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FIELD TOXICITY STUDIES AND JUVENILE SALMON DISTRIBUTION IN PORT ANGELES HARBOR, WASHINGTON

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ABSTRACT

In partial fulfillment of the objectives of a joint Federal-State Conference on Puget Sound and the Strait of Juan de Fuca a study was made in Port Angeles Harbor, Washington to determine water quality conditions, the presence and distribution of Juvenile Pacific salmon in areas of pulp mill waste discharges and the effect that such discharges may have on those salmon.

The primary cause of toxicity was determined to be sulfides originating from the anaerobic decomposition of sludge deposits at the bottom of the harbor.

Sulfide levels of 0.3 mg/l were toxic to juvenile salmon but distress was noted at concentrations of 0.1 and 0.2 mg/l. Toxicity was also dependent upon the stage of the tide.

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FIELD TOXICITY STUDIES AND JUVENILE SALMON DISTRIBUTION IN PORT ANGELES HARBOR, WASHINGTON

A joint Federal-State Conference held on January 16 and 17, 1962 between officials of the Washington State Water Pollution Control Commission and the United States Public Health Service concerning "Pollution of Interstate Waters ..... Puget Sound, Strait of Juan de Fuca and their Tributaries and Estuaries," initiated an extensive cooperative study to evaluate the effects of waste discharges on these receiving waters. In partial fulfillment of the objectives of this conference, a study was made by the Washington Water Pollution Control Commission of water quality conditions in Port Angeles Harbor, the presence, if any, of migrating juvenile salmon in areas of industrial waste discharges, and the effect, if any, that such waste discharges may have on those salmon.

The estuary plays a major role in the success of a salmon population. After hatching, the young fish spend a portion of their life in fresh water and then undergo physiological conversion from fresh to salt water in the tidal areas of their natal stream. Further growth is attained in the estuary which enables them to compete satisfactorily in the open waters of Puget Sound and the Pacific Ocean.

Port Angeles Harbor, the Elwha and Dungeness Rivers, Morse Creek and other smaller streams in the Port Angeles area are important natural spawning and rearing grounds for several species of salmon, anadromous trout, crabs,

and many other fish and shellfish species. Although juvenile salmon use these areas for feeding, rearing and migration, specific knowledge of their distribution was not known. There was also some question as to whether or not juvenile salmon enter areas near pulp mills, and further, whether the waters adjacent to these mills were capable of supporting fish life.

With the above questions in mind the study was designed, (1) to determine the distribution and occurrence of juvenile salmon in Port Angeles Harbor, (2) to determine whether toxic water quality conditions occurred in the harbor, and (3) if toxicity problems did exist, when did they occur, what areas were affected and what were the causes.

The study was initiated early in April and continued through May, 1964.

METHODS AND PROCEDURES

Fish Distribution and Occurrence. Beach-seine stations (Figure 1) were established at various locations in the harbor. Each seine haul was made parallel to the shoreline for approximately 100 feet and the fish collected were identified, counted and released.

Floating Field Laboratory. A floating field laboratory was constructed specifically for use in areas of industrial waste discharges (Figure 2). It provided the means of evaluating the toxicity of such discharges to juvenile salmon.

When assembled, the structure was nine feet long, eight feet wide, with an open center section three feet wide and eight feet long. In the open center section, a live box consisting of a wooden frame covered with 16 mesh plastic screen was suspended by ropes cleated to the surface of the float. The platform space on both sides of the open section was sufficiently large to contain all sampling and chemical apparatus, plus three men.

