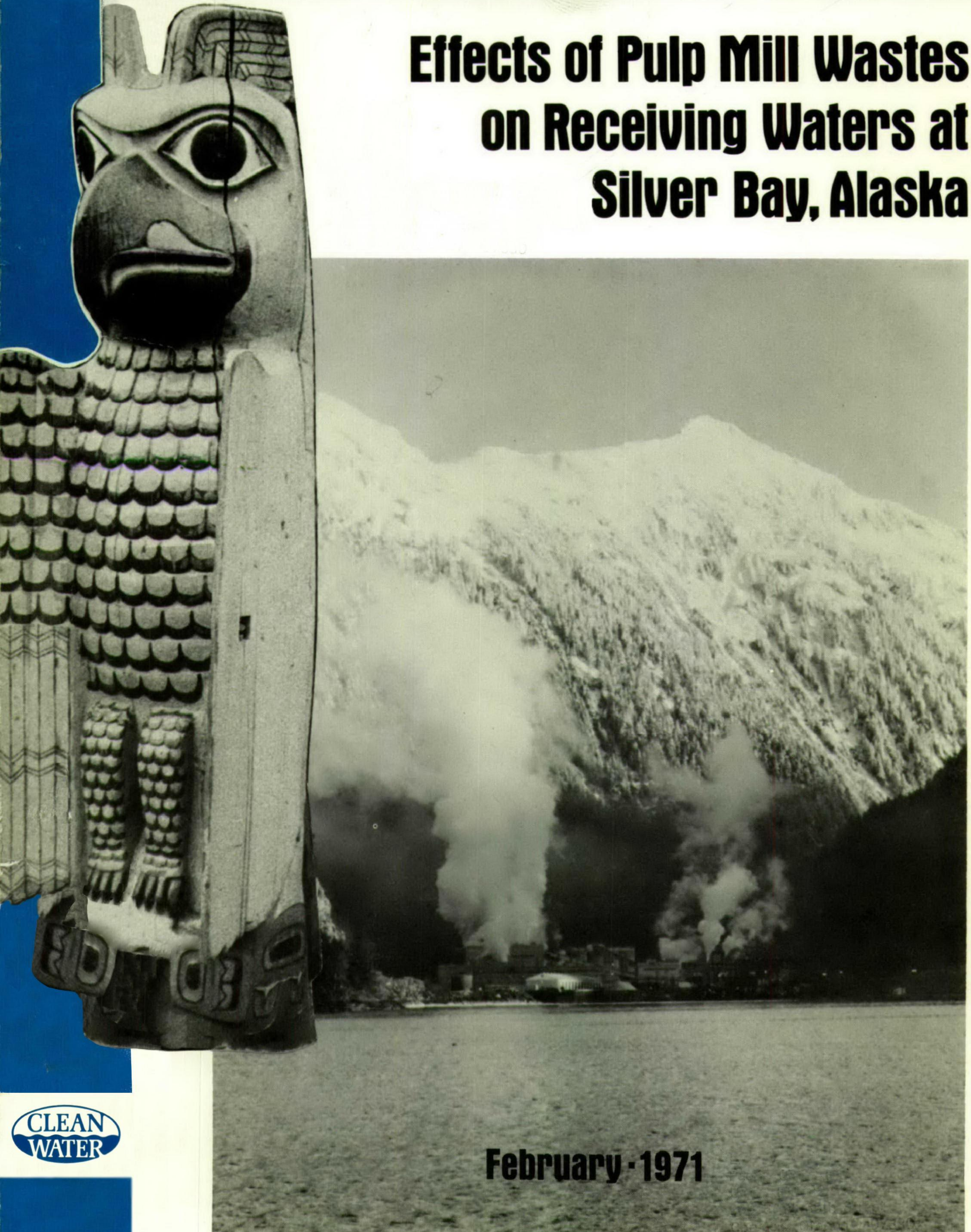
ENVIRONMENTAL PROTECTION AGENCY
WATER QUALITY OFFICE, NORTHWEST REGION
ALASKA OPERATIONS OFFICE

Effects of Pulp Mill Wastes on Receiving Waters at Silver Bay, Alaska



CLEAN WATER

February · 1971

EFFECTS OF PULP MILL WASTES

ON

RECEIVING WATERS AT SILVER BAY, ALASKA

Environmental Protection Agency
Water Quality Office
Northwest Region
Alaska Operations Office
Anchorage, Alaska

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INTRODUCTION

Statement of Problem

Many water quality problems in Alaska are associated with the industrial development of estuarine areas. Water quality standards have been adopted by the State and approved by the Federal Government, with exceptions, to protect estuarine water resources for present and future uses. To assure compliance with the approved standards, the adequacy of industrial waste treatment and disposal systems at Silver Bay was evaluated.

The Alaska Lumber and Pulp Company operates a magnesium-base, sulfite process pulp mill at Silver Bay. The mill does not provide primary treatment, but relies upon chemical recovery and screening before discharging wastes into Silver Bay. The water quality standards adopted by the State of Alaska stipulate:

> Secondary treatment is required for all industrial and municipal waste unless engineering studies approved by the Department of Health and Welfare, and where interstate waters are affected, concurred in by the Federal Water Quality Administration, show that the water quality standards can be met with primary treatment. Primary treatment is the minimum acceptable treatment. (1)

Objectives

The objectives of this study were to answer the following questions:

1. What is the present water quality in Silver Bay relative to the water quality standards?

2. What is the magnitude of the effect of industrial waste discharges on the aquatic environment of Silver Bay?

3. What changes in industrial operation should be made to improve water quality in Silver Bay?

Scope of Study

The effects of industrial waste discharges upon the estuarine waters of Silver Bay were investigated in 1968 and 1969 by the Federal Water Quality Administration (formerly the Federal Water Pollution Control Administration) in cooperation with the U. S. Fish and Wildlife Service.[1/] Water quality data from this investigation, and from previous studies by the State of Alaska and the Federal Water Quality Administration established the significance of changes caused by the long-term discharge of pulp mill wastes into Silver Bay.

Authority

Section 5 of the Federal Water Pollution Control Act, as amended, authorizes the Secretary of Interior to conduct studies relating to the causes, control, and prevention of water pollution. The study was requested by the Alaska Department of Health and Welfare.

[1/] On December 3, 1970, the Presidential Order creating the independent Environmental Protection Agency (EPA) took effect. The EPA incorporates many Federal programs concerning the environment, including water pollution control. The Federal Water Quality Administration in the Department of Interior was abolished and the water pollution control responsibilities and authorities of the Secretary of the Interior were transferred to the Administrator of the EPA.

SUMMARY

The present waste treatment provided by the Alaska Lumber and Pulp Company is insufficient to assure compliance with the Alaska Water Quality Standards.

High sulfite waste liquor (SWL) concentrations, ranging from 137 to over 3000 parts per million (ppm), were found at various times of the year throughout an 11-square mile area in Silver Bay and Eastern Channel. Three hundred eighty-five samples were taken in the top 20 meters of water at 34 stations between March 1968 and August 1970. Sixty-eight percent of the samples had SWL concentrations greater than 10 ppm, 48 percent greater than 50 ppm, 29 percent greater than 200 ppm, and 10 percent exceeded 400 ppm.

SWL concentrations of 50 ppm, known to exceed the level toxic to phytoplankton and salmon fishfood organisms were found throughout Silver Bay and a large portion of Eastern Channel, as far as the southeast entrance to Sitka Harbor. Ten parts per million SWL, found to be damaging to immature forms of fish and shellfish in similar environments occurred over an even greater area. The discharge of SWL has significantly reduced populations of blue mussels, *Mytilus edulis*, throughout Sawmill Cove and along the northwest shore of Silver Bay to its mouth.

Discarded solids, wood chips, and pulp fibers form sludge deposits that blanket 0.2 square miles, covering half of the bottom of Sawmill Cove and extending along the northwest shore of Silver

Bay half way to its mouth. These black sludge deposits emit hydrogen sulfide gas and prevent the establishment of the variety of bottom-associated organisms that are found in similar, but unpolluted, habitats. Many of these sludge deposits completely lack benthic animals; the deposits which do contain animal life support only pollution tolerant, ooze dwelling species of polychaete worms.

At times the anaerobic decomposition of organic bottom deposits causes "bulking", the formation of gas and the subsequent respension of benthic solids. Bulking releases hydrogen sulfide gas in the water and creates floating sludge mats on the surface of the Bay. Sulfide toxicity levels for fish have been exceeded, killing over 100,000 fish on September 11, 1970.

The SWL discharged into Silver Bay, the organic bottom deposits resulting from the discharge of solid materials, and the inability of the waters of Silver Bay to effectively disperse the SWL, combine to reduce the dissolved oxygen concentrations in Silver Bay and Eastern Channel on a year-round basis. During the summer the dissolved oxygen content of surface portions of these waters is reduced below 6 miligrams per liter (mg/l), the minimum level allowed by the Alaska Water Quality Standards.

RECOMMENDATIONS

1. The Alaska Lumber and Pulp Company should take immediate steps to implement the following recommendations.

a. Provide treatment of wastes to remove all settleable solids and at least 70 percent of volatile suspended solids. Primary treatment by 1972 is called for in the Implementation Plan for the State of Alaska. The established deadline should be met.

b. Modify log handling practices to minimize accumulation of wood solids in Sawmill Cove. Recent improvements have been made in log storage and handling. Efforts should continue, however, to minimize log handling and storage in the water by developing complete land storage and handling capabilities.

c. Remove all existing sludge beds associated with mill discharge and log handling. These highly organic deposits should be removed entirely from the water and disposed of on land in a suitable containment area. Removal should be accomplished during biologically non-critical periods, particularly as regards salmon spawning, and conducted in a manner to minimize water quality degradation.

2. The Alaska Lumber and Pulp Company should develop and implement an abatement program to assure that sulfite waste liquor (SWL) concentrations do not exceed 10 parts per million, beyond an immediate dispersion zone, in the surface ten meters of Sawmill Cove, Silver Bay, and Eastern Channel. Included in this program must be the following specific items:

a. Install increased chemical recovery capacity.

b. Provide adequate storage capacity at the mill to assure that, in the event of equipment failure, etc., strong waste liquors are not discharged to the receiving waters without treatment or recovery.

c. Modify or improve in-plant processes and house-keeping procedures to minimize losses of SWL.

d. Construct an outfall system designed to minimize the dispersion zone and locate it away from the near-shore areas.

3. The plans and schedules for implementing recommendations 1 and 2 must be submitted to the State and Federal regulatory agencies for approval. Detailed plans for the oceanographic and water quality studies required to support the design of an outfall system must also be submitted for review.

4. The Alaska Lumber and Pulp Company must comply with the Alaska Water Quality Standards by providing secondary treatment, unless it can demonstrate that primary treatment will meet water quality standards. Such evidence should include a study and monitoring program to evaluate compliance with water quality criteria in both Silver Bay and Eastern Channel. Study plans must be submitted to the State and Federal regulatory agencies for approval.

STUDY AREA

General Description

Silver Bay is an estuary located about 3.5 miles southeast of Sitka, Alaska (Figure 1), connecting with Sitka Sound through Eastern Channel. The Bay is 6.8 miles long and varies in width from 0.4 to 0.9 miles. It is 120 meters deep at the mouth, decreasing to 45 meters at the head of the bay. The bay covers an area of about 4.2 square miles. There are a number of sources of fresh water entering Silver Bay. Three streams enter at the head of the bay, seven creeks enter between Bear Cove and Herring Cove, and Sawmill Creek enters at Sawmill Cove. Process water for the Alaska Lumber and Pulp Company is drawn from Blue Lake which is also the source of water for Sawmill Creek.

The Alaska Lumber and Pulp Company is the only industrial development at Silver Bay. It is located at the head of Sawmill Cove, about 1.5 miles from the mouth of the bay. There are no residential areas or municipal developments near the mill. The mill is the only source of waste water discharges to Sawmill Cove and Silver Bay.

