annelids.

A sculpin, Malococottus zonorus – fed on a variety of benthic invertebrates – many annelids, isopods, some crabs (mostly E. isenbeckii), shrimp, and a few amphipods.

Pacific cod, Gadus macrocephalus – selectively fed primarily on red Irish lord, and crabs (usually E. isenbeckii).

Walleye pollock, Theragra chalcogramma – Pollock caught offshore obviously differed in food habits from those collected nearshore; nearshore fish fed on mysids, those offshore fed largely on euphausiids.

Arrowtooth flounder, Atherestes stomias – polychaete annelids major food organisms found versus the shrimp and a sculpin found in four specimens collected in 1970.

Rock sole, Lepidopsetta bilineata – unlike those found nearshore, contained brittlestar remains and a few annelids.

Searcher, Bathymaster signatus – yielded only unidentifiable fish and a few stones but no amphipods (which characterized the inshore specimen).

Roughscale rattail, Coryphaenoides acrolepis – stomachs contained Northern lampfish, Stenobranchius leucopsarus, a lantern fish, Hierops thompsoni, the Pacific viperfish, Chauliodus macouni, a deep-water mysid, Gnathophausia gigas, jellyfish, and squid. (Most of these food organisms were commonly caught in nighttime midwater trawl hauls in which these rattails were captured; it would appear that these fish follow these food organisms.)

Nearshore Fishes. The nearshore-fish diets included:

Rock greenling, Hexagrammos lagocephalus – benthic and bathypelagic invertebrates, primarily amphipods, molluscs, annelids, and isopods were found. (Increased contributions to the diet by mysides and fish may suggest trophic differences between greenling from the exposed Bering Sea coast and the previous specimens from the Constantine Harbor area or the Pacific Ocean side.)

Atka mackerel, Pleurogrammus monopterygius – mysids were major food item as in previous surveys, amphipods and especially copepods showed increased contribution. (It is thought that the influence of the closely adjacent offshore communities is reflected here, as most of the specimens originated from the Sand Beach Cove area.)

Red Irish lord, Hemilepidotus hemilepidotus – this benthic sculpin contained benthic invertebrates, primarily amphipods and molluscs.

Great sculpin, Myoxocephalus polyacanthocephalus – the one fish examined contained a Pacific sand lance, Ammodytes hexapterus. (Earlier analyses showed large contributions by amphipods.)

Armorhead sculpin, Gymnocanthus galeatus – contained fish and molluscs in a greater proportion of the stomachs than in earlier analyses. (The sculpins, most of which had been collected in the Sand Beach Cove area, differed in stomach contents from those taken from Pacific coastal waters in 1970.)

Calico sculpin, Clinocottus embryum – this small, tidepool sculpin fed predominately on small amphipods and copepods.

Sharpnose sculpin, Clinocottus acuticeps – two tidepool sculpins examined contained only amphipods.

High cockscomb, Anoplarchus purpureus – contained insect larvae and annelids. (Those earlier had mostly amphipods.)

Crescent gunnel, Pholis laeta – this intertidal gunnel contained amphipods, small molluscs (gastropods and bivalves), and miscellaneous organisms such as isopods and insect larvae.

Searcher, Bathymaster signatus – contained only amphipods.

Spotted snailfish, Liparis callyodon – consumed primarily amphipods, molluscs, insect larvae, and algae. (This spotted snailfish is a small liparid usually associated with intertidal algae and the kelp canopy.)

Lobefin snailfish, Polypera greeni – fed on amphipods, including many caprellid amphipods, molluscs, shrimp, brittlestars, annelids, and small fish, such as the juvenile smooth lumpsucker, Aptocyclops ventricosus. (This liparid, larger than L. callyodon and commonly associated with the kelp canopy.)

Smooth lumpsucker, Aptocyclops ventricosus – The one stomach, from a female that was extremely gravid, was empty.

Pacific cod, Gadus macrocephalus – contained predominantly fish (Pacific sand lance, red Irish lord, armorhead sculpins) crabs, and shrimp; occasionally annelids, amphipods, and bivalves.

Pacific halibut, Hippoglossus stenolepis – contained fish (great sculpins, armorhead sculpins, and rockfish) and octopus. (A high proportion of these halibut had empty stomachs.)

Dusky rockfish, Sebastes ciliatus – had eaten only amphipods.

Dolly Varden, Salvelinus malma – contained mostly fish (almost always Pacific sand lance), copepods, and mysids. (Specimens were obtained before they entered freshwater to spawn.)

Pink salmon, Oncorhynchus gorboscha – contained pelagic fish larvae, euphausiids, mysids, amphipods, and isopods. (The one stomach examined taken from a fish that had been captured in a sea otter net in Kirilof Bay.)

Pacific sand lance, Ammodytes hexapterus – a pelagic schooling species, this sand lance fed selectively on copepods and hyperiid amphipods.

Rock sole, Lepidopsetta bilineata – fed mostly on annelids and infrequently on amphipods and mysids as with most flatfish.

Pacific sandfish, Trichodon trichodon – fed exclusively on fish (unidentifiable) and amphipods. (This is an odd nearshore fish that occasionally buries itself vertically in the sand until only its mouth protrudes.)

Sturgeon poacher, Agonus acipenserinus – contained diverse benthic invertebrates, including amphipods, molluscs, shrimp, and annelids.

Walleye pollock, Theragra chalcogramma – contained primarily euphausiids, mysids, amphipods, and fish (Pacific sand lance and an unidentified cottid) with a few copepods. (The abundance of mysids in their stomachs suggests these pollock moved into the nearshore waters to feed. Not commonly found nearshore in abundance, these fish were caught in Sand Beach Cove.)

Kelp greenling, Hexagrammos decagrammos – like the rock greenling, contained diverse benthic fauna (shrimp, chitons, gastropods, brittlestars) as well as red Irish lord.

Northern rockfish, Sebastes polyspinis – (The one stomach examined was empty.)

Marine Invertebrates

Objectives and Tasks

Research was oriented primarily toward assessing the effects of physical disturbance caused by Cannikin on intertidal (littoral) organisms. The physical disturbance of localized intertidal areas by Cannikin was the major factor in Cannikin effects studies on marine invertebrates (and on algae discussed in the following section). To reduce text volume and duplication, the primary features of the intertidal area disrupted by Cannikin are included in the invertebrate section. A complete discussion of the biological consequences of the physical disruption awaits the receipt of final physical survey information and our utilization of this information in future field surveys.

Materials and Methods

In August 1970, forty 0.25m² permanent intertidal plots were designated for algal and invertebrate sampling on the Bering Sea side of Amchitka near Cannikin SZ. Of these plots, 25 were located at IA-2, 15 were located at IA-3, both sites on the Bering Sea coast adjacent to Cannikin SZ (Figure 7). The exact location, preevent elevation, and method of sampling of the plots are discussed in Burgner and Nakatani (1972). Sites IA-2 and IA-3 were sampled for invertebrates in August 1970 and in September 1971 prior to Cannikin. Postevent sampling was conducted in December 1971, February

1972, and April 1972. An additional 11 plots were sampled postevent in February and April 1972, in order to monitor changes in uplifted sublittoral areas and on newly exposed bare-rock surfaces and to compensate for plots buried by rockfalls. Sampling methods remained the same during the sampling periods except that the bimonthly collection of 80-mm-diameter, 14-mm-thick subsamples was discontinued after August 1970. The cumulative effect of sampling itself was considered sufficiently disruptive to warrant discontinuing subsampling. Instead, semiquantitative records were kept on abundances of the tiny, abundant species. Because of limitations on sampling time during the December 1971 and February 1972 trips, trends in species abundances during these months were monitored only at selected plots at both sites.

FIGURE 7. MAP OF A PORTION OF AMCHITKA ISLAND INDICATING THE AREAS DISCUSSED AND THEIR RELATION TO CANNIKIN SURFACE ZERO

The intertidal grid established at Banjo Point was sampled in August 1971 and will be sampled again in 1972 to determine the effects of lesser magnitudes of uplifting on invertebrate populations.

Seasonal sampling of control populations at St. Makarius Bay will continue until June 1972. Data from this study will show the magnitude of seasonal fluctuations in invertebrate populations under natural conditions.

Invertebrate samples collected during midwater trawling were also analyzed for indications of potential Cannikin-induced changes in midwater fauna.

Results and Discussion

Intertidal Invertebrates. A direct effect of Cannikin was the 1-m uplift along about 2 km of the Bering Sea coastline (U. S. Geol. Surv., 1972). Lesser uplift exists for several kilometers on each side of this area of maximum uplift. Preliminary data from the physical survey indicate that permanent uplifting in the plots at these areas ranged from 0.4 to 1.1 m. The maximum uplifting seen in the intertidal was 1.1 m in area IA-2 (U. S. Geol. Surv., 1972); thus, this area should provide information on the effects of extreme uplifting from Cannikin. Since the final data from the physical survey were not available at the time of writing, a detailed discussion correlating uplifting with biological effects is not included here.

The magnitude of the immediate effect on littoral vertebrate populations following uplifting was evaluated from changes in the number of species (species richness) per plot. Preliminary examination of the data from the uplifted permanent plots at IA-2 and IA-3 indicates that the effect of uplifting on littoral invertebrates varied depending on their tidal level and degree of exposure to wave splash. Tables 4 and 5 show differences in preevent and postevent species richness at IA-2 and IA-3, respectively. Plots are grouped according to zone. The upper eulittoral plots, where the influence of exposure appeared to be greatest, were divided into inner (shoreward) and outer (seaward) bench categories. Early trends in species richness in areas formerly sublittoral and in plots on newly exposed surfaces are also included in Table 4.

Studies at St. Makarius Bay concurrent with the IA-2 and IA-3 studies were designed to show seasonal fluctuations in invertebrate populations. Analysis of samples from St. Makarius Bay is not as yet complete. Comparison of data from the two pre-event sampling periods at IA-2 and IA-3 in roughly the same season shows that species numbers remained essentially constant from 1970 to 1971 prior to Cannikin (Tables 4 and 5). Plots 5, 16, 21, 23, and 24 at IA-2 are notable exceptions. Between-year differences in species richness on three (5, 16, and 24) of these five plots can be accounted for in two ways: (1) rare or very small invertebrates were not considered during August 1970, especially since subsamples were taken; (2) highly motile amphipod and isopod species may have been transient on the plots in September 1971. These could not account for the difference in species numbers between 1970 and 1971 on the two plots (21 and 23) that showed the greatest discrepancy between years. Both of these plots had additions of littorine species and Thais lima in 1971. There is no immediate explanation for the presence of these species in one year and not the other. As Plots 16 and 21 were buried by rockfalls during Cannikin, they are not included in the analysis of the effects of uplifting.

At IA-2, invertebrate populations in the upper eulittoral zone of the inner bench were severely affected by Cannikin. Complete destruction of invertebrate populations on Plots 1 to 4 had taken place by April 1972. The slight resurgence in species richness on Plots 2 to 4 was actually due to immigration of terrestrial species (the amphipod Orchestia sp., dipterans of the family Coelopidae, and other insect larvae) into the area containing these plots. Community destruction is not as yet complete on Plots 18, 22, and 23; nevertheless, all that remains of the former invertebrate populations are littorines and a few representatives of other species, such as Thais or Turtonia. Plot 24 alone appears to have suffered little reduction in species richness; however, it is an exception in that it is located in a shallow depression where seawater from wave splash can collect. This depression provides a refuge from desiccation for the uplifted species, which could otherwise not tolerate the prolonged emersion at this level.

TABLE 4. PREEVENT AND POSTEVENT SPECIES RICHNESS
ON PERMANENT PLOTS AT IA-2

Preevent Tidal Zones	Plot	Species Richness ^(a)				
		Preevent		Postevent		
		Aug. 1970	Sept. 1971	Dec. 1971	Feb. 1972	Apr. 1972
Upper eulittoral inner bench	1	5	8	4	-	0
	2	9	11	5	0	3
	3	1	5	0	-	3
	4	11	12	1	-	3
	6	7	6	Buried	Buried	Buried
	16	2	8	Buried	Buried	Buried
	18	8	7	-	-	4
	22	9	11	-	-	3
	23	7	16	-	-	4
	24	11	16	6	11	10
Upper eulittoral outer bench	5	7	12	10	8	8
	9	7	8	11	9	8
	10	4	3	3	5	4
	11	8	6	9	7	8
	13	16	12	3	2	2
	14	9	8	-	-	1
	15	5	5	-	7	9
	19	4	4	-	-	8
	20	16	18	12	6	4
	26	-	-	-	4	6
Lower eulittoral	7	12	15	Buried	Buried	Buried
	21	7	16	Buried	Buried	Buried
Sublittoral fringe	8	12	12	Buried	Buried	Buried
	12	19	18	18	1	3
	17	13	-	-	-	3
	25	9	-	5	1	1
	27	-	-	-	8	8
Sublittoral	28	-	-	-	11	9
	32	-	-	-	11	12
	33	-	-	-	14	6
	34	-	-	-	9	5
	35	-	-	-	9	7
	36	-	-	-	9	-
New surfaces [postevent ^(b)]	29	-	-	-	2	3
	30	-	-	-	3	3
	31	-	-	-	1	3

(a) A dash (-) indicates no observation.