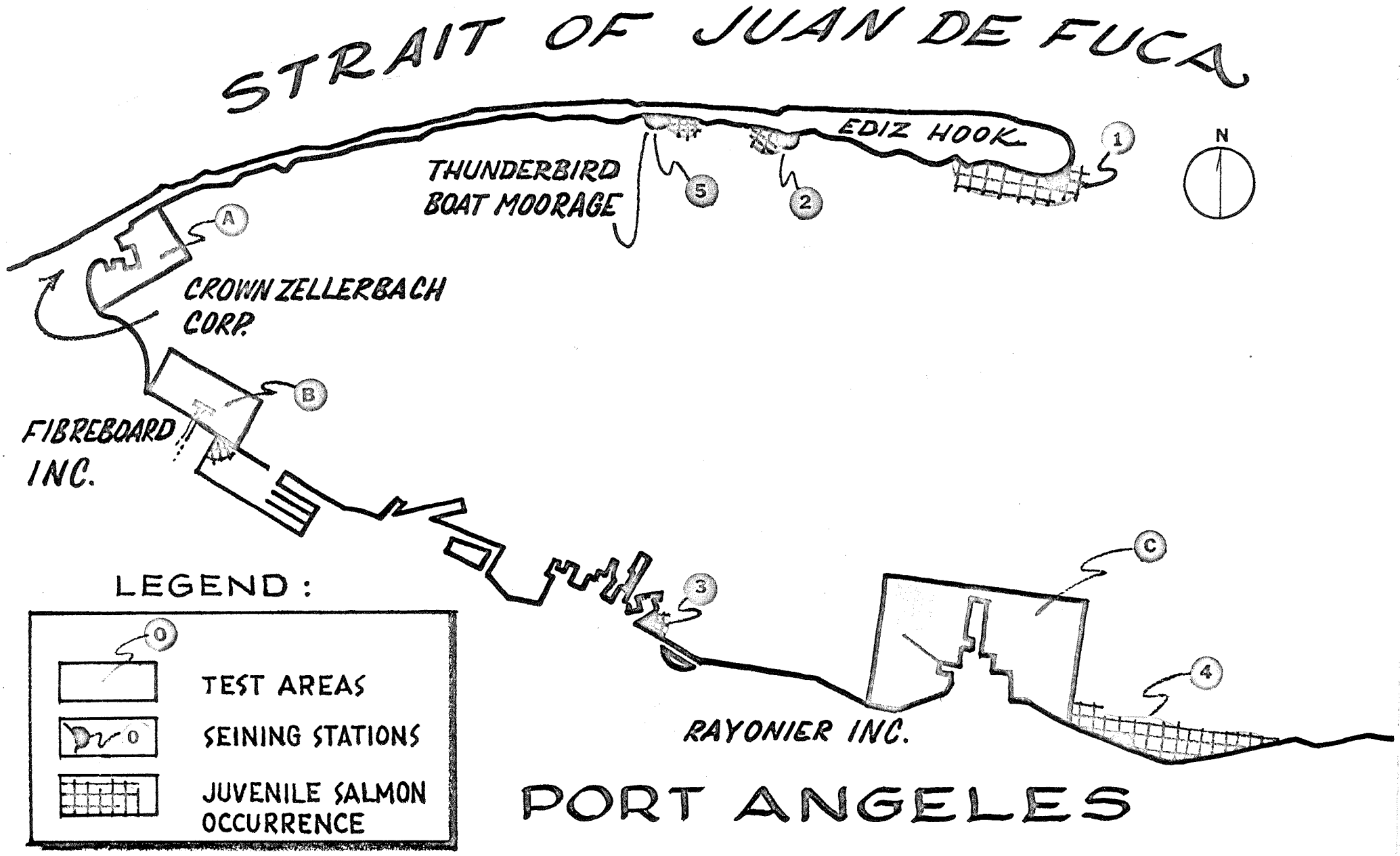

Figure 1. Study area, Port Angeles Harbor, Washington.

