OCEAN FALLS
ENVIRONMENTAL SURVEILLANCE PROGRAM, 1974

by

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OCEAN FALLS

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ABSTRACT

During the summer of 1974 the Environmental Protection Service carried out two brief environmental quality surveys of the receiving waters in the vicinity of the Ocean Falls Corporation paper mill located at Ocean Falls, B.C. The primary objectives of the surveillance program were to determine prevailing oceanographic characteristics of Cousins Inlet, qualitatively assess the shallow subtidal benthic fauna at various sites, delimit the extent of fibre deposition on the bottom of the inlet and compare the data obtained with those of previous surveys.

In general terms the results indicated that the condition of the inlet appears to be improving in all respects measured and should continue to do so, provided that waste loading and toxicant addition to the inlet continue to be reduced or are maintained at a sufficiently low rate to permit the natural processes of Cousins Inlet to operate more effectively.

The inlet was highly stratified with respect to all oceanographic parameters measured, namely temperature, salinity and dissolved oxygen. Temperature and salinity gradients were similar to those reported in 1961, 1964 and 1970 with no unusual features. Bottom water dissolved oxygen values, particularly at the head of the inlet, were relatively low, but nevertheless represented a considerable improvement over those reported previously at comparable times of year.

SCUBA observations at selected sites beyond the immediate vicinity of the mill revealed subtidal communities typical of most protected rocky coastal regions of British Columbia with evidence of relatively recent recolonization.

The extent and composition of the fibre deposit did not appear to have changed appreciably since the last benthic survey in 1970. The fibre bed was found to extend approximately 1.75 nautical miles down the inlet from the mill and was composed primarily of fibrous hydrogen sulphide ooze with some bark, chips and natural sediment. The deposit appeared to be devoid of macroinfauna, with the exception of some polychaete worms (*Capitella* sp.) which were found in the oxygenated surface 1.5 cm of some areas of the fibre bed in June.

RÉSUMÉ

Pendant l'été de 1974, le Service de protection de l'environnement a entrepris deux courtes études sur la qualité des eaux réceptrices près de l'usine à papier "Ocean Falls Corporation" à Ocean Falls (C.-B). Ces études visaient surtout à découvrir les caractéristiques océanographiques dominantes de l'anse Cousins, à faire un relevé qualitatif de la faune benthique subtidale en eau peu profonde à divers endroits, à mesurer l'étendue des substances fibreuses qui se déposent au fond de l'anse et à comparer les données recueillies avec celles des études antérieures.

Les résultats indiquent en général que l'état de l'anse semble s'améliorer à tous points de vue et que ce progrès devrait continuer pourvu que l'on persiste à réduire le nombre des déchets déversés dans l'anse, ou que leur taux de déchargement soit assez bas pour que le processus naturel de l'anse Cousins puisse se dérouler sans ambages.

Selon tous les paramètres océanographiques mesurés, soit la température, la salinité et l'oxygène en solution, l'anse était fortement stratifiée. Les degrés de température et de salinité étaient semblables à ceux que l'on a notés en 1961, 1964 et 1970, sans particularité saillante. La quantité d'oxygène en solution au fond de l'eau était relativement faible, surtout à l'entrée de l'anse, mais représentait néanmoins une amélioration considérable par rapport aux données antérieures recueillies à des périodes semblables de l'année

À des endroits choisis au-delà du voisinage immédiat de l'usine, les plongeurs ont trouvé une faune subtidale semblable à celle qui vit habituellement dans les régions abritées par les rochers côtiers de la Colombie-Britannique; les plongeurs ont tout de même constaté que cette recolonisation était relativement récente.

L'importance et la composition de ce dépôt fibreux ne semblent pas avoir beaucoup changé depuis 1970. La couche fibreuse s'étendait à l'intérieur de l'anse sur une distance d'environ 1.75 mille nautique à partir de l'usine, et elle se composait surtout d'une boue fibreuse d'hydrogène sulfuré porteuse d'écorce, de copeaux et de sédiments. Ce dépôt semble être dépourvu d'infaune macroscopique, à l'exception de quelques vers polychètes (du type Capitella) qui y vivent jusqu'à une profondeur de 1.5 cm à certains endroits.

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INTRODUCTION

During the summer of 1974 the Environmental Protection Service carried out two brief environmental quality surveys of the receiving waters in the vicinity of the Ocean Falls Corporation paper mill located at Ocean Falls, B.C.

The primary objectives of the surveillance program were to:

a) determine oceanographic characteristics of Cousins Inlet with particular reference to dissolved oxygen, temperature and salinity.

b) qualitatively assess the shallow subtidal (0-15 m) benthic fauna at various sites in Cousins Inlet

c) delimit the extent of fibre deposition on the bottom of Cousins Inlet caused by historical and continuing pulp and paper mill activities.

This report documents the results obtained during the 1974 sampling program and provides a comparison with data obtained in previous surveys.

STUDY AREA

The Ocean Falls Corporation paper mill is located at the head of Cousins Inlet approximately 325 miles north of Vancouver (Figure 1). Cousins Inlet heads due north from the junction of Fisher and Dean Channels, between Bella Bella and Bella Coola. Three rivers, the Martin, Link and Ikt, flow into Cousins Inlet, as well as numerous small runoff streams. The Link River, dammed to form Link Lake reservoir, provides a continuous flow of 1×10^9 imp gal/day into the head of Cousins Inlet, (Plate I). This flow is constant year-round but may be decreased in the case of an extremely dry summer.

The climate of Ocean Falls is extremely wet, having an average of 221 days per year with measurable precipitation and a mean annual precipitation of 172.82 inches. Due to its modified maritime climate, air temperatures at Ocean Falls fluctuate very little throughout the year. A complete summary of precipitation and temperature data collected by the Atmospheric Environment Service is contained in Table I.

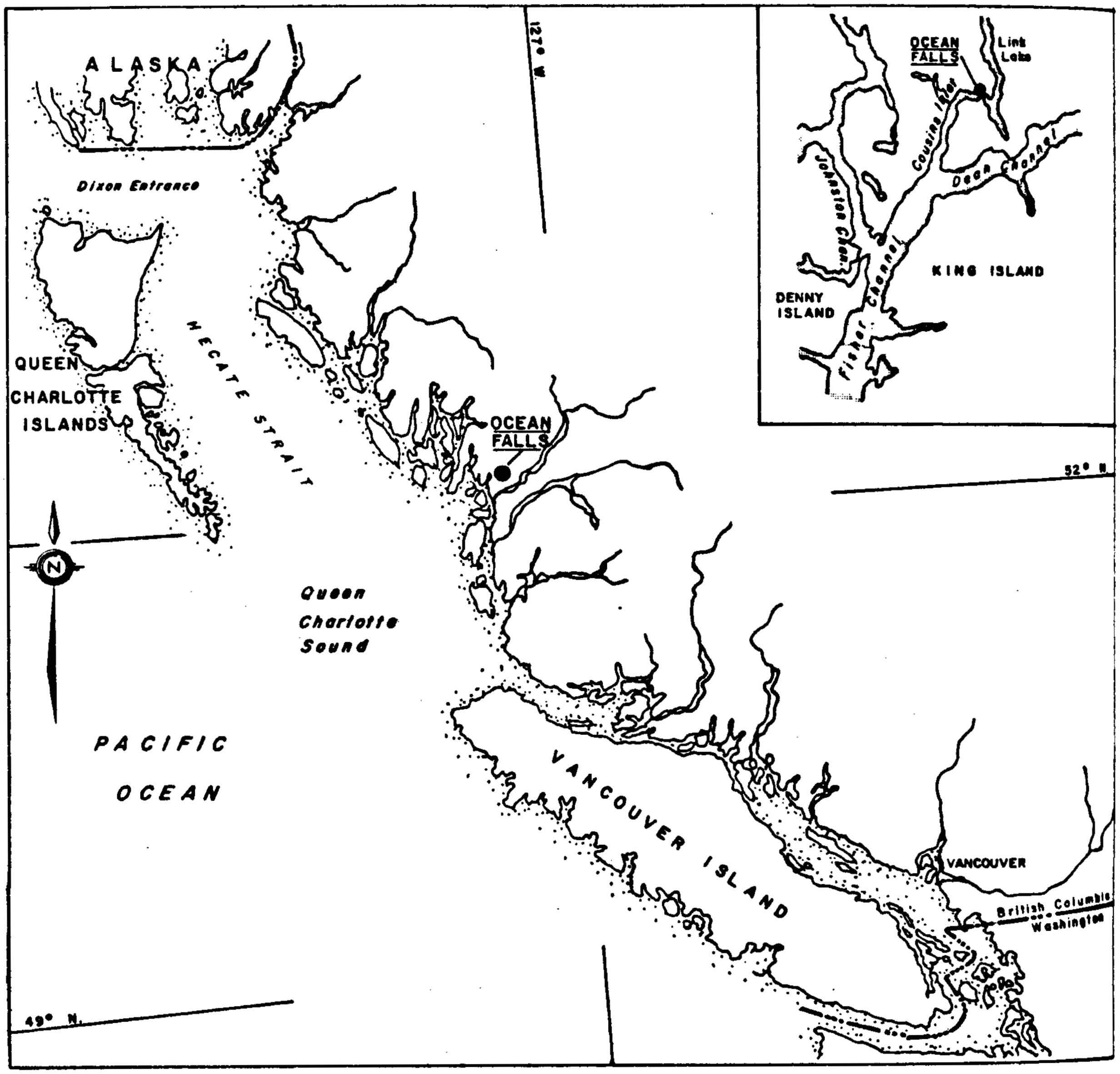


FIGURE 1. OCEAN FALLS

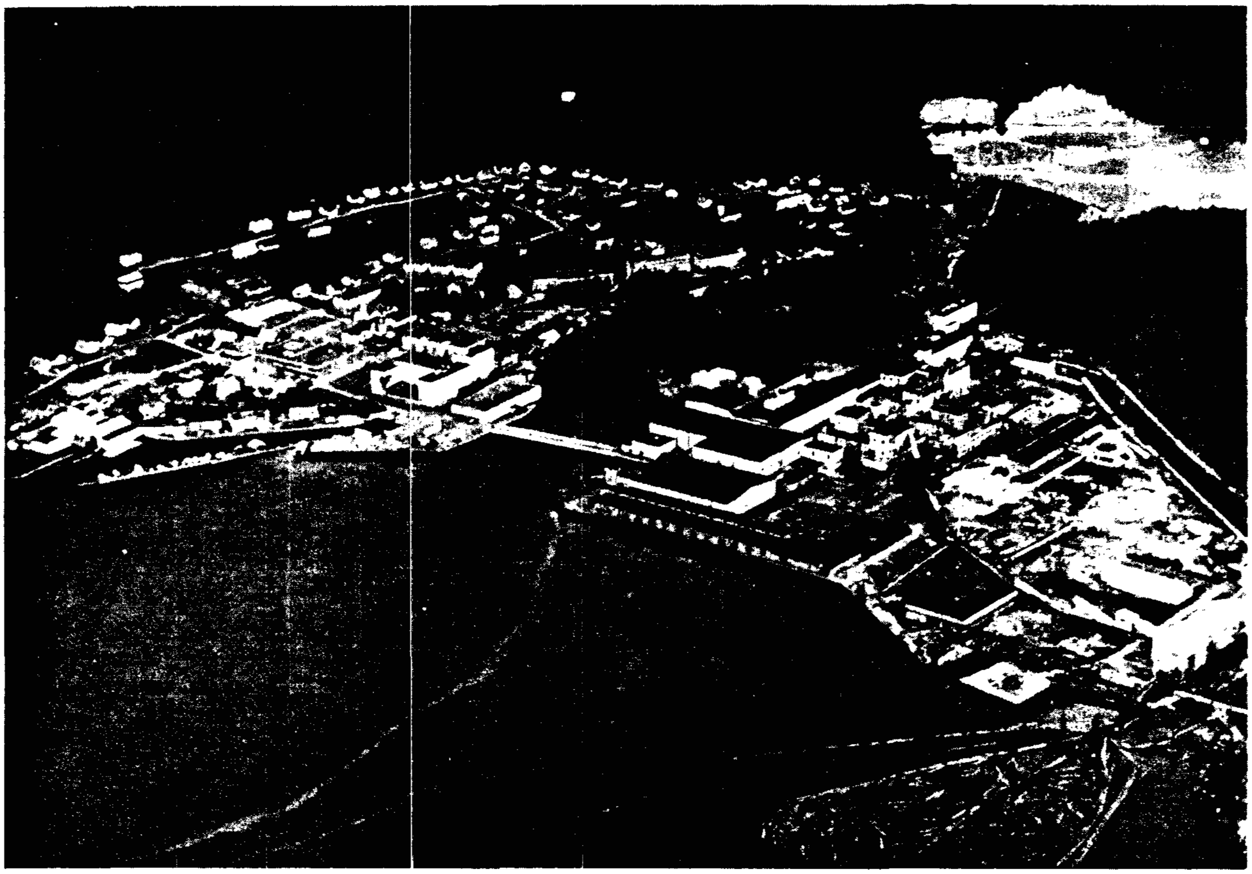


Plate I Ocean Falls showing the mill, townsite, Link Lake Reservoir and the hydro dam. (B.C. Forest Service photo)

Plate II Aerial view of Cousins Inlet from the mouth to Martin River (B.C. Forest Service photo)

TABLE 1: CLIMATOLOGICAL DATA FOR OCEAN FALLS (FROM AES TEMPERATURE AND PRECIPITATION 1941-1970, BRITISH COLUMBIA)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Mean Daily Temp. °F	32.9	36.7	39.0	44.2	51.5	57.1	60.8	61.5	57.6	48.8	40.8	36.0	47.2
Mean Rainfall (inches)	16.43	13.73	12.94	12.52	7.96	6.97	6.39	9.25	14.84	25.46	20.48	19.56	166.54
Mean Snowfall (inches)	20.3	13.9	6.6	0.7	0.0	0.0	0.0	0.0	0.0	0.0	5.6	15.6	62.7
Mean Total Precip	18.46	15.12	13.60	12.59	7.96	6.97	6.39	9.25	14.84	25.47	21.04	21.13	172.82
No. Days $\overline{w}$ Meas Precip	21	18	19	19	16	15	14	14	17	23	23	22	221

Cousins Inlet is surrounded by rugged mountainous terrain (Plate II) with a forest cover representative of the coastal Western Hemlock - Western Red Cedar Zone (Krajina,1965). Hunting and fishing are the major recreational attributes of this area for the local residents. In the past, both shores of Cousins Inlet were utilized extensively for log-booming, an activity which extended well beyond Coolidge Point. However, at present, due to decreased production and the import of semi-bleached kraft pulp, booming activities have greatly decreased, such that booms are only located in that part of the inlet adjacent to the pulp mill. The inlet is also used for marine and floatplane transportation. Government and private wharves and two marinas are located directly adjacent to the town for use by fishing vessels, coastal freighters, barges and craft belonging to the local populace (Plate I).