(b) The preevent tidal zone of the areas where these new surfaces were created by Cannikin were at and below the sublittoral fringe.

The sublittoral fringe at IA-2 experienced destruction of the invertebrate community comparable to that of the upper eulittoral, inner bench area. Complete die-off and/or emigration of resident species had taken place by February 1972 at Plots 12, 17, and 25. These plots were almost exclusively occupied by littorine snails, Littorina atkana, L. aleutica, and L. sitkana (Plot 12 contained a few Turtonia) by April 1972. Plot 27, established postevent, still contained remnants of lower level invertebrate populations during April 1972. Although species richness on this plot was probably greater preevent, it is not possible to know how much greater. It has undoubtedly retained some preevent species because it is at the very outer edge of the bench and derives benefit from wave splash during most tidal stages.

The upper eulittoral, outer bench appears to have been affected least severely by uplifting. The majority of plots in this zone showed no appreciable reduction in species numbers although some individual abundance levels decreased. The proximity to the seaward edge of the bench and the exposure of these plots to regular wetting with seawater undoubtedly are the prime reasons for invertebrate survival in this zone. Whether or not these populations can remain in this area is not known; it will have to be studied at least through two more seasons. Reductions in species richness on some of the plots between February and April 1972 indicate that it would be premature to state that death and/or emigration has proceeded as far as it is going to in this zone.

Unfortunately the lower eulittoral plots at IA-2 (Table 4) were buried by rockfalls during Cannikin. Monitoring of lower eulittoral plots at IA-3 indicates that community destruction in this zone is comparable to that of the sublittoral fringe.

There are few data available as yet on postevent changes on formerly sublittoral and newly exposed surfaces. Several former species still remain on the sublittoral plots, but complete or nearly complete die-off is expected. Newly exposed surfaces had immigrants by February 1972 if not earlier. Most of these were littorine snails. Modest species additions had taken place by April 1972. It is expected that succession toward a "climax" community will begin on newly exposed surfaces first.

Postevent data from the IA-3 permanent plots are not as complete as those from IA-2 (Table 5). Available information indicates that trends in the reduction of species richness after Cannikin were similar to but less abrupt than at IA-2. Preliminary surveying data show that uplifting was less extreme at IA-3. Undoubtedly this difference is the major reason why invertebrate communities at IA-3 were less severely affected initially. Three of the four zones (upper eulittoral, inner bench; lower eulittoral, and sublittoral fringe) showed a more gradual decrease in species numbers than did the same zones at IA-2 did. Unlike at IA-2, the upper eulittoral, outer bench at IA-3 incurred a significant reduction in species richness more closely paralleling that of the inner bench. IA-3 is more sheltered than IA-2 and its outer-bench plots are not as close to the seaward edge of the bench as at IA-2; as a result the IA-3 plots do not benefit from wave splash as those at IA-2 do.

TABLE 5. PREEVENT AND POSTEVENT SPECIES RICHNESS ON PERMANENT PLOTS AT IA-3

Zone	Plot	Species Richness ^(a)				
		Preevent		Postevent		
		Aug. 1970	Sept. 1971	Dec. 1971	Feb. 1972	Apr. 1972
Upper eulittoral inner bench	3	-	11	-	5	3
	4	-	8	-	-	6
	5	-	8	-	-	5
	13	-	12	-	-	4
	14	-	10	-	-	0
	15	-	10	-	-	3
Upper eulittoral outer bench	6	11	20	5	8	5
	8	-	16	2	7	5
	9	20	16	-	-	2
	10	9	10	3	6	4
	11	15	18	Buried	Buried	Buried
	12	11	11	Buried	Buried	Buried
Lower eulittoral	2	-	18	9	13	5
	7	12	17	11	11	7
Sublittoral fringe	1		14	11	19	9

(a) A dash (-) indicates no observation.

The magnitude of the early effect of Cannikin-induced uplifting on intertidal invertebrate communities varied depending on the preevent tidal level of those communities and the degree to which they were exposed to wave splash and sea spray postevent. At IA-2, the upper eulittoral, inner bench and the sublittoral fringe were most severely affected. Former invertebrate populations were completely lost and were being replaced by terrestrial (on the extreme inner bench) and upper eulittoral species, especially. On the upper eulittoral, outer bench, species richness was little reduced, but for the most part individual species abundance was significantly reduced. Plots in the lower eulittoral could not be followed because they were buried by rockfall (Table 4).

At IA-3 reductions in species richness occurred less rapidly, but by April 1972 they were nearly as pronounced as at IA-2, especially in the lower eulittoral and sublittoral fringe (Table 5). Complete replacement of former upper eulittoral, inner bench species with terrestrial species had not yet taken place. The distinction between inner bench and outer bench reductions in species richness at IA-3 was not as pronounced as at IA-2 because IA-3 is less exposed than IA-2. Also, the outer bench plots at IA-3 were farther back from the seaward edge of the bench than at IA-2.

Midwater Invertebrates. About one-third of the invertebrate samples captured offshore in midwater trawls have been processed, but taxonomic determination continues to consume considerable time. Table 6 presents the list of species identified

TABLE 6. IDENTIFIED INVERTEBRATES CAPTURED IN MIDWATER TRAWLING, 1971

Mysidacea - Mysids	Cephalapoda - Squid and Octopus
<u>Gnathophausia gigas</u>	<u>Gonatus fabricii</u>
Euphausiacea - Euphausiids	<u>G. magister</u> ^(a)
<u>Euphausia pacifica</u>	<u>Gonatopsis borealis</u>
<u>Thysanoessa inermis</u>	<u>Galiteuthis armata</u>
<u>T. longipes</u>	<u>Japatella heathi</u>
<u>Tessarobranchion oculatus</u>	Chaetognatha - Arrow worms
Caridea - Shrimp	<u>Sagitta elegans</u>
<u>Sergestes similis</u>	<u>S. planctonis</u>
<u>Hymenodora frontalis</u>	
<u>Nostostomus japonicus</u>	

(a) Also identified in 1970 midwater sampling.

to date. High variability and inconsistency of the preliminary data indicate that the sampling would be insensitive to possible Cannikin effects on midwater invertebrate fauna. However, some differences in species composition of euphausiids between Pacific Ocean and Bering Sea catches appear to suggest the existence of distinct water masses. However, the remaining samples need to be analyzed and the horizontal and vertical distribution of species adequately evaluated to determine if this phenomenon is real.

Marine Algae

Objectives and Tasks

- Evaluate the effects of Milrow and Cannikin on intertidal algae.
- Resample established intertidal control transects.
- Continue studies of the taxonomy and ecology of crustose coralline algae.
- Initiate a study of recolonization of experimentally disturbed intertidal algal communities.

Materials and Methods

IA-1. To document Milrow-induced long-term changes in disturbed algal populations, the plots established in the Duck Cove (IA-1) intertidal bench area in the spring of 1970 were resampled on July 19, October 5, December 1, 1971, and on February 22 and April 15, 1972.

IA-2. Algal sampling was carried out on the IA-2 and IA-3 area plots described in the invertebrate section three times preevent – August 15, 1970, and July 23, and October 9, 1971 – and postevent – December 3, 1971, and February 19, and April 16, 1972.

Coastal Intertidal. During July 20 to August 6, 1971, the coastal intertidal was surveyed during equivalent low tides. Notes were taken on evidence of naturally occurring die-off.

The April 14-30, 1972, field trip provided the first opportunity to observe the effects of Cannikin on intertidal algal communities during daylight hours (winter low tides occur at night). The Bering Sea coast from just east of Sea Otter Point to Square Bay (15.4 km) was surveyed on April 18 and 19. Obvious uplifting and die-off on the Pacific Ocean coast had not been reported by the immediate-postshot beach-survey teams, thus efforts were devoted primarily to studying the Bering Sea coast areas at that time. On April 20, observations were made of intertidal algal communities along the Pacific Ocean coast southwest of "D" site, where uplifting from Cannikin was expected to be nil. These observations were compared with those at the "Juxta" monument area (Figure 7), which is about the nearest Pacific coastal area to Cannikin SZ. These surveys were designed to indicate the geographical extent of die-off from permanent uplifting induced by Cannikin.

Control Transects T-1 and T-2. The original intertidal transects established by Weinmann at St. Makarius Bay (T-1) and Square Bay (T-2) were remarked and were sampled for algae simultaneously with the IA-1, IA-2, and IA-3 areas.

Taxonomy and Ecology of Coralline Algae. The field work has been completed. It involved underwater photographic sampling of ledge populations in summer 1971 and gathering of some additional information in April 1972. The major effort now will be put into laboratory work and statistical analysis of the data.

Recolonization of Experimentally Disturbed Intertidal Algae Communities. Studies were initiated at Amchitka in March 1971 to obtain information on recolonization in experimentally disturbed algal communities on intertidal rock benches. If Cannikin disturbed intertidal algal communities or displaced subtidal or terrestrial areas into intertidal areas, data obtained from these experimentally manipulated areas would indicate the recolonization patterns to be expected in various intertidal zones disturbed by Cannikin. There is no practical way to raise or lower study areas to simulate test-induced uplifting or subsidence. However, this was not necessary since it was reasoned that recolonization of a disturbed area would be determined by its new level (or zone) and not by its previous one. Thus, if uplifting or subsidence moved part of the subtidal or terrestrial area into the intertidal area, recolonization would occur here as it would in experimentally disturbed intertidal areas created in various zones whose elevation had not changed.

Study sites were established bimonthly (except in November 1971) on intertidal rock benches at three locations on the Pacific side of Amchitka: St. Makarius Bay, a sheltered

area; Rifle Range Point, an exposed area; and Duck Cove, an intermediate area. Season, exposure to wave action, zonation, community type, substratum, and distance to Cannikin SZ were considered in establishing study areas since they could influence recolonization rates and species composition.

Five major intertidal algal communities were defined on the basis of importance in biomass and space occupied. These communities are, from the lowest intertidal zone (seaward) to the highest (shoreward): (1) Laminaria dominated by L. longpipes, a straplike brown alga up to 1 m long with an intermeshed holdfast network; (2) Alaria, dominated by A. crispa, a straplike brown alga up to 3 m long with a single, flat, discoid holdfast; (3) Corallina, dominated by Corallina vancouveriensis, an articulated red alga up to 4 cm long; (4) Hedophyllum, dominated by H. sessile, a cabbagelike brown alga up to 80 cm in diameter with a single, tall holdfast; and (5) Halosaccion, dominated by H. glandiforme, an erect saclike red alga up to 8 cm high. Not all five communities were studied at each location (Table 7). These communities differ from those described on Amchitka by Weinmann (1969).

TABLE 7. EXPERIMENTALLY DISTURBED INTERTIDAL COMMUNITIES, LOCATIONS, MANIPULATION, AND DATES OF ESTABLISHMENT AND EXAMINATION

Community	Location	Manipulation	Date	
			Established	Examined
<u>Laminaria</u>	St. Makarius Bay	Rock exposed	Dec. 71	Feb. 72, Apr. 72
<u>Laminaria</u>	St. Makarius Bay	Canopy removed	Dec. 71	Feb. 72, Apr. 72
<u>Hedophyllum</u>	St. Makarius Bay	Rock exposed	Dec. 71	Feb. 72, Apr. 72
<u>Halosaccion</u>	St. Makarius Bay	Rock exposed	Dec. 71	Feb. 72, Apr. 72
<u>Corallina</u>	Rifle Range Point	Rock exposed	Dec. 71	Feb. 72, Apr. 72
<u>Alaria</u>	Duck Cove	Rock exposed	Dec. 71	Feb. 72, Apr. 72
<u>Alaria</u>	Duck Cove	Canopy removed	Dec. 71	Feb. 72, Apr. 72
<u>Hedophyllum</u>	Duck Cove	Canopy removed	Dec. 71	Feb. 72, Apr. 72
<u>Corallina</u>	Duck Cove	Rock exposed	Dec. 71	Feb. 72, Apr. 72

To study recolonization on newly denuded rock, 1-square meter (m^2) areas occupied by Laminaria, Alaria, Hedophyllum and 0.25- m^2 areas occupied by Corallina and Halosaccion were scraped clean with a shovel, putty knife, and wire brush, then burned twice with a 1:1 mixture of fuel oil and white gas.