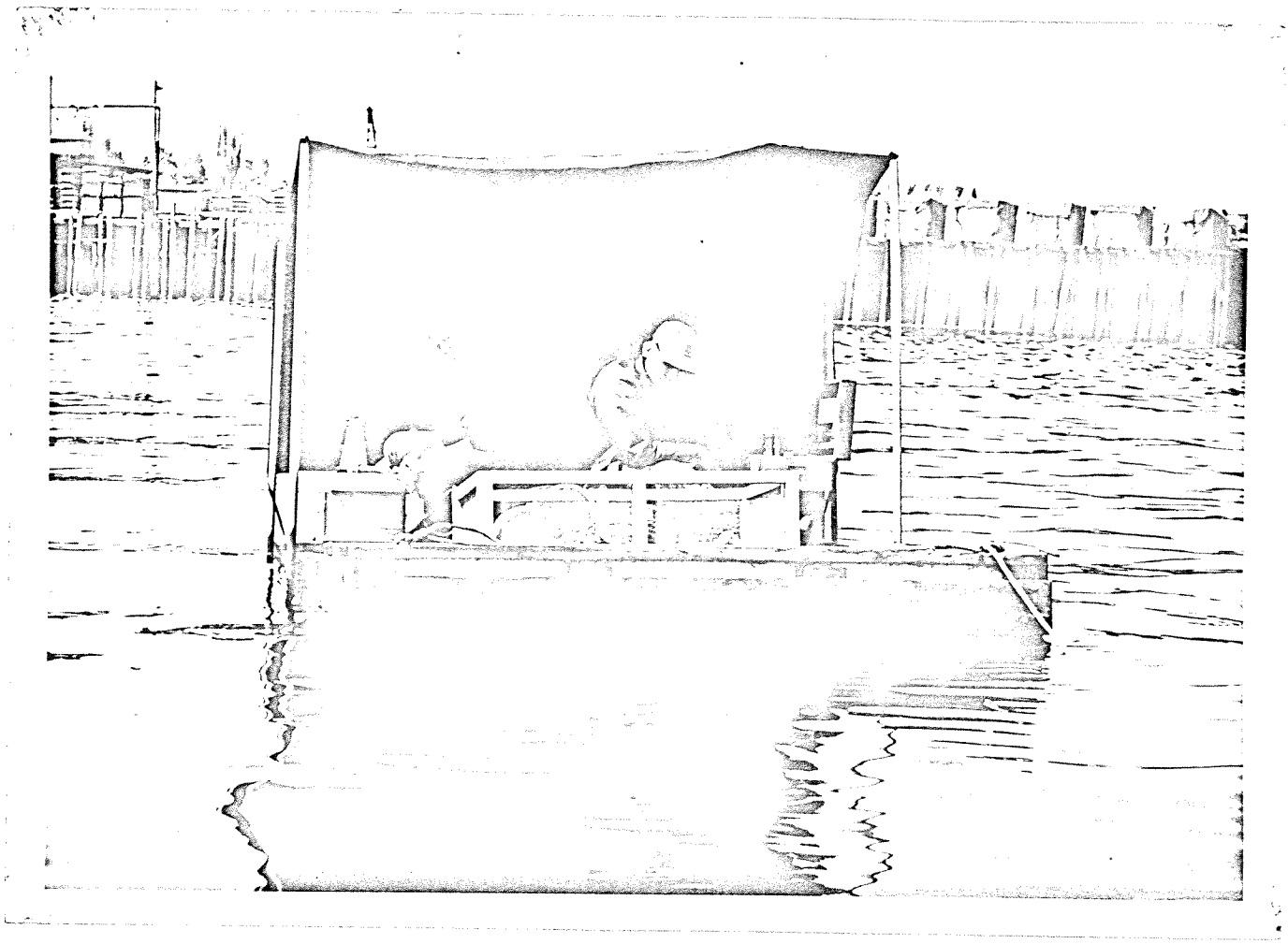

Figure 2. Floating field laboratory used during the field toxicity studies in Port Angeles Harbor, Washington.

The FFL, floating field laboratory, was towed from area to area with an outboard powered boat. For a more detailed description of this unit see Ziebell (1).

Area Concept and Field Test Procedure. Test areas were established in the vicinity of three pulp and paper mills which were operating in Port Angeles Harbor. These were Crown Zellerbach Corporation (Area A); Fibreboard Products, Incorporated (Area B); and Rayonier, Incorporated (Area C). Four field tests were conducted in each of these areas during the study period (Figure 1 and Table 2).