HISTORY OF THE OCEAN FALLS PULP MILL (after Bergman, 1973)

The first industry at Ocean Falls was a sawmill established in 1908. A dam was constructed in 1910 to form Link Lake and provide water power. The sawmill was later replaced by a pulp and paper mill operation beginning in 1912 with a 150 ton per day groundwood pulp mill. In 1917 a sulphite and a sulphate kraft pulp mill and four paper machines were added. Two additional paper machines were installed in the twenties and the dam was raised.

In 1965 the groundwood mill was modernized and No. 6 paper machine was shut down. In 1966 No. 3 paper machine was shut down. In 1967 the Kraft pulp mill, the bleach plant, the sulphite pulp mill, lime plant, and Kraft recovery boilers were shut down as they were obsolete and no longer economic units. In July 1971, No. 1 paper machine was shut down.

In May, 1972, Crown Zellerbach announced that the balance of the mill (numbers 2, 4, and 5 paper machines, woodmill, and groundwood mill) would be closed down by the end of March, 1973, as the operation was no longer economic. The operation was phased out as planned by Crown Zellerbach, but prior to the final shutdown the mill was purchased by the Provincial Government and is currently being operated as a Crown Corporation.

The mill is presently producing about 280 tons of newsprint per day, with the groundwood mill supplying groundwood pulp, and semi-bleached kraft pulp imported from outside sources. For more information on the history of the mill and the Ocean Falls area in general, the reader is referred to Ramsey (1971).

SOURCES AND QUALITY OF EFFLUENT DISCHARGES

The effluent from the Ocean Falls mill is discharged at a combined rate of approximately 14,500,000 Imperial gallons/day through six outfalls into the head of Cousins Inlet (Figure 2.). A brief description of each sewer follows (after Bergman, 1973).

Woodmill Sewer. This sewer services the woodmill with the effluent flow being almost entirely from the Hansel hydraulic barker.

Flume Water. The blocks from the woodmill are conveyed to the groundwood mill by means of a block flume. Water for the flume is supplied from Link Lake to the woodmill end of the flume and discharged at the groundwood mill end of the flume into Cousins Inlet. The flume water is not recirculated, but makes a single pass through the flume.

No. 1. Sewer. This sewer services the Steam Plant and is basically clean water. It is also the main sewer handling domestic effluent.

No. 3. Sewer. This sewer services the groundwood mill and contains coarse screen rejects, secondary cowan screen rejects, and white water overflow. It also receives some domestic wastes.

Nos. 1A and 2 Sewers. These two sewers service the newsprint machines. No. 2 sewer contains primarily white water overflow from the paper machine broughton boxes while No.1A sewer contains the tertiary centricleaner rejects. Losses from the paper machine Jonson screens are negligible due to the large size of the holes in the screen plate.

With the exception of the woodmill sewer, all mill wastes are discharged into the large flow of well aerated water from the tailrace of the hydro-electric plant. According to Bergman (1973), the mill is presently discharging approximately 11 tons/day of suspended solids as compared to 28 tons/day when Crown Zellerbach still operated the mill and a further reduction to 4.25 tons/day is projected by the end of 1977 if proposed abatement measures are instituted.

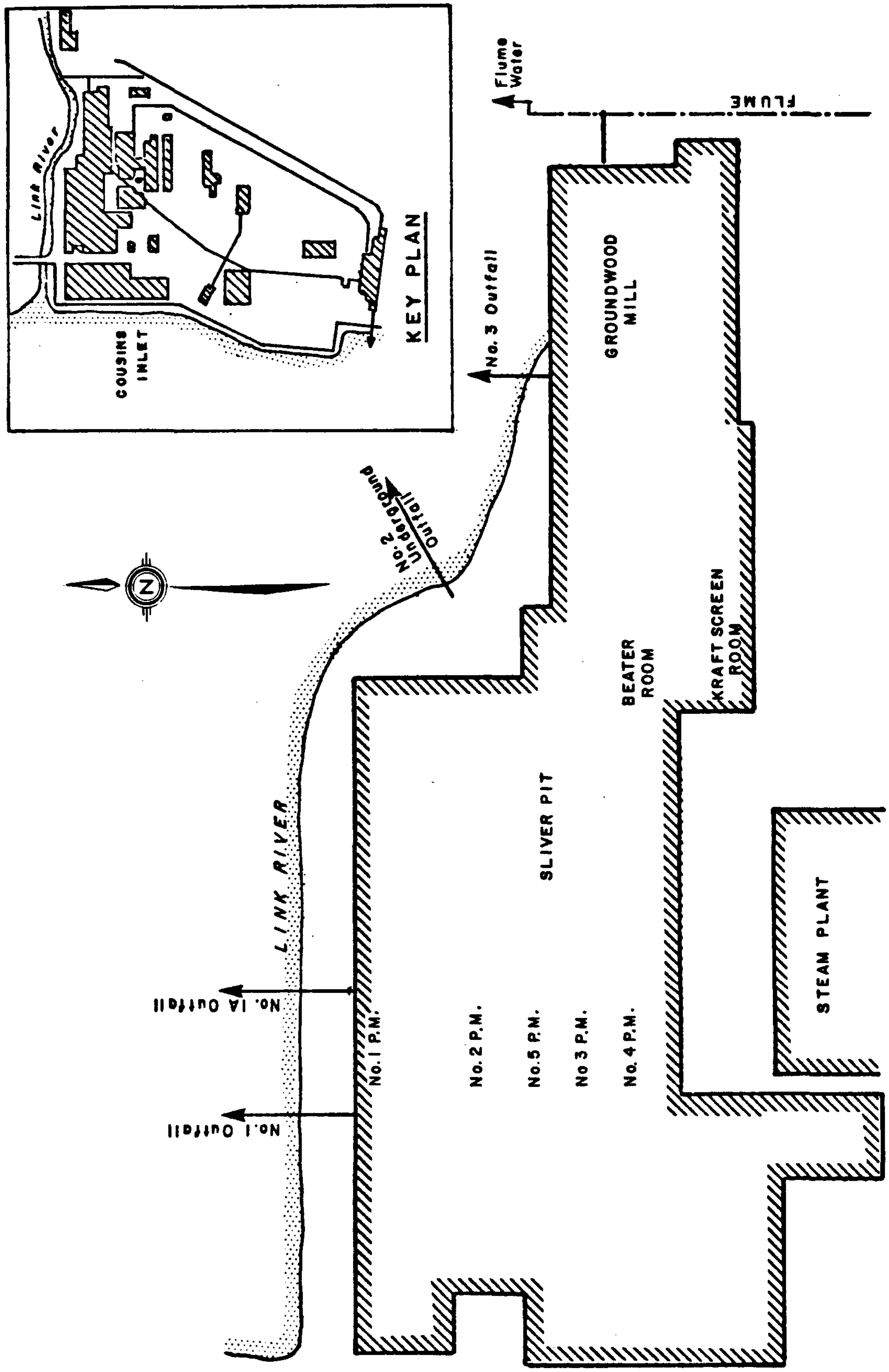


FIGURE 2 OCEAN FALLS CORPORATION

In addition to the discharge of fibre and associated BOD, the Ocean Falls Corporation is the only mill on the west coast still utilizing zinc hydrosulphite for groundwood bleaching. The remainder have switched to sodium hydrosulphite bleaching using the Boral process.

Zinc hydrosulphite bleaching has been identified as a cause of zinc contamination problems associated with shellfish in receiving waters as well as a major factor contributing to the toxicity of mill effluents (Environment Canada, 1973). Unpublished work carried out by the Environmental Protection Service in 1973 at Ocean Falls revealed that Mytilus edulis, the only intertidal bivalve found in Cousins Inlet at that time, contained approximately twice the concentration of zinc found in M. edulis collected from a control station established in Elcho Harbor some 25 miles from Ocean Falls (Env Can ,unp 1974). Although the actual concentrations found were relatively low this condition should still be considered a cause for concern.

The use and subsequent discharge of zinc was also reflected in toxic responses exhibited by fingerling coho salmon exposed to the various mill effluents. Grab samples were collected in October 1973 by Environment Canada, transported to Vancouver and tested under static conditions for 96 hours using freshwater as the diluent. Sewer 3 was found to be the most toxic with an *LC 50 of 3.2%, followed by sewers 1A, the woodmill, and 2, with LC 50's of 15.5%, 18% and 42%, respectively, and the remainder which were not acutely toxic. These results corresponded directly with zinc concentrations of the effluents as analyzed by the B.C. Research Council during a 5 day period in early October of the same year (Bergman,1973).

Results of this survey ranged from an average of 35 ppm of zinc in effluent from sewer 3, to 7-10 ppm for sewers 1A and 2 and none in the remaind The high toxicity of the woodmill effluent could not be attributed to zinc as none was present, but was probably due to resin acids or other organic derivatives associated with the effluent from this operation.

*96 hour LC_{50} - This notation refers to Median Lethal Concentration or that level of a measurable lethal agent required to kill the 50th percentile in a group of test organisms, over the time period of 96 hours. The 50th percentile is meant to represent the average organism.

METHODS AND MATERIALS

During the 1974 field season, two surveys of Cousins Inlet were completed. The initial survey was conducted between June 11 and June 15, while the latter was undertaken towards the end of the summer between September 4 and September 8. It was felt that, by sampling during differing seasonal periods, data could be obtained to demonstrate seasonal variations in the three oceanographic parameters measured, namely temperature, salinity and dissolved oxygen.

1) Physical Oceanographic Sampling:

The oceanographic stations sampled were those established by Waldichuk (1962) as well as two new stations, 6a and 7a (Figure 3). Station locations were established by a hand-bearing compass and Hurst plotter in June and by sextant and Douglas protractor in September. All oceanographic sampling was conducted on rising tides, (Figure 3) commencing at station O-5, in order to minimize the effects of tidal flushing. Water samples were collected with Van Dorn bottles in June and Nansen bottles in September. Water temperature was measured using a standard centigrade thermometer as soon as possible after collection of the samples. Dissolved oxygen was determined by the azide modification of the Winkler method (Davidson et al, 1974). Dissolved oxygen expressed as percent saturation was calculated according to the equation of Gameson and Robertson, (1955). Salinity was measured with a hydrometer on the first trip and a refractometer calibrated by hydrometric and electro-conductivity techniques, during the September sampling period.

2) SCUBA Survey

In an attempt to ascertain the past and present effects of mill wastes on the subtidal fauna of Cousins Inlet, qualitative SCUBA observations were carried out at four specific sites within the inlet (Figure 4). Dives of approximately 30 minutes duration, to an average depth of 15 meters, were completed at each station. Qualitative observations of the macrofauna