To evaluate the effects of canopy removal, the blades of Laminaria, Alaria, and Hedophyllum were removed with a wire cutter in the 1- m^2 areas while everything else remained intact. Halichondria panicea, an incrusting sponge, and crustose coralline algae were under all three algae, and Iridaea, a small erect red alga, and Halosaccion were under all but the Laminaria.

One corner of each study area was marked by a 0.3-m length of cord secured with a concrete nail and numbered washer. Each 1- m^2 area was divided into four contiguous 0.25- m^2 plots. Plots were delineated by concrete nails and identified by a numbered piece of survey flagging. Each of the 0.25- m^2 areas was delineated by an additional concrete nail located diagonally from the cord and identified by the marked washer.

The perimeter of each area was cleared of all plants and animals in order to minimize physical disturbance from adjacent algae during surge at high tide and from grazing benthic invertebrate herbivores (limpets and chitons). Each study area had a replicate and control.

All study areas (replicate and control) were surveyed as often as possible. Color transparencies were taken bimonthly at each 0.25-m² plot except in November. Each transparency was projected and species composition and percent cover were determined for each plot.

Only data on recolonization in study areas established during the first four days of December 1971 and observed in February and April 1972 are used in this report. Recolonization rates and types in the study areas are considered suitable for comparison with those in the portion of the intertidal rock bench uplifted by Cannikin on the Bering Sea side of the island because (1) the study areas were not damaged by Cannikin, (2) the study areas were established near the date of Cannikin, and (3) types of damage to algal communities incurred by Cannikin – exfoliation of portions of the rock bench creating bare rock surfaces, and algae exposed to desiccation on uplifted benches leaving thinned communities of dying and dead algae – were simulated by the newly exposed rock and canopy-cleared plots, respectively.

Results and Discussion

Long-term Effects of Milrow. General observations made at IA-1 have shown a slow recolonization pattern, primarily involving the settling and growth of Fucus distichus in a zone where previously Hedophyllum had occurred. Fucus normally occupies a higher intertidal level than Hedophyllum and, as predicted, replaced the latter after the bench was uplifted. Similar changes in other algal species may be seen once the photographs are finally analyzed.

The earliest estimate of the area of algal die-off at IA-1 was 235 m² (Burgner, et al., 1971b). Now, 4 ha (40,000 m²) is thought to be the maximum possible area affected at IA-1 by the uplifting caused by Milrow (Lebednik, in press). The area at IA-1 with obvious effects is about 4,000 m². Accurate area measurements are not available since a suitable aerial photography project was not undertaken. However, the total impact on the Island ecosystem was small because it affected only a small fraction (several hundred meters) of the total Amchitka coastline (190 km)*, and our data indicate most of the affected area could be recolonized by algal species of higher intertidal zones.

IA-2 and IA-3. The observations in areas IA-2 and IA-3 provided information concerning natural population turnover, the sequence of occurrence of species affected by Cannikin-induced uplifting, and the extent of the effects. Iridaea cornucopiae was one of the first high intertidal species to exhibit obvious die-off at IA-2 postshot. The spring season is a period when new blades are produced in this species and no natural die-off occurs; thus, it appears to be a good indicator of test-related die-off. It is also a conspicuous species, and die-off can be seen from 100 m away during beach walks.

*Map readings made with a Hamilton model 331 map reader on a 1:250,000 scale USGS map and a 1:25,000 scale "LRL" map yielded Island coastline distance of 187 km (116 miles) and 190 km (118 miles) respectively.

In general, it can be stated that the intertidal algae at IA-2 experienced nearly total mortality, but IA-3 suffered less mortality. Additional mortality at IA-3 during the summer of 1972 is expected; hence, although mortality may be delayed, eventually it is expected to be total or nearly so. The least-uplifted plot at IA-3 underwent an uplift three times that at the IA-1 area, where extensive die-off occurred. Ephemeral "succession" of newly appearing species was obvious in February and has continued, but no species thought to be permanent recolonizers have been observed. Similarly, at IA-1, Fucus did not appear until 1 year after Milrow. Sampling should continue on a bimonthly schedule at least until December 1972. The major recolonization should occur during 1973 and 1974.

Control Transects T-1 and T-2. The control transects showed that the following are all natural phenomena in the intertidal during each spring: attrition of the blades of uppermost plants of Laminaria longipes and Hedophyllum sessile, a bleaching to white fronds of Corallina vancouveriensis on outer-bench areas, and occasional bleaching of Clathromorphum circumscriptum and C. loculosum. Thus, none of these phenomena can be attributed to Cannikin.

Effects of Cannikin. The broad effects of Cannikin can now be discussed keeping in mind the observations of natural die-off. Smothering of intertidal communities by rockfall is marked in certain localities, especially at points of land along the Bering Sea coast, but the areas involved are much smaller than the uplifted areas. The most significant effects from Cannikin are due to permanent uplifting of the coastal areas; thus, the studies have been directed toward this type of disturbance.

Bering Sea Coast. Coastal landslides were visible from Sea Otter Point to Petrel Point, but algal die-off did not become apparent until just east of Petrel (Figure 7). From there to Point 9B, die-off appeared light and patchy. Boulder and cobble, constituting the substrate along a large percentage of the intertidal shore, may have masked or modified the gradation in die-off from that expected on the basis of observations of rock benches east of White Alice Creek (See below).

Between Points 9B and 10B, die-off was more extensive and involved more species.

Just west of Point 10B to the mouth of White Alice Creek, die-off was very extensive and apparently comparable to that at IA-2. Die-off of Iridaea cornucopiae appeared to be ameliorated in the vicinity of the creek flow over the bench.

To the east of the mouth of White Alice Creek, die-off was moderate and somewhat discontinuous. On Banjo Point only one zone, that of Alaria-Odonthalia-Corallina vancouveriensis, exhibited die-off. Elsewhere up to Point P8, portions of the Iridaea cornucopiae, Laminaria longipes, and crustose coralline populations showed die-off attributable to uplift (Figure 7).

Eastward from Point P8 to Point 96B, die-off was detectable in the Iridaea cornucopiae and Laminaria spp. populations. Beyond Point 96B, no die-off in addition to what was believed to be natural die-off was observed.

The observations on algal die-off on the Bering Sea coast are summarized in Figure 8. The distances indicated are those measured approximately at the high-water line. Basically, the entire intertidal zone from mean low to high is described here. The categories of die-off are as follows:

Detectable — from one to a few species showing some die-off

Moderate — a few species showing extensive die-off (more than about one-third of the total population)

Severe — all abundant species exhibiting extensive to complete die-off.

FIGURE 8. BERING SEA INTERTIDAL ALGAL DIE-OFF
DUE TO CANNIKIN, APRIL 1972

It can be expected that die-off may increase both geographically and quantitatively during the summer. Probably most of the extensive die-off has already occurred and the additional die-off expected in the future will be moderate.

Pacific Ocean Coast. No evidence of die-off attributable to Cannikin was observed on the Pacific Coast. Unless physical survey data indicate a permanent uplifting greater than 12 cm there, no further observations will be made there. From previous work on area 1A-1, the area uplifted by Milrow, it is known that changes resulting from this amount of uplifting can be detected by the methods used. Theoretically, population changes will occur whenever there is any uplifting but they may be difficult to detect when uplifting is less than 12 cm.

TABLE 8. ALGAL SPECIES AND PERCENT COVER ON NEWLY
 DENUDED ROCK AREAS ESTABLISHED IN DECEMBER
 1971 ON INTERTIDAL ROCK BENCHES

Community	Location	February 1972		April 1972	
		Cover	Percent	Cover	Percent
<u>Laminaria</u>	St. Makarius Bay	Filamentous	61	Filamentous brown algae	1
		diatoms		<u>Ulva</u>	94
		Rock	39	<u>Halosaccion</u>	1
				<u>Iridaea</u>	1
				<u>Hedophyllum</u>	1
				<u>Alaria</u>	1
				<u>Rock</u>	1
<u>Alaria</u>	Duck Cove	Filamentous	100	Filamentous brown algae	5
		diatoms		Filamentous green algae	4
		Rock	0	<u>Iridaea</u>	1
				<u>Rock</u>	90
<u>Hedophyllum</u>	St. Makarius Bay	Filamentous	6	Filamentous brown algae	1
		diatoms		Filamentous green algae	1
		Rock	94	<u>Ulva</u>	56
				<u>Halosaccion</u>	1
				<u>Iridaea</u>	1
				<u>Hedophyllum</u>	1
				<u>Alaria</u>	1
				<u>Rock</u>	38
<u>Corallina</u>	Duck Cove	Filamentous	67	Filamentous brown algae	30
		diatoms		Filamentous green algae	60
		Rock	33	<u>Ulva</u>	7
				<u>Halosaccion</u>	1
				<u>Iridaea</u>	1
				<u>Rock</u>	1
<u>Corallina</u>	Rifle Range Point	Filamentous	70	Filamentous brown algae	40
		diatoms		Filamentous green algae	58
		Rock	30	<u>Ulva</u>	1
				<u>Rock</u>	1
<u>Halosaccion</u>	St. Makarius Bay	Filamentous	2	<u>Ulva</u>	20
		diatoms		<u>Halosaccion</u>	10
		Rock	98	<u>Iridaea</u>	1
				<u>Rock</u>	69

The types of recolonization observed in the study areas can occur on the intertidal rock bench uplifted by Cannikin (1) if sufficient portions of the bench are still intertidal, (2) if the substratum of the once lower bench is suitable for settling of algae at the elevated level, and (3) if spores are available from the dying or nearby communities. Recolonization will advance farther and occur sooner in the areas of moderate rather than maximum uplifting. The algal communities may also develop quite well since many benthic intertidal herbivores were killed by the uplifting.

The type of intertidal algae community that eventually develops on the uplifted bench, as well as the speed of its development, will depend on the new level of the bench and on how physical and biological factors shape this newly disturbed area. Severe or unstable conditions favor pioneer species. Thus, much time may elapse before communities of more-advanced algal species occupy the uplifted bench.

Surface Sea Current Studies

Objectives

Fisheries Research Institute carried out three vessel-days of preevent physical oceanography studies to determine gross surface water (to 5 m) movement and mixing in the waters adjacent to Cannikin SZ. Such studies could help ascertain the potential oceanic transport of radionuclides in the unlikely event of any release of radionuclides into the marine environment from Cannikin. The work was performed in an area of the Bering Sea waters expected to be downwind after the Cannikin detonation. No work was conducted in the adjacent Pacific Ocean waters.

Materials and Methods

Drift-pole studies somewhat similar to those conducted during 1967 (Burgner and Associates, 1968) and 1969 (Burgner et al., 1970) were performed on October 21, 22, and 24, 1971 in the Bering Sea waters adjacent to Cannikin SZ with the charter vessel M/V Commander. Two poles, one shallow and one with drogue vanes 5 m under the surface, were set simultaneously. In previous studies the poles were set adrift from the same location after each drift interval. However, in this study the poles were allowed to drift with the water mass and/or wind movement, and their positions were plotted at frequent intervals with the aid of radar. Thus, rather than defining the net movement of the water mass in a specific locality for a definite time period, this method portrayed the net water movement of a specific mass of water as it moved over a definite time period. This would more appropriately portray the potential path of any radionuclide released into that region under similar conditions. In addition to the drift pole stations, two transects were also run on October 24.

In addition, surface water transport was studied through the documentation of the drift of approximately 100 marked oranges released from the M/V Commander on October 24. As with the drift poles, the position of the center of the orange group was plotted by triangulation at frequent intervals. Aerial photographs were obtained of the pattern of the drifting oranges approximately 3 hours after release.

In conjunction with the water-movement studies, temperature/salinity surveys were conducted to describe the character of the water mass and to evaluate the degree of mixing in the area studied by the drift poles. All temperature/salinity values were recorded using a Beckman RS5-3 portable salinometer. The corresponding sigma-t

Recolonization. Species composition and percent cover in the denuded rock study plots are shown in Table 8. Only diatoms had appeared by February. By April these had been replaced by a variety of algae. Ulva, a flat, green alga, was the most abundant species. Diatoms were more abundant in the more-exposed* areas and lower zones than in the less-exposed areas and higher zones. Ulva and Halosaccion were more abundant in the more-exposed areas than in the less-exposed areas. Hedophyllum and Halosaccion were the only algae that had recurred by April in zones originally occupied by these species. Both occurred in lower zones. Alaria occurred in a higher and lower zone, whereas Laminaria and C. vancouveriensis did not occur in any zone studied. While analysis of the data from the areas from which canopy had been removed has not been completed, preliminary results are available (Table 9). Five days after the canopy had been removed from all three communities the sponge and Corallina were dead. By February, Ulva, a new species, had appeared and Iridaea had increased slightly in abundance. By April two new red algae, Dumontia and an unknown foliose red species had settled, and Ulva and Halosaccion had more than doubled in amount.