On a given day, the FFL was anchored in an area, and five or six live boxes of a second type were then placed at intervals around the perimeter of the FFL. These live boxes were made of fiberglass pipe, 12 inches in diameter and 18 inches long. The open ends were covered with small mesh nylon netting held in place by strips of tire tube. They were equipped with two brass eye-bolts with attached brass snaps. The boxes were secured to screw eyes affixed to boom logs or attached to anchored floats.

Test fish used in these field observations were either pink salmon Oncorhynchus gorbuscha (Walbaum) or chum salmon Oncorhynchus keta (Walbaum) fingerlings. All fish were collected with a beach seine from seining stations 1, 2 and 5 (Figure 1). They were then transported to a holding box located outside the industrial zone near the Thunderbird boat moorage and held for a minimum of 24 hours. This holding period made it possible to detect and remove any injured fish prior to their use in the field tests.

Water samples were collected with a 12 volt D.C. battery-operated centrifugal pump with rubber impeller. The hoses used were of nontoxic plastic. Water samples were collected from a depth of eight inches within the live box of the FFL every 20 minutes and were analyzed immediately for pH, temperature, dissolved oxygen and total sulfide.

When lethal water quality conditions became evident, as indicated by the reactions of the test fish and by water analysis, continuous sampling was conducted.

Ten salmon fingerlings were placed in the live box of the FFL and were kept under constant observation. Ten fish were also put into each perimeter live box.

Weather conditions, tide ranges, wind direction and velocity were recorded during the observations.

Current studies to determine surface patterns through the FFL had been carried out previously by introducing rhodamine "B" dye into the bay at various points. The dye was observed until a current pattern was established.

Experiments were conducted to evaluate water quality conditions under different tidal elevations. The length of each experiment varied, but most were conducted during the last stages of an ebb tide and one hour past the tide reversal.

Chemical Analysis and Methods. Dissolved oxygen was determined according to the Alsterberg (Azide) modification of the Winkler method. A Beckman, Model N, pH meter was used for pH determination and total sulfides were determined by the colorimetric method described in Section II, part B-4 of Standard Methods for the Examination of Water and Wastewater, Eleventh Edition, 1960. Salinity samples were stored in citrate bottles and returned to the Washington Water Pollution Control Commission laboratory in Olympia for analysis with a Hytech salinometer. Sulfite waste liquor, SWL, concentrations were determined by the Pearl-Benson test, PBI (2). Water temperatures were taken with a standard centrigrade thermometer suspended in the live box of the FFL at the depth of the water sampling intake hose.

FISH DISTRIBUTION AND OCCURRENCE

To properly evaluate the effect of water quality conditions in Port Angeles Harbor on young salmon, it was necessary to (1) determine whether or not these fish actually entered the harbor; (2) determine what areas they utilized; and (3) relate this information to the FFL toxicity studies.

The species of salmon found in the harbor during the study were pinks and chums. The pink salmon originated from either the Dungeness or Elwha Rivers. The smaller streams in the vicinity of Port Angeles Harbor had not supported a pink run for the last four or five cycles because of low water when the adults enter the parent streams.[1]

The number and species of fish collected at each station are shown in Table 1. Figure 1 shows the areas within the harbor where pink and chum salmon were observed or captured. The largest number of fish were found at station 5, in and around the Thunderbird boat moorage. Distressed fish were often collected

[1] Personal communication. Washington Department of Fisheries, 1964.

at station 4, east of Area C, when Northwest winds on an ebbing tide had a tendency to concentrate sulfite waste liquor along the beach at this station. The same conditions were true at station 3 when the opposite wind and tide conditions prevailed. However, station 3 could only be seined effectively during a high tide and no distressed fish were ever collected.

The physical characteristics of the shoreline, and log rafting near Area A and Area B made beach seining impossible. Visual observations were attempted but were unsuccessful because of turbid waters. On one occasion, however, a school of approximately 35 juvenile pink salmon was observed in the Port Angeles boat basin.

The study of juvenile pink and chum salmon distribution evidenced that these fish entered Port Angeles Harbor. They were collected adjacent to Area C which was found to have, on occasion, conditions toxic to fish. It is also suspected that the juvenile salmon follow the shoreline and enter waters near the other pulp and paper mills.