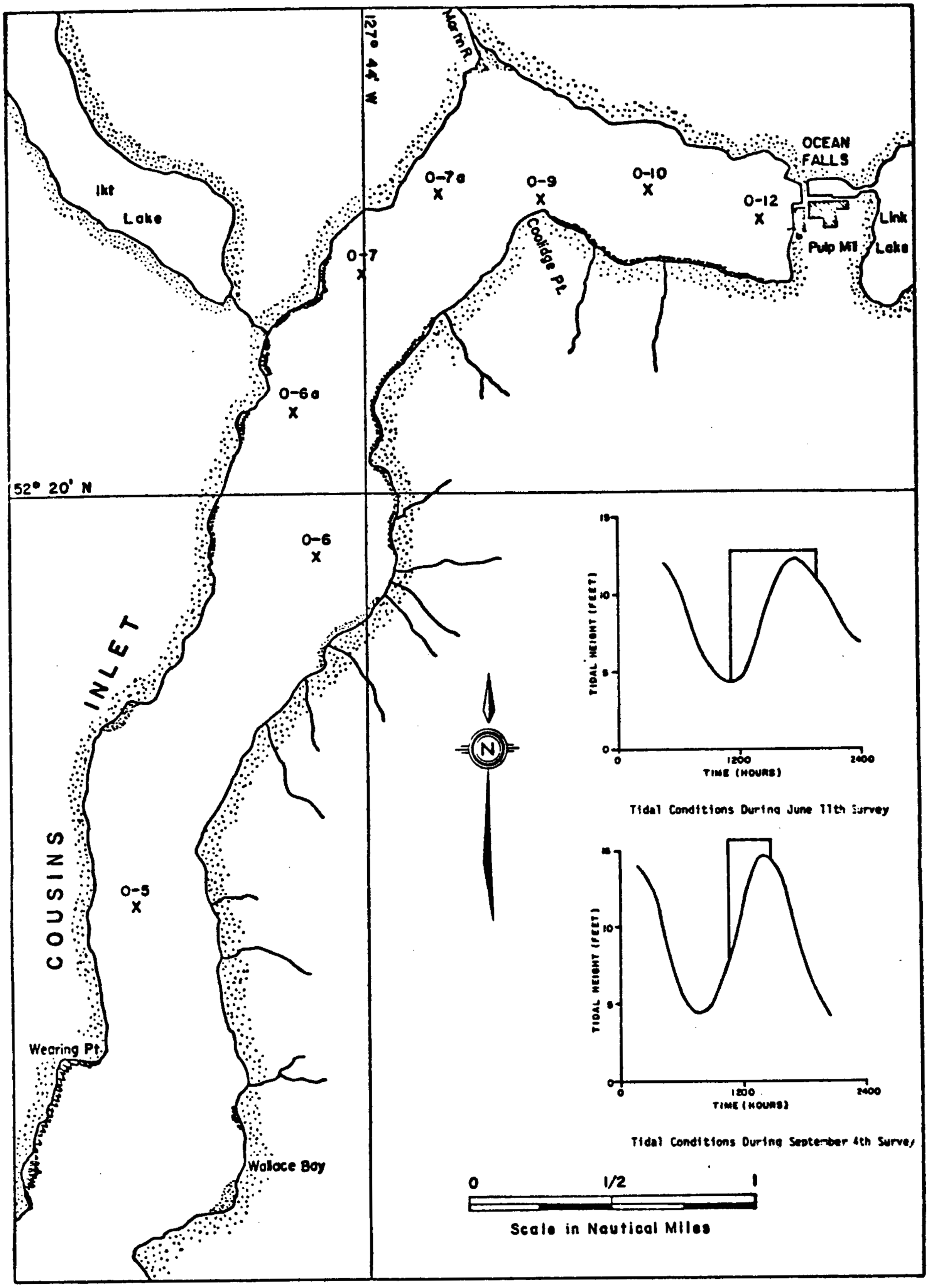


FIGURE 3 OCEANOGRAPHIC STATIONS

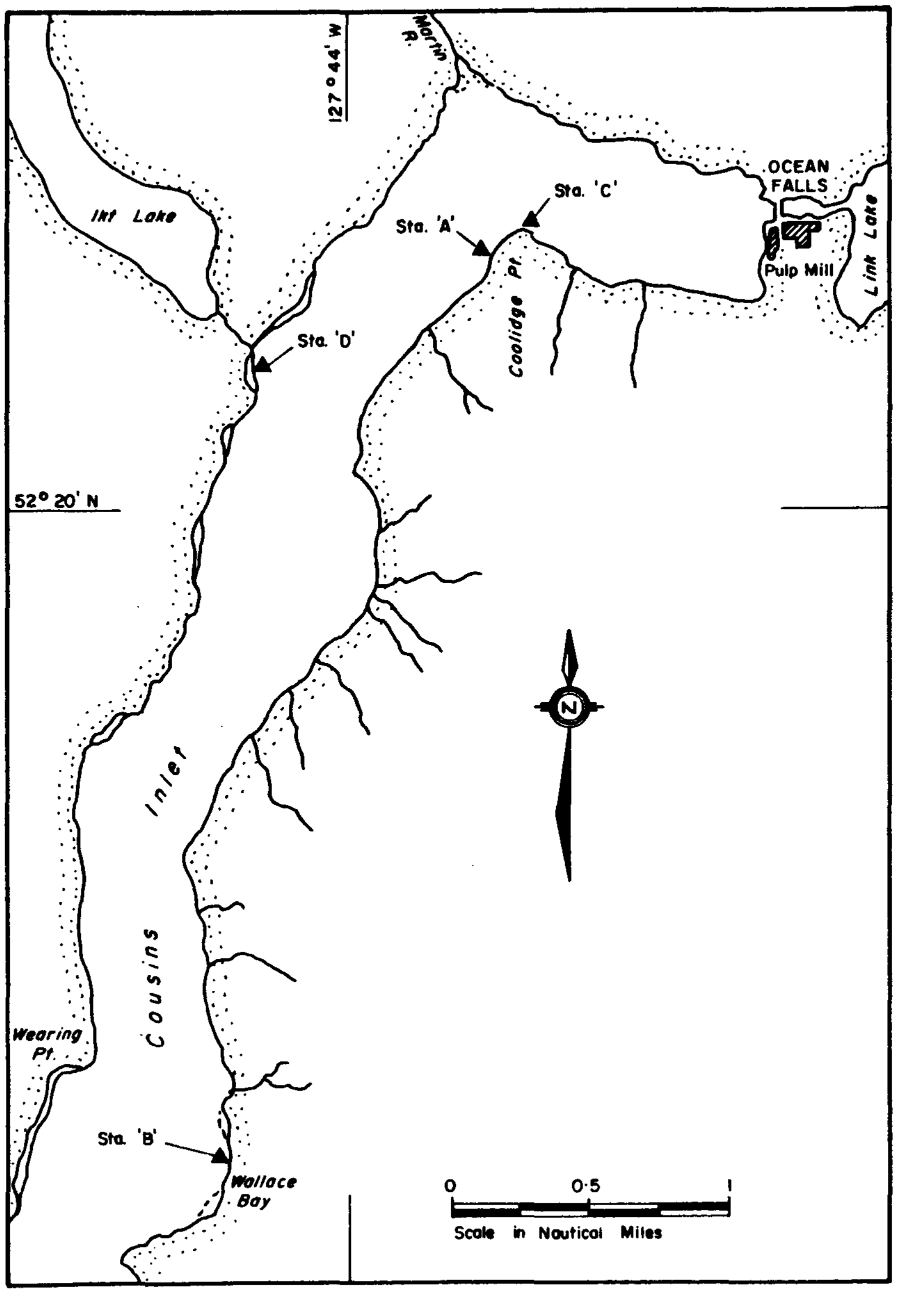


FIGURE 4 SCUBA STATIONS

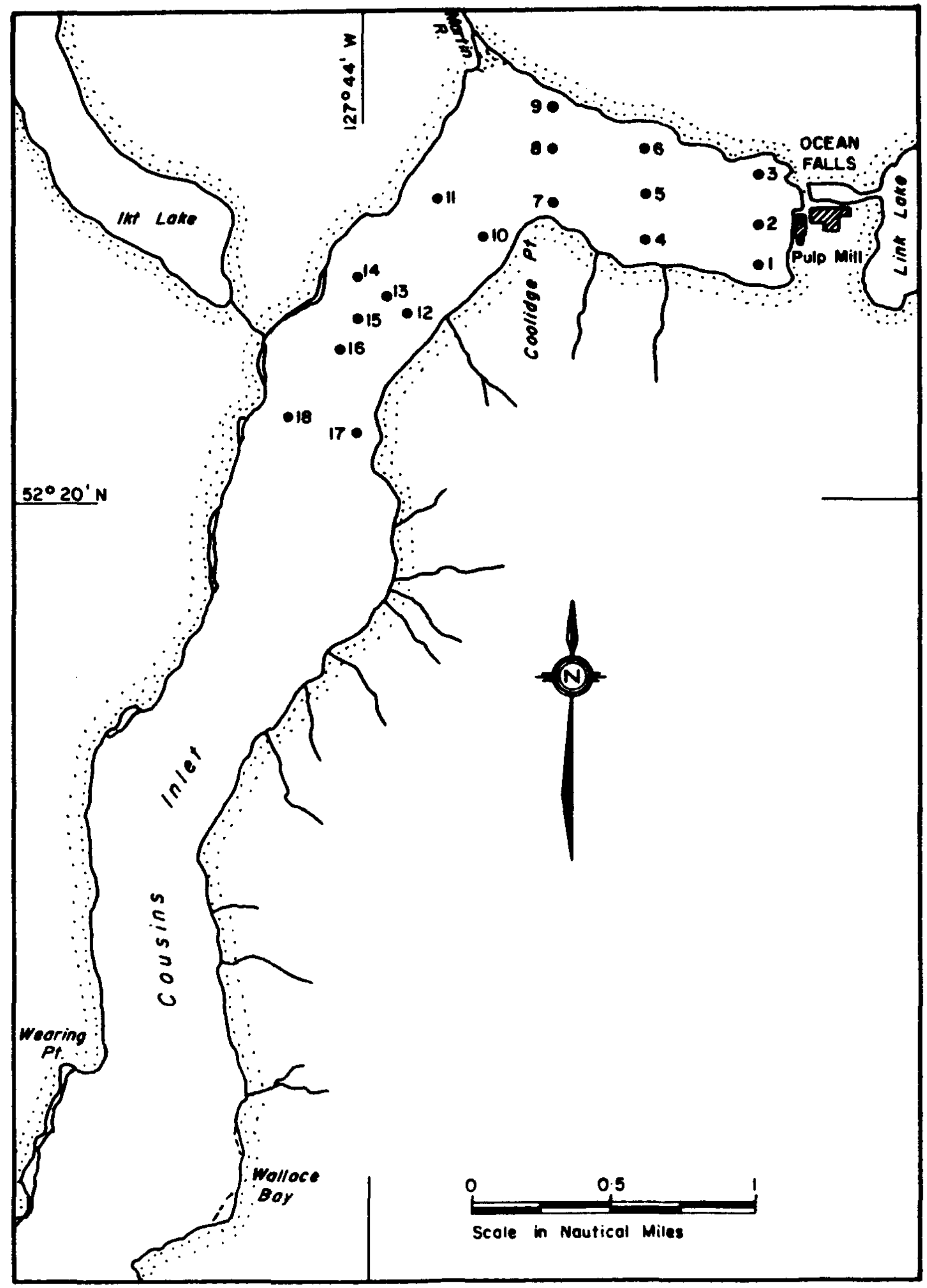


FIGURE 5 BENTHIC STATIONS

were made and the results summarized into a general species list.

3) Benthic Dredge Sampling

In June a qualitative benthic survey was conducted to determine the characteristics of and the distribution of the fibre deposit in Cousins Inlet. Samples were obtained with a 0.092 m^2 Ponar dredge. A handful of sediment and the majority of the organisms in the dredge sample were collected at most stations and preserved for later analysis at the Vancouver Lab. A total of 18 stations, illustrated in Figure 5 were sampled.

RESULTS

1) Oceanography

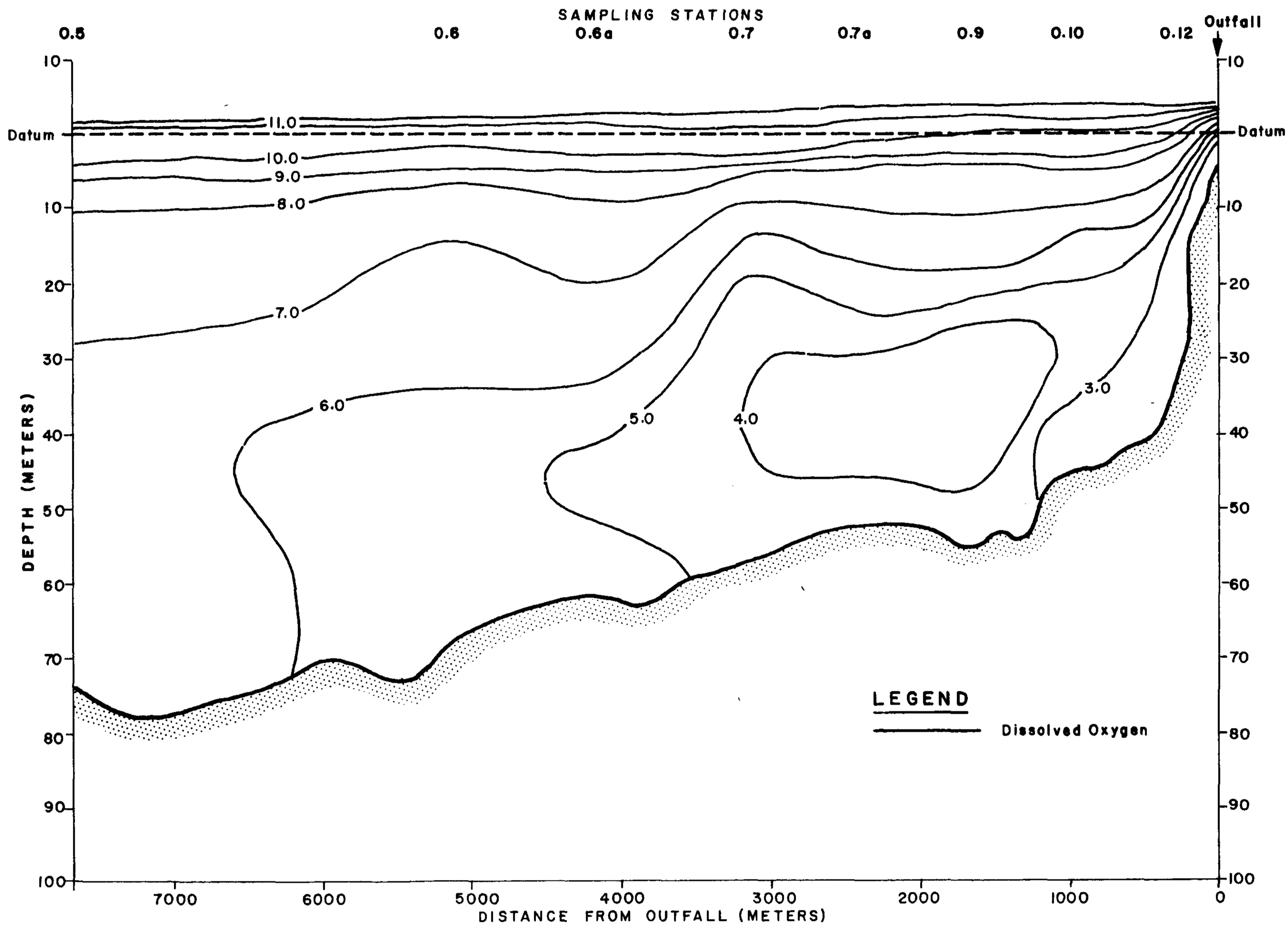
Appendix I tabulates all of the oceanographic data obtained from the two surveys completed at Cousins Inlet during the summer of 1974.

In an attempt to summarize and profile these characteristics of the water column throughout the length of the inlet, a series of graphic overlays were prepared for each sampling period and presented as Figures 6 and 7. These two figures depict the overall condition of water temperature salinity and dissolved oxygen concentration on June 11 and September 4, respectively. To facilitate inspection of the profiles for individual parameters the reader is requested to refer to Appendix II or to view the specific templates over a white background.