TABLE 9. UNDERSTORY ON INTERTIDAL ROCK BENCHES
FROM WHICH CANOPY WAS REMOVED IN
DECEMBER 1971

Community	Location	December 1971	February 1972	April 1972
<u>Laminaria</u>	St. Makarius Bay	<u>Sponge</u> <u>Corallina</u>	<u>Ulva</u> <u>Halosaccion</u>	<u>Ulva</u> <u>Halosaccion</u>
<u>Alaria</u>	Duck Cove	<u>Sponge</u> <u>Corallina</u> <u>Halosaccion</u> <u>Iridaea</u>	<u>Ulva</u> <u>Halosaccion</u> <u>Iridaea</u>	<u>Ulva</u> <u>Halosaccion</u> <u>Iridaea</u> <u>Dumontia</u> Foliose red
<u>Hedophyllum</u>	Duck Cove	<u>Sponge</u> <u>Corallina</u> <u>Halosaccion</u> <u>Iridaea</u>	<u>Ulva</u> <u>Halosaccion</u> <u>Iridaea</u>	<u>Ulva</u> <u>Halosaccion</u> <u>Iridaea</u> <u>Dumontia</u>

Recolonization studies conducted on Amchitka indicate that rock substratum cleared (and remaining at original tidal levels) in December had been recolonized by early pioneer species by February and by more advanced algae by April. The type and density of algae present was related to availability of spores and substratum, wave exposure, and tidal zonation.

Removal of the canopy of large intertidal algae in December resulted in the death of the obligatory** understory, sponge and Corallina. The facultative*** understory, small red algae, improved; while shade-intolerant species, Ulva and the foliose red alga, settled and held space.

*Exposure is here defined as the availability to wave action

**Flora and fauna requiring shade from a vegetative canopy

***Flora and fauna which tolerate, but do not require shade from a vegetative canopy

(σ_t) value (a density value in which $\sigma_t = [\rho_t - 1] (1000)$, where ρ_t is the actual density as determined from the temperature and salinity) was calculated for each point of measurement.

Results and Discussion

The plotted positions of the drift poles and oranges for 3 days' experiments are shown in Figure 9. Vector plots of the drift pole and orange movements are illustrated in Figure 10. Wind vectors were obtained from NOAA Amchitka Station 8 Data listed in Appendix Table C-1. Incremental velocities of a drifting shallow drift pole ranged from 9.3 cm/sec to 24.3 cm/sec setting (bearing) generally to the east to southeast. Velocities of the deep drift pole varied from 5.6 cm/sec to 37.5 cm/sec setting east to southeast. The oranges drifted east to southeast at from 8.7 cm/sec to 37.0 cm/sec. As can be seen in Figure 10, the tidal stage during all 3 days of experiments was during high slack. Winds varied from the southwest to northeast to 24 k.

FIGURE 9. DRIFT POLES AND RELEASED ORANGES POSITIONS FOR THREE DAYS IN BERING SEA WATERS ADJACENT TO CANNIKIN SZ

All drifts are easterly. Grid is a 1,000-m UTM grid.

It is evident that, within ≤ 20 -k winds, tidal currents are the dominant influence of surface-water movement in the Bering Sea waters studied. When winds surpass 18-20 k the surface water flow is mediated by the wind forces. For the high-tide cycle, at least, net water movement appears to be dominantly eastwardly at a mean velocity

a. Shallow Drift-Pole Movement

b. Deep Drift-Pole Movement

c. Both Drift-Pole Movements

d. Shallow Drift-Pole Movement

e. Deep Drift-Pole Movement

f. Orange Drift Movement

FIGURE 10. VECTOR PLOTS OF DRIFT MOVEMENTS ON INDICATED DAYS

range of 14-20 cm/sec under the study conditions. When the water mass reaches the inshore (10-20 fm) region its movement becomes more complex, entering into a gyre-like movement perhaps influenced by the projecting structure of Crown Reefer Point.

The lack of low-velocity-wind influence on surface-water movement was also summarized from the 1967 studies (Burgner and Associates, 1968).

The positions of 24 salinity-temperature stations studied during October 21, 22, and 24, 1971, are illustrated in Figure 11. Salinities, temperatures, and calculated values of σ_t are given in Appendix Table C-2.

FIGURE 11. POSITIONS OF SALINITY-TEMPERATURE STATIONS IN THE BERING SEA WATERS ADJACENT TO CANNIKIN SZ

Grid is a 1,000-m UTM grid.

Contrary to the water stability and stratification found in the 1967 studies (Burgner and Associates, 1968), the October 1971 study in the Banjo Point-Crown Reefer region of Amchitka's Bering Sea water showed a thoroughly mixed water mass as indicated by the random temperature and σ_t values with depth and the lack of stratification. This may, in fact, be a feature unique to more inshore waters. (Note that Transect 1 of the 1968 studies ran from 1 to 4 miles offshore of Crown Reefer Point.) It might also be noted that suspected upwelling of Bering Sea water in this region may be sustained inshore because of the steep seabed and rugged submarine features close to the Island.

Surface-water temperatures also indicate that wind (direction and velocity) may be the dominant factor in temperature stability in this water mass.

Radiological Sampling

FRI's Amchitka staff assisted the University of Washington Laboratory of Radiation Ecology and the U. S. Geological Survey with the collection of marine samples for radiological analysis. Offshore samples collected during the M/V Commander charter cruises included bottom fish, salmon, plankton, and water samples. Nearshore fish and intertidal invertebrates and algae were also collected during several field trips.

SUMMARY OF EFFECTS OF UNDERGROUND
NUCLEAR TESTS, MILROW AND CANNIKIN

Here are summarized the current assessment of the effects of Milrow and Cannikin on the marine ecology of Amchitka. Additional marine studies not included are under study by other groups (Kirkwood and Fuller, 1972; Held, 1971).

Milrow Effects

Early observations and evaluations of the short-term effects of Milrow (October 2, 1969) on the marine environment have been published (Burgner, et al., 1970, 1971, and 1971b, and Burgner and Nakatani, 1972). Other reports have been published with summary comments of total bioenvironmental effects of Milrow (Merritt, 1970; Kirkwood, 1970 and 1971; and Fuller, 1971). Hence, details are not reiterated here, but in brief the most visible effects of Milrow (yield of about 1 megaton) on the marine environment were (1) the vertical displacement, "uplift" of about 12 cm at the south side of an existing fault in the intertidal bench area (designated IA-1) in Duck Cover, (2) fracturing and crumbling of rocks, and (3) accumulation of rock debris and sand in Square Bay.

FRI biologists first noticed the disturbed area at IA-1 in April, 1970, some 6 months after Milrow at which time extensive die-off of growths of some algal species in the immediate vicinity of the fault was evident. A precise statement of the disturbed area cannot be obtained without considerable effort because of the irregular pattern of the disturbed area, but it was estimated a possible maximum area of about 4 ha with the obvious die-off area observed more in the order of 4,000 m² (Lebednik, in press). Changes were limited to the intertidal zone and the sublittoral zone was probably not affected.

Lebednik abstracts the effects at IA-1 as follows:

"Uplifting of a portion of an intertidal rock bench by the Milrow underground nuclear test at Amchitka Island, Alaska, affected algal abundance, species composition, and zonation. Parts of the populations of eight species died off, primarily in the Hedophyllum zone and mostly within the first six months after the disturbance. The center of abundance of these species shifted seaward. A species (Fucus distichus) newly appeared in the area and recolonized a portion of the Hedophyllum zone. The observations indicate that intertidal algal communities at Amchitka Island are very sensitive to positive elevation change."

In addition to detailed analysis of postevent observations and data collected at IA-1, studies in FY 1972 continued a bimonthly survey of 45 intertidal plots (0.25 m² each) by photographic means to record long-term effects. Final evaluation and details on the comparison of photo series between IA-1 and control sites at St. Makarius Bay (T-1) and Square Bay (T-2) are still in progress; however, the observations at the close of FY 1972 may be summarized as follows:

- Slow recovery and recolonization continued in the areas (IA-1) uplifted by Milrow.
- A Fucus zone has become established in an area at IA-1 previously occupied by Hedophyllum.
- The Duck Cove succession site near IA-1 (including several rocks moved by Milrow onto the high intertidal) had patterns of colonization comparable to FY 1971 (Burgner and Nakatani, 1972). Halosaccion glandiforme was well established in April, 1972, and appeared the same as on adjacent "pre-Milrow" rocks in the high intertidal.
- Observations at the Square Bay siltation site in April, 1972, indicated the smothered intertidal area was reduced (approximately 9 m wide and 15 m long) but had the same maximum depth (5 cm) as reported for FY 1971 (Burgner and Nakatani, 1972). More plants of Ulva sp. were observed growing through the sediment as compared to earlier observations. Wave action is removing more material from this bench area than is coming onto the bench from the Square Bay slide area activated by Milrow.

Cannikin Effects

Research efforts specifically oriented to Cannikin (yield of about 5 megatons), November 6, 1971, include the preevent studies begun in July, 1970, and concentrating in the Bering Sea area adjacent to Site C (later Cannikin SZ) were reported in Burgner and Nakatani (1972).

Cannikin effects evaluation reports including summary comments on Cannikin's effects on the marine environment are included in a D+30 Day Report (U.S. AEC, 1972) and a D+2 Months Report (Kirkwood and Fuller, 1972).

The following outline briefly summarizes the presently known or estimated effects of Cannikin on the marine environment:

Marine Fishes

- Comparisons of catch-per-unit of effort for rock sole between preevent and postevent offshore bottom trawls revealed statistically significant reductions after the test.
- A dead black rockfish was captured in one bottom trawl set on D+2 days (November 9, 1971).
- Large schools of fish (thought to be rockfish) were observed around pinnacles in the Bering Sea during echosounding before the test, but not after the test.
- Recoveries of dead nearshore fish (primarily 277 dead rock greenling) in the post-event beach walks provided evidence of a localized kill of some nearshore fishes. Recoveries were not complete, however, because of offshore windstorms, land slides covering benches, predation of dead fish by rats and birds, and the inability to thoroughly examine all windrows of kelp piles on the beaches.

- Nearshore trammel net sets also indicated an initial decline in abundance of rock greenling immediately postevent. Dead fish retrieved were apparently only a small portion of the total killed. Further sampling is planned for August-October, 1972.
- The localized disruption of the bottom (observed by NMFS SCUBA divers) and the relatively small amount of displaced intertidal habitat is not expected to markedly reduce the nearshore fish carrying capacity. Recovery of fish populations by immigration and reproduction is expected.

Marine Invertebrates

- Intertidal invertebrate communities on the Bering Sea coast adjacent to Cannikin SZ were disrupted as a result of maximum vertical displacement of intertidal benches of about 1 m. The biological effect generally varied with the degree of uplift and displacement of the original position of the community on the intertidal benches.
- At study area IA-2, where maximum uplift occurred, upper (back bench) eulittoral communities were completely destroyed, primarily by uplift and to a lesser degree by smothering. Areas closer to the seaward face of the bench (front bench) had remnants of some original invertebrate communities. Former subtidal invertebrate communities displaced into the intertidal zone suffered major damage. Newly exposed rock surfaces had some established algae and invertebrates (littorine snails) present in April, 1972.
- Most of the disruption types observed at IA-2 were also seen at study area IA-3, an area of intermediate uplift, but they were of lesser magnitudes.

Marine Algae

- Surveys of intertidal algae showed die-off. Extent depended primarily on magnitude of uplift and original bench position of the algal community, and, to a lesser degree, on smothering.
- Surveys of the Bering Sea coastline in April, 1972, indicated severe die-off of intertidal algal communities along 1.9 km (estimated at mean high water level) of shoreline, moderate die-off along 1.5 km, and detectable die-off along 2.7 km.
- Limited surveys of the Pacific Ocean coastline did not show algal die-off attributable to Cannikin.
- Final postevent physical survey information (the FRI survey and the USGS Bering Sea and Pacific Ocean coastline survey) along with further data from complementary biological surveys in the summer and fall, 1972, are needed before we can fully evaluate the effects of Cannikin.

Total Impact

The available information limits any attempt to describe precisely the total impact of Milrow and Cannikin. There are uncertainties due to the complexity of estimating

numbers of animals or areas of algae killed, particularly for organisms under the sea's surface. In addition, the total pretest Island populations of various species of fish and invertebrates nearshore and offshore are not known. Total impact of intertidal effects is hindered by the lack of estimates of total Amchitka intertidal area. Studies are continuing in the marine environment because changes are still occurring; and thus, the present statements may be modified by observations in the summer and fall 1972.