Table 1. Fish distribution and occurrence studies, Port Angeles Harbor. Species of fish observed or collected.

Station	Species	Total Number Collected by Seine	Approximate Number Visual Observations
1	Pink and Chum	419	50
	Chinook	2	
	Silver	1	
2	Pink and Chum	2	
3	Pink and Chum	78	
	Smelt	50	
	Starry Flounder	1	
4	Pink and Chum	205	
	Cutthroat	4	
	Starry Flounder	4	
	Smelt	*	
5	Pink and Chum	349	1,100
Port Angeles boat basin.	Pink and Chum		35

* Smelt were consistently captured at this station but were not counted.

DISCUSSION

The data collected showed that toxicity problems and marginal water quality conditions existed in the vicinity of all three pulp and paper mills. Many of the field tests, however, indicated that the water quality was periodically acceptable for juvenile salmon under certain circumstances in these same areas. It is recognized that the water in an area toxic to juvenile salmon on one day may not exhibit the same toxic properties on subsequent days and vice versa. Even when taking this variability of water quality into consideration, the data still pointed out the general areas where toxicity could be expected.

Field observations indicated that toxicity developed rapidly and that all of the test fish in the live boxes were killed within a short period of time. Furthermore, the toxic conditions subsided almost as quickly as they developed. This observation of rapid toxicity development was significant because it suggests that juvenile salmon could enter an area when the water quality was favorable and may be unable to escape a developing toxic condition.

Since the mortalities occurred rapidly, and the test fish sank to the bottom after death, a kill of migrating juvenile salmon could occur because of toxic water conditions, and not be detected. The victims would sink to the bottom and be hidden from sight.

Sulfides. Fish mortalities in the field tests were correlated with sulfide levels of 0.3 mg/l or more (Table 2). The sulfides originated in the organic sludge deposits which were undergoing active anaerobic decomposition at the bottom of the harbor in the test areas. By the time sulfides were detected, the test fish were at the surface and displayed signs of distress. The lower analytical limit of the sulfide test was 0.1 mg/l $\pm$ 10 per cent. Therefore, a positive distress reaction was observed at less than 0.1 mg/l.

Juvenile pink salmon were slightly more tolerant to sulfides than chum salmon, but a precise minimum lethal concentration was not established. Pink salmon were observed to tolerate 0.2 mg/l of sulfide for one hour without any mortalities.

The possibility of a delayed mortality after an apparent sub-lethal exposure was suggested. Fish were transported to the control area after they were exposed to 0.2 mg/l of sulfide and held for a period of 24 hours. A 10% mortality was observed and it was concluded that sulfide levels in excess of 0.2 mg/l for one hour would be required to cause significant pink salmon mortalitites. Both pink and chum salmon tolerated a momentary sulfide exposure of 0.3 mg/l, but an exposure to 0.5 mg/l caused immediate distress, loss of equilibrium and immobility.

Dissolved Oxygen. The dissolved oxygen values determined during some of the field tests have been demonstrated by many investigators to adversely affect or cause mortalities in salmonid fishes (3) (4). It has also been shown that certain reducing substances, such as sulfides and SWL, interfere with the Winkler test (5).

An "iodine correction," as used by Williams, *et al.* (5) was applied to some of the dissolved oxygen values during field test 8 to determine the relative magnitude of interference by the reducing agents in the water. It was found that the Winkler values were as much as 1.5 mg/l lower than the actual dissolved oxygen after the "iodine correction" was applied. This should be kept in mind when reviewing the dissolved oxygen data in Table 2.

Temperature, Hydrogen Ion Concentration and Salinity. Water temperatures ranged from 8.0 to 14.0 degrees celsius during the tests. Temperature fluctuations were gradual and ranges were well within tolerable limits for pink and chum salmon (6).