Climatic Conditions

The Sitka-Silver Bay area is in the cold maritime belt of Southeastern Alaska. Average annual precipitation is 100 inches, and annual snowfall is less than 100 inches. Prevailing winds are generally off-shore (from east and southeast) during autumn, winter and spring, and generally on-shore (from southwest and northwest)

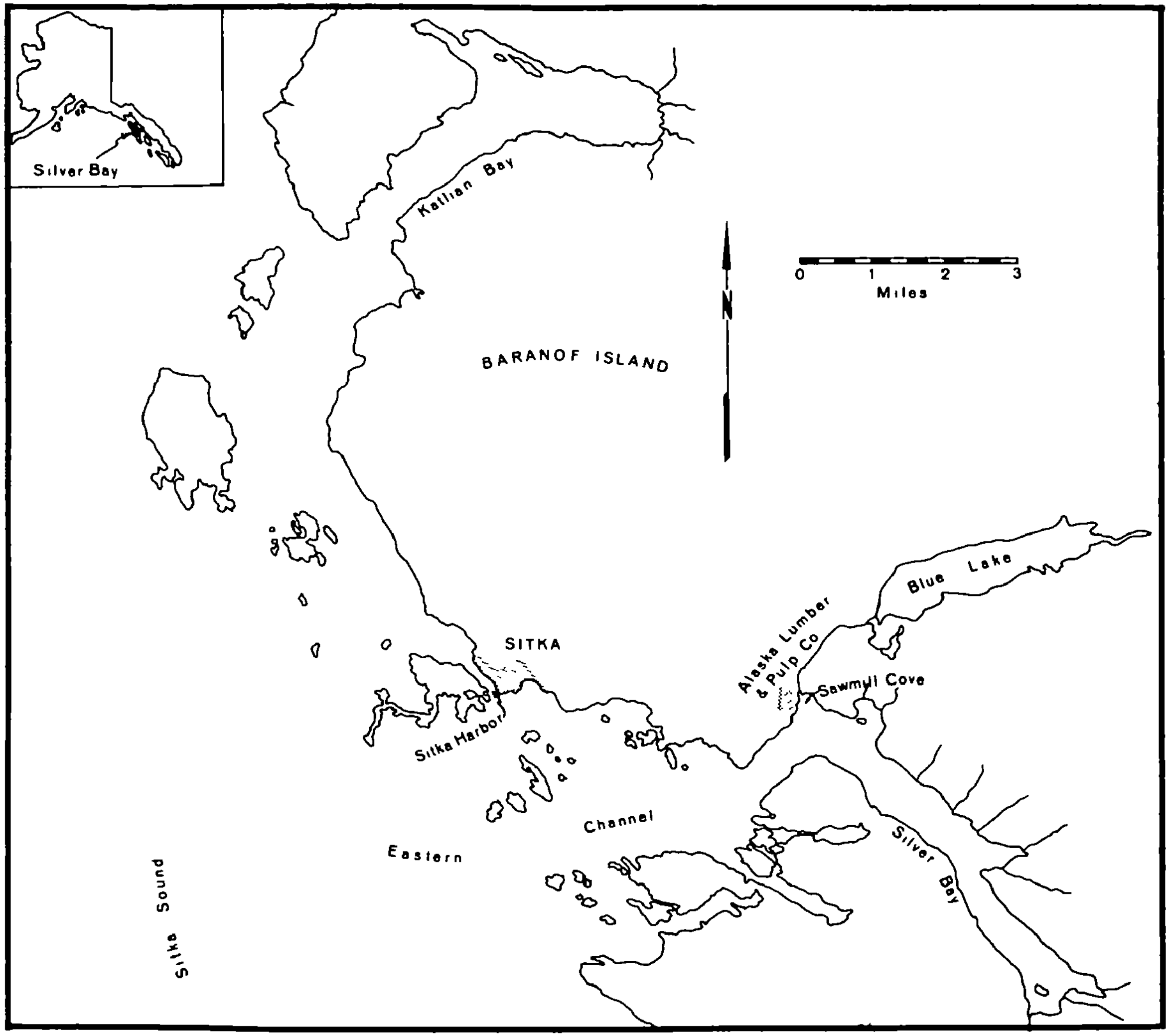

Figure 1. Silver Bay, Eastern Channel and Katlian Bay

during summer. The mean high and low temperatures for January are 38°F and 28°F, respectively. Icing seldom occurs on the marine waters in the Sitka area.

The main input of fresh water to Sawmill Cove comes from the mill outfalls and Sawmill Creek. The flow of waste water from the pulp mill is estimated at 46 million gallons per day or 71 cubic feet per second (based on an estimated output of 600 tons per day). Sawmill Creek, from data for 1945 through 1950, had a yearly mean discharge of 481 cubic feet per second (cfs) with a maximum daily flow of 4860 cfs and a minimum of 34 cfs. The discharge of water from Sawmill Creek is partially dependent on pulp mill water use. Since the damming of Sawmill Creek, flow data have not been obtained, and only a rough approximation of the present fresh water input to Sawmill Cove can be made. The daily input from the mill discharge and Sawmill Creek can be expected to vary between 4930 and 105 cfs, with a mean flow of 550 cfs. Watershed flow retention is moderate due to the heavy precipitation and steep stream gradient.

Oceanography

The fresh water input to Silver Bay mixes with saline waters and forms a shallow surface layer of brackish water. Beneath this surface layer, horizontal and vertical gradients are small and salinities are near oceanic values.

The temperature of the surface layer is determined by seasonal variations in temperature and by the temperature and volume of fresh water input. Again, below the surface layer, horizontal and vertical temperature gradients are small and temperatures are near oceanic values.

In 1956 and 1957 current studies in Silver Bay showed that the circulation patterns are determined by the amount of fresh water run-off, density differences between Silver Bay and Sitka Sound, wind stresses, and, to a lesser degree, tidal forces. (3) During high runoff, from June to October, the circulation pattern is of the classical fjord type, with a strong outflow in the shallow surface layer and the inflow immediately below the surface layer. In July, 1956, at the entrance to Silver Bay the surface layer was 6 meters thick, with a maximum outward current of 0.15 meters per second. The lower layer was 15 meters thick, with a maximum inflow of 0.05 meters per second. The lower 60 meters of water were essentially motionless. Strong west winds blowing up the Bay can reverse the surface currents for short periods of a few days.

From January through April, runoff to Silver Bay is at a minimum. Winds are predominantly from the southeast, tending to drive the surface waters out of the Bay. The dense oceanic water flows in along the bottom and then moves upward to replace the surface water driven outward by the wind. Inflow-outflow occurs throughout the entire depth of the Bay, in contrast to the high flow period, when only the top one-third of the Bay is affected. In March 1957 current measurements showed the surface layer to be 30 meters thick, with a maximum outflow of 1.10 meters per second. The bottom layer was 60 meters thick, with a maximum inflow of 0.02 meters per second.

Tidal forces are usually insufficient to cause the surface layer to flow into the Bay during flood tide. In December, 1956, however, when neither wind stress nor density differences were great, surface transport into Silver Bay was observed during a flood tide. (3)

Sulfite waste liquor, temperature, and salinity data obtained in the present study (Table 1 and Appendix, Table 1A) agree with the data of the study described above. Pollutants in the surface waters of Silver Bay at Sawmill Cove are affected by wind conditions and the volume of fresh water entering the Bay. Normally, the wastes flow out of the Bay into Eastern Channel. An up-bay wind will drive high concentrations of sulfite waste liquor to the head of the Bay. On other occasions, when fresh water input is low (during winter months), upwelling, and thus vertical mixing, occured in the upper reaches of the Bay.

Flushing times for Silver Bay, which indicate how long a consertive constituent will remain in the Bay, can be estimated from the data obtained in earlier studies. (3) During low runoff, the flushing time is 320 days; during high runoff, the flushing time is 87 days.

Water Uses

Fisheries resources in Silver Bay are an important asset to Southeastern Alaska and especially to the Sitka area (3). Silver Bay is an important wintering ground for herring and also serves as a nursery ground for young herring which either migrate into the Bay or are spawned there. Tributaries entering Silver Bay support salmon runs and the bay serves the important functions of providing a nursery area for young salmon and a feeding ground for adult salmon. The introduction of SWL and other wastes into Silver Bay limits its uses for these purposes. Such wastes can have extremely serious consequences on the fisheries resources of the bay. Several fish kills have occurred in Silver Bay. On September 11, 1970, an estimated 100,000 fish died as a consequence of poisoning by hydrogen sulfide.

Silver Bay is very accessible and, except for the Sawmill Cove area, is used for recreational fishing and boating by local residents. The bay offers aesthetically pleasing sites within a major scenic area of Alaska.

Previous Studies

Water quality data for Silver Bay and Sitka Sound, collected between May, 1956, and March, 1957, showed very high water quality. At the time of the 1956-57 surveys, 3 years before mill operation, no wastes were being discharged to the Bay. Previously, wastes from logging and sawmill operations had been introduced into the Bay, but grossly perceptible after-effects on water quality were not observed. Biochemical oxygen demand (BOD) measurements in July, 1956, were less than 2 mg/1, demonstrating the high quality of these waters.

A great variety of marine life was found in the inter and sub-tidal zones. In many benthic reaches of the bay, marine life was scarce because of anaerobic bottom conditions in areas deeper than

27 meters, as indicated by odors of hydrogen sulfide gas. In shallow waters near stream mouths, flushing prevented the bottom from becoming anaerobic. Of particular interest in the 1957 report is the almost complete absence of hydrogen sulfide and anaerobic conditions in Sawmill Cove.

During the 1957 study, dissolved oxygen values throughout the surface waters of Silver Bay showed seasonal variations, characteristic of clean waters. The values for surface waters ranged from 7.1 mg/l during the winter to 18.2 mg/l during the spring. At the 100-foot depth, dissolved oxygen varied from 6.9 to 12.9 mg/l.

Studies conducted in August, 1965, revealed high SWL concentrations throughout the surface waters of Silver Bay. (5) The threshold toxicity of SWL to important food chain organisms, such as copepods, euphausids, mysids, and candlefish, was exceeded. Near-surface SWL values were greater than those found to cause 100 percent mortality of egg and larvae stages of oysters and certain bottom fish.

Dissolved oxygen in Silver Bay was less than the concentrations found during the 1956-57 study. In 1965 dissolved oxygen values in surface layers ranged from 4 to 6 mg/l. Between 2 and 10 meters, dissolved oxygen values increased to 7 to 8 mg/l. Dissolved oxygen concentrations less than 6 mg/l were found in the mill outfall. In August, 1965, prior to the discharge of pulp mill wastes into Silver Bay, dissolved oxygen concentration ranged from 9.0 to 11.5 mg/l in the surface waters, from 8.5 to 11.0 mg/l at the 5-meter depth, and from 8.1 to 10.8 mg/l at the 30-meter depth. Degradation of surface waters, as shown by decreased dissolved oxygen concentrations, was attributed to the biochemical oxygen demand of pulp mill wastes and to a possible inhibition of phytoplanktonic oxygen production resulting from high concentrations of SWL.

WATER QUALITY STANDARDS

The State of Alaska Water Quality Standards (1) designate all marine waters, including Silver Bay and Eastern Channel, as Class D and E. The standards are designed to protect beneficial uses of marine waters, which include growth and propagation of aquatic life and waterfowl, furbearers, and other water-associated life. Of particular interest in this study are the standards for dissolved oxygen, residues in the form of floating solids and sludge deposits, toxic substances, and aesthetic considerations:

Dissolved Oxygen

Class D - greater than 6 mg/l in salt water. Minimum of 7 mg/l fresh water.

Class E - greater than 6 mg/l saturation in the larval stage; greater than 5 mg/l in the adult stage.

Residue

Class D - none alone or in combination with other substances of wastes as to make receiving water unfit or unsafe for the use indicated, except that no waste oils, tars, greases or animal fats are permitted.

Class E - no visibile evidence of wastes. Less than acute or chronic problem levels as revealed by bioassay or other appropriate methods.

Toxic Substances

Class D - shall be absent or below concentrations affecting public health or the ecological balance.

Class E - less than acute or chronic problem levels as revealed by bioassay or other appropriate methods.

Aesthetic Considerations

Class D and E - Shall not be unreasonably impaired by the presence of materials or their effects (excluding those of natural origin) which are offensive to the senses of sight, smell, taste or touch.

WASTE SOURCES IN SILVER BAY

The Alaska Lumber and Pulp Mill is a magnesium-base, sulfite process, pulp mill. The mill produces an estimated 600 tons of dissolving grade pulp per day. Recovery units collect, concentrate and burn the strong pulping liquor. In the process, magnesium oxide and sulfur dioxide are partially recovered for recycling. Primary treatment of the plant effluent is not provided. All wastes from the mill are discharged to Sawmill Cove through three outfalls. The main outfall is shown in Figure 2.

Although chemical recovery is provided, and the concentrated strong liquor and woodroom wastes are burned, enough wastes are discharged to have a serious impact on Sawmill Cove and Silver Bay. There are no facilities, such as a lagoon, for storing strong liquors when the recovery units are by-passed. Thus, waste concentrations in the main outfall can reach very high levels. It is not uncommon to find SWL concentrations up to 9600 ppm near the main outfall, and 2,000 to 3,000 ppm extending from the main outfall seaward to sampling station 16 (Figure 4).

A deep layer of solid wastes covers the bottom of Sawmill Cove in the vicinity of the loghaul and the main outfall. The log dump, log haul, and woodroom are shown in Figure 3; foam and floating solids are evident in the picture. The deposition of pulp fiber, wood chips, and bark results in an anaerobic environment that extends over half of the bottom area of Sawmill Cove.

Figure 2. Main Outfall, Alaska Lumber and Pulp Company

Figure 3. Upper reaches of Sawmill Cove showing foam and floating solids near log dump, log haul and wood room.

On occasion these wastes will bulk (a term used to describe the formation of gas and subsequent rising of bottom sediments), releasing hydrogen sulfide gas and floating sludge to the water. This is apparently what caused a fish kill estimated at more than 100,000 fish on September 11, 1970.