Milrow

The impact of Milrow on the marine environment on the intertidal benches and the bay at Duck Cove are thought to be small, because of the small localized area involved. Short-term offshore effects of Milrow (Kirkwood, 1970 and 1971; Burgner, et al., 1971 and 1971b) and longer term nearshore studies (Burgner and Nakatani, 1972) indicate little or no effects on adjacent fish populations. Nearshore fish catches were extremely variable and no effect due to Milrow could be detected. Three fish were observed floating on the surface after test, but no fish were recovered in postevent helicopter overflights. The intertidal fault shift (IA-1), the succession rock study at Duck Cove, and the siltation area in Square Bay all occupy very small areas relative to the total intertidal area of Amchitka Island. Further recovery in all disturbed areas continued.

The total impact of Milrow has been estimated to be minimal because of the direct localized biological disruption and limited nature of the physical disruption. With the biological recovery that is occurring in the intertidal study area and little or no effects observed in the nearshore and offshore areas, no long-term impact of Milrow is expected.

Cannikin

The larger Cannikin test had considerably more marked effects on the marine areas adjacent to Cannikin SZ compared to the few observed effects from Milrow. The total impact of Cannikin was many times greater than Milrow, but the effects were still restricted to localized areas and represented a small part of the total Amchitka marine environment. With the exception of the intertidal bench areas lifted out of the marine intertidal zone, the nature of the disruption to the intertidal, nearshore, and offshore areas is such that biological recovery is expected by recolonization of algae and invertebrates followed by replacement of any localized reduction in fish populations by immigration from unaffected areas. This is expected to proceed to preevent levels for almost all plant and animal species. The small area of intertidal bench uplifted out of the intertidal zone by Cannikin (possibly several kilometers shore-line distance along the Bering Sea coast) is small compared to the Island's total shore-line distance (roughly estimated as 180 to 200 km) and related intertidal bench area. Changes in species composition of flora and fauna are occurring in the intertidal benches formerly located in the subtidal zone which were lifted into the intertidal zone by Cannikin. Areas with algae die-offs are being recolonized by other species of algae and invertebrates better adapted to the new elevation in relation to Amchitka's tidal cycles.

The overall impact of the Cannikin test is therefore known to be greater than the Milrow test, but again in perspective to the total marine ecosystem at Amchitka Island, both Cannikin and Milrow produced localized, restricted disruption of the ecosystem from which, for the most part, it will recover. No marked impact on the Amchitka marine ecosystem occurred or is expected as a result of the Milrow and Cannikin underground nuclear tests.

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FUTURE STUDIES

Future field studies will be primarily involved with evaluation of the long-term effects of Cannikin, especially in the localized intertidal area displaced by the test.

Offshore studies with the chartered M/V Commander are scheduled for a 20-day period beginning in mid-August, 1972. Bottom and midwater trawling and salmon longlining are planned in areas similarly sampled before and after Cannikin for evaluation of long-term effects.

Nearshore sampling will be limited to trammel net fishing in areas sampled before and after Cannikin for evaluation of long-term effects.

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Ole A. Mathisen	Field Coordination
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Robert T. Paine	Intertidal Studies
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Gregory J. Tutmark	Invertebrate Studies

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APPENDIX A

STATISTICS FOR OFFSHORE AND
NEARSHORE FISH SAMPLING

TABLE A-1. LONGLINE SETS AND CATCHES IN THE WATERS OFF AMCHITKA

(See Figure 3 for locations.)

Set	Date	Depth, f	Duration, hr	Sockeye Salmon	Chum Salmon	Silver Salmon	King Salmon
1	8-31	35	1.2				1
2	9-1	50	1.1				
3	9-2	265	1.2		1		
4	9-3	355	1.2				
5	9-4	500	1.2				
6	9-6	385	1.2				
7	9-10	350	1.2			1	1
8	9-11	500	1.2		8		
9	9-24	330	1.0		15		
10	9-25	455	1.2		8		
11	9-30	440	1.0		20		
12	11-15	425	1.3	1			
13	11-20	--	1.3	6			
14	11-21	--	1.3	2			

TABLE A-2. BOTTOM TRAWL SETS AND CATCHES

(See Figure 2 for locations.)

Set	Date	Depth, f	Duration, hr	Pacific Ocean Perch	Flag Rockfish	Pacific Cod	Walleye Pollock	Pacific Halibut	Rock Sole	Arrowtooth Flounder	Rex Sole	Poachers	Sturgeon Poacher	Sculpins	Northern Staghorn	Great Sculpin	Malacocottus	Brown Irish Lord	Triglops	Searchers	Snailfish	Lithoid Crabs
1	9-13	33	0.4			2	8	79	4													
2(a)	9-13	40	0.6					24	162	2	1	5		1								
3	9-13	16	0.6			1	7	48				1										
4(b)	9-13	50	0.3	4		1	1	2							2							
5	9-14	48	0.4	12					13	2		3		12						5		
6(b)	9-14	32	0.1																			
7(a)	9-16	32	0.7					14	77	1		3										
8(d)	9-16	27	1.0	1				51	143			4		1								
9(a)	9-16	28	1.2					2	83													
10(a)	9-17	35	0.7					2	41	1		2		2							1	
11(a)	9-17	48	1.0			8	11	265				8		6								
12	9-18	35	0.9			2		6						19						4		
13	10-4	40	0.3					2	27				5		7							
14	10-4	50	0.5					4	103				6									
15	10-4	40	0.5					5	97							1						
16(c)	10-6	100	0.8	10		10	64	1						20								6
17(c)	10-6	100	0.8	3		12	27		4	3				25						1		
18	10-7	100	1.0	3		37	17		18	8			1			1	46	55	24	15	43	
19	10-7	93	1.0	79	1	81	22		8	1							19	2	1		2	
20	10-11	50	0.6			4		22	151			16		1								
21(a)	10-11	50	0.9			21			55			2		1								
22(a)	10-11	46	1.0			6		9	91	1		3		15						1		
23	10-12	64	0.3	3		10	4							4						1		
24(c)	10-17	100	1.0	9		110	371	1	33	15				107						1		5
25(c)	10-17	100	1.0	2		277	4		13			3		45								
26(b)	11-7	25	0.1																			
27(b)	11-7	22	0.1			1																
28(d)	11-7	20	0.8												1							
29(d)	11-7	25	0.9					4														
30	11-7	40	0.2						1	1		3										
31(d)	11-7	40	0.7			3		42	45		2	7		1						4		
32(d)	11-7	30	0.8			36		48	12					8								
33(d)	11-9	22	0.7		1 (dead black rockfish)	1		11	6					23								
34(d)	11-9	25	0.8					4	2					3								
35(d)	11-9	38	0.7			14		17	75					2								
36(d)	11-9	35	0.6			1		10	12			1		29								
37(d)	11-11	27	0.3																			
38(d)	11-11	35	0.3					1	7			1		1								
39(d)	11-11	40	0.3					5	7	1		2		1								
40(c)	11-18	100	1.0			46		1	10	2				41								2
41(c)	11-18	92	1.0			81			11	4				33						3		12
42(d)	11-21	24	1.0					4						1								
43(d)	11-21	30	1.0	1				65	20	2												1
44(d)	11-21	35	0.4					27	7					2								

(a) Preevent samples.

(b) Not an effective haul.

(c) Pacific side of Island.

(d) Postevent samples.

TABLE A-3. CATCH AND EFFORT STATISTICS BY FISH SPECIES AND GROUPS AND BY GEAR TYPE FOR NEARSHORE FISH SAMPLING IN THE WATERS OFF AMCHITKA, MAY 1, 1971, THROUGH MAY 30, 1972

Set	Date	Location	Depth, m	Greenling	Sculpins	Pacific Cod	Walleye Pollock	Atka Mackerel	Ronquils	Rockfish	Rock Sole	Pacific Halibut	Dolly Varden	Liparids/Lumpsuckers	Salmon	Pacific Sandfish	Pricklebacks/Gunnels	Poacher	Unknown/Larvae/Other	Total Fish	Sampling Time, hr:min	Catch Per Unit of Effort, fish/hr	Remarks
Bottom Gillnet																							
71BG 1	5/13/71	IA-2	11	40	1	1	1													43	23:45	1.81	1 auklet in net
71BG 2	5/14/71	Sand Beach Cove	5		8											1				9	23:10	0.39	
71BG 3	5/15/71	IA-2/IA-3	11	13	3															16	24:45	0.65	
71BG 4	7/9/71	Constantine Harbor	18	21														2		23	8:05	2.84	Tagged 19 greenling
71BG 5	7/16/71	Constantine Harbor	18	22														6		28	6:35	4.25	Tagged 19 greenling
71BG 6	7/23/71	Sand Beach Cove	18	51	4	7	69	16												147	19:01	7.74	
71BG 7	8/26/71	IA-2/IA-3	22		5	5	12				1	1								24	21:25	1.12	1 cod skeleton
71BG 8	8/28/71	IA/2	37						1	4										5	19:55	0.25	
Subtotal				147	21	13	69	29	1	4	1	1			1		8			295			
Surface Gillnet																							
71SG 1	5/13/71	IA-2	9													2				2	23:10	0.09	
71SG 2	5/14/71	Sand Beach Cove	4													1				1	22:50	0.04	
71SG 3	5/15/71	Constantine Harbor	4	32	4							1								37	20:30	1.80	
71SG 4	7/23/71	Sand Beach Cove	18																	0	18:45	0.00	Attached to 71BG 6
71SG 5	8/9/71	Sand Beach Cove	20					1												1	18:20	0.05	Attached to 71TR 2
71SG 6	8/11/71	IA-2	27																	0	24:30	0.00	Attached to 71TR 3
71SG 7	8/12/71	Sand Beach Cove	11					3								3				6	17:20	0.35	Attached to 71TR 4
71SG 8	8/17/71	Sand Beach Cove	35																	0	16:25	0.00	Attached to 71TR 5
71SG 9	8/23/71	Sand Beach Cove	13													3			1	4	25:05	0.16	Other is <u>Ammodytes hexapter</u> Attached to 71TR 6
71SG 10	8/26/71	Sand Beach Cove	18					3								1				4	19:05	0.21	Attached to 71TR 7
71SG 11	8/28/71	IA-2	37					16												16	19:35	0.81	Attached to 71BG 8
71SG 12	9/6/71	Constantine Harbor	1									2								2	1:00	2.00	
71SG 13	9/10/71	Constantine Harbor	1									8								8	3:00	2.29	
71SG 14	10/1/71	Constantine Harbor	27																	0	2:52	0.00	
71SG 15	10/1/71	Constantine Harbor	27																	0	2:35	0.00	"S" in end of net, Attached to 71SG 14
Subtotal				32	4			23				11			10			1		81			

TABLE A-3. (Continued)

Set	Date	Location	Depth, m	Greenling	Sculpin	Pacific Cod	Walleye Pollock	Atka Mackerel	Ronquils	Rockfish	Rock Sole	Pacific Halibut	Dolly Varden	Liparids/Lumpsuckers	Salmon	Pacific Sandfish	Pricklebacks/Gunnels	Poacher	Unknown/Larvae/Other	Total Fish	Sampling Time, hr min	Catch Per Unit of Effort, fish/hr	Remarks
Trammel Net																							
71TR 1	7/23/71	Constantine Harbor	14	23	13	5					3	1						6		51	16:53	3.02	
71TR 2	8/9/71	Sand Beach Cove	22	10	7	11														28	19:10	1.46	
71TR 3	8/11/71	IA-2	27	8	3	5		6				1								24	24:30	0.98	
71TR 4	8/12/71	Sand Beach Cove	13			3					1	3								7	17:35	0.40	
71TR 5	8/17/71	Sand Beach Cove	34		3			3												6	16:40	0.36	
71TR 6	8/23/71	Sand Beach Cove	13	6	2	1					7	8								24	25:10	0.95	1 halibut skeleton
71TR 7	8/26/71	Sand Beach Cove	18	10	3	11		3		2										29	77:25	0.37	2 greenling, 7 cod skeletons
71TR 8	8/28/71	IA-3	18	39	7				1			1		2						50	21:15	2.35	
71TR 9	9/2/71	Constantine Harbor	21	10	1					1										12	3:10	3.80	
71TR 10	9/2/71	Constantine Harbor	26	1	6						1							1		9	2:35	3.49	
71TR 11	9/3/71	Constantine Harbor	8			4						4								8	17:35	0.46	
71TR 12	9/3/71	Constantine Harbor	8	1								2								3	5:15	0.52	
71TR 13	9/5/71	Constantine Harbor	16	42	3			1												46	4:20	1.06	
71TR 14	9/5/71	Constantine Harbor	9	44		1					3		1							49	3:15	15.08	
71TR 15	9/5/71	Constantine Harbor	4										1							1	2:25	0.41	
71TR 16	9/6/71	Constantine Harbor	15	26	2	7					1									36	5:00	7.20	
71TR 17	9/8/71	Constantine Harbor	16	6	1						2									9	4:35	0.20	
71TR 18	9/8/71	Constantine Harbor	27	3	1						3	1								8	4:50	1.66	
71TR 19	9/12/71	Constantine Harbor	16	12																12			Net moved
71TR 20	9/13/71	Constantine Harbor	22	20	2															22	2:15	9.78	
71TR 21	10/1/71	Constantine Harbor	18	47					1	5										53	3:15	16.31	
71TR 22	10/1/71	Silver Salmon	7	55									2							57	1:35	36.08	
71TR 23	10/2/71	Constantine Harbor	15	87	2															89	3:05	28.90	
71TR 24	10/2/71	Constantine Harbor	15	58						1										59	2:30	23.60	
71TR 25	10/3/71	Constantine Harbor	13	24		1														25	3:40	6.83	
71TR 26	10/3/71	Constantine Harbor	13	14	5															19	3:45	5.07	
71TR 27	10/21/71	IA-2	12	18																18	2:00	9.00	
71TR 28	10/21/71	IA-2/IA-3	9	24																24	2:15	10.67	
71TR 29	11/4/71	Constantine Harbor	22	59																59	4:45	12.42	
71TR 30	11/11/71	IA-2/IA-3	11	11																11	3:20	3.30	
71TR 31	11/11/71	Sand Beach Cove	9																	0	3:20	0.00	
71TR 32	11/15/71	IA-2	8	20																20	5:00	4.00	