Hydrogen ion concentration, pH, values were generally acceptable to salmonid fishes (7) with the exception of test 11 when the pH was found to have dropped to 4.0. Fish mortalities were observed during this test, however, sulfide concentrations ranged from 0.3 to 0.5 mg/l. Such low pH values are known to increase toxicity when sulfides are the toxicant (8).

/s and summary of pertinent water quality data, 1964 bioassay study in Port Angeles

arent ed Oxygen /l			PBI mg/l				pH				Mortalities in Perimeter live boxes (%)					
ı.	Mean	N.	Max.	Min.	Mean	N.	Max.	Min.	Mean	N.						
4	6.4	1	--	--	--	--	6.8	6.8	6.8	1	100	20	0	0	0	--
7	5.8	9	20	18	19	3	7.8	7.4	7.6	9	--	--	--	--	--	--
7	6.8	13	813	16	318	4	8.0	7.3	7.7	13	0	0	0	0	0	
3	4.8	13	94	30	67	4	7.3	6.9	7.2	9	100	100	20	10	0	--
2	5.9	11	627	23	306	4	7.6	7.1	7.4	11	100	10	0	0	0	--
3	5.8	8	96	57	73	3	7.7	7.6	7.7	8	100	10	0	0	0	--
4	6.1	10	593	143	196	3	7.8	7.3	7.6	10	10	0	0	0	0	0
)	4.0	7	1,320	102	711	2	7.3	6.4	6.7	5	100	100	100	100	100	--
5	4.5	3	1,010	1,010	1,010	1	6.9	6.9	6.9	3	--	--	--	--	--	--
)	2.4	8	8,870	941	3,830	3	6.8	5.9	6.3	8	80	70	30	30	30	0
)	0.0	1	2,270	2,270	2,270	1	4.0	4.0	4.0	1	--	--	--	--	--	--
5	4.6	11	644	57	222	4	7.5	7.1	7.3	11	100	100	0	0	0	0
4	3.7	2	67	67	67	1	7.2	7.2	7.2	2	--	--	--	--	--	--

: tests. Salinities varied from 29.4 to 31.5 °/oo. Dissolved oxygen values have not
erference.

Salinity values ranged from 26.5 to 31.5 parts per thousand and were not considered to be a significant factor in this study.

Sulfite Waste Liquor. Sulfite waste liquor concentrations were found to be highest in area C during test 10 (Table 2). Fish mortalities occurred when SWL values were 8,870 mg/l and trace amounts of sulfides were detected. A minimum pH value of 5.9 was also recorded. The data indicates that the waters were devoid of dissolved oxygen, however, because of the known interferences with the Winkler test by SWL, the actual dissolved oxygen content is not known.

While the direct relationship between fish mortalities and SWL was not specifically established, the possibility of such influence must not be overlooked. The short term tests conducted were designed to determine acute toxicity, and toxic effects from SWL have been shown to be more of a chronic nature (5). It appears that the high concentrations of SWL were most significant as an interference in the measurement of dissolved oxygen by the Winkler method.

Tide and Surface Currents. Water quality conditions deteriorated most rapidly and fish mortalities occurred more frequently when the tide elevation ranged between zero and 2.5 feet below mean lower low water. Most mortalities were observed during the period from one-half hour before slack ebb through one hour of the flood tide.

When tidal elevations dropped to minus levels, blankets of sludge from the bottom of the area being tested often came to the surface. When this happened, mortalities invariably occurred in either the FFL or the perimeter live boxes.

Surface water currents caused by tidal activity had a direct influence upon the movement of toxic substances. The degree of significance was not as pronounced as tide elevation, but was considered a factor when defining toxic zones in the three test areas.