Log storage and handling practices have recently been improved by banding the logs into bundles for transporation and storage. The bundles are lifted from the water onto a dry deck for debanding and sorting. The bands are disposed of on land. Some of the logs which are to be taken to the sawmill at Wrangle are rebanded and skidded back into Sawmill Cove for transportation to Wrangle. Although these modifications have reduced the wood solids contributed to Silver Bay, improvement is still needed, as evidenced by the floating wood solids and shoreline debris in Figure 3.

SAMPLING PROGRAM

The first phase of the present study was conducted in cooperation with the U.S. Fish and Wildlife Service, Auke Bay Biological Laboratory. It included two trips in 1968, in the spring and summer, to collect data on dissolved oxygen, SWL, temperature, salinity, water currents, and marine life in Silver Bay, and the adjacent waters of Sitka Sound and Katlian Bay. After the data from these two trips were evaluated, the Federal Water Quality Administration continued the study to document water quality conditions in the fall and winter, and again in spring.

Sampling Stations

Thirty-four stations were established within Silver Bay and the adjacent waters of Eastern Channel (Figure 4). An additional five stations were established from Sitka Harbor to the head of Katlian Bay (Figure 5).

Routine sampling for SWL was restricted to the top 10 meters because SWL concentrations below the 10-meter depth generally were less than the lower limit of accuracy of the analytical method. Dissolved oxygen (DO) measurements were made at various depths. Temperature and salinity data were obtained throughout the entire water column during the first two trips. On later trips these data were obtained only in the top 15 meters of water to define stratification within the surface waters.

Biological sampling was accomplished during several trips to the area. Benthic samples were collected at Stations 3, 4, 8, 16,

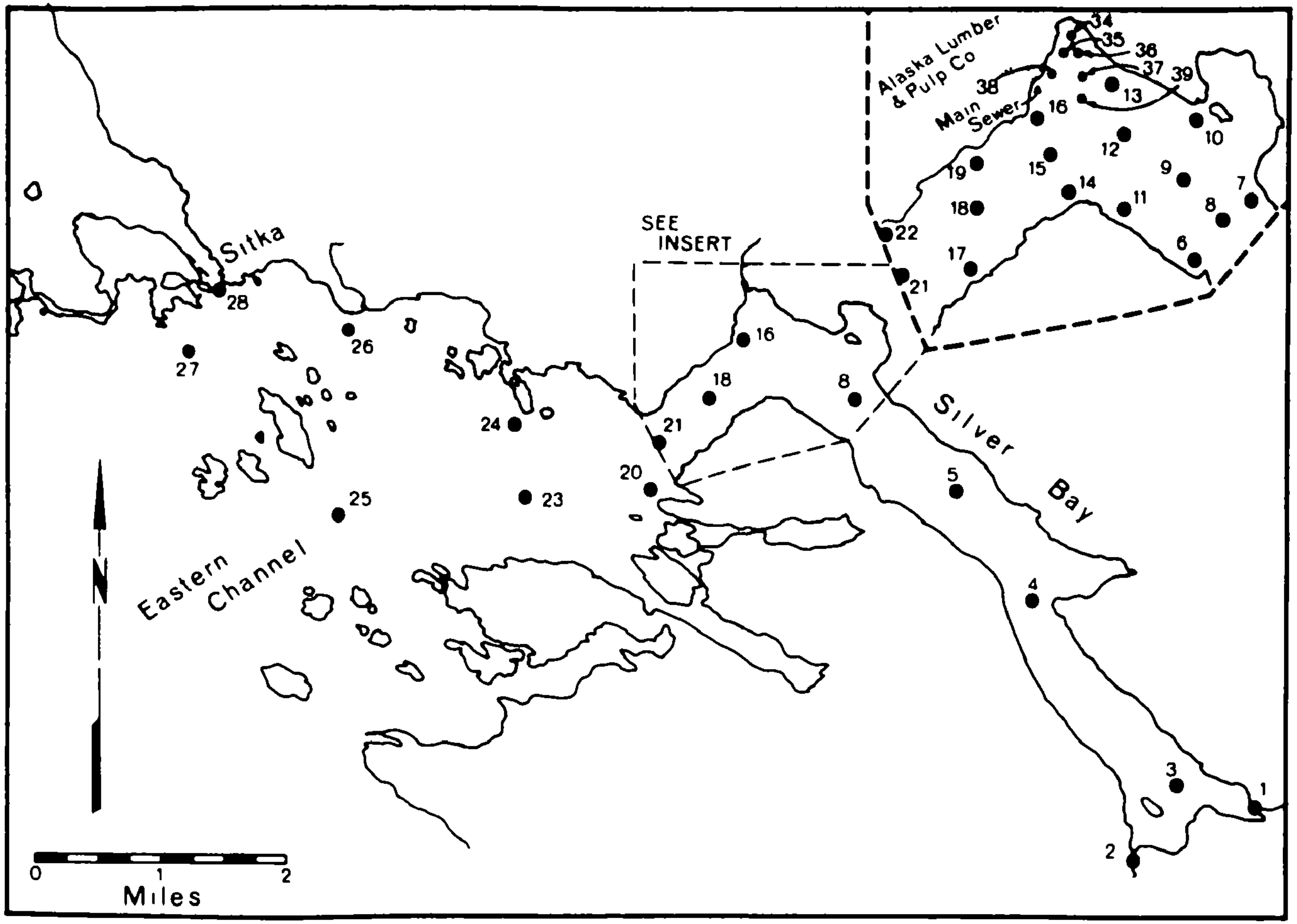

Figure 4. Location of sampling stations in Silver Bay, Eastern Channel and Sitka Harbor

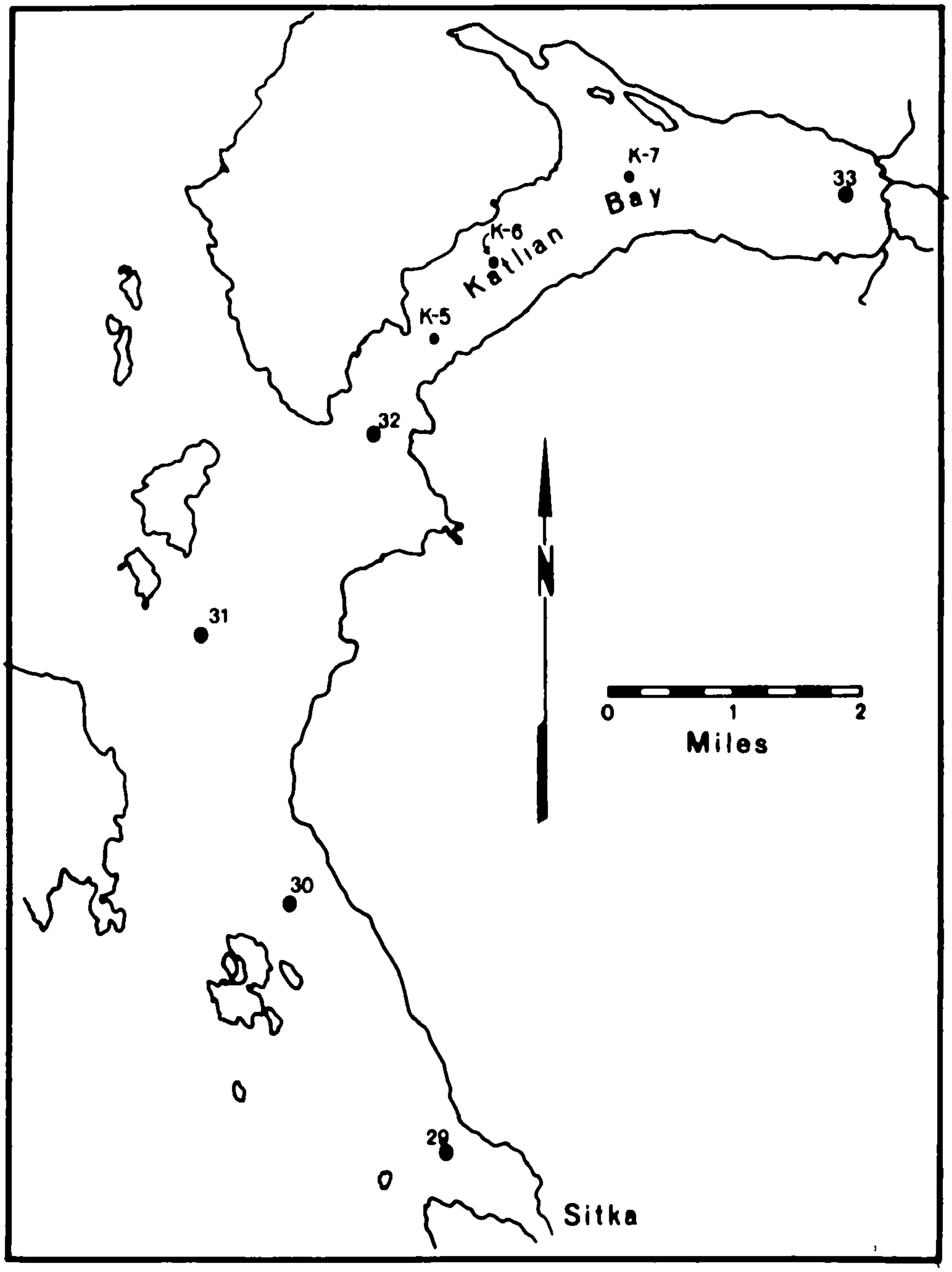

Figure 5. Location of sampling stations Northwest from Sitka Harbor and in Katlian Bay

19, 21, 22, 25, and Stations 34 through 38. Samples of blue mussels, Mytilus edulis, were collected at six intertidal zone sites in Silver Bay and four in Katlian Bay.

Sampling Schedule

Sampling was scheduled throughout the year to determine the seasonal variation of water column stability and its correlation with the DO and SWL concentrations within Silver Bay. The sampling periods are shown on Figure 6. Sampling often required a 12-hour tidal cycle. Thus, samples for chemical determination were obtained at various tidal phases as shown in the figure.

Methods

Water samples were collected with Nansen bottles[2/] and subdivided into appropriate 250 or 500 milliliter containers. Dissolved oxygen was measured using either Yellow Springs Instrument Model 54 or an Electronic Instrument Limited Model 15A. Dissolved oxygen meters were used because of the possibility of SWL interferring with the azide modification of the Winkler method. The dissolved oxygen probes were routinely calibrated against the Winkler method.

Temperature data were obtained either with the above dissolved oxygen meters, a Beckman Instruments Model R55-3 Portable Salino-

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[2/] Use of product and company names is for identification only and does not constitute endorsement by the Environmental Protection Agency.

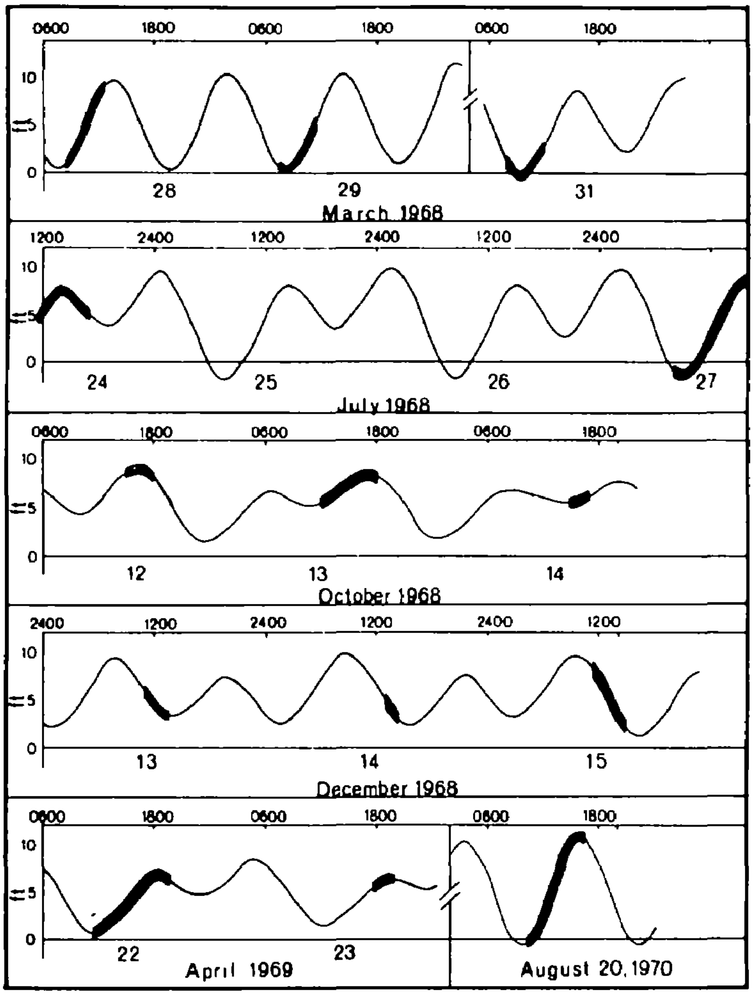

Figure 6. Sampling periods with respect to tidal phase and stage height

meter, or with a bathythermograph. Salinity measurements were made with the salinometer, by titration with silver nitrate (6), or by hydrometers.