TABLE A-3. (Continued)

Set	Date	Location	Depth, m	Greenling	Sculpins	Pacific Cod	Walleye Pollock	Atka Mackerel	Ronquils	Rockfish	Rock Sole	Pacific Halibut	Dolly Varden	Liparids/Lumpsuckers	Salmon	Pacific Sandfish	Pricklebacks/Gunnels	Poacher	Unknown/Larvae/Other	Total Fish	Sampling Time, hr min	Catch Per Unit of Effort, fish/hr	Remarks
Trammel Net (cont)																							
71TR 33	11/15/71	Sand Beach Cove	16	1								4								5	5:20	0.94	
71TR 34	11/21/71	IA-3	13	16																16	2:15	7.11	
71TR 35	11/21/71	IA-2	9	18																18	2:10	8.33	
71TR 36	11/21/71	Sand Beach Cove	10	1		1														2	2:00	1.00	
71TR 37	4/19/72	IA-2	9	16																16	2:10	7.41	
71TR 38	4/19/72	IA-2	9	13																13	2:25	5.39	
71TR 39	4/19/72	Sand Beach Cove	11																	0	2:30	0.00	
71TR 40	4/25/72	Sand Beach Cove	15	1						1				1						3	3:50	0.78	
71TR 41	4/25/72	Sand Beach Cove	16	1																1	3:38	0.28	
Subtotal				745	61	50		13	3	8	23	25	4	3				7		942			
Plankton Net																							
71PN 1	5/12/71	IA-2/IA-3	2																	0	0:10	0.00	
71PN 2	5/12/71	IA-3	2																	0	0:10	0.00	
71PN 3	7/8/71	Kirilof Pt.	6																	0	0:10	0.00	
71PN 4	7/8/71	Bat Island	6																16	16	0:10	95.81	
71PN 5	7/9/71	Kirilof Rocks	6											1						1	0:10	5.99	
71PN 6	7/9/71	Kirilof Pt.	6																	0	0:10	0.00	
71PN 7	7/9/71	Kirilof Pt.	6																1	1	0:10	5.99	
71PN 8	7/16/71	Constantine Harbor	1																	0	0:10	0.00	
71PN 9	7/16/71	Constantine Harbor	2																	0	0:10	0.00	
71PN 10	7/16/71	Constantine Harbor	3																	0	0:10	0.00	Kelp haul
71PN 11	7/16/71	Constantine Harbor	3		1															1	0:10	5.99	Kelp haul
71PN 12	8/23/71	Crown Reefer Pt.	2																	0	0:05	0.00	
71PN 13	8/23/71	Crown Reefer Pt.	2																1	1	0:05	12.05	
71PN 14	8/28/71	Crown Reefer Pt.	2		2									2						4	0:05		Kelp haul
71PN 15	8/28/71	Sand Beach Cove	2		1															1	0:05	12.05	Kelp haul
71PN 16	8/28/71	IA-3	2																	0	0:05	0.00	Kelp haul
Subtotal					4									3					18	25			
Bottom Longline																							
71BL 1	8/16/71	Sand Beach Cove	18																	0		0.00	Lost-line chafed 100 hooks
71BL 2	8/23/71	Sand Beach Cove	18		1							3								4	25:00	0.16	Some hooks off bottom -100 hooks

TABLE A-3. (Continued)

Set	Date	Location	Depth, m	Greenling	Sculpin	Pacific Cod	Walleye Pollock	Atka Mackerel	Ronquils	Rockfish	Rock Sole	Pacific Halibut	Dolly Varden	Liparids/Lumpsuckers	Salmon	Pacific Sandfish	Pricklebacks/Gunnel	Poacher	Unknown/Larvae/Other	Total Fish	Sampling Time, hr min	Catch Per Unit of Effort, fish/hr	Remarks
Bottom Longline (cont)																							
71BL 3	8/26/71	Sand Beach Cove	15									1								1	67 24	0.15	Some hooks off bottom
71BL 4	8/28/71	Sand Beach Cove	18		2	3						5								10	20 15	0.49	- 30 hooks
71BL 5	9/9/71	Constantine Harbor	29		4	15				3	3									25	27 40	0.90	- 100 hooks
71BL 6	9/10/71	Constantine Harbor	18			1					7									8	24 00	0.33	- 150 hooks
71BL 7	10/9/71	Constantine Harbor	22		9	1														10	24 30	0.41	- 95 hooks
71BL 8	10/28/71	Constantine Harbor	33		32						1									33	4 20	7.62	- 150 hooks
71BL 9	10/29/71	Constantine Harbor	22	2	1						2									5	18 00	0.28	- 150 hooks
71BL 10	10/30/71	Constantine Harbor	27		35	2					3									40	2 00	20.00	- 150 hooks
71BL 11	10/31/71	Constantine Harbor	27	20	20	3					1									44	1 45	25.14	- 150 hooks
71BL 12	10/31/71	Constantine Harbor	29	2	15	1		2												20	5 50	3.43	Lost 1.5 skates - 75 hooks
71BL 13	11/1/71	Constantine Harbor	33	48	66			8		1	1									124	5 00	24.00	- 150 hooks
Subtotal				72	185	26			10	4	27									324			
Hand Collections																							
71H 1	6/24/71	Square Bay	1-	1																1			
71H 2	6/25/71	St. Makarius Bay	1-																1	1			Other is <u>A. hexapterus</u>
71H 3	7/6/71	Duck Cove	1-	1																1			
71H 4	7/17/71	Duck Cove	5		2									1						3			SCUBA collected
71H 5	7/20/71	Banjo Pt.	1-		2															2			
71H 6	9/11/71	Kirilof Pt.	3		3															3			SCUBA collected
71H 7	11/7/71	IA-2	0	44																44			Cannikin kill
71H 8	11/7/71	IA-2	0	34																34			Cannikin kill
71H 9	11/7/71	Sand Beach Cove	0																1	1			Other is <u>A. ferox</u> Cannikin kill
71H 10	11/7/71	IA-2/IA-3	0	17																17			Cannikin kill
71H 11	11/7/71	Banjo Pt.	0	96																96			Cannikin kill
71H 12	11/7/71	Sand Beach Cove	0	1												1				2			
71H 13	4/28/71	St. Makarius Bay	1-										1							1			
Subtotal				194	7								2		1				2	206			

TABLE A-3 (Continued)

Set	Date	Location	Depth, m	Greenling	Sculpins	Pacific Cod	Walleye Pollock	Atka Mackerel	Ronquils	Rockfish	Rock Sole	Pacific Halibut	Dolly Varden	Liparids/Lumpsuckers	Salmon	Pacific Sandfish	Pricklebacks/Gunnels	Poacher	Unknown/Larvae/Other	Total Fish	Sampling Time, hr-min	Catch Per Unit of Effort, fish/hr	Remarks
Rotenone Applications																							
71R 1	7/7/71	Clam Pt	1-	1	171											13	4	188	1 35	118.98			
71R 2	7/17/71	Clam Pt	1-		80											1		82	1 00	82.00			
71R 3	7/17/71	Clam Pt	1-		145								14			4		163	1 38	103.16			
Subtotal					1	396							14			18	4	433					
Hook and Line Collections																							
71HL 1	5/11/71	St Makarius Bay	1-	3									1					4	1 00	0.25			
71HL 2	11/4/71	Constantine Harbor	18	79	4													83	3 00	27.67			
Subtotal					82	4							1					87					
Shrimp Trap Sets																							
71ST 1	9/3/71	Constantine Harbor	21		1													1	23 30	0.04			
71ST 2	9/5/71	Constantine Harbor	21		5													5	52 05	0.10			
71ST 3	9/6/71	Constantine Harbor	22		2													2	25 55	0.08			
71ST 4	9/8/71	Constantine Harbor	22															0	41 35	0.00			
71ST 5	9/9/71	Constantine Harbor	15															0	24 55	0.00			
71ST 6	9/12/71	Constantine Harbor	26		1													1	72 15	0.01			
71ST 7	10/9/71	Constantine Harbor	26	3	2													5	604 30	0.01	3 juv king crabs		
Subtotal					3	11												14					
Total					1276	693	89	69	65	14	12	28	53	16	22		12	18	15	25	2407		

TABLE A-4. STOMACH-CONTENT ANALYSIS AND BIOLOGICAL DATA FOR 23 FISH SPECIES CAPTURED OFF AMCHITKA
APRIL, 1971 THROUGH MAY, 1972

Species	Sample Size ^(a) , n	Length $\bar{x}$, mm	Weight $\bar{x}$, g	Stomach Condition Factor ^(b) $\bar{x}$	Stomach Digestion Factor ^(c) $\bar{x}$	Weight of Contents $\bar{x}$, g	Percent Composition by Weight (g) Including (Top) and Excluding (Underlined) Unidentified Organisms and Percentage Occurrence (In Parentheses)									Volume $\bar{x}$, ml
							Unidenti- fied	Amphi- pods	Fish	Mysids	Deca- pods	Mollusks	Cope- pods	Miscel- laneous		
Nearshore																
Rock greenling	180 ²	285	348	5.17	3.15	7.49	49.92 (97.80)	8.61 <u>17.20</u> (75.82)	4.15 <u>8.29</u> (20.88)	5.42 <u>10.83</u> (29.67)	0.92 <u>1.84</u> (6.04)	2.91 <u>5.81</u> (48.35)	0.19 <u>0.38</u> (4.95)	27.95 <u>55.80</u> (84.07)		7.29
Atka mackerel	30 ⁴	244	169	4.67	2.97	2.81	33.94 (78.79)	1.08 <u>1.63</u> (24.24)	0.32 <u>0.49</u> (3.03)	43.53 <u>65.91</u> (45.45)	0.43 <u>0.65</u> (9.09)	4.85 <u>7.34</u> (6.06)	15.73 <u>23.82</u> (45.45)	0.11 <u>0.16</u> (3.03)		2.70
Red Irish Lord	25	221	216	4.14	3.14	6.47	34.74 (86.21)	35.64 <u>54.61</u> (72.41)	2.82 <u>4.33</u> (17.24)	0.75 <u>1.14</u> (10.34)	2.45 <u>3.76</u> (13.79)	2.02 <u>3.10</u> (10.34)	00 <u>00</u> (00)	21.58 <u>33.06</u> (51.72)		6.31
Great sculpin	1 ¹	135	373	1.33	1.00	8.33	7.60 (100)	0.40 <u>0.43</u> (100)	92.00 <u>99.57</u> (100)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)		8.33
Armorhead sculpin	21	242	158	5.71	3.71	4.75	26.88 (95.24)	32.00 <u>43.76</u> (71.43)	7.12 <u>9.74</u> (33.33)	6.92 <u>9.47</u> (28.57)	00 <u>00</u> (00)	10.93 <u>14.95</u> (19.05)	00 <u>00</u> (00)	16.15 <u>22.09</u> (66.67)		4.38
Calico sculpin	3	46	1	5.67	3.00	1.33	00 (00)	25.00 <u>25.00</u> (33.33)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	75.00 <u>75.00</u> (100)	00 <u>00</u> (00)		1.33
Sharpnose sculpin	2	42	1	6.00	5.00	0.02	00 (00)	100.00 <u>100.00</u> (100)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)		0.10
High cockscomb	2	80	3	6.00	3.50	0.05	0.90 (100)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	60.00 <u>100.00</u> (100)		0.05
Crescent gunnel	5	139	14	5.40	4.20	0.51	20.78 (80)	64.31 <u>81.19</u> (100)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	2.75 <u>3.47</u> (40)	00 <u>00</u> (00)	9.02 <u>11.39</u> (100)		0.5
Searcher	2	170	72	4.00	3.50	0.30	66.67 (50)	33.33 <u>100.00</u> (100)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)		0.55
Spotted snailfish	8	65	5	6.50	4.88	0.29	7.86 (12.50)	90.83 <u>98.58</u> (100)	00 <u>00</u> (00)	00 <u>00</u> (00)	00 <u>00</u> (00)	0.44 <u>0.47</u> (12.50)	00 <u>00</u> (00)	0.87 <u>0.95</u> (12.50)		0.19

