The