SWL concentrations were determined using the Pearl-Benson Index (7), and were based on the spectrophotometic determination of the ligin-sulfonate concentration of the samples relative to a reference solution containing 10 percent dry solids by weight of calcium-base sulfite waste liquor. As an analytical quality control, standards of various SWL concentrations were handled exactly as the samples, i.e., frozen and shipped to the laboratory along with the samples. The SWL analyses were conducted either in the laboratory onboard the survey boat or, after preservation by freezing, at the Alaska Water Laboratory in College, Alaska.

Bottom samples of muds and aquatic life were collected using a core-sampler, a Ponar dredge, and Marukawa and Eckman dredges. Samples were preserved and transported to the laboratory where they were analyzed. Blue mussels, *Mytilus edulis*, were collected from inter-tidal reaches at low tide by two persons collecting, in half an hour, as many mussels as possible from the sector of greatest density at each of ten sampling sites. These samples were preserved and taken to the Auke Bay Biological Laboratory for analysis.

RESULTS AND DISCUSSION

Sulfite Waste Liquor

During six trips to the Silver Bay area, 385 samples from the top 20-meters were collected and analyzed. These samples were collected at 34 stations distributed over an area greater than 11 square miles. Sixty-eight percent of the samples had SWL concentrations greater than 10 ppm; 48 percent had concentrations greater than 50 ppm; 29 percent had concentrations greater than 200 ppm; 10 percent had concentrations greater than 400 ppm.

Concentrations of SWL in the first meter of water varied throughout Silver Bay and adjacent waters from one study period to the next, and were higher in summer than in winter (Table 1). The highest concentrations of SWL, ranging from 137 ppm to over 2800 ppm, were found on July 24 and 27, 1968. The region in which these concentrations were found extended from the head of Silver Bay, 5.5 miles from the mill, to the southeast entrance to Sitka Harbor, 5.25 miles from the mill. SWL concentrations greater than 137 ppm were found at various times of the year in an 11.1 square-mile area throughout Silver Bay and Eastern Channel (Figure 7). Within this area, nearer the mill outfalls, SWL concentrations were greater than 400 ppm in a 0.6 square-mile zone.

Vertically, SWL generally was distributed throughout the surface waters to the 5 to 10-meter depth. The highest concentrations of SWL were found in the first meter of water. Significant concentrations of SWL were measured in the surface to four-

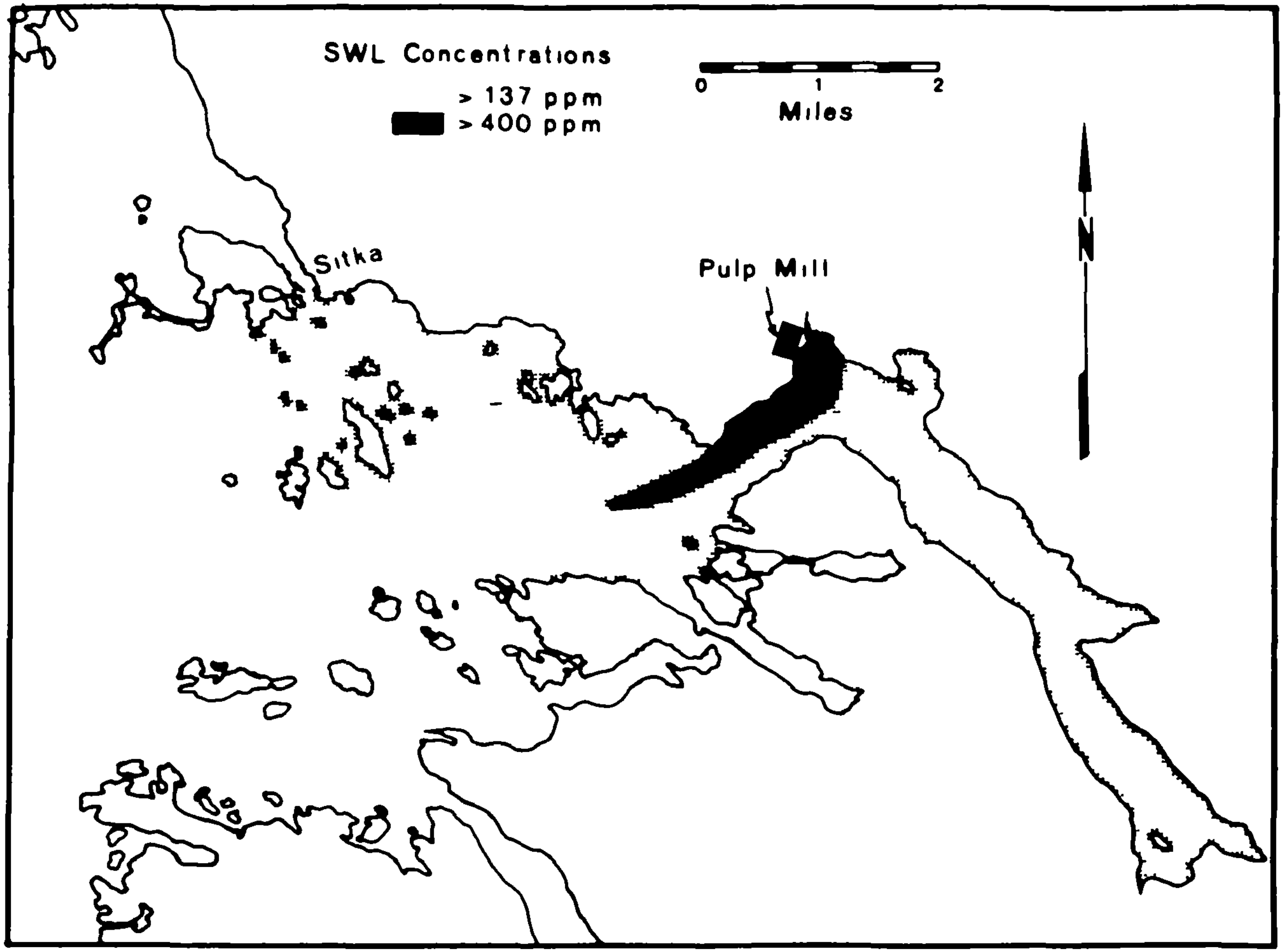

Figure 7. Zones in Silver Bay and Eastern Channel where high SWL concentrations can be expected at various times throughout the year

TABLE 1
SULFITE WASTE LIQUOR CONCENTRATIONS (PPM)
WITH DEPTH (METERS) IN SILVER BAY AND ADJACENT WATERS, 1968-1970

	Station Numbers															
DEPTH	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
							March 28, 29, 31, 1968									
0	53	<5	<5	8	33	438	-	-	269	51	491	-	235	2250	2050	-
1	-	-	-	-	23	17	-	-	96	27	252	-	14	69	576	-
2	-	<5	<5	1	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	<5	8	-	-	-	11	101	-	-	-	-	-
4	-	-	-	-	-	-	-	-	<5	-	-	-	-	-	-	-
5	-	<5	<5	7	-	-	-	-	-	-	8	-	<5	<5	5	-
							July 24, 1968									
0	-	165	225	364	266	196	-	245	152	266	310	106	268	314	271	252
1	-	-	-	-	228	388	-	268	450	267	291	447	278	545	1930	190
2	-	324	20	22	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	20	15	-	9	16	27	7	33	26	26	33	31
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
							July 27, 1968									
0	-	158	250	323	205	330	-	90	264	222	142	137	215	131	115	211
1	-	156	136	229	288	290	-	358	202	61	261	260	31	190	176	81
2	-	98	55	97	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	25	69	-	24	93	28	41	50	20	43	97	12
4	-	58	49	86	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	9	<5	18	7	17	33	-

TABLE 1 (Continued)
SULFITE WASTE LIQUOR CONCENTRATIONS (PPM)
WITH DEPTH (METERS) IN SILVER BAY AND ADJACENT WATERS, 1968-1970

DEPTH	OF*	18	19	20	22	23	24	25	26	27	28	29
							March 28, 29, 31, 1968					
0	-	188	611	-	461	299	361	178	80	152	193	-
1	-	-	72	-	102	45	17	39	-	86	17	25
2	-	15	-	-	-	-	-	-	75	-	-	-
3	-	-	53	-	68	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-
5	-	5	-	-	-	6	5	<5	-	13	<5	7
							July 24, 1968					
0	2370	400	635	269	438	480	375	361	373	265	324	-
1	-	372	109	191	533	202	336	113	133	99	88	-
2	-	-	-	-	-	-	-	-	-	-	-	-
3	-	39	27	40	10	-	-	-	-	-	18	-
4	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	<5	<5	-	-	-	-	-	-	-
							July 27, 1968					
0	873	259	702	167	291	237	248	233	280	295	269	-
1	283	341	213	67	111	484	321	141	185	268	136	45
2	-	-	-	-	-	-	-	-	-	-	-	-
3	376	23	58	<5	10	24	35	35	53	39	48	-
4	-	-	-	-	-	-	-	-	-	-	-	-
5	76	10	36	-	10	-	-	-	-	-	-	-

TABLE 1 (Continued)
SULFITE WASTE LIQUOR CONCENTRATIONS (PPM)
WITH DEPTH (METERS) IN SILVER BAY AND ADJACENT WATERS, 1968-1970

	Station Numbers																	
DEPTH	1	2	3	4	8	16	18	21	23	24	25	28	29	30	31	32	33	OF*
October 12, 13, 14, 1968																		
0	<5	<5	<5	<5	239	542	994	1044	59	9	167	<5	26	<5	<5	<5	<5	-
1	-	-	<5	<5	10	180	482	7	30	63	48	8	-	-	-	-	-	-
3	-	-	-	-	<5	<5	6	<5	-	-	-	-	-	-	-	-	-	-
5	-	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	-
10	-	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	-	-	-
20	-	-	<5	<5	<5	<5	<5	-	-	-	-	-	-	-	-	<5	<5	-
December 13, 14, 15, 1968																		
0	6	7	<5	<5	<5	290	419	216	20	173	-	35	7	<5	<5	-	-	9650
1	-	-	<5	<5	<5	218	31	146	19	170	-	34	7	-	-	-	-	-
5	-	-	<5	<5	<5	7	<5	6	7	58	-	24	5	-	-	-	-	-
10	-	-	<5	<5	<5	<5	7	<5	<5	<5	-	7	-	-	-	-	-	-
20	-	-	-	-		<5	<5	-	-	-	-	-	-	-	-	-	-	-
April 22, 23, 1969																		
0	8	14	<5	6	8	952	697	124	61	77	53	191	66	<5	-	-	-	528
3	-	-	<5	6	12	844	267	86	60	48	44	109	7	<5	-	-	-	-
5	-	-	<5	<5	<5	11	15	10	21	11	26	21	7	8	-	-	-	-
10	-	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	-	-	-	-	-	-	-
20	-	-	-	-	6	<5	<5	<5	-	-	-	-	-	-	-	-	-	-

*Outfall

TABLE 1 (Continued)
SULFITE WASTE LIQUOR CONCENTRATIONS (PPM)
WITH DEPTH (METERS) IN SILVER BAY AND ADJACENT WATERS, 1968-1970

	Station Numbers							
DEPTH	13	16	34	35	36	37	38	39[1]
				August 20, 1970				
0	95	374	495	202	326	230	252	253
1	215	1885	824	868	495	665	1670	3099
5	7	32	18	24	15	15	22	36
10	-	-	-	134	11	-	-	-

[1]Station 39, midway between Stations 13 and 16 was omitted from Figure 3.

meter depth at the head of the Bay and at the southeastern entrance to Sitka Harbor down to the five-meter depth (Table 1).

Water quality at stations 16 and 18, which are 0.25 and 0.75 miles, respectively, from the main sewer outfall, typically reflected the yearly variation between March, 1968, and April, 1969 (Figure 8). Higher SWL concentrations occured during the spring, summer, and fall, than occured during the winter. Such variation is to be expected because of seasonal differences in fresh water input, water column stability, variations in storm activity, and upwelling of deep oceanic waters. Thus, during the seasons when stratification of the water column is apparent, the disruption and subsequent dispersal of the surface brackish water layer containing the SWL wastes was minimal, and high SWL concentrations were widely distributed. The SWL concentrations were lowest in the winter when storms and upwelling associated with low flow input increase horizontal and vertical mixing.

Normally, SWL was not found in the upper reaches of Silver Bay unless predominately westerly winds drove it upbay, as was observed during the July, 1968 survey.

Dissolved Oxygen

Dissolved oxygen concentrations in Silver Bay and Eastern Channel have been considerably reduced from levels measured prior to mill operation. In the surface waters of Silver Bay dissolved oxygen concentrations have occasionally fallen below 6 mg/l, the minimum allowed by the Alaska Water Quality Standards (Table 2).