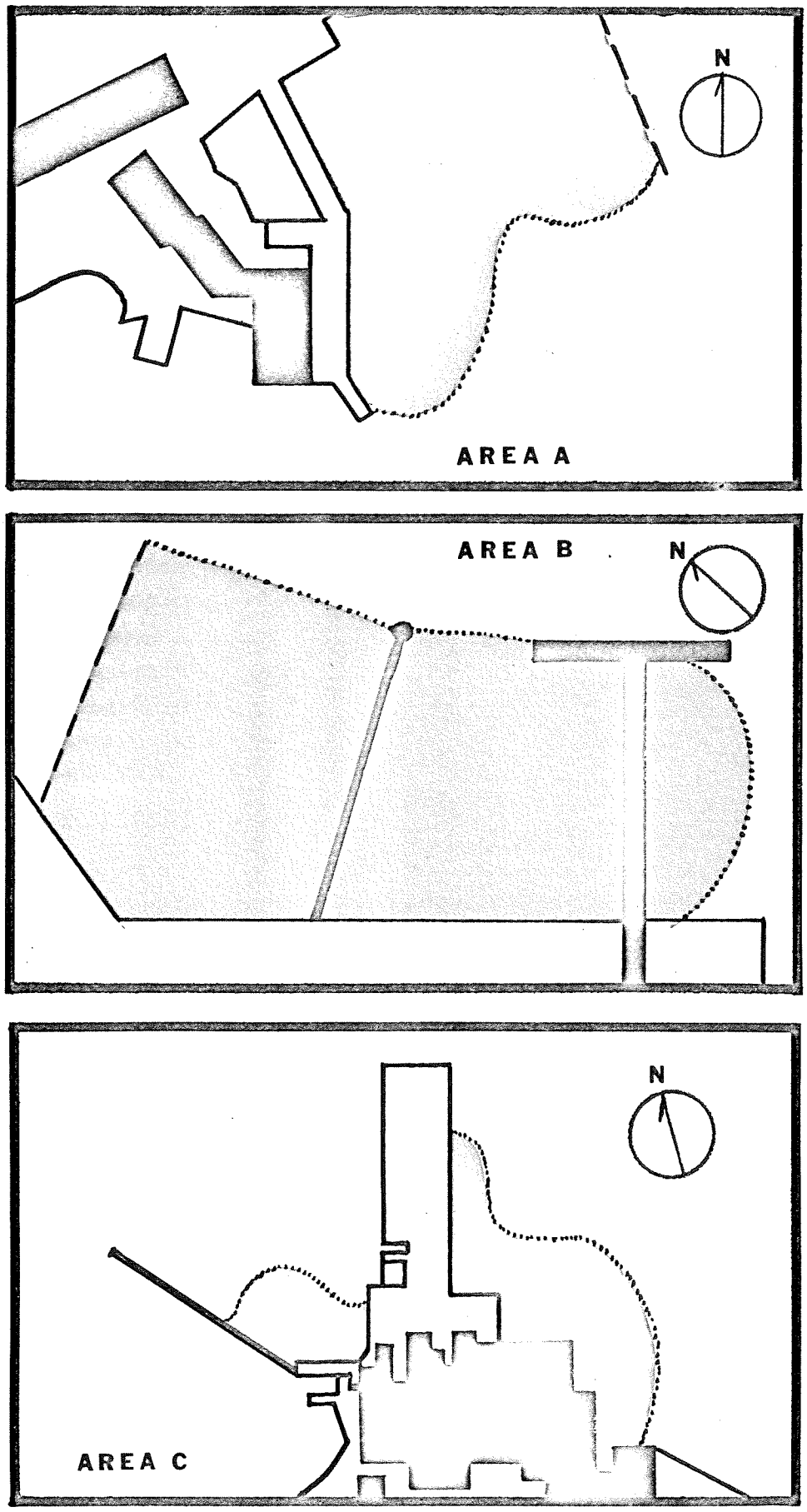

Figure 3. Zones of acute toxicity, Port Angeles Harbor, Washington. April and May, 1964.

Defined Zones of Acute Toxicity. Sufficient data was gathered during the study to define the zones where acute toxicity problems could be expected. The field tests suggested that the area of acute toxicity could change rapidly and vary in size and shape. Figure 3 shows the indicated toxic zones in the three test areas where experimental fish mortalities occurred in the perimeter live boxes and in the FFL, and where toxic substances were found in concentrations demonstrated to be lethal to pink and chum salmon in the FFL tests. The field tests suggested that the area of acute toxicity could change rapidly and be several acres in size.

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