In general, the oceanographic conditions prevailing in Cousins Inlet during the summer of 1974 were fairly typical of a deep marine fjord with a substantial, constant, inflow of surface fresh water at the head, thereby creating a net surface movement seaward. As Figures 6 and 7 clearly demonstrate, approximately the top ten meters of the water column throughout the inlet during both sampling periods were strongly stratified with respect to the three parameters measured, namely temperature, salinity and dissolved oxygen concentration. Below this highly stratified surface layer the water column was more representative of oceanic conditions and differences were generally much less dramatic, with the

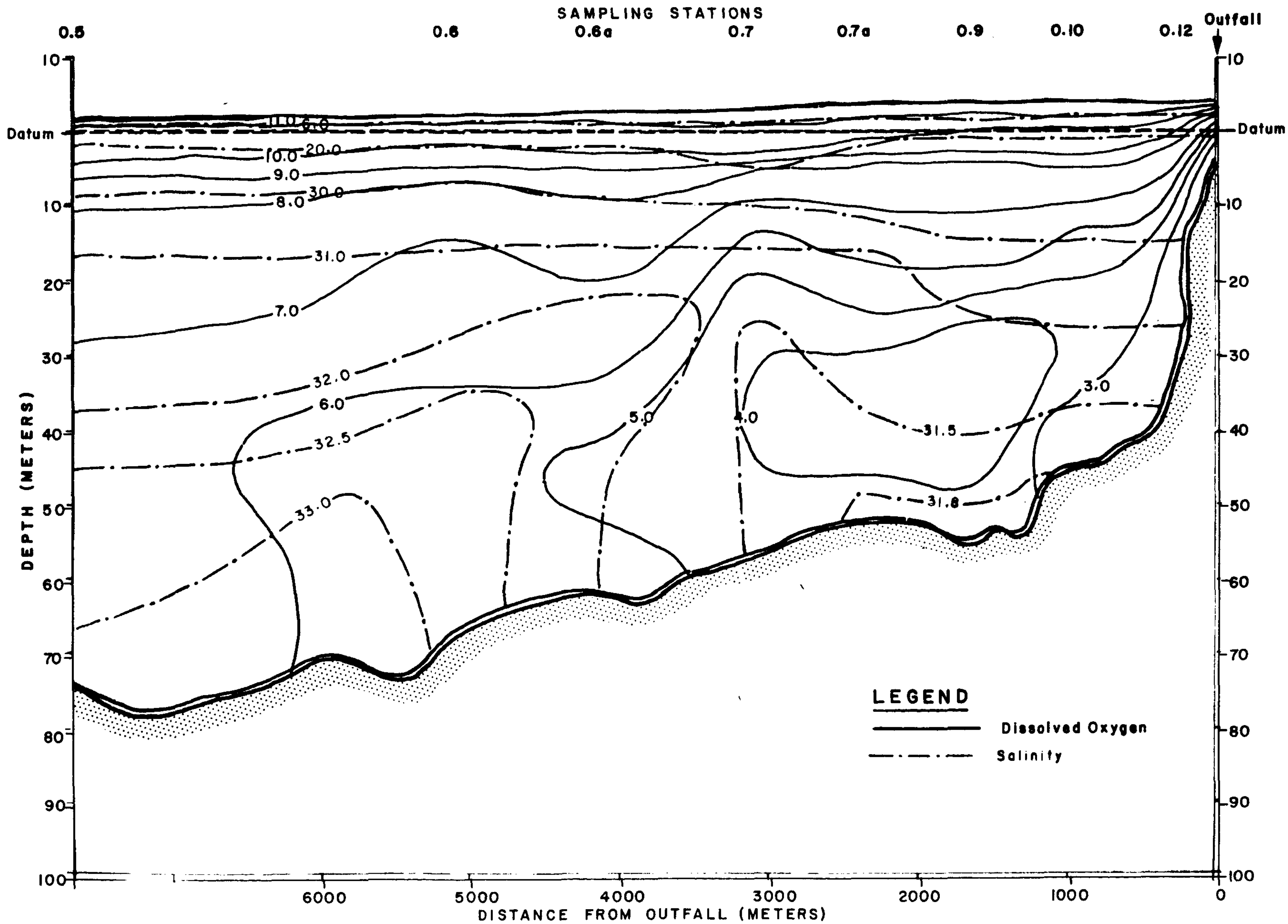
Figure 6

Longitudinal Distribution of Temperature, Salinity and Dissolved Oxygen in Cousins Inlet on June 11,1974.



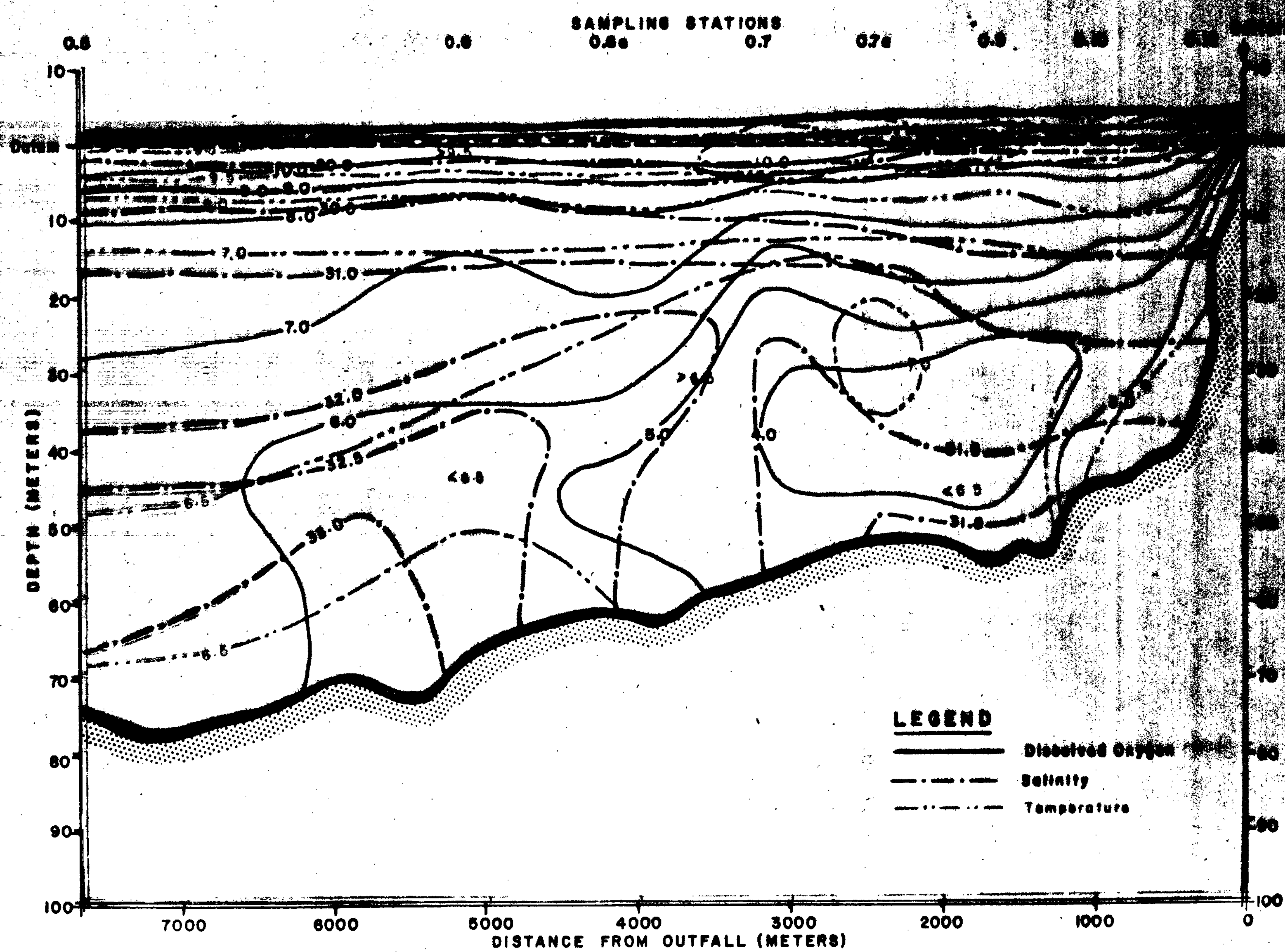
DISSOLVED OXYGEN PROFILE (mg/ℓ)

JUNE 11, 1974



SALINITY PROFILE (‰) DISSOLVED OXYGEN PROFILE (mg/ℓ)

JUNE 11, 1974

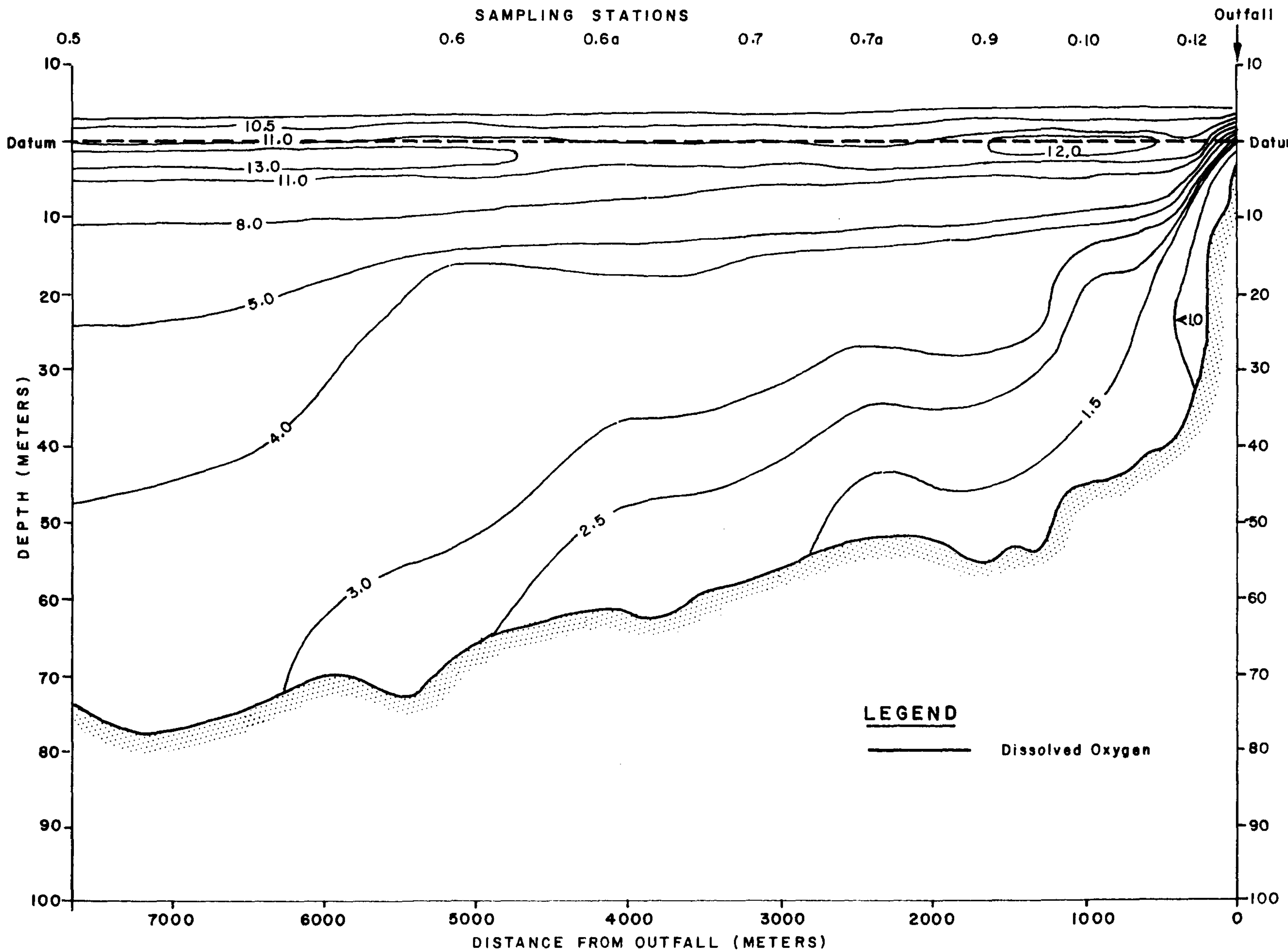


TEMPERATURE PROFILE (°C) SALINITY PROFILE (‰) DISSOLVED OXYGEN PROFILE (mg/l)

JUNE 11, 1974

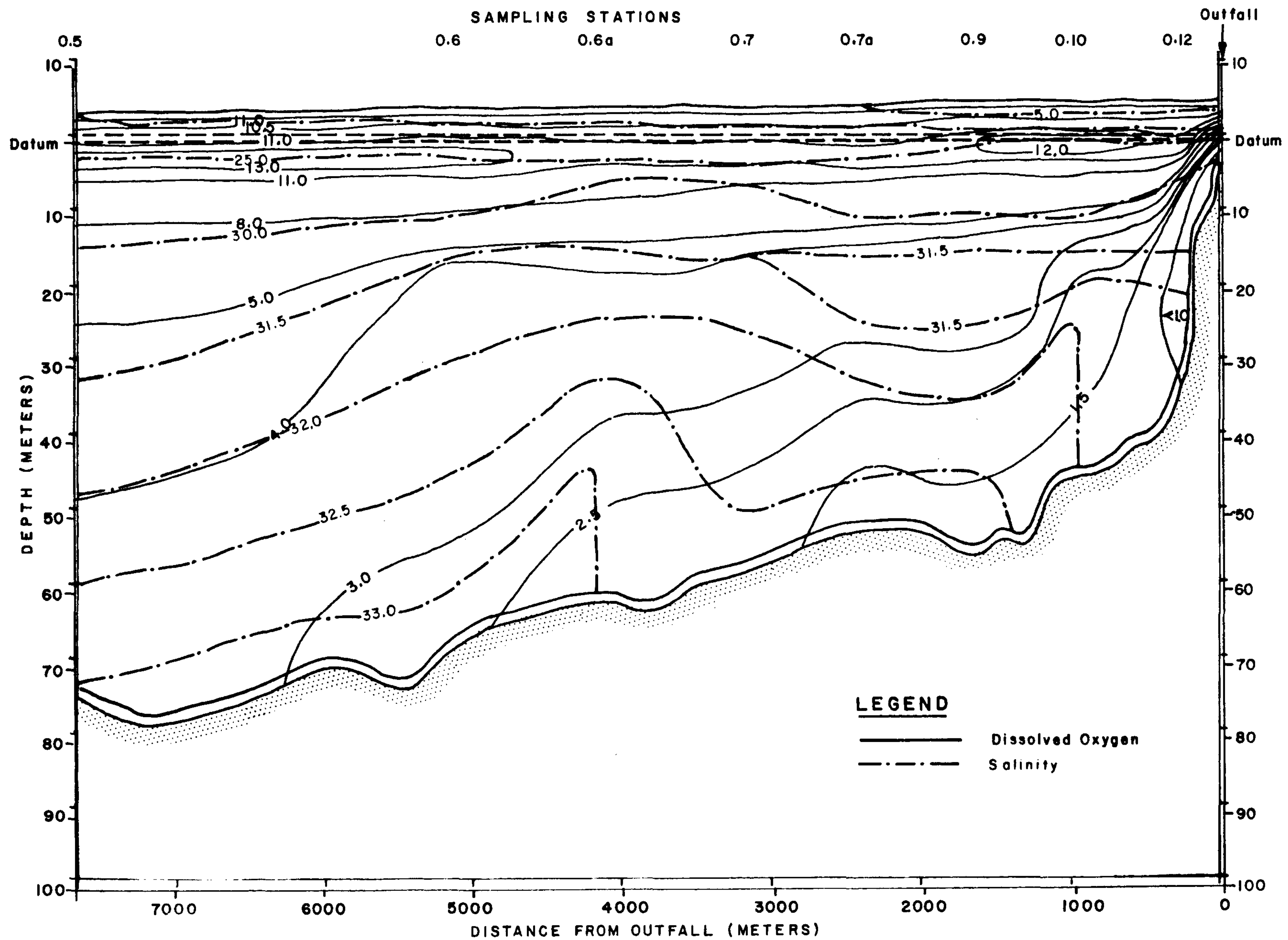
Figure 7.