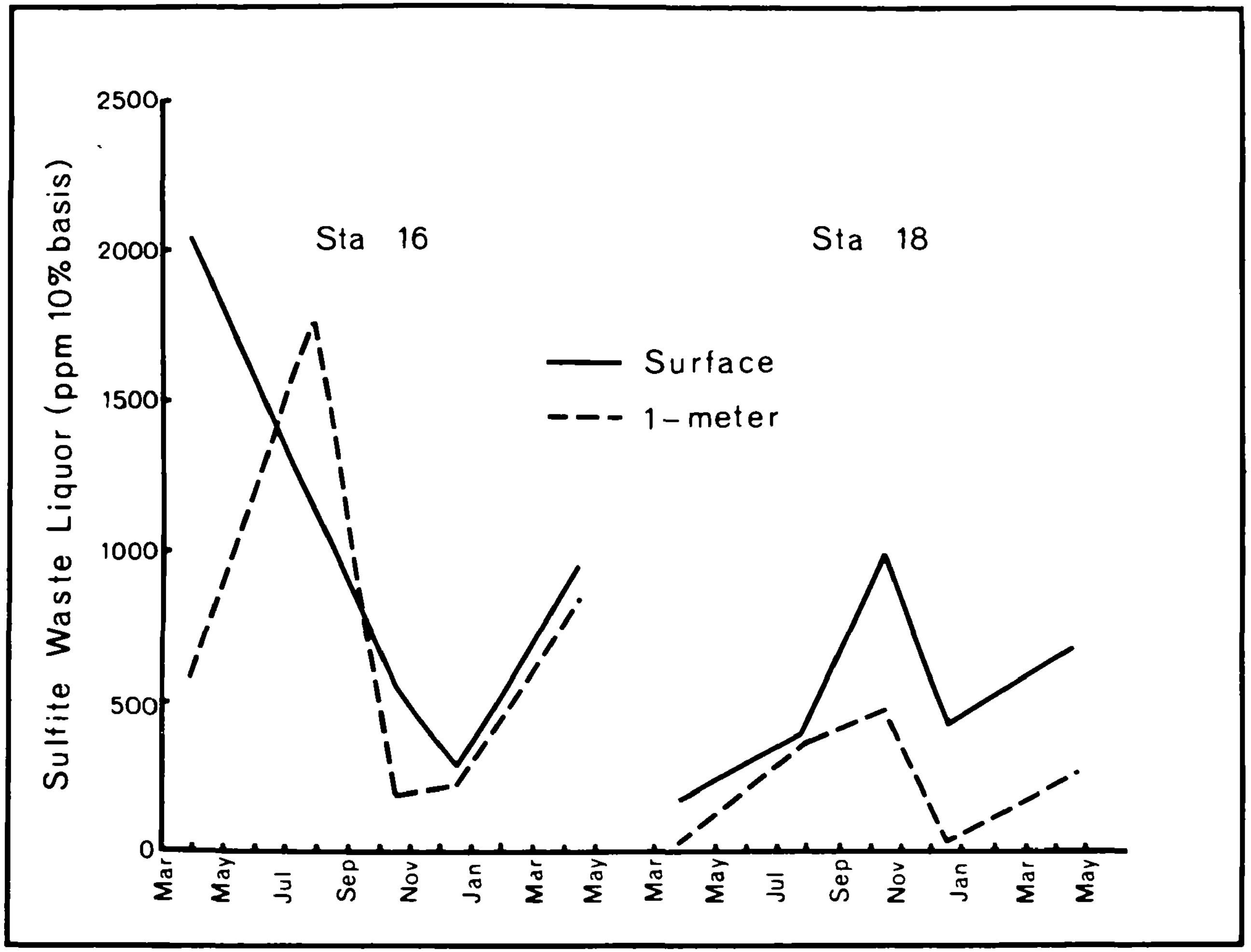

Figure 8. Typical annual distribution of SWL concentrations at Stations 16 and 18 in Silver Bay, March, 1968 through April, 1969

TABLE 2
DISSOLVED OXYGEN CONCENTRATIONS (mg/l)
WITH DEPTH (METERS) IN SILVER BAY, EASTERN CHANNEL AND KATLIAN BAY
1968-1969 and August 1970.

	Station Numbers								
DEPTH	5	18	25	3	4	5	18	23	18
	March 27, 1968			March 28, 1968					April 3, 1968
0	6.56	6.76	7.07	7.12	7.10	7.08	6.76	6.75	6.48
2	7.00	6.90	-	7.17	7.10	6.91	6.98	6.90	6.52
5	6.96	6.90	6.89	6.98	6.82	6.82	7.00	7.04	6.71
10	6.89	6.89	7.00	6.97	6.71	-	7.01	7.00	6.60
15	6.71	6.75	-	7.06	6.76	6.78	-	-	-
20	6.56	6.53	6.74	6.64	6.76	-	6.84	-	6.34
25	-	-	-	-	-	6.46	-	-	-
30	-	-	-	6.05	-	-	-	6.76	6.62
40	6.44	6.54	6.69	6.05	6.22	-	6.30	-	6.57
45	-	-	-	-	-	6.14	-	-	-
60	5.75	6.17	-	-	5.61	-	5.74	6.56	6.48
65	-	-	-	-	-	5.83	-	-	-
70	-	-	-	-	-	5.65	5.60	-	-
80	5.39	5.66	6.13	-	-	-	-	-	-

TABLE 2 (Continued)
DISSOLVED OXYGEN CONCENTRATIONS (mg/l)
WITH DEPTH (METERS) IN SILVER BAY, EASTERN CHANNEL AND KATLIAN BAY
1968-1969 and August 1970.

	Station Numbers								
DEPTH	32	K-5	K-6	K-7	33	K-5	K-6	K-7	33
	March 30, 1968					April 2, 1968			
0	10.70	10.25	11.46	11.38	10.53	10.79	11.77	12.19	10.70
5	8.25	8.87	9.30	9.08	9.83	7.08	6.68	6.94	7.53
10	7.26	6.98	7.68	7.41	7.73	6.49	6.33	6.43	6.62
20	7.06	7.56	6.64	6.37	6.56	6.30	6.34	6.18	5.72
30	-	-	-	-	-	-	-	-	5.55
40	6.39	5.96	6.34	5.59	5.70	6.17	5.95	6.08	5.58
60	6.26	6.29	5.59	5.62	5.94	6.04	5.87	5.94	5.58
80	6.16	5.42	5.43	5.66	5.72	5.50	5.72	5.71	5.59
100	6.18	5.38	5.57	5.63	-	5.36	5.36	5.46	-
120	6.23	5.21	5.60	5.63	-	5.55	5.54	5.54	-
130	6.31	-	5.60	5.73	-	-	5.43	5.58	-
140	-	5.52	-	-	-	5.55	5.47	5.46	-
160	-	5.50	-	-	-	-	-	-	-

TABLE 2 (Continued)
DISSOLVED OXYGEN CONCENTRATIONS (mg/l)
WITH DEPTH (METERS) IN SILVER BAY, EASTERN CHANNEL AND KATLIAN BAY
1968-1969 and August 1970.

	Station Numbers							
DEPTH	4	8	16	16	18	21	24	28
				December 13, 14, 15, 1968				
0	-	-	8.4	-	8.8	9.2	8.6	8.0
1	-	-	8.6	7.4	8.2	8.8	8.5	7.6
5	-	-	8.1	-	8.4	8.7	8.6	8.3
10	-	-	-	8.4	-	-	8.3	8.3
20	-	-	-	8.2	-	-	-	-
				April 22, 1969				
0	11.9	11.6	11.9	-	11.3	11.7	-	-
1	13.3	12.8	12.2	-	11.6	11.9	-	-
2	-	12.7	12.7	-	11.7	-	-	-
3	-	12.4	12.1	-	11.4	-	-	-
5	11.1	11.1	11.4	-	11.2	11.8	-	-
7	-	10.6	11.0	-	11.0	-	-	-
10	-	9.8	10.7	-	10.7	-	-	-
14	-	9.5	10.5	-	10.2	-	-	-

TABLE 2 (Continued)
DISSOLVED OXYGEN CONCENTRATIONS (mg/l)
WITH DEPTH (METERS) IN SILVER BAY, EASTERN CHANNEL AND KATLIAN BAY
1968-1969 and August 1970.

	Station Numbers							
DEPTH	13	16	34	35	36	37	38	39
				August 20, 1970 [a/]				
0	9.3	8.0	4.5	9.5	8.3	8.6	8.5	-
1	6.7	4.6	5.2	5.1	5.5	5.7	4.9	-
5	8.3	7.5	5.4	7.9	8.0	8.2	8.1	-
10	-	-	-	8.1	8.3	-	-	-

a/ Analyses were made by the Azide modification of the Winkler method. SWL concentrations measured were below levels shown to cause interference per Moore, M., Rieck, R., and Moore, W. "Determination of Dissolved Oxygen in the Presence of Sulfite Waste Liquor", Journal of the Water Pollution Control Federation, Vol. 39, No. 10, pp. R64-R69, 1967.

These low oxygen levels were measured in August, when mill wastes would be expected to have the greatest influence on the waters of Silver Bay. The continued discharge of inadequately treated wastes, however, will ultimately decrease the dissolved oxygen to levels where this standard will be violated on a sustained basis.

Prior to mill operation, dissolved oxygen concentrations in the surface 15 feet of water in Silver Bay ranged seasonally from 8.0 mg/l to 18.0 mg/l (Figure 9). During spring, when phytoplankton activity is greatest, dissolved oxygen levels were highest, reaching 179 percent saturation. The minimum values occurred during fall and winter because of reduced phytoplankton activity and the upwelling of deep oceanic waters with low oxygen content.

The data collected in March and April, 1968, revealed the surface waters of Silver Bay and Eastern Channel contained dissolved oxygen concentrations ranging from 6.5 to 7.1 mg/l. The surface waters of Katlian Bay had dissolved oxygen concentrations of 10.3 to 12.2 mg/l. During a comparable period prior to mill operation, the surface waters of Silver Bay and Eastern Channel had dissolved oxygen levels ranging from 9.0 to 18.2 mg/l. The difference between dissolved oxygen levels in Silver Bay and Eastern Channel and those in Katlian Bay is too great to be the result of natural processes. The lower levels in Silver Bay and Eastern Channel are primarily the consequence of waste discharges in Sawmill Cove and Silver Bay. Dissolved oxygen values below the 10-meter depth in Silver Bay and Eastern Channel are similar to those

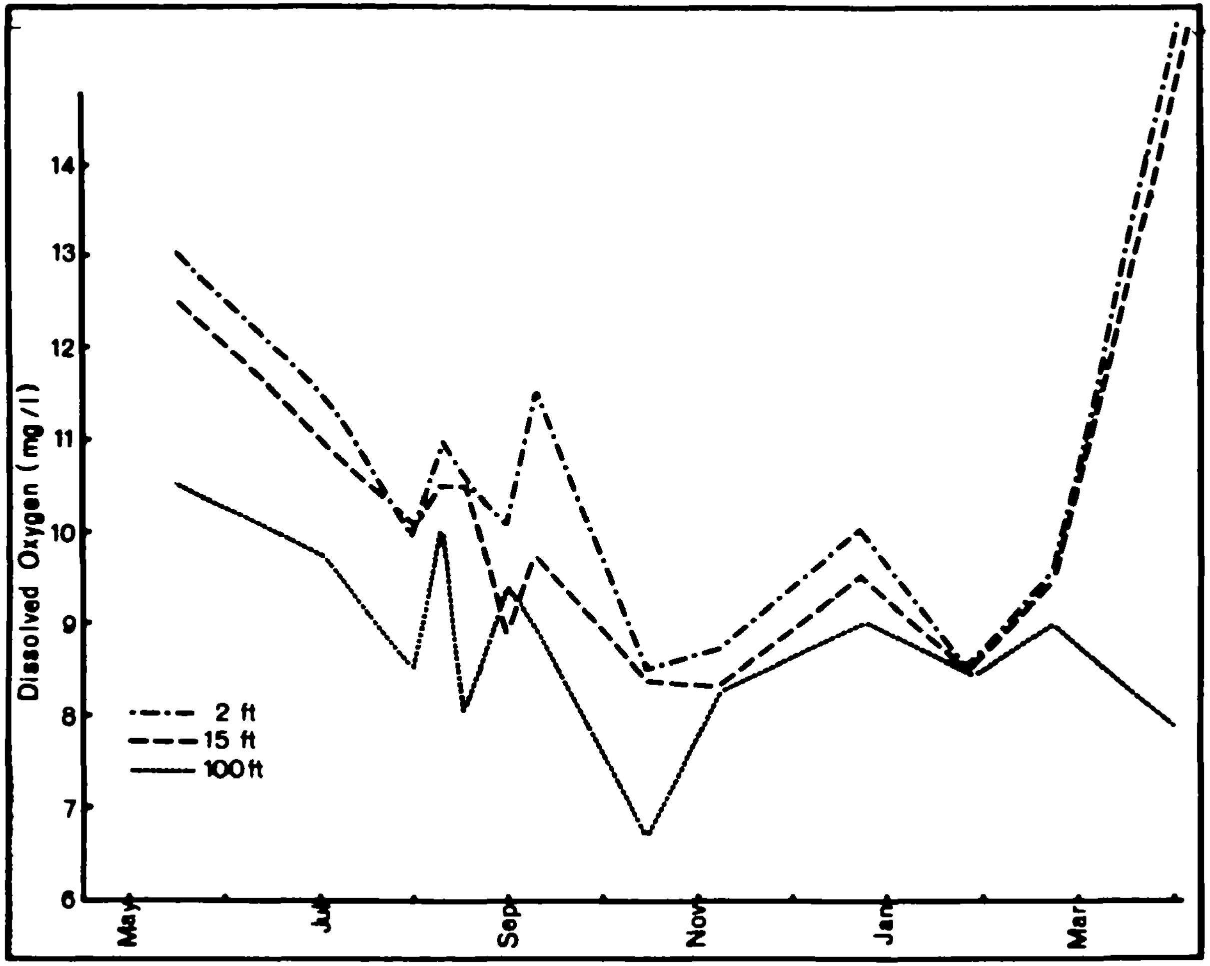

Figure 9. Typical dissolved oxygen concentrations in Silver Bay prior to construction of Pulp Mill, May, 1956 through April, 1957 (from Reference #3)

reported for Katlian Bay and in the pre-mill data.