TABLE A-4. (Continued)

Species	Sample Size ^(a) , n	Length $\bar{x}$, mm	Weight $\bar{x}$, g	Stomach Condition Factor ^(b) $\bar{x}$	Stomach Digestion Factor ^(c) $\bar{x}$	Weight of Contents $\bar{x}$, g	Percent Composition by Weight (g) Including (Top) and Excluding (Underlined) Unidentified Organisms and Percentage Occurrence (In Parentheses)									Volume $\bar{x}$, ml
							Unidenti- fied	Amphi- pods	Fish	Mysids	Deca- pods	Mollusks	Cope- pods	Miscel- laneous		
Nearshore (Cont)																
Lobefin snailfish	2	298	366	6.00	3.50	8.95	63.13	31.84	0.58	00	1.12	0.58	00	3.91	9.00	
							(100)	86.36	1.52	00	3.03	1.52	00	10.61		
Smooth lumpsucker	1	345	1485	1.00	1.00	0	00	00	00	00	00	00	00	00	00	
							(00)	00	00	00	00	00	00	00		
Pacific cod	33 ¹	413	1186	4.03	3.38	18.95	37.79	3.43	40.82	5.42	7.39	0.68	00	4.05	17.29	
							(97.06)	5.51	65.62	8.71	11.88	1.10	00	6.51		
Pacific halibut	13 ⁵	314	20941	3.11	2.44	34.44	33.18	0.16	40.64	00	00	25.96	00	0.06	8.83	
							(66.67)	0.24	60.82	00	00	38.85	00	0.10		
Dusky rockfish	2 ²	132	299	1.25	1.25	0.67	48.15	51.85	00	00	00	00	00	00	0.77	
							(50)	100.00	00	00	00	00	00	00		
Dolly Varden	2	393	571	5.00	4.00	11.95	15.90	6.69	54.39	2.09	00	00	20.92	00	21.00	
							(100)	7.96	64.68	2.49	00	00	24.88	00		
Pink salmon	1	568	1485	6.00	4.00	7.20	54.17	23.61	2.78	11.11	4.17	00	00	4.17	7.00	
							(100)	51.52	6.06	24.24	9.09	00	00	9.09		
Pacific sand lance	1 ¹	114	22	3.50	1.50	0.65	23.08	7.69	00	00	00	00	69.23	00	0.50	
							(100)	10.00	00	00	00	00	90.00	00		
Rock sole	9 ²	216	221	4.55	3.00	3.35	20.87	10.30	00	0.27	00	00	00	68.56	3.27	
							(72.73)	13.01	00	0.34	00	00	00	86.64		
Pacific sandfish	2 ¹	94	28	3.33	1.67	0.50	66.67	13.33	20.00	00	00	00	00	00	0.50	
							(66.67)	40.00	60.00	00	00	00	00	00		
Sturgeon poacher	13	256	79	4.85	3.54	0.58	47.33	32.67	2.00	1.33	10.67	00	00	6.00	0.68	
							(84.62)	62.03	3.80	2.53	20.25	00	00	11.39		
								(100)	(15.38)	(7.69)	(38.46)	(00)	(00)	(38.46)		

TABLE A-4. (Continued)

Species	Sample Size ^(a) n	Length $\bar{x}$, mm	Weight $\bar{x}$, g	Stomach Condition Factor ^(b) $\bar{x}$	Stomach Digestion Factor ^(c) $\bar{x}$	Weight of Contents $\bar{x}$, g	Percent Composition by Weight (g) Including (Top) and Excluding (Underlined) Unidentified Organisms and Percentage Occurrence (In Parentheses)								Volume $\bar{x}$, ml
							Unidenti- fied	Amphi- pods	Fish	Mysids	Deca- pods	Mollusks	Cope- pods	Miscel- laneous	
Nearshore (Cont)															
Walleye pollock	44 ⁵	190	55	5.86	3.80	1.18	22.59	7.34	9.85	57.92	00	00	2.32	00	1.25
								9.48	12.72	74.81	00	00	2.99	00	
							(77.27)	(31.82)	(18.18)	(88.64)	(00)	(00)	(13.64)	(00)	
Kelp greenling	2	390	711	6.00	3.50	15.30	52.94	0.65	28.10	00	6.86	5.56	00	5.88	15.00
								1.39	59.72	00	14.58	11.81	00	12.50	
							(100)	(100)	(50)	(00)	(100)	(100)	(00)	(100)	
Northern rockfish	1	131	31	1.00	1.00	0	00	00	00	00	00	00	00	00	0
							00	00	00	00	00	00	00	00	
							(00)	(00)	(00)	(00)	(00)	(00)	(00)	(00)	
Offshore															
Chum salmon	9 ¹⁸	151	552	0.70	0.41	1.10	97.65	0.34	1.34	00	00	00	0.67	00	1.12
								14.29	57.14	00	00	00	28.57	00	
							(25.93)	(3.70)	(3.70)	(00)	(00)	(00)	(3.70)	(00)	
Sockeye salmon	5 ¹	385	942	1.83	2.00	1.62	48.45	5.15	45.36	00	00	00	00	1.03	1.50
								10.00	88.00	00	00	00	00	2.00	
							(83.33)	(66.67)	(16.67)	(00)	(00)	(00)	(00)	(16.67)	
Pacific halibut	28 ⁴	346	616	3.63	3.00	13.21	28.58	0.14	42.84	00	25.95	1.18	00	1.30	11.79
								0.20	59.99	00	36.34	1.66	00	1.82	
							(81.25)	(6.25)	(71.88)	(00)	(40.63)	(3.13)	(00)	(25)	
Great sculpin	1	452	1510	6.00	4.00	63.00	20.63	00	00	00	79.37	00	00	00	63.00
								00	00	00	100.00	00	00	00	
							(100)	(00)	(00)	(00)	(100)	(00)	(00)	(00)	
Red Irish Lord	6	342	544	5.17	3.50	14.33	29.77	6.28	00	00	50.58	00	00	13.37	14.17
								8.94	00	00	72.02	00	00	19.04	
							(100)	(50)	(00)	(00)	(83.33)	(00)	(00)	(50)	
<u>Malococottus</u> <u>zonorus</u>	11	254	390	4.91	2.64	7.12	71.65	0.89	0.77	00	4.47	0.89	00	21.33	7.00
								3.15	2.70	00	15.77	3.15	00	75.23	
							(100)	(54.55)	(9.09)	(00)	(36.36)	(27.27)	(00)	(72.73)	
Pacific cod	4	650	1463	3.75	4.00	68.00	5.59	0.40	80.74	00	10.15	0.11	00	3.01	33.50
								0.43	85.51	00	10.75	0.12	00	3.19	
							(100)	(25)	(75)	(00)	(100)	(25)	(00)	(75)	
Walleye pollock	22	497	833	5.23	4.09	8.54	15.75	1.86	7.03	00	73.18	2.24	00	0.16	8.36
								2.21	8.34	00	86.86	2.65	00	0.19	
							(72.73)	(31.82)	(31.82)	(00)	(95.45)	(13.64)	(00)	(4.55)	

TABLE A-4. (Continued)

Species	Sample Size ^(a) n	Length $\bar{x}$, mm	Weight $\bar{x}$, g	Stomach Condition Factor(b) $\bar{x}$	Stomach Digestion Factor(c) $\bar{x}$	Weight of Contents $\bar{x}$, g	Percent Composition by Weight (g) Including (Top) and Excluding (Underlined) Unidentified Organisms and Percentage Occurrence (In Parentheses)									Volume $\bar{x}$, ml
							Unidenti- fied	Amphi- pods	Fish	Mysids	Deca- pods	Mollusks	Cope- pods	Miscel- laneous		
Offshore (Cont)																
Arrowtooth flounder	2 ¹	286	413	1.33	3.33	0.57	00	00	00	00	00	00	00	100.00	0.70	
							00	00	00	00	00	00	00	100.00		
							(00)	(00)	(00)	(00)	(00)	(00)	(00)	(66.67)		
Rock sole	4	368	593	5.00	4.00	7.52	31.89	00	00	00	00	00	00	68.11	7.50	
							00	00	00	00	00	00	00	100.00		
							(100)	(00)	(00)	(00)	(00)	(00)	(00)	(100)		
Searcher	1	260	165	6.00	4.00	1.3	30.77	00	61.54	00	00	00	00	7.69	1.30	
							00	88.89	00	00	00	00	00	11.11		
							(100)	(00)	(100)	(00)	(00)	(00)	(00)	(100)		
Roughscale rattail	4	899	2811	4.00	3.00	28.10	68.42	0.09	14.41	1.33	0.18	5.16	00	10.41	27.75	
							0.28	45.63	4.23	0.56	16.34	00	32.96			
							(100)	(25)	(100)	(50)	(25)	(25)	(00)	(100)		

(a) Superscript numbers in the Sample-size column indicate the number of fish with empty stomachs.

(b) Index of stomach fullness 1 = 0 percent, 2 = trace, 3 = 25 percent, 4 = 50 percent, 5 = 75 percent, 6 = 100 percent - full, and 7 = distended.

(c) Index of contents digestion 1 = all contents unidentifiable, 2 = same as 1 but includes traces of various organisms, 3 = less than 1/2 of contents identifiable, 4 = more than 1/2 of contents identifiable, and 5 = 0 contents digested.

TABLE A-5. ANALYSIS OF VARIANCE TABLES FOR OFFSHORE FISH STATISTICS

Source of Variation	Sums of Squares	d. f.	Mean Square	F	
(1) Compare salmon catches in FY 72 with catches from FY 70 and 71. $H_0: \mu_1 = \mu_2$					
Between groups	1.6179	1	1.6179	9.0627	(0.01)
Within groups	5.1772	29	.1785		
Total	6.7951	30			
(2) Is there a relationship between rock sole catch and depths (postevent). $H_0: \beta = 0$					
Regression	3.6282	1	3.6282	16.42	(0.01)
Residual	2.8720	13	0.2209		
Total	6.5002	14			
(3) Is there a relationship between total catch (all fish) and depth (postevent). $H_0: \beta = 0$					
Regression	2.8491	1	2.8491	8.826	(0.05)
Residual	4.1967	13	0.3228		
Total	7.0458	14			
(4) Is there a relationship between total catch (all fish except rock sole) and depth (postevent). $H_0: \beta = 0$					
Regression	1.7725	1	1.7725	5.969	(0.05)
Residual	3.8604	13	0.2970		
Total	5.6329	14			
(5) Is there a relationship between rock sole catch and depth (preevent). $H_0: \beta = 0$					
Regression	0.0747	1	0.0747	0.4536	n. s.
Residual	2.3064	14	0.1647		
Total	2.3811	15			
(6) Is there a relationship between total catch (all fish) and depth (preevent). $H_0: \beta = 0$					
Regression	0.1316	1	0.1316	1.842	n. s.
Residual	1.0005	14	0.0715		
Total	1.1321	15			

(7) Is there a relationship between rock sole catch (preevent and postevent) and date (date - no. of days after September 12). $H_0: \beta = 0$. Used stepwise regression. Depth was entered in first step, date in second, so an F ratio for date alone can be calculated by

$$F = \frac{RSS_2 - RSS_1}{ReSS_2}$$

(RSS_n = regression sums of squares for the n^{th} step, $ReSS_n$ = residual sums of squares for the n^{th} step).

Preevent

$$F = \frac{.08375 - .07473}{2.2974} = .004$$

Postevent

$$F = \frac{3.6329 - 3.6282}{2.8674} = .002$$

FIGURE A-1. PRE- AND POSTEVENT CATCHES AND EXPECTED POSTEVENT CATCHES OF ROCK SOLE WITH DEPTH

Estimates of pre- (∇) and postevent (△) catches at 70.5-m depth are shown.