Longitudinal Distribution of Temperature, Salinity and Dissolved Oxygen in Cousins Inlet on September 4,1975.



DISSOLVED OXYGEN PROFILE (mg / ℓ)

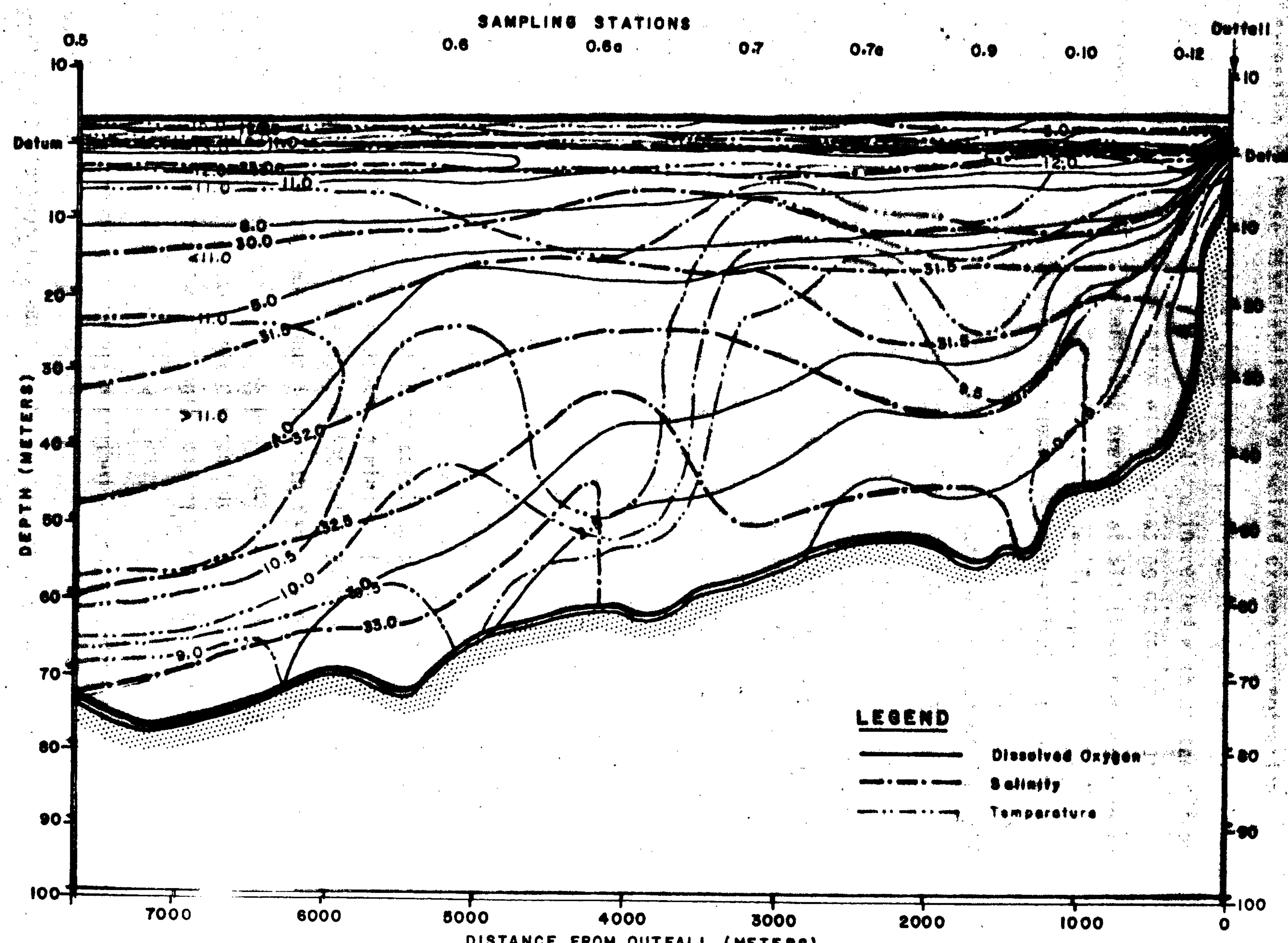
SEPTEMBER 4, 1974



SALINITY PROFILE (‰)

DISSOLVED OXYGEN PROFILE (mg/ℓ)

SEPTEMBER 4, 1974



TEMPERATU...

SALINITY PROFILE (‰)

DISSOLVED OXYGEN PROFILE (mg/ℓ)

...TEMBER 4, 1974

exception of those associated with dissolved oxygen concentrations.

The longitudinal temperature profiles for both sampling periods showed that in general, water temperature increased with distance from the head of the inlet and decreased with increasing depth. A relatively shallow thermocline (approx 5 meters) was present at all times but was more marked at all stations by September 4. Temperatures ranged from maxima of 10^{o}C and 15^{o}C at the surface on June 11 and September 4, respectively, to minima of 6.5^{o}C and 9.0^{o}C, respectively, at a depth of 70 meters. Generally the isotherms tended to slope upwards from seaward to the head of the inlet and in June several discontinuous "temperature clouds" were found.

The longitudinal salinity profiles for both surveys showed characteristically low surface values (0-5^{o}/oo), particularly near the head of the inlet, increasing to much more saline water (33^{o}/oo) at a depth of 70 meters. All substantial salinity fluctuations between sampling periods were limited to the surface waters while below 10 meters there was little change in the isohalines. The well defined positive salinity gradient prevailing at all stations throughout the summer would appear to be a constant feature of the oceanography of Cousins Inlet and as reported by Waldichuk (1962) is the primary factor contributing to the marked density gradient and therefore the stability which must characterize the water column of this area.

The longitudinal dissolved oxygen profiles demonstrated some interesting and unusual features not normally expected in an inlet with a substantial surface outflow. Dissolved oxygen concentrations were consistently greatest at the surface during both sampling periods (approximately 11 mg/1) diminishing with increasing depth to minima of 2.7 mg/1 on June 11 and 0.1 mg/1 on September 4, at the bottom (30 meter depth) near the head of the inlet. Dissolved oxygen reductions with depth were also found at the more seaward stations but were not as pronounced as at station 0-12. Greater sub-surface oxygen depletions were recorded during the September survey and the lowest value measured was 0.1 mg/1, directly over the fibre bed adjacent to the mill.

The results for oxygen content of the seawater expressed as percent saturation, are summarized in Appendix I. The top 5 meters at all stations during both surveys was near to, or in most cases, above the 100% saturation level, with exceptionally high values (up to 152%) recorded at 5 meters at all stations in September. Below this layer, percent saturations generally decreased with increasing depth and proximity to the head of the inlet, down to minimum bottom values of 25% at station 0-10 (45m) in June, and 1% at station 0-12 (25 m) in September.

2. SCUBA Survey

Qualitative SCUBA work was undertaken at four sites previously illustrated in Figure 7. Faunal observations were made and a species list for each station prepared (Appendix III). It should be noted that the lists are by no means complete but should serve as a preliminary guide to some of the more abundant macrofauna inhabiting these areas.

Station A on the south side of Coolidge Point was characterized by a steeply sloping bottom composed of rocks and boulders. At approximately 11 meters the rocky face gave way to a softer, more gently sloped substrate composed of fibre, bark and sediment. A visibility of approximately 15 ft was encountered below the turbidity layer (resulting from freshwater-saltwater mixing) present at about the 2 meter depth.

A large number of fingerling salmonids were observed in the warm shallow waters of the intertidal zone in and around clumps of brown algae (Fucus sp.) and unidentified filamentous red algae. The rocky area was essentially fibre free, and supported a biotic community typical of rocky shores of British Columbia (McDaniel, 1973). Coon-striped shrimp, Pandalus danae were present in surprisingly large numbers throughout the area on rocks, under bark and logs and on the soft sediment. Sea anemones, Metridium senile, were abundant on rock faces and logs, as was the large sea cucumber, Parastichopus californicus. Other notably present organisms included the sea stars Pycnopodia helianthoides, Pisaster ochraceus, Evasterias troschelli, and Dermasterias imbricata, the green sea urchin, Strongylocentrotus droebachiensis, the rock oyster, Pododesmus macroschisma and some hermit crab species, Pagurus sp.

The bottom at station B in Wallace Bay was somewhat different, with a rocky reef (Guns Rock) emerging from an extensive flat, sandy bottom. A turbidity layer was again present at 2 meters, below which visibility ranged to approximately 25 ft. No evidence of fibre or other wood remnants was found at this site. The sandy bottom was inhabited by a large population of scallops, Chlamys rubida, unidentified buried bivalves (probably Mya sp.) the large snail, Fusitriton oregonensis, and of particular interest because of its sensitive nature, a single chrinoid, Florometra serratissima. Guns Rock was sparsely populated in comparison with that of the sandy bottom community. The only organisms found in any abundance were the green sea urchin, S. droebachiensis, the snail F. oregonensis, the starfish P. helianthoides, and some serpulid worms.

Station C at Coolidge Point was an almost vertical rock face swept relatively clean by currents passing the point. Large numbers of shrimp dominated by P. danae were again noted, as well as some crabs, Cancer magister, on rock ledges, several species of starfish, and serpulid worms.

The shore profile at station D near the Ikt River was a combination of a rocky steep sloping bank on descent and a sheer rock face to the south on ascent. Visibility at this site was hampered to some extent by unidentified suspended solids limiting light penetration and hence the depth to which effective observations could be made. A brown-green algal scum was noted on the rocks at the middle intertidal level. Within the lower intertidal to upper sub-tidal zone some of the rocks and the rock face were encrusted with dense populations of mussels, Mytilus edulis, and barnacles, Balanus sp. These shellfish were all of a uniform small size, probably less than 3 years old. Below 6 meters the fauna diversified to include species such as M. senile, Psolus chitonoides, P. californicus, P. helianthoides, D. imbricata, several types of crabs (Pagurus sp., Phyllolithodes papillosus, Hyas lyratus) and the tunicate, Boltenia villosa.

3) Benthic Survey

The Ponar dredge survey carried out in June showed that the bottom at most stations was characteristically composed of wood fibre intermingled with lesser quantities of bark, woodchips, and some sédiment. This deposit was found to extend beyond Coolidge Point to approximately stations 12 and 13 where it gave way to a fine sediment composed almost entirely of faecal pellets (probably originating from plankton or small pelagic fish) suggesting the end of the fibre bed. Samples taken from further down the inlet (i.e. stations 15,16,17 and 18) contained mainly faecal pellets intermingled with some bark and residual fibrous material.

Adjacent to the millsite the surface layer of the fibre deposit consisted of what appeared to be fresh undecomposed white fibres extending to a depth of approximately 1.5 cm. Beneath this were layers of dark-coloured to black fibrous ooze emitting moderate to strong hydrogen sulphide odors. Beyond the immediate vicinity of the mill the deposit continued to retain its layered, odiferous state but the surface 1.5 cm had undergone some decomposition, as judged by the partial breakdown and subsequent discoloration of fibres from white to grey-brown.

The surface 1.5 cm of the fibre deposit throughout most of its length was inhabited by a randomly distributed population of polychaete worms, primarily capitellids, but no life was found beneath the oxidized layer. Considerable numbers of small empty bivalve shells (mainly Mytilus and Macoma sp) were encountered at various sites but no live ones. South of Coolidge point at the end of the fibre deposit benthic diversity increased to include live bivalves, a few ophiuroids (brittle stars) and holothurians (sea cucumbers) and several larger species of polychaetes (nereids and terrebellids). A complete summary of the benthic findings is presented in Appendix IV.

DISCUSSION

The 1974 oceanographic surveys carried out at Cousins Inlet indicated that conditions for all parameters, with the exception of those associated with oxygen, were generally typical of those for a deep marine fjord with a substantial surface outflow.

Stommel (1964) classified estuaries in terms of the distribution of water properties. According to his system and our results, Cousins Inlet can be classified as a Type C, or highly stratified estuary. In the highly stratified estuary, of which many B.C. fjords are typical, the upper layer increases in salinity from at or near zero at the head, to a value close to that of the outside area at the mouth (Pickard, 1968). In the case of Cousins Inlet, the latter condition is not encountered until well into Fisher Channel (Waldichuk et al, 1968) because of the high surface outfow of adjacent rivers and inlets.

Continuing with Pickard's description of the Type C estuary, "the deep water, however, is of almost uniform salinity from head to mouth. There is a net outflow of surface water in the upper layer and inflow in the deeper water. In these estuaries there is a very strong halocline between the upper water and the deep water, particularly at the head where vertical salinity gradients of 10 to 20°/oo/m may occur during the period of greatest river run off." This situation was encountered in our work as well as by Waldichuk (1962), Waldichuk et al (1968) and Bishop et al (1970).