Dissolved oxygen concentrations in Sawmill Cove measured during August, 1970, ranged from 4.5 to 9.5 mg/l in the first 5 meters of water (Table 3). Dissolved oxygen levels ranging between 4.6 and 8.0 mg/l were measured in August, 1965, throughout Sawmill Cove, other portions of Silver Bay, and Eastern Channel. (5)

Low dissolved oxygen levels in the spring and summer are consistent with the reduction of phytoplankton activity expected when SWL concentrations reach the high levels measured during these sampling periods. Oxygen-producing phytoplankton in the upper water layers are adversely affected by the toxicity of SWL. The lower dissolved oxygen observed in December, and expected throughout the winter, when SWL concentrations were relatively low, probably was the result of lower decomposition rates, decreased phytoplankton activity, and the intrusion of oceanic bottom waters that characteristically are low in dissolved oxygen.

Biological

Benthic Plants and Animals

According to information published in 1957 (3), many clean-water bottom organisms such as mussels, snails, crabs, shellfish, starfish, urchins, and green and brown algae, thrived in great abundance in the intertidal and bottom areas extending downward to about 27 meters in Sawmill Cove and adjacent portions of Silver Bay. Such organisms, unlike fish, reflect water quality over a long period of time, usually a year, because they have limited mobility.

During the 1968-69 study and again in August, 1970, visual inspection of the intertidal zone within Silver Bay revealed that many of the plants and animals found during the 1956-57 study no longer could be found in the Sawmill Cove area. Farther from the mill, along the northern shoreline toward the mouth of the bay, some of the organisms could be observed, but these appeared to be stunted. In the upper portion of Silver Bay and along much of its southern shoreline the effect of SWL on the organisms was either slight or imperceptible.

Blue mussels, Mytilus edulis, sampled at six sites in Silver Bay (Figure 10) and four sites in Katlian Bay (Figure 11) were abundant in Katlian Bay and in those portions of Silver Bay significantly distant from the pulp mill. Along the northern shoreline, between the pulp mill and the mouth of the bay, the number of blue mussels was drastically reduced (Table 3 and Appendix, Table 2A). At stations 1 through 4 in both Silver Bay and Katlian Bay more than 400 of these organisms were found per sampling unit. At stations 5 and 6 in Silver Bay, less than 100 were found. Populations of these semi-pollution tolerant animals decreased from station 5 toward the mill until none were found.

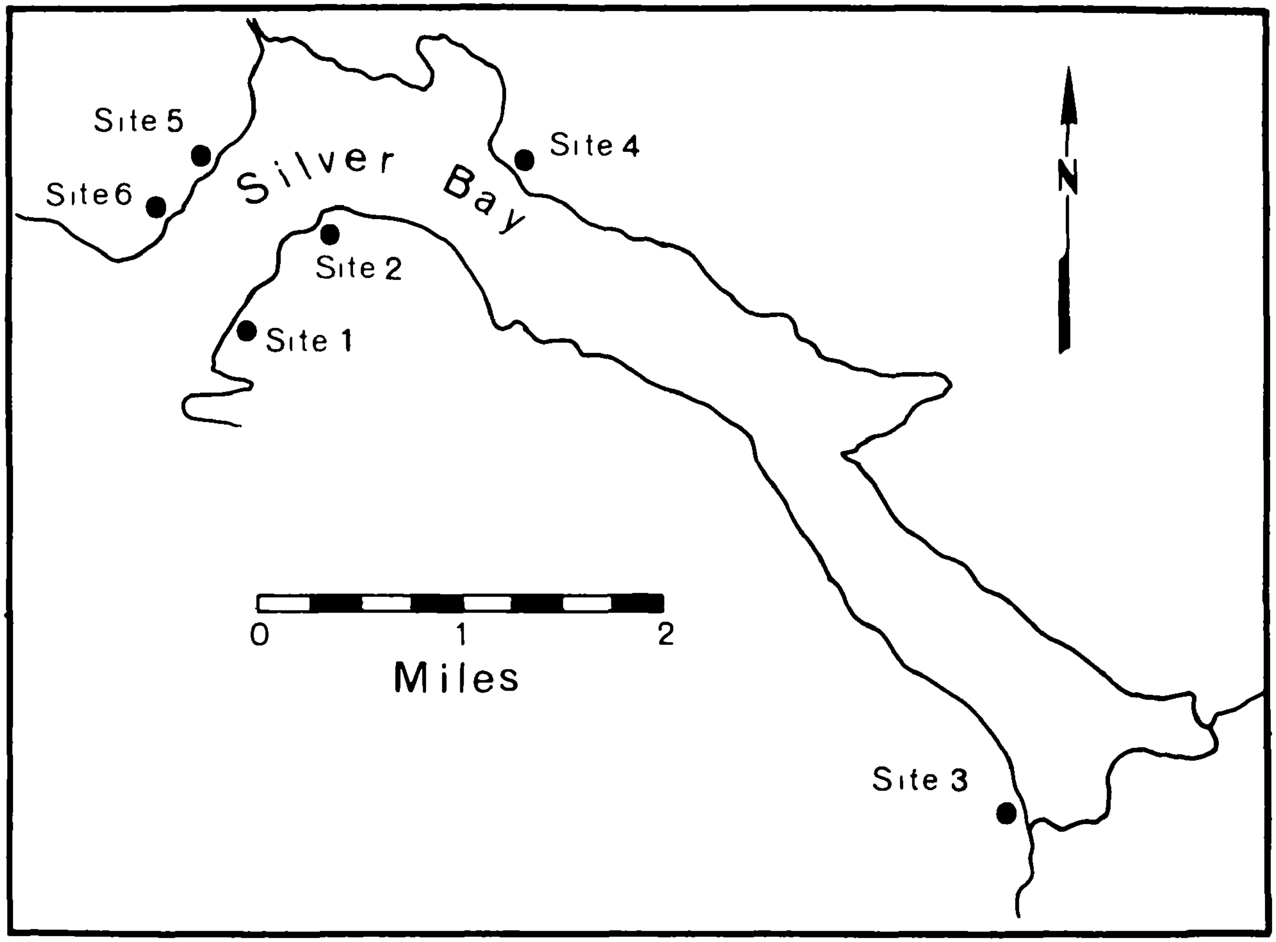

Figure 10. Location of intertidal stations in Silver Bay where *Mytilus edulis* samples were collected

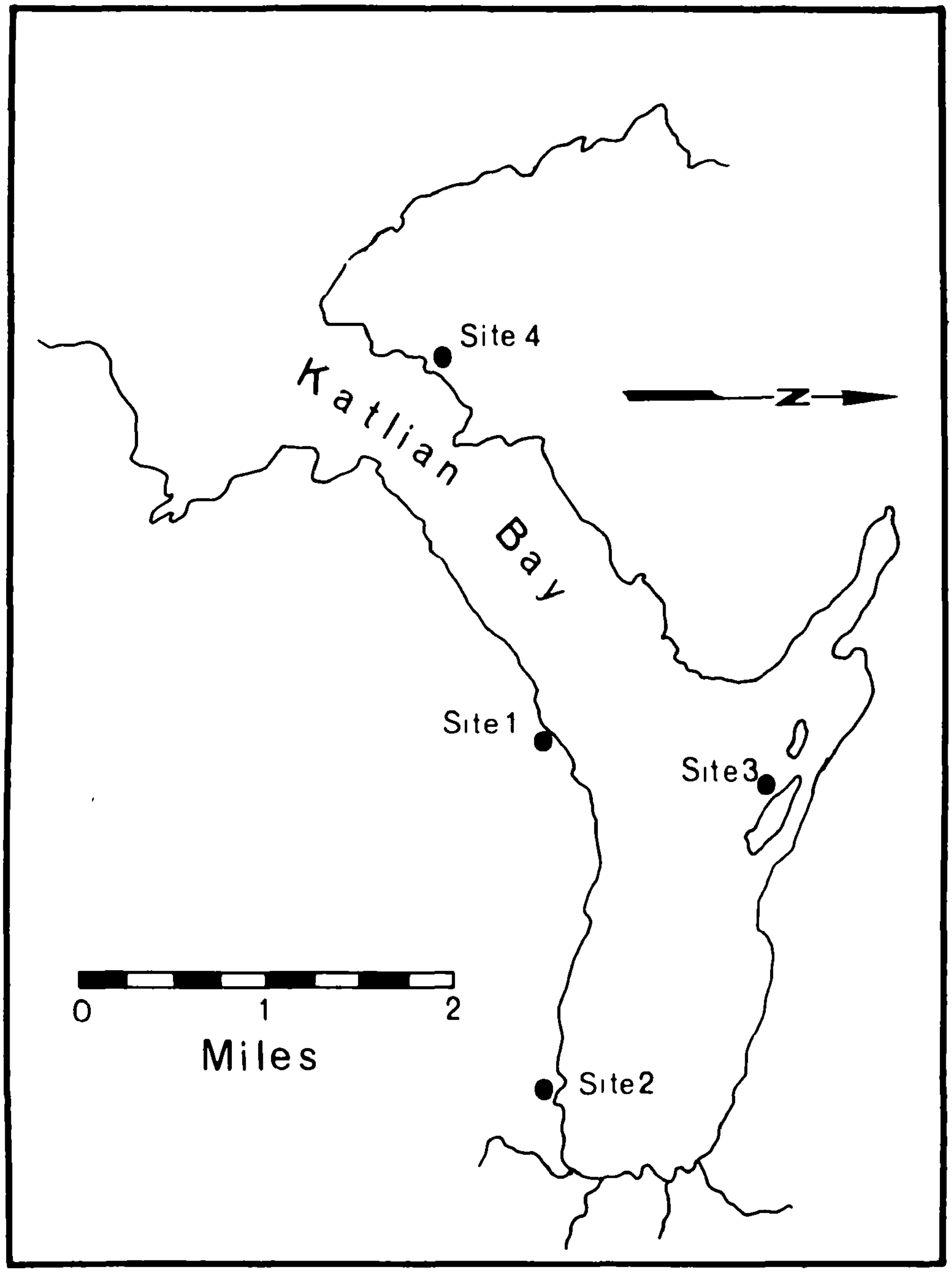

Figure 11. Location of intertidal stations in Katlian Bay where *Mytilus edulis* samples were collected

TABLE 3
TOTAL NUMBERS OF BLUE MUSSELS, MYTILUS EDULIS,
COLLECTED PER 30 MINUTE SAMPLING EFFORT AT 6 INTERTIDAL STATIONS
IN SILVER BAY AND 4 INTERTIDAL STATIONS IN KATLIAN BAY,
JULY, 1968.

	Stations					
	1	2	3	4	5	6
Silver Bay	1886	526	774 a/	474	39	68
Katlian Bay	575	414	1451	647		

a/ 15 minute sampling effort.

The reduction of aquatic life and the prevalence of black, foul-smelling sludge, that contains wood chips and pulp fibers, attest to the severely polluted condition of Sawmill Cove and adjacent portions of Silver Bay. (Figure 12). Sludge blankets nearly 0.2 square miles of the bottom of Sawmill Cove and Silver Bay (Figure 13). Some samples of bottom materials from Sawmill Cove and along the north shore toward the mouth of the Bay contained only polychaete worms. Other samples contained no macroscopic life.

Analyses of the sludge samples collected from Sawmill Cove in August, 1970, showed a carbon content ranging from 26.9 to 42.1 percent and a nitrogen content of 0.24 to 0.66 percent (Table 4). Enriched bottom deposits from an unpolluted area often have a carbon content of less than 5 percent and a nitrogen content of less than 0.10 percent. The carbon and nitrogen data show that a significant area of Sawmill Cove is intensively polluted. The high organic carbon and nitrogen values are similar to those associated with other raw wastes, such as sewage or wastes from packing houses.