FIGURE A-2. PRE- AND POSTEVENT TOTAL TRAWL CATCHES AND EXPECTED TOTAL TRAWL CATCHES WITH DEPTH

Estimates to pre- (∇) and postevent (△) catches at 70.5-m depth are shown.

APPENDIX B

PLANNED CANNIKIN LIVE-BOX EXPERIMENTS

APPENDIX B

PLANNED CANNIKIN LIVE-BOX EXPERIMENTS

Prediction of over- and underpressure regimes in the marine waters adjacent to Cannikin SZ, and research into the lethal-pressure thresholds of fishes suggested that fish mortalities would result from the Cannikin test (Burgner and Nakatani, 1972). To estimate the effect of Cannikin on the marine fish in the Bering Sea adjacent to the test site it was deemed important to (1) determine the species of fish injured by the shock wave, (2) determine the relationship of distance from the test site and water depth to the occurrence or extent of injury to fish, (3) verify the mechanism of the injury by autopsy, and (4) obtain measurement of the over- and underpressures which the fish experienced.

Simple observation of dead fish floating at the water's surface is neither a reliable nor a sufficient indicator of these factors. Thus, in addition to the aerial and vessel-based observations, in vivo experiments were designed to hold representative fishes in live boxes positioned at known distances and depths in the Bering Sea waters adjacent to the test site during the test. Figure B-1 illustrates the planned locations of five live-box "strings" proposed to be set the night before the test day (D-1) and retrieved immediately upon the charter vessel's return to the area soon after the test.

Figure B-2 indicates the general design of a live-box string, in this case the Station 2 string. Table B-1 outlines statistics about the planned live-box string locations, the predicted over- and underpressures at each, and the experimental animals intended for each live-box.

TABLE B-1. PLANNED LIVE-BOX STRING LOCATIONS, DEPTH, PREDICTED PRESSURES AND ANIMALS INTENDED FOR EACH LIVE BOX

Station	Live-Box Location	Depth, f	Predicted Bottom Overpressure, psi	Predicted Bottom Underpressure, psi	Proposed Experimental Animals		
					Species	Maximum Number	Total
1	Bottom	10	+200	-25 to -50	Rock greenling	5	10
					Red Irish lord	5	
					Armorhead sculpin	5	
					Pacific cod	5	
	Surface	1			Dolly Varden	5	5
2	Bottom	20	+300	-50 to -75	Rock greenling	5	30
					Armorhead sculpin	5	
					Pacific cod	5	
					Pacific halibut	5	
					Rock sole	5	
					Dusky rockfish	5	
	Midwater	10			Dolly Varden	5	5
3	Surface	1			Dolly Varden	5	5
	Bottom	40	+200	-100 to -125	Pacific cod	5	20
					Pacific halibut	5	
					Rock sole	5	
					Red Irish lord	5	
4	Surface	1			Dolly Varden	5	5
	Bottom	60	-50	-150 to -200	Pacific cod	5	20
					Pacific halibut	5	
					Rock sole	5	
					Red Irish lord	5	
5	Bottom	80	-50	-150 to -200	Pacific cod	5	10
					Dusky rockfish	5	
					Lithodid crabs	10	
	Surface	1			Dolly Varden	5	5

FIGURE B-1. LIVE-BOX STRING LOCATIONS PLANNED
(Grid is a 1,000-m UTM grid.)

FIGURE B-2. LIVE-BOX STRING DESIGN
[Example is three live-box string for 2
(Figure B-1) in 20 f of water.]

By D-1, some 125 fish and 25 lithodid crabs had been captured, tagged, and were being held alive in the circulating-seawater holding tanks at the dock area.

A control experiment was performed on November 4 in Constantine Harbor to determine whether or not the experimental fishes would suffer significant physiological stress other than test effects during the live-box operation. The 10-f live-box string, containing five rock greenling and five Dolly Varden in the surface live-box and one Pacific cod, one Pacific halibut, and five rock greenling in the bottom live-box, was lowered to the bottom and the fish observed by SCUBA divers for signs of any abnormal behavior or damage. The rock greenling and Pacific cod appeared normal. All but two of the Dolly Varden were also observed to be normal; the two in question persistently lay on their sides in the live-box. However, all fish, upon transfer back into the holding tanks, were doing well after 48 hours had elapsed.

Inclement weather throughout the day and night (November 5) preceding the test created sea conditions extremely unsuitable for continuing the live-box experiments as planned. For safety reasons, they were abandoned. Further details of the testtime operations on Amchitka are reported elsewhere (Kirkwood and Fuller, 1972).

APPENDIX C

PHYSICAL OCEANOGRAPHY DATA

TABLE C-1. AMCHITKA WIND DATA^(a), OCTOBER 21, 22, AND 24, 1971

Hour	October 21		October 22		October 24	
	Direction ^(b)	Velocity ^(c)	Direction ^(b)	Velocity ^(c)	Direction ^(b)	Velocity ^(c)
1000	210	05	350	13	215	09
1100	215	05	010	12	205	10
1200	255	05	005	14	230	14
1300	295	06	005	14	215	13
1400	350	14	360	12	215	18
1500	005	13	355	21	215	18
1600	005	20	360	19	195	21
1700	010	20	360	24	185	24

(a) Source: Air Resources Laboratory, ESSA/NOAA, Las Vegas, Nevada (Armstrong, personal comm.).

(b) Direction true.

(c) Velocity in knots/hour.

TABLE C-2. PHYSICAL OCEANOGRAPHY DATA

Station	Time	Depth, ft	Temper- ature, C	Salinity, ppt	Density Value ^(a) , σ_t	Station	Time	Depth, ft	Temper- ature, C	Salinity, ppt	Density Value ^(a) , σ_t
October 21, 1971						October 21, 1971 (cont)					
1	1054	Surface	5.22	27.92	22.08	9	1430	Surface	5.14	28.62	22.64
		10	5.18	28.08	22.21			10	5.14	28.84	22.81
		20	5.15	28.10	22.22			20	5.10	29.23	23.13
		30	5.16	28.32	22.40			30	5.11	29.60	23.42
		40	5.12	28.03	22.16			40	5.08	29.62	23.44
		50	5.12	28.14	22.27			50	5.11	29.76	23.54
		100	5.12	28.70	22.70						
3	1137	Surface	5.20	32.95 ^(b)	26.05 ^(b)	9A	1445	Surface	5.17	29.87	23.62
		10	5.07	30.94	24.48			10	5.13	29.73	23.52
		20	5.09	30.97	24.50			20	5.13	30.17	23.87
		30	5.10	31.00	24.53			30	5.10	30.28	23.96
		40	5.07	30.80	24.36			40	5.08	30.24	23.92
		50	5.08	30.96	24.50			50	5.08	30.23	23.91
		100	5.02	30.75	24.34			100	5.11	30.27	23.95
								200	5.09	30.12	23.83
4	1158	Surface	5.06	29.94	23.69	10	1505	Surface	5.00	30.10	23.83
		10	5.08	29.96	23.70			10	5.02	30.63	24.24
		20	5.10	29.96	23.70			20	5.02	30.60	24.21
		30	5.07	29.61	23.43			30	5.04	30.61	24.22
		40	5.07	30.03	23.75			40	5.02	31.32	24.79
		50	5.06	29.90	23.66			50	5.01	31.31	24.78
		100	5.06	30.01	23.75						
5	1230	Surface	5.35	30.04	23.73	11	1535	Surface	5.09	30.86	24.41
		10	5.22	30.35	24.00			10	5.05	30.32	23.99
		20	5.18	30.32	23.98			20	5.10	30.43	24.06
		30	5.12	30.48	24.11			30	5.05	30.40	24.04
		40	5.10	30.38	24.04			40	5.07	30.42	24.06
		50	5.10	30.28	23.96			50	5.02	30.60	24.21
		100	5.09	30.30	23.97						
6	1300	Surface	5.42	30.09	23.77	12	1600	Surface	5.18	30.55	24.16
		10	5.15	30.18	23.87			10	5.18	30.61	24.20
		20	5.13	30.12	23.83			20	5.18	30.10	23.80
		30	5.11	30.29	23.96			30	5.13	30.27	23.94
		40	5.07	30.27	23.95			40	5.12	30.29	23.96
		50	5.12	30.30	23.96			50	5.10	30.28	23.96
		100	5.10	30.24	23.92						
7	1330	Surface	5.22	27.89	22.06	October 22, 1971					
		10	5.14	28.08	22.22	1	0955	Surface	4.77	30.65	24.28
		20	5.13	28.18	22.02			10	4.80	30.72	24.34
		30	5.09	28.12	22.25			20	4.83	30.70	24.32
		40	5.12	28.16	22.28			30	4.89	30.66	24.28
		50	5.05	28.60	22.64			40	4.86	30.68	24.30
		100	5.00	28.60	22.64			50	4.89	30.70	24.31
								100	4.92	30.62	24.24
8	1400	Surface	5.10	28.53	22.57	1A	1010	Surface	4.85	30.43	24.10
		10	5.08	28.57	22.60			10	4.88	30.40	24.07
		20	5.03	28.91	22.87			20	4.91	30.35	24.30
		30	5.02	28.15	23.07			30	4.80	30.43	24.10
		40	5.05	29.43	23.29			40	4.92	30.44	24.10
		50	5.04	29.28	23.17			50	4.93	30.40	24.07
								100	4.98	30.40	24.06
								200	4.87	30.98	24.53

C-3 and C-4

TABLE C-2. (Continued)

Station	Time	Depth, ft	Temper- ature, C	Salinity, ppt	Density Value ^(a) , σ_t	Station	Time	Depth, ft	Temper- ature, C	Salinity, ppt	Density Value ^(a) , σ_t
October 22, 1971 (cont)						October 24, 1971 (cont)					
2	1055	Surface	4.83	30.70	24.32	3	1120	Surface	4.72	33.52	26.55
		10	4.90	30.50	24.15			10	4.71	33.59	26.62
		20	4.90	30.43	24.09			20	4.74	33.60	26.62
		30	4.88	30.76	24.36			30	4.73	33.58	26.63
		40	4.94	30.68	24.29			40	4.74	33.63	26.64
		50	4.90	30.66	24.27			50	4.75	33.58	26.60
		100	4.96	30.73	24.33			100	4.76	33.61	26.62
								150	4.76	33.69	26.69
2A	1110	Surface	4.86	30.68	24.30	4	--	Surface	4.73	33.50	26.54
		10	4.95	30.50	24.15			10	4.79	33.55	26.57
		20	4.96	30.62	24.24			20	4.78	33.58	26.59
		30	4.94	30.72	24.32			30	4.77	33.49	26.61
		40	4.95	30.57	24.20			40	4.72	33.56	26.58
		50	4.99	30.66	24.26			50	4.78	33.60	26.61
		100	4.95	30.62	24.24			100	4.77	33.53	26.56
		200	4.83	30.77	24.37			150	4.80	33.60	26.61
								200	4.74	33.69	26.69
3	1208	Surface	4.92	30.46	24.11	A	1455	Surface	4.90	33.27	26.34
		10	4.94	30.68	24.29			10	4.84	33.35	26.41
		20	4.94	30.66	24.27			20	4.84	33.34	26.41
		30	4.94	30.67	24.28			30	4.85	33.38	26.43
		40	4.95	30.67	24.28			40	4.80	33.42	26.48
		50	4.96	30.64	24.26			50	4.78	33.40	26.45
		100	4.94	30.71	24.31			100	4.73	33.55	26.42
		200	4.92	30.68	24.29						
October 24, 1971						B	1507	Surface	4.79	33.35	26.41
1	1050	Surface	4.54	33.69	26.71			10	4.80	33.37	26.42
		10	4.68	33.54	26.58			20	4.79	33.47	26.50
		20	4.60	33.65	26.67			30	4.83	33.39	26.44
		30	4.72	33.68	26.68			40	4.82	33.42	26.46
		40	4.75	33.62	26.63			50	4.82	33.43	26.46
		50	4.74	33.64	26.65			100	4.78	33.48	26.52
								150	4.80	33.45	26.49
2	1110	Surface	4.66	33.53	26.57	C	1520	Surface	4.78	33.40	26.45
		10	4.75	33.52	26.55			10	4.84	33.42	26.47
		20	4.72	33.63	26.64			20	4.84	33.42	26.47
		30	4.73	33.62	26.63			30	4.82	33.42	26.47
		40	4.74	33.59	26.61			40	4.82	33.41	26.46
		50	4.77	33.64	26.65			50	4.80	33.42	26.47
		100	4.74	33.66	26.66			100	4.81	33.43	26.47
								150	4.75	33.50	26.54
								200	4.75	33.52	26.55

(a) $\sigma_t = [(\rho_t - 1)(1000)]$, where ρ_t is density as determined from temperature and salinity.

(b) Value is questionable.