With highly stratified estuaries there is vertical mixing but this results primarily in an upward movement of salt water from below into the upper layer, with little downward movement of fresh water. Another feature of stratified estuaries is that the depth of the halocline, i.e., the thickness of the upper (low salinity) layer remains substantially the same from head to mouth of the estuary for a given river runoff. (Pickard,1968). This circumstance applied to Cousins Inlet where the low salinity layer was constantly located within the top two meters of the water column. It is probably also a more consistent feature throughout the year than in most other similar estuaries because of the regulated flow of freshwater coming from the tailrace of the Link River hydro-electric power plant.

However, in spite of the substantial continuous outflow of surface fresh water and the absence of a shallow sill seaward of the head of the inlet, which could impede the exchange of bottom water, the condition of the upper end of the inlet with respect to dissolved oxygen was probably less than should be expected. The top 5 meters were highly oxygenated at all stations with exceptionally high percent saturation values of up to 150% reported in the September survey. The fairly large flow of well-oxygenated freshwater from the tailrace, combined with an unusually sunny summer period encouraging increased phytoplankton photosynthesis can explain the high surface dissolved oxygen values observed. Below the top 5 meters, and particularly east of Coolidge Point, oxygen concentration and percent saturation levels dropped relatively quickly down to what would appear to be abnormally low levels for this type of estuary. As suggested by Waldichuk (1962) the low dissolved oxygen concentrations found in the bottom water at this end of Cousins Inlet are probably primarily the result of the high biochemical oxygen demand placed upon the water column by the fibre bed covering the bottom of the inlet, and to a lesser extent, by the effluent discharged from Ocean Falls Corporation.

However, it must also be reported that in comparing our 1974 results with those of Waldichuk (1962), Waldichuk et al (1968), and Bishop et al (1970 unp) a considerable improvement in the oxygen content of the water column seems to have taken place over the past few years. Waldichuk (1962) reported finding almost anoxic conditions (>0.1<0.5 mg/l) in the bottom water from the head of the inlet to beyond station O-9 in September 1961, and to station O-7 in October 1964 (Waldichuk et al 1968). Bishop et al (1970 unp) found similar circumstances in August, 1970. In September 1974 the exceedingly low oxygen values of less than 0.1 mg/l were limited to the bottom waters between station O-12 and the mill.

The improved condition of the water column with respect to dissolved oxygen can probably be attributed in large part to the phase-out of the sulphite and sulphate operations at the mill in 1967. The resultant dramatic reduction of effluent BOD and suspended solids from these sources to the inlet, combined with the gradual biodegradation and probably burial of the active surface of the old fibre bed with natural sediment, appear to have reduced the oxygen demand placed upon the system to a point that permits a more substantial amount of oxygen to remain in the water column. Presumably, as time progresses and especially if the remaining groundwood and newsprint operations continue to tighten up on their fibre losses, the condition near the head of Cousins Inlet with respect to dissolved oxygen should continue to improve.

More oceanographic sampling will be required in the future on both an annual and seasonal basis to verify or reject this apparent trend, but for the moment present signs are most encouraging.

SCUBA examination of the intertidal and shallow subtidal fauna of Cousins Inlet beyond the immediate vicinity of the mill revealed communities typical of most protected rocky coastal regions of British Columbia, such as those reported in Howe Sound by McDaniel (1973) and in Puget Sound by Kozloff (1973). There appeared to be no observable deleterious effects stemming from present mill activities, although some signs of previous effects were noted, such as the uniform growth of obviously juvenile mussels

(Mytilus edulis) and barnacles (Balanus glandula) at station D. At this station it appeared as if the previous sedentary community had been destroyed, possibly by past log-booming or other mill-related causes, and had been replaced by this more recent new growth.

Cancer crabs (C. magister, C. productus) and shrimp(Pandalus danae) were noted at several stations and are probably present at all of them. A Mr. Brosseau, who has worked at the mill for over 15 years and is also an experienced diver reported that, prior to the shutdown of the sulphate and sulphite mills, crabs, shrimps and other desirable species could not be found closer than Wallace Bay. In recent years he has observed a tremendous improvement in water clarity and colour, and has noted the rapid recolonization of upper Cousins Inlet with the more mobile macroinvertebrates. Our observations did not extend east of Coolidge Point, although it may be assumed that conditions would deteriorate in that direction due to the presence of log booming activities and the proximity to the mill outfalls.

The large numbers of fingerling salmonids seen in the inshore shallows at station A are another encouraging sign that surface water quality at least is sufficiently suitable for the rearing of salmonids originating from the Martin River system. Further evidence of good water quality at the surface of the inlet is provided by the results of a salmon rearing experiment conducted from October 1, 1971 to May 27, 1972 in Cousins Inlet by researchers from the University of Washington. This investigation reported that chinook salmon and rainbow trout grew well under the prevailing conditions with no abnormal mortalities and no impairment of fish flavour (Koski.,1973 unp).

Fisheries and Marine Service statistics (unpublished) report that small but viable runs of coho, pink and chum salmon have been spawning in the Martin River since 1920 when recorded observations were first instituted. Considerable sports troll-fishing was noted seaward of Coolidge Point during the summer and a substantial number of spawners were reported present in the inlet in September by local fishermen.

The extent and composition of the fibre deposit does not appear to have changed appreciably in the last few years. Bishop et al in 1970 reported that it extended in excess of two miles down the inlet from the mill, and was composed of black fibrous ooze, chips and bark. In the 1974 survey the deposit was found to extend approximately 1.75 nautical miles down the inlet. Fibrous ooze, emitting hydrogen sulphide comprised the major portion of the bed, but the surface 1.5 cm was oxygenated and contained a randomly distributed population of polychaete worms, primarily Capitella sp., not previously reported (Waldichuk, 1962). Continued oxygenation of the fibre surface should lead to a more rapid and complete decomposition of the fibre bed in the future. This, combined with decreased fibre loss resulting from mill process changes and reduced production should also limit further extension of the deposit. Finally, indications of natural deposition over the fibre bed were found in both the benthic and SCUBA surveys. The continued deposition of natural refuse should act to seal off the oxygen consuming fibre and will in the process provide a more substantial substrate leading to the development of a larger, more diverse and more normal infaunal community.

SUMMARY

1. In general, the physical oceanography of Cousins Inlet in 1974 was typical of that expected for a fjord with a substantial, relatively constant surface outflow and no shallow seaward sill. The inlet was highly stratified with respect to all parameters measured, namely temperature, salinity and dissolved oxygen.

2. The temperature and salinity gradients were similar to those reported previously by Waldichuk (1962), Waldichuk et al (1968) and Bishop et al (1970 unp.) at the same time of year, with no unusual features.

3. The top ten meters of the water column throughout Cousins Inlet was highly oxygenated at all times but below this depth dissolved oxygen and therefore percent saturation values dropped rapidly, particularly at the bottom near the head of the inlet, and more so in September. Nevertheless, the levels of dissolved oxygen found in 1974 represented a considerable improvement over those reported in 1961, 1964 and 1970, at comparable times of year.

4. The prevailing low dissolved oxygen concentrations can probably be attributed to the accumulation of oxygen demanding mill wastes on the

bottom of the upper end of the inlet plus that created by the continuing discharge of approximately 14.5×10^6 IGD of mill and domestic effluent to the inlet. The apparent improvement of conditions with respect to dissolved oxygen over time seems to be primarily the result of shutdown of the sulphite and sulphate mills in 1967 and the subsequent reduction of effluent and associated oxygen demanding wastes.

5. SCUBA observations of the intertidal and shallow subtidal fauna at selected sites beyond the immediate vicinity of the mill revealed communities typical of most protected rocky coastal regions of British Columbia. Signs of relatively recent recolonization, such as uniform new growths of juvenile mussels (*Mytilus edulis*) and barnacles (*Balanus* sp.) were noted, as were substantial populations of shrimp (*Pandalus danae*) a wide assortment of starfish, and some cancer crabs (*C. magister* and *C. productus*) where formerly there were none.

6. A large number of fingerling salmonids was observed in the shallow inshore area at station A in June suggesting adequate water quality for fish rearing in the surface zone.

7. The extent and composition of the fibre deposit does not appear to have changed appreciably since the last survey in 1970, with the exception that the surface layer (approx. 1.5 cm) was oxygenated in June and contained some polychaetes which had not been reported previously. The fibre bed was found to extend approximately 1.75 nautical miles down the inlet and was composed primarily of fibrous hydrogen sulphide ooze with some bark, chips, and natural sediment.

8. It would appear that the condition of the inlet is generally improving in all respects and should continue to do so, provided that waste loading and toxicant addition to the inlet continue to be reduced or are maintained at a sufficiently low rate to permit the natural processes of Cousins Inlet to operate more effectively. More work should be carried out in future years to verify or reject this apparent trend.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance and cooperation received from the management and staff of the Ocean Falls Corporation. Our thanks are also extended to the Photographic Section, Information Division, B.C. Forest Service for permitting us to use two of their photos, D. Brosseau for assisting us with SCUBA gear and an air supply, L. Pearson for the drafting and J. Diver for typing the report.

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APPENDIX I

Cousins Inlet Water Quality Data.

APPENDIX I: COUSINS INLET WATER QUALITY DATA

Ocean Falls Survey June 11 1974

Station	Time	Depth (m)	Salinity °/oo	Temperature °C	Dissolved Oxygen mg/l	% Saturation
0-5	1055	0	5.2	9.2	11.2	104
		5	24.8	9.7	10.3	108
		10	30.0	7.6	8.2	85
		20	31.4	6.6	7.5	76
		50	32.7	6.5	6.1	63
		75	33.3	6.5	6.1	63
0-6	1200	0	5.8	9.7	11.2	105
		5	23.0	9.7	9.9	103
		10	30.3	7.8	7.7	80
		20	31.6	6.7	6.9	70
		50	32.95	6.4	5.7	59
		65	32.95	7.0	5.9	62
0-6a	1255	0	4.3	9.8	11.2	150
		5	20.3	9.8	10.1	104
		10	28.2	8.2	8.3	86
		20	31.5	6.7	7.4	76
		50	32.1	6.2	4.8	49
		65	32.1	6.5	5.7	59
0-7	1425	0	4.3	10.0	11.2	105
		5	13.6	10.8	10.8	109
		10	29.5	7.6	7.2	74
		20	31.6	7.5	5.4	55
		30	31.5	6.8	3.8	39
		55	31.5	6.5	4.6	47

Ocean Falls Survey June 11 1974

Station	Time	Depth (m)	Salinity ‰	Temperature °C	Dissolved Oxygen mg/l	% Saturation
0-7a	1540	0	4.6	9.5	11.2	104
		5	21.2	10.0	9.9	103
		10	29.1	8.2	7.5	79
		20	31.1	6.5	6.0	61
		30	31.1	7.0	4.4	45
		53	31.8	6.5	4.2	43
0-9	1745	0	3.3	8.2	11.8	105
		5	22.9	9.6	9.8	102
		10	28.5	8.1	7.9	82
		20	30.4	6.8	6.7	68
		30	31.1	6.5	4.0	41
		55	31.8	6.0	4.1	42
0-10	1845	0	3.3	7.8	11.3	100
		5	24.4	9.2	9.3	96
		10	27.7	8.5	8.0	83
		20	30.3	7.0	5.6	58
		30	31.0	6.5	4.2	43
		45	31.6	7.0	2.5	25
0-12	1920	0	3.9	9.2	11.1	102
		5	24.4	9.5	8.8	92
		10	28.4	8.3	7.0	73
		20	30.3	6.9	5.6	57
		30	31.0	7.0	2.7	28

Ocean Falls Survey Sept.4,1974

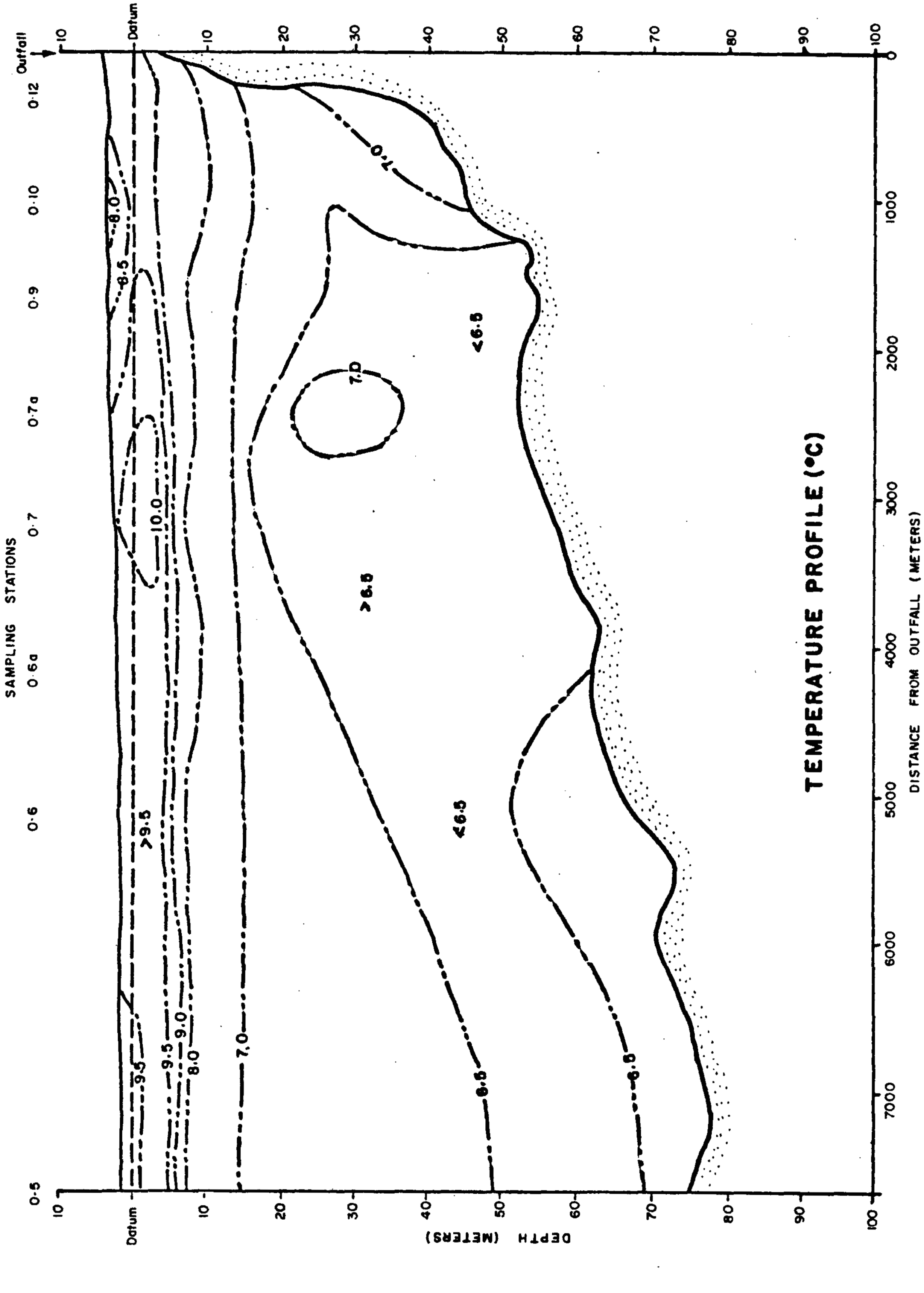
Station	Time	Depth (m)	Salinity °/oo	Temperature °C	Dissolved Oxygen mg/l	% Saturation
0-5	1030	0	11.0	15.8	9.9	110
		5	24.5	12.7	13.2	149
		10	28.5	11.0	10.2	114
		20	31.0	10.9	5.4	61
		50	32.0	11.2	4.0	46
		75	33.0	8.6	3.7	40
0-6	1115	0	10.0	15.6	9.9	108
		5	24.5	12.5	13.6	153
		10	29.5	11.5	9.8	111
		20	31.5	10.6	4.0	45
		50	32.5	9.8	3.8	42
		65	33.0	9.6	2.6	29
0-6a	1140	0	9.5	15.7	9.7	106
		5	22.5	12.8	11.6	129
		10	30.0	11.7	8.2	94
		20	31.5	11.0	4.1	46
		50	33.0	11.0	2.7	31
		62	33.0	9.3	2.0	22
0-7	1213	0	6.5	14.8	9.7	102
		5	23.5	12.9	11.9	134
		10	30.0	10.5	7.5	83
		20	31.5	9.8	3.9	43
		30	32.0	9.3	3.4	37
		55	32.5	9.1	2.2	24