TABLE 4
PERCENTAGES (DRY WEIGHT) OF ORGANIC CARBON AND ORGANIC NITROGEN FROM SAWMILL COVE BOTTOM DEPOSITS
AUGUST 1970

Station Number	% Organic Carbon	% Organic Nitrogen
34	40.28	0.52
35	30.40	0.66
38	26.90	0.24
Discharge from Sewer on Dugway	42.14	0.39

Floating sludge was collected from the waters of Silver Bay on September 11, 1970, when a fish kill occurred, culminating in the loss of at least 100,000 fish. Chemical analysis of the sludge showed a total sulfide concentration of 270 ppm, an initial oxygen demand of 320 ppm, and a chemical oxygen demand of 68,450 ppm.

Figure 12. Typical decomposing sludge consisting of wood chips and pulp fibers in the Sawmill Cove and Silver Bay study area

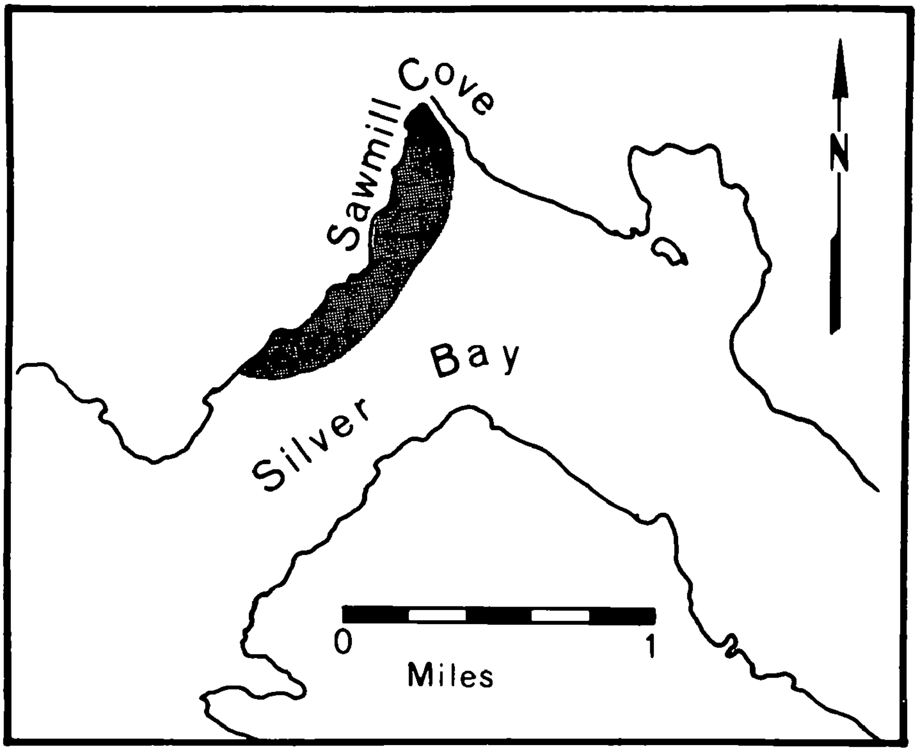

Figure 13. Silver Bay sludge deposits

Plankton

Sampling for microscopic plants and animals floating in the water (Appendix, Table 3A) was qualitative only, and was inadequate to establish patterns of plankton numbers and diversity associated with oxygen production and pollutional effects of the SWL. Nevertheless, studies in other waters that have dealt with plankton as related to oxygen production are generally applicable to Silver Bay. (3, 8)

High dissolved oxygen concentrations in estuarine and near-shore marine waters typically are the consequence of algae or other plant populations (attached or planktonic). These exhibit patterns of abundance associated with seasonal changes in water column mixing, nutrients, temperature, and daylight. Characteristically, northern marine waters are nutrient-rich in early spring as a result of poor plant growing conditions in winter and winter mixing of the water column. This, coupled with increased water column stability, increased temperature, and lengthening days, creates favorable conditions for phytoplankton activity, and a bloom begins. The bloom is evidenced by an increase in phytoplankton reproduction with an associated increase in dissolved oxygen production which may be followed by an increase in zooplankton. Often the water becomes supersaturated with dissolved oxygen. The spring bloom of algae in shallow waters usually is most noticeable in late April or early May. Shortly thereafter, it begins to subside because nutrients are depleted. As the algae become less abundant, the dissolved oxygen decreases to lower levels that persist throughout the summer.

In late August or early September, water stability established during the summer begins to decline, mixing follows, and nutrients may stimulate another phytoplankton bloom and associated increase in dissolved oxygen. This bloom is often short-lived because temperature and lengths of days are decreased to winter levels.

This annual phytoplankton cycle is inferred by plotting dissolved oxygen concentrations for one year or more. This was done with dissolved oxygen data for Silver Bay prior to operation of the pulp mill (Figure 9). It is apparent that dissolved oxygen was sufficiently abundant to result in supersaturation, and the cyclic pattern of phytoplankton abundance with blooms in May and August is implied.

The 1968-69 data showing reduced oxygen content in Silver Bay imply a toxic effect of SWL on phytoplankton (Table 2). SWL inhibits phytoplankton activity at concentrations exceeding 50 ppm. (3) The color of SWL also reduces the amount of light entering Silver Bay waters. It is axiomatic that the photosynthetic process of phytoplankton and attached algae is decreased if light is decreased, and that oxygen production will be reduced. Biochemical oxygen demand of the SWL and associated wastes discharged to Silver Bay also contribute to the decrease in dissolved oxygen.

Fish And Other Associated Animals

Extensive studies in Puget Sound have shown that SWL concentrations above 10 ppm are detrimental to many forms of biological life, particularly larval stages which are found in the upper 10 meters of the water column. (8). The Puget Sound studies also determined that survival and well-being of salmon were impaired when the following criteria were not met:

SWL-less than 1000 ppm

Total sulfides-no detectable amount

Dissolved oxygen-greater than 5 mg/l

pH -greater than 6.5

Ammonia Nitrogen-0.2 mg/l

The first two of these criteria frequently are not met in Silver Bay and dissolved oxygen, at times, is reduced below 6 mg/l. In the vicinity of the mill outfalls and in extensive benthic reaches of Sawmill Cove, sulfides were so apparent that they were detected readily by their strong hydrogen sulfide odor. During the August 20, 1970, survey, extensive gas formation due to anerobic decomposition of bottom deposits of wood chips and pulp fibers was occurring over the western half of Sawmill Cove. Floating sludge deposits were also observed in this area. On September 11, 1970, the sludge beds resulting from the discharge of inadequately treated mill wastes "bulked" and released a large mat of floating sludge. At the same time, the hydrogen sulfide and total sulfide concentrations in the waters of Sawmill Cove increased to high levels. A fish kill estimated at over 100, 000 occurred in conjunction with the "bulking" of these bottom sludges.

A previous study showed that calcium-base SWL is toxic or inhibitory to certain salmon-food and associated organisms at concentrations exeeding 50 ppm. (3) This study concluded that "to be entirely on the safe side of the toxicity range, concentrations of sulfite waste liquor solids should not exceed 50 ppm" in waters where salmon are expected to feed. A concentration of 50 ppm of SWL was exceeded, at times, over 11 square miles of the study area in Silver Bay and Eastern Channel.

It should be pointed out that while SWL concentrations less than 1000 ppm can be tolerated by juvenile salmon, they would be toxic, or otherwise harmful, to salmon-food and associated organisms. Thus, 50 ppm of SWL, or less, appears to be the upper limit necessary for the sustained survival and well-being of salmon food; 10 ppm appears to be the upper threshold for other aquatic organisms, particularly during larval stages (8).

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APPENDIX

TABLE 1A
TEMPERATURE, SALINITY AND DENSITY WITH DEPTH (METERS)
IN SILVER BAY AND EASTERN CHANNEL
1968-1969

DEPTH	Station Numbers 3[1]			4[1]			5			5[1]		
	T°C	S°/oo	σt	T°C	S°/oo	σt	T°C	S°/oo	σt	T°C	S°/oo	σt
	March 27, 28 and April 3, 1968											
0	5.07	31.13	24.63	5.00	30.69	24.29	4.90	30.15	23.87	4.76	30.51	24.17
2	5.33	31.49	24.89	5.32	31.40	24.82	5.34	31.00	24.50	5.26	31.12	24.61
5	5.29	31.55	24.94	5.28	31.55	24.94	5.29	31.40	24.82	5.28	31.50	24.90
10	5.20	31.58	24.97	5.16	31.58	24.98	5.22	31.51	24.91	-	-	-
15	5.14	31.60	25.00	5.14	31.58	24.98	5.18	31.52	24.93	5.18	31.60	25.00
20	5.06	31.61	25.01	5.08	31.60	25.01	5.06	31.56	24.97	-	-	-
25	-	-	-	-	-	-	-	-	-	5.10	31.66	25.04
30	5.05	31.69	25.08	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-	-	-	-
40	5.09	31.73	25.10	5.08	31.71	25.09	5.10	31.62	25.01	-	-	-
45	-	-	-	-	-	-	-	-	-	5.12	31.75	25.11
60	-	-	-	5.25	31.80	25.14	5.16	31.70	25.07	-	-	-
70	-	-	-	-	-	-	-	-	-	5.26	31.81	25.15
80	-	-	-	-	-	-	-	31.67	-	-	-	-

	Station Numbers 18			18[1]			23[1]			25		
	T°C	S°/oo	σt	T°C	S°/oo	σt	T°C	S°/oo	σt	T°C	S°/oo	σt
	March 27, 28 and April 3, 1968											
0	5.10	28.78	22.78	4.98	29.19	23.11	5.29	29.92	23.67	4.86	30.28	23.98
2	5.27	31.21	24.67	5.22	31.16	24.64	4.92	30.25	23.95	-	-	-
5	5.30	31.38	24.80	5.26	31.46	24.87	5.03	30.95	24.49	5.10	31.26	24.73
10	5.28	31.51	24.90	5.28	31.54	24.93	5.30	31.46	24.86	5.32	31.43	24.84
15	5.22	31.42	24.84	-	-	-	-	-	-	-	-	-
20	5.17	31.58	24.98	5.24	31.62	25.00	-	-	-	5.22	31.57	24.96
30	-	-	-	-	-	-	5.29	31.68	25.04	-	-	-
40	5.11	31.57	24.97	5.11	31.71	25.08	-	-	-	5.28	31.67	25.03
60	5.15	31.66	25.04	5.22	31.79	25.14	5.32	31.79	25.13	-	-	-
70	-	-	-	5.28	31.82	25.15	-	-	-	-	-	-
80	-	31.77	-	-	-	-	-	-	-	5.29	31.81	25.14

[1]March 28, 1968
[2]April 3, 1968

TABLE 1A (Continued)
TEMPERATURE, SALINITY AND DENSITY WITH DEPTH (METERS)
IN SILVER BAY AND EASTERN CHANNEL
1968-1969

	Station Numbers												
	2			3			4	8			16		
	T°C	S°/oo	σt	T°C	S°/oo	σt	S°/oo	T°C	S°/oo	σt	T°C	S°/oo	σt
December 13, 14, 1968													
0	6.0	27.1	21.4	-	-	-	-	-	-	-	5.0	20.5	16.3
1	6.0	28.0	22.1	-	-	-	-	-	-	-	7.0	27.3	21.4
5	7.2	30.2	23.7	-	-	-	-	-	-	-	7.0	30.4	23.8
10	-	22.8	-	-	-	-	-	-	-	-	-	30.8	-
20	-	-	-	-	-	-	-	-	-	-	-	29.9	-
December 15, 1968													
0	-	27.7	-	-	27.1	-	30.4	-	30.8	-	-	25.7	-
1	-	30.4	-	-	22.8	-	30.9	-	30.1	-	-	30.1	-
5	-	30.8	-	-	30.9	-	30.6	-	30.8	-	-	30.6	-
10	-	30.9	-	-	31.1	-	31.1	-	30.8	-	-	30.6	-
20	-	-	-	-	-	-	-	-	-	-	-	30.8	-
April 22, 1969													
0	-	27.5	-	5.0	18.2	14.5	23.0	5.6	26.2	20.7	5.5	27.1	21.4
1	-	30.0	-	5.0	31.7	25.1	31.0	5.1	29.5	23.4	5.7	29.2	23.0
2	-	-	-	4.9	-	-	-	5.1	-	-	5.0	-	-
3	-	-	-	4.9	-	-	-	5.0	-	-	4.2	-	-
4	-	-	-	4.9	-	-	-	-	-	-	-	-	-
5	-	31.2	-	4.8	31.7	25.1	31.7	4.9	31.5	24.9	4.0	31.3	24.9
7	-	-	-	4.8	-	-	-	4.9	-	-	4.0	-	-
10	-	31.5	-	4.8	31.8	25.2	31.7	4.8	31.6	25.0	3.9	31.5	25.0
14	-	-	-	4.6	-	-	-	4.8	-	-	3.7	-	-
20	-	31.6	-	4.6	-	-	-	-	31.7	-	-	31.5	-