Ocean Falls Survey Sept. 4,1974

Station	Time	Depth (m)	Salinity ‰	Temperature °C	Dissolved Oxygen mg/l	% Saturation
0-7a	1235	0	5.0	14.0	9.9	102
		5	24.0	12.2	11.3	126
		10	29.5	11.5	7.4	84
		20	31.5	9.4	3.4	37
		30	31.5	9.3	3.0	33
		50	32.5	9.1	1.4	15
0-9	1345	0	5.0	14.0	9.9	99
		5	24.0	12.2	11.3	133
		10	29.5	11.5	7.4	77
		20	31.5	9.4	3.4	37
		30	31.5	9.3	3.0	39
		50	32.5	9.1	1.4	17
0-10	1415	0	2.5	13.0	10.0	99
		5	27.0	10.5	12.8	140
		10	29.5	10.8	7.2	80
		20	31.5	9.7	2.6	29
		30	32.0	9.4	1.8	20
		45	32.0	8.7	1.3	14
0-12	1440	0	1.5	12.9	10.1	100
		5	25.5	11.7	11.7	130
		10	30.0	10.3	5.8	64
		20	31.5	8.8	2.6	28
		25	31.5	8.9	0.1	1

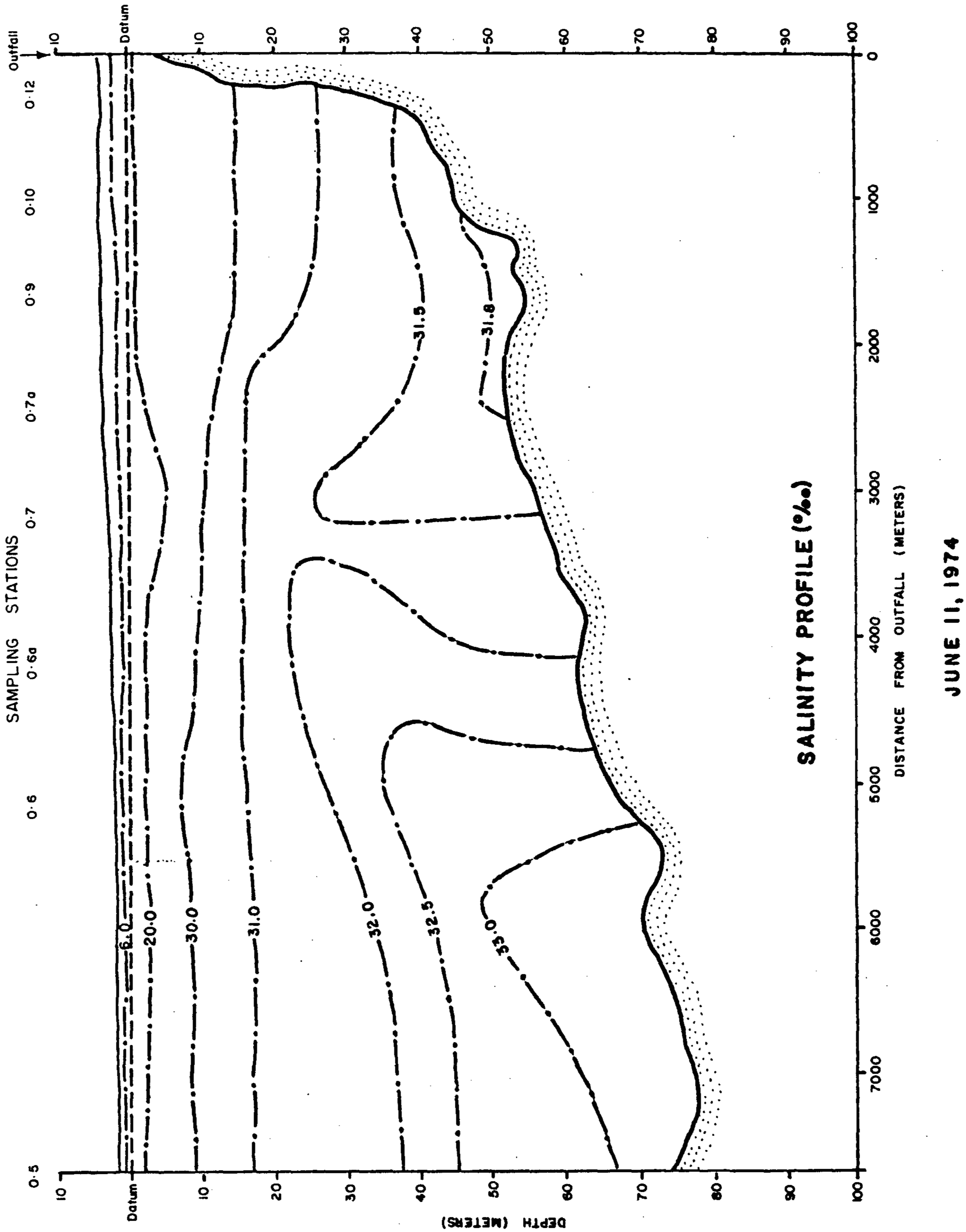
APPENDIX II

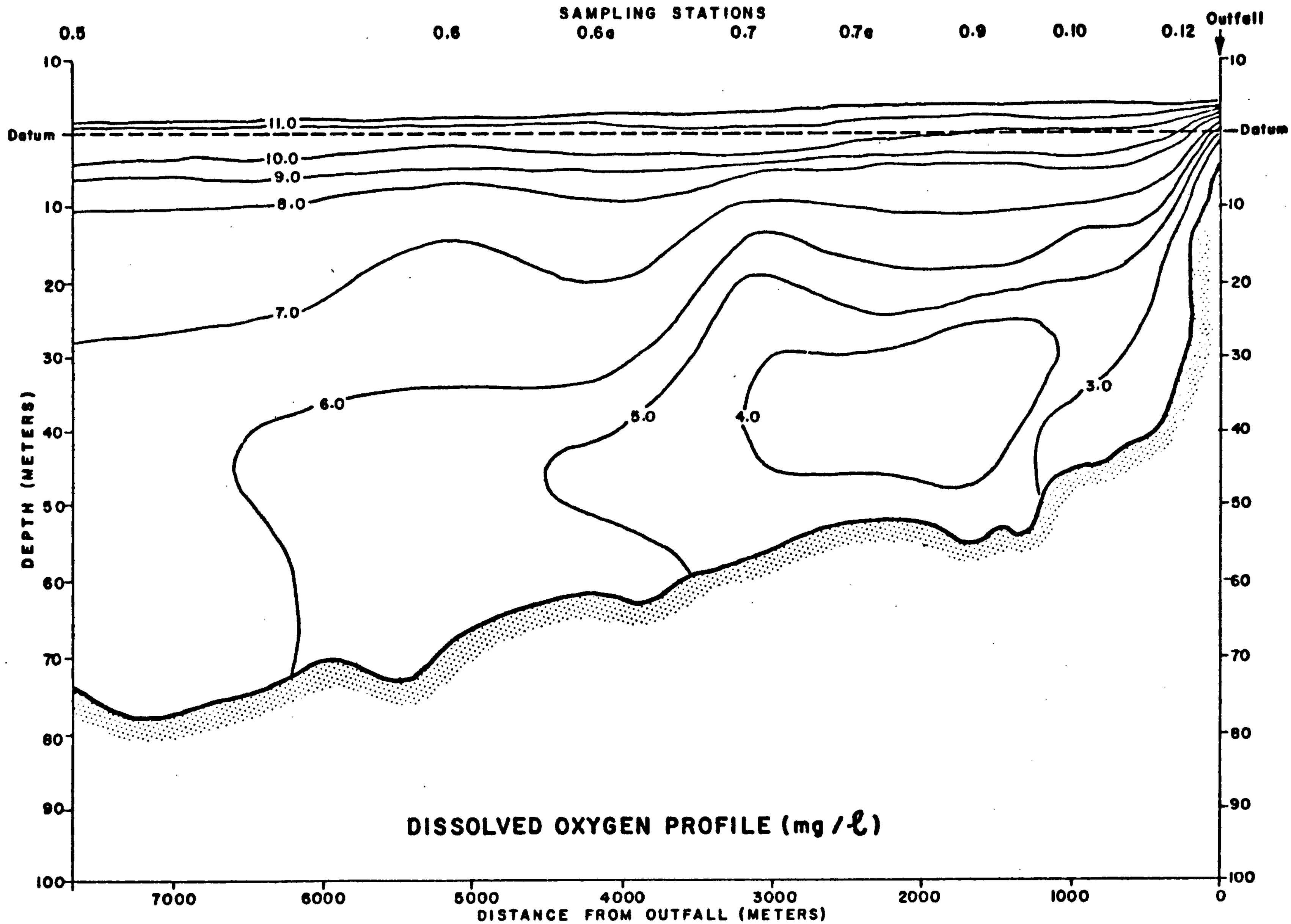
Longitudinal Temperature, Salinity and Dissolved Oxygen Profiles of Cousins Inlet on June 11 and September 4, 1974.



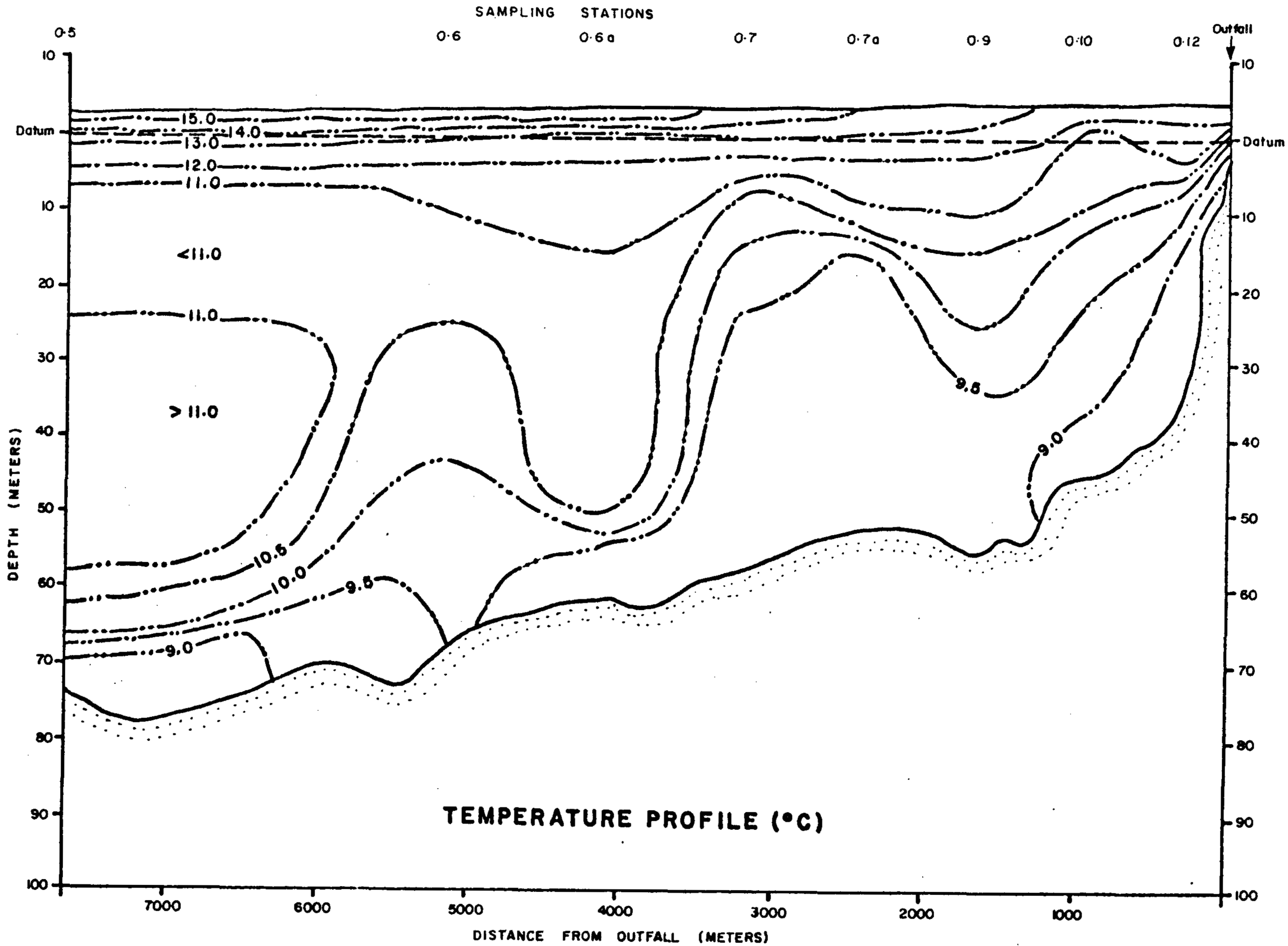
TEMPERATURE PROFILE (°C)

JUNE 11, 1974


SAMPLING STATIONS
Outfall
0·12
0·10
0·9
0·7a
0·7
0·6a
0·6
0·5
Datum
DEPTH (METERS)
DISTANCE FROM OUTFALL (METERS)
0
1000
2000
3000
4000
5000
6000
7000
10
20
30
40
50
60
70
80
90
100
6.0
20.0
30.0
31.0
31.5
31.8
32.0
32.5
33.0
SALINITY PROFILE (‰)
JUNE 11, 1974

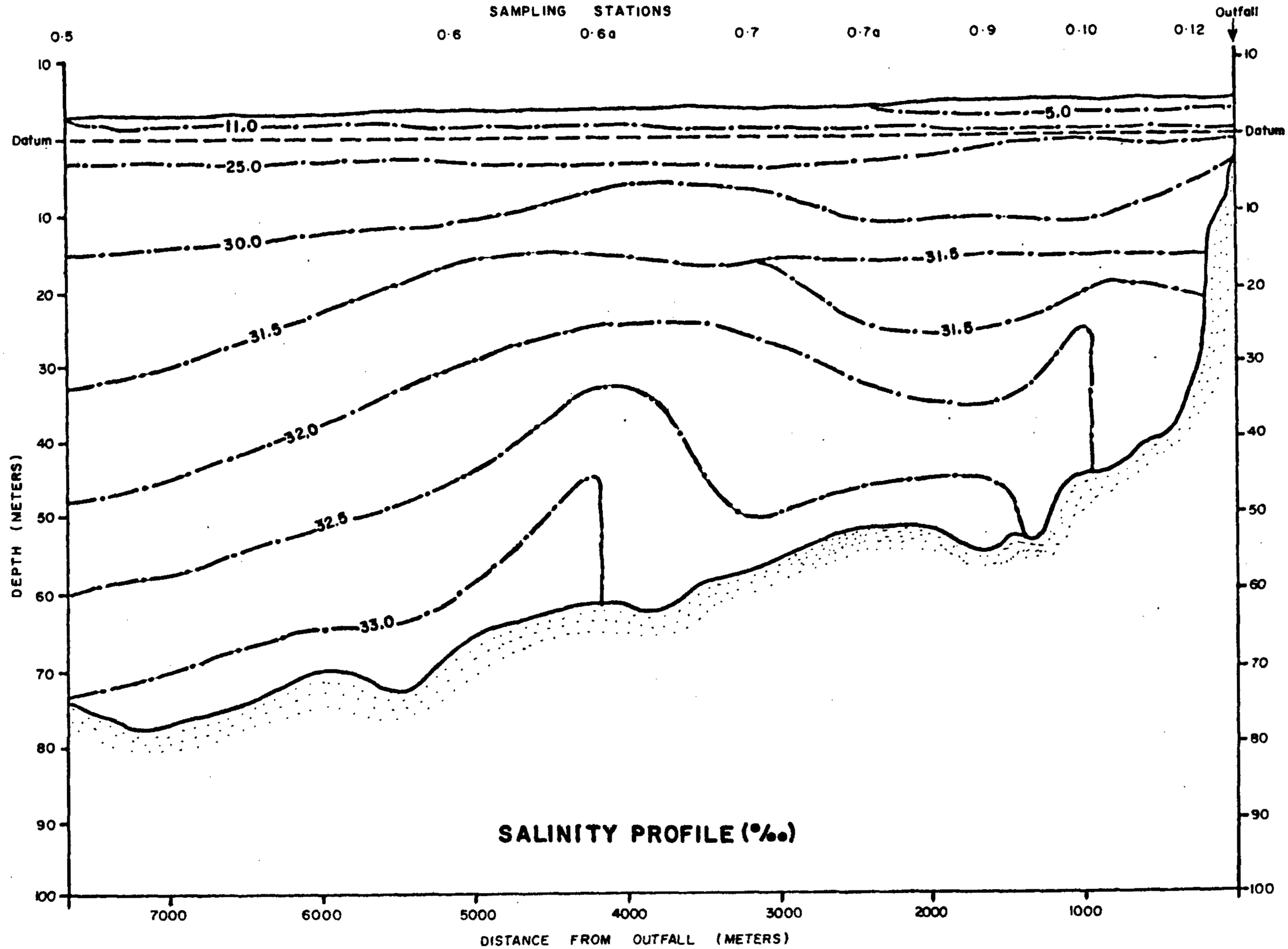

SAMPLING STATIONS
0.5
0.6
0.6a
0.7
0.7a
0.9
0.10
0.12
Outfall
Datum
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
DEPTH (METERS)
10
10
20
30
40
50
60
70
80
90
100
DISSOLVED OXYGEN PROFILE (mg / ℓ)
7000
6000
5000
4000
3000
2000
1000
0
DISTANCE FROM OUTFALL (METERS)

JUNE 11, 1974



SEPTEMBER 4, 1974

SEPTEMBER 4, 1974



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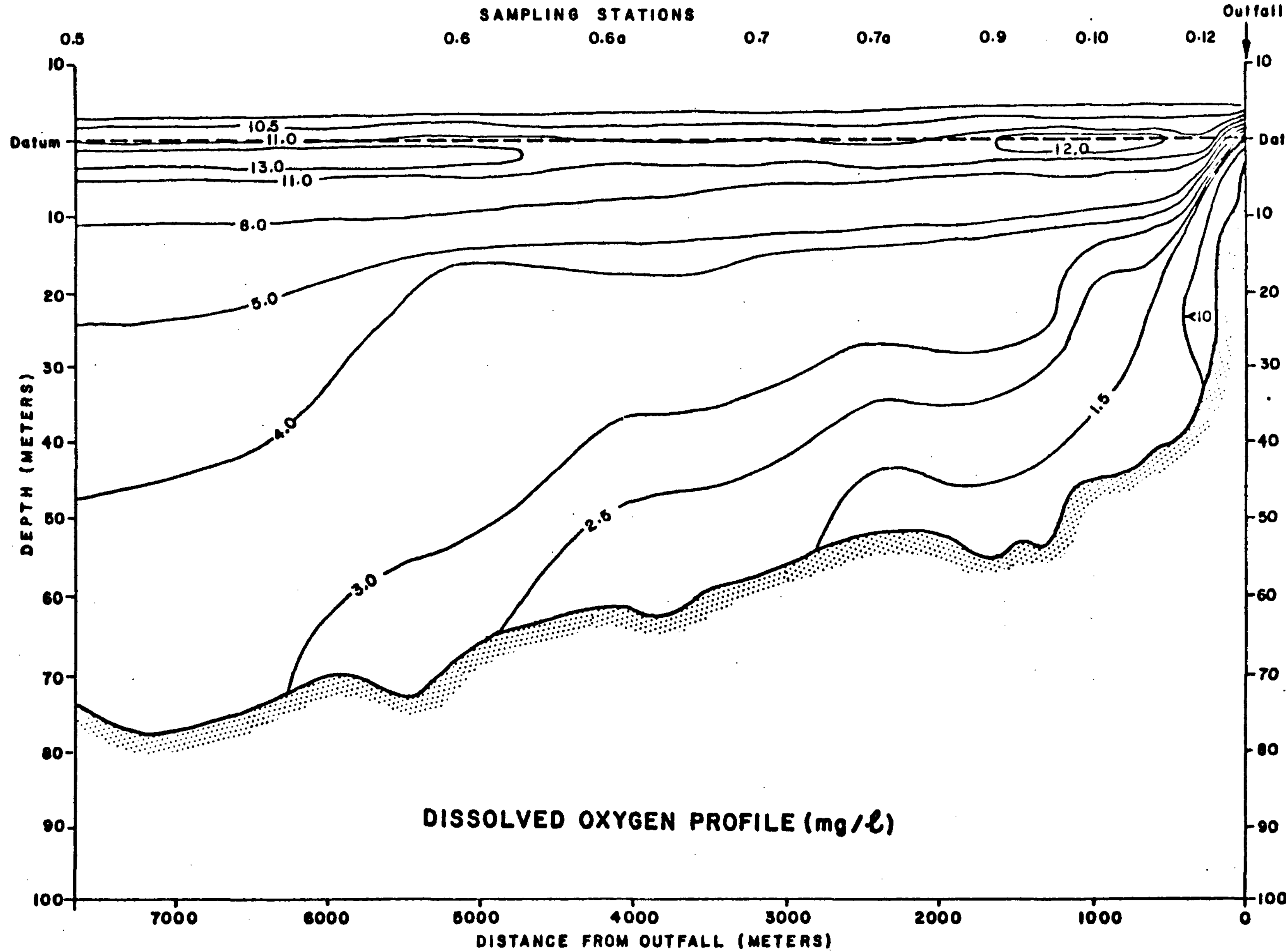

SEPTEMBER 4, 1974

APPENDIX III

Partial List of Macrobenthos of Cousins Inlet.

APPENDIX III: PARTIAL LIST OF MACROBENTHOS OF COUSINS INLET

(present X)
(abundant *)

	STATION NUMBER			
	A	B	C	D
PORIFERA				
Cl Demospongia				
Esperiopsis sp.	X		X	X
Mycale adhaerens		X		
CNIDARIA				
Cl. Anthozoa				
Metridium senile	x*	X	X	X
Tealia crassicornis	X		X	
BRACHIOPODA				
Cl. Articulata				
Terebratalia transversa				X
MOLLUSCA				
Cl. Amphineura				
Mopalia sp.	X		X	X
Cl. Gastropoda				
Littorina sp.	X		X	X
Fusitriton oregonensis		X*		
Collisella pelta	X		X	X
Ceratostoma foliatum	X	X	X	
Thais lamellosa	X	X	X	X
Anisodoris nobilis		X		
Cl. Pelecypoda				
Mytilus edulis	X		X	X*
Pododesmus macroschisma	X		X	X
Chlamys rubida		X*		
Mya sp.		X*		

	STATION NUMBER			
	A	B	C	D
ANNELIDA				
Cl. Polychaeta				
Serpula vermicularis	X	X	X	X
Spirorbis pacifica	X		X	
ARTHROPODA				
Cl. Crustacea				
Balanus glandula	X	X	X	X*
Pandalus danae	X*	X	X*	X
Spirontocaris brevirostris	X		X	
Cryptolithodes typicus				X
Phyllolithodes papillosus	X		X	X
Pagurus sp.	X	X	X	X
Cancer Magister			X	
Cancer productus			X	X
Hemigrapsus nudus	X		X	X
Oregonia gracilis	X	X	X	X
Hyas lyratus	X	X	X	X
ECHINODERMATA				
Cl. Crinoidea				
Florometra serratissima		X		
Cl. Holothuroidea				
Parastichopus californicus	X*	X	X	X
Cucumeria miniata	X		X	X
Psolus chitonoides				X
Cl. Echinoidea				
Strongylocentrotus droebachiensis	X	X	X	X
Strongylocentrotus franciscanus		X		

	STATION NUMBER			
	A	B	C	D
Cl. Asteroidea				
Dermasterias imbricata	X	X	X	X
Pteraster tesselatus	X	X	X	
Pisaster ochraceus	X*	X	X	X
Orthasterias koehleri	X		X	X
Pycnopodia helianthoides	X*	X	X*	X*
Evasterias troschelli	X	X	X	X
CHORDATA				
Corella willmeriana	X			
Boltenia villosa	X		X	X

APPENDIX IV

Ponar Dredge Sampling Data.

APPENDIX IV: PONAR DREDGE SAMPLING DATA

Station Number	Sediment Characteristics	Organisms
1	- grey-green-black sediment large fibres and bits of bark and wood	- a few Capitellid polychaetes
2	- grey-green-black, almost pure fibre moderate H_2S odour	- no apparent organisms
3	- grey-green-black,almost pure white fibre . - surface 1.5 cm oxygenated - moderate H_2S odour	- Capitella rather small unidentified polychaetes
4	- grey-green-black,blacker than other adjacent stations - heavier H_2S odour - large strips of brark	- a few Capitella and small empty mussel shells.
5	- greyish-green, mainly fibre - considerable amount of large wood chips and bark - some 1mm gravel & coarse sand	- some Capitella
6	- grey-green-black	- sample contained what appeared to be terebellid tentacles. - empty Mytilus up to two inches - some small empty clam shells (Macoma sp.)
7	- grey-green-black,almost pure fibre - no bark or chips	- no apparent organisms - some dead bivalves(Macoma sp.)

Station Number	Sediment Characteristics	Organisms
8	- greyish-green, almost pure fibre - some sand and gravel	- some empty bivalve shells (Macoma sp.)
9	- mainly bark w̄ some fibre	- a few small polychaetes and empty bivalve shells
10	- pure fibre	- no apparent organisms 1 empty bivalve
11	- grey-green-black fibre, some bark	- colony of tunicates - few polychaetes & empty shells
12	- pure fibre	- terebellid polychaete
13	- considerable bark & woodchips w̄ remainder being fibre	- no apparent organisms
14	- almost pure faecal pellets - some woodchips	- 1 small ophiuroid - some polychaetes
15	- almost pure faecal pellets - no fibre present - some wood chips	- several polychaete species, nemerteans, holothurians (Eupentacta quinquesemita
16	- faecal pellets & possibly remnants of old fibre bed	- no apparent organisms
17	- faecal pellets	- no apparent organisms

Station Number	Sediment Characteristics	Organisms
18	- faecal pellets & old fibre bed - residual H_2S smell.	- no apparent organisms