TABLE 1A (Continued)
TEMPERATURE, SALINITY AND DENSITY WITH DEPTH (METERS)
IN SILVER BAY AND EASTERN CHANNEL
1968-1969

Station Numbers

DEPTH	18			23	24			25	28		
	T°C	S°/oo	σt	S°/oo	T°C	S°/oo	σt	S°/oo	T°C	S°/oo	σt
December 13, 14, 1968											
0	5.5	21.4	16.9	30.6	6.5	29.6	23.2	-	6.0	29.7	23.4
1	6.5	29.7	23.3	30.1	6.5	29.4	23.1	-	6.0	30.1	23.7
5	7.0	30.4	23.8	30.8	6.0	30.1	23.7	-	6.4	30.2	23.8
10	-	30.8	-	-	-	-	-	-	-	-	-
20	-	30.8	-	-	-	-	-	-	-	-	-
December 15, 1968											
0	-	21.9	-	30.4	-	29.6	-	-	-	30.2	-
1	-	30.8	-	30.6	-	29.6	-	-	-	30.4	-
5	-	30.4	-	30.4	-	29.6	-	-	-	30.3	-
10	-	30.4	-	30.8	-	30.6	-	-	-	30.4	-
20	-	30.8	-	-	-	-	-	-	-	-	-
April 22, 1969											
0	5.3	29.0	22.9	27.4	-	29.4	-	31.1	-	28.4	-
1	4.9	29.0	23.0	30.0	-	30.3	-	30.0	-	29.1	-
2	4.4	-	-	-	-	-	-	-	-	-	-
3	3.7	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-
5	3.3	31.3	24.9	30.9	-	31.1	-	30.6	-	31.0	-
7	3.8	-	-	-	-	-	-	-	-	-	-
10	3.8	30.9	24.6	31.4	-	31.5	-	30.8	-	31.5	-
14	3.8	-	-	-	-	-	-	-	-	-	-
20	-	31.8	-	-	-	-	-	-	-	-	-

TABLE 1A (Continued)
TEMPERATURE, SALINITY AND DENSITY WITH DEPTH (METERS)
IN SILVER BAY AND EASTERN CHANNEL
1968-1969

Station Numbers

DEPTH	13			16			34			35			36		
	T°C	S°/oo	t	T°C	S°/oo	t	T°C	S°/oo	t	T°C	S°/oo	t	T°C	S°/oo	t
							August 20, 1970								
0	10.0	8.9	<7.6	11.6	12.5	9.3	10.8	6.8	<7.5	10.7	10.8	8.1	10.8	11.5	8.6
1	12.1	20.9	15.7	12.7	27.5	20.7	11.8	23.4	17.7	12.0	23.2	17.5	11.9	23.0	17.4
2	12.1	32.0	24.3	12.2	29.9	22.6	12.2	27.2	20.5	11.5	31.7	24.2	12.3	28.5	21.5
5	11.4	30.1	22.9	11.7	31.6	24.0	11.6	31.5	24.0	11.2	32.1	24.5	11.5	31.8	24.2
10	-	-	-	11.4	32.0	24.4	-	-	-	12.0	28.9	21.9	11.3	32.0	24.4
15	-	-	-	-	-	-	-	-	-	-	-	-	11.2	32.2	24.6
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Station Numbers

DEPTH	37			38			39		
	T°C	S°/oo	σt	T°C	S°/oo	σt	T°C	S°/oo	σt
0	11.3	11.4	8.5	11.2	11.2	8.4	11.3	13.5	10.1
1	12.3	25.4	19.1	13.1	26.3	19.7	13.4	27.7	20.7
2	12.1	29.8	22.6	12.2	29.5	22.3	12.3	29.8	22.5
5	11.5	31.9	24.3	11.5	31.8	24.2	11.7	31.6	24.0
10	11.1	32.3	24.7	11.2	32.4	24.7	11.5	32.1	24.5
15	-	-	-	-	-	-	11.2	32.1	24.5
20	-	-	-	-	-	-	11.1	32.2	24.6
25	-	-	-	-	-	-	10.9	32.3	24.7
30	-	-	-	-	-	-	10.3	32.4	24.9
35	-	-	-	-	-	-	9.7	32.2	24.8
40	-	-	-	-	-	-	8.9	32.2	25.0
45	-	-	-	-	-	-	8.7	32.4	25.2
50	-	-	-	-	-	-	8.1	32.4	25.3
55	-	-	-	-	-	-	7.4	32.8	25.7

TABLE 2A
LENGTH-FREQUENCY DISTRIBUTION OF BLUE MUSSELS, <u>MYTILUS EDULIS</u>,
AT 6 SITES IN SILVER BAY AND 4 SITES IN KATLIAN BAY
JULY 1968.

	Silver Bay						Katlian Bay			
Site/Length in mm	15 min. 1	2	15 min. 3	4	5	6	1	2	3 app	4
1		2					11	8	550	123
2	3	11	1	1	2		23	10	72	32
3	30	46	2	4			8	23	69	32
4	52	64	3	8	3		8	17	58	29
5	44	84	1	13	2	1	6	17	62	26
6	35	58		14	6		16	12	46	21
7	32	47	4	11	2	1	13	9	48	21
8	51	43	5	11	4	2	16	12	27	18
9	49	33	1	8		3	14	17	30	28
10	57	35		13		2	25	14	35	18
11	69	24		11		3	24	8	21	37
12	68	23		19	2	2	14	9	32	35
13	62	24		28	3		13	13	18	26
14	68	9		35	5	6	30	16	15	25
15	51	8	1	30	1	3	13	7	17	28
16	41	6		30	2	6	25	14	21	32
17	43	3		27	2	7	20	10	14	16
18	28	1	1	27	1	3	22	11	20	20
19	34	3		31	1	4	21	10	13	15
20	29	1		31	2	5	25	6	13	9
21	16			29		7	15	4	7	7
22	20		1	23		6	15	4	7	8
23	16		2	18		1	12	5	13	8
24	8		1	8		3	22	6	13	4
25	8		5	17		1	16	11	7	8
26	6	1	2	3		2	13	2	10	5
27	5		3	9	1	2	19	5	10	4
28	4			6			15	4	3	
29	2		1	1		5	14	2	5	2
30	1		2	4		5	13	9	9	3
31	3		4			3	16	6	8	
32	3		7				9	2	8	1
33	2		8				11	5	11	
34	3		10	3		2	8	4	9	2
35			6				8	2	14	2
36			6				4	4	9	1
37			17			2	11	6	9	2

TABLE 2A (Continued)
LENGTH-FREQUENCY DISTRIBUTION OF BLUE MUSSELS, MYTILUS EDULIS, AT 6 SITES IN SILVER BAY AND 4 SITES IN KATLIAN BAY JULY 1968.

	Silver Bay						Katlian Bay			
Site/Length in mm	15 min. 1	2	15 min. 3	4	5	6	1	2	3	4
38			12				4	2	8	1
39			22	1			3	6	5	
40	1		24				2	4	8	
41			27				4	6	6	
42			27			1	3	2	11	
43			27				1	2	9	
44			28					1	8	
45			31					5	3	
46			24					7		
47			13					4	5	
48			13					5	8	
49			12					4	4	
50			10					4	2	
51			8					4	5	
52			2					3	5	
53			5					6	7	
54			4					5	4	
55			2					6	2	
56			2					5	1	
57								2		
58								1		
59								1	2	
60								3	2	
61								1		
62									3	
63									1	
64									3	
65									3	
66									2	
68								1	1	
TOTAL	943	526	387	474	39	88	575	414	1451	647

TABLE 3A
PERCENTAGES OF PHYTOPLANKTON IN SAMPLES
FROM SILVER BAY, EASTERN CHANNEL AND KATLIAN BAY
1968-1969

Station	Nos.	Coscinodiscus) Thalassiosira)	Chaetoceros	Ditylum	Thalassiothrix	Nitzschia	Eucampia	Biddulphia	Corethron	Skeletonema	Asterionella	Rhizoselenia	Ceratium	Peridinium	Fragillaria	Total Individuals Counted	Depth of Haul	Direction - Vertical or Oblique
Oct. 1968	3	3	57	1	31	5	1	<.5	<.5	1	--	--	<.5	<.5	--	4,836	25	O
	4	2	62	1	29	3	1	--	--	1	<.5	--	<.5	<.5	--	10,837	25	O
	8	3	64	2	24	5	<1	--	--	1	--	--	<.5	--	--	1,893	25	O
	16	10	33	3	36	13	1	--	<.5	3	--	--	<.5	<.5	--	733	25	O
	18	8	38	5	40	6	--	--	<.5	1	--	--	<.1	<.5	--	1,161	25	O
	21	8	33	3	46	7	--	--	<.5	2	--	--	<.5	<.5	--	1,824	25	O
	24	6	45	6	34	5	<.5	--	<.5	2	--	--	1	--	--	1,152	25	O
	23	6	53	4	29	5	--	--	<.5	1	--	--	1	<.5	--	983	25	O
	25	3	49	4	35	6	<.5	--	<.5	1	--	<.5	<.5	<.5	--	1,604	25	O
	30	13	76	5	1	3	--	--	--	--	--	--	1	<.5	--	392	25	O
	31	8	81	3	5	1	--	--	<.5	--	--	--	1	<.5	--	526	25	O
	32	9	65	3	16	2	--	--	--	1	--	--	3	<.5	--	384	25	O
	31	20	63	4	10	1	--	--	--	<1	--	--	<1	<.5	--	897	25	O
Dec. 1968	3	68	14	4	--	--	7	--	--	--	--	--	5	1	--	76	2	V
		88	7	1	--	--	--	--	--	--	--	--	1	2	--	82	30	V
	4	86	2	1	11	--	--	--	--	--	--	--	1	--	--	119	2	V
		73	13	7	--	--	--	--	--	--	--	2	4	1	--	99	30	V
	8	75	8	4	7	--	--	--	--	--	--	--	5	--	--	96	2	V
		63	21	4	8	--	--	--	<.5	--	--	<.5	2	1	--	301	30	O
	16	92	--	2	--	--	--	--	--	--	--	--	2	2	3	62	2	V
		90	--	1	3	--	2	--	--	--	--	--	1	2	--	160	30	O
	18	65	12	8	--	--	12	--	--	--	--	--	2	1	--	85	2	V
		69	13	4	5	--	3	--	--	--	--	--	5	--	--	251	25	O

TABLE 3A (Continued)
PERCENTAGES OF PHYTOPLANKTON IN SAMPLES
FROM SILVER BAY, EASTERN CHANNEL AND KATLIAN BAY
1968-1969

Station Nos.	Coscinodiscus) Thalassiosira)	Chaetoceros	Ditylum	Thalassiothrix	Nitzschia	Eucampia	Biddulphia	Corethron	Skeletonema	Asterionella	Rhizoselenia	Ceratium	Peridinium	Fragillaria	Total Individuals Counted	Depth of Haul	Direction - Vertical or Oblique
21	69	7	5	3	--	7	--	--	--	--	--	6	< 2	--	134	2	V
	77	5	5	7	--	3	<.5	--	--	--	--	3	<.5	--	308	25	0
24	93	3	1	--	--	--	--	--	--	--	--	2	--	--	118	2	V
	75	8	1	11	--	--	2	< 1	--	--	--	2	.5	--	234	25	0
23	70	8	5	9	--	--	--	--	--	--	--	8	<.5	--	208	2	V
	83	5	4	6	--	--	<.5	--	--	--	--	1	--	--	235	25	0
29	63	10	15	6	--	--	--	--	--	--	--	6	--	--	48	2	V
	78	3	3	--	--	--	--	--	--	--	--	13	3	--	32	10	V
22 April, 1969						RELATIVE ABUNDANCE PHYTO PLANKTON R-Rare, 0-Occasional; C-Common											
3	OC	C	--	--	R	--	--	--	--	--	--	--	0	0		25	0
4	OC	C	--	--	--	--	--	--	--	--	--	--	0	0		25	0
8	RC	C	R	--	R	--	--	--	--	--	--	--	R	0		25	0
16	OC	C	R	--	0	--	R	--	R	--	--	--	0	R		25	0
18	RO	C	R	--	0	--	--	--	R	--	--	--	0	R		25	0
21	OC	C	--	--	0	--	--	R	--	--	--	--	0	0		25	0
24	RC	C	--	--	0	--	R	--	--	--	--	--	0	R		25	0
23	OC	C	R	R	0	--	R	--	--	--	--	--	0	R		25	0
25	OC	C	R	--	0	--	R	--	--	--	--	--	0	R		25	0
Near Outfall	OC	C	--	--	0	--	--	R	--	--	--	--	--	R		5	0
33	OC	C	--	--	0	--	R	--	0	--	--	R	R	0		25	0
32	OC	C	--	R	0	--	R	R	0	--	--	--	R	0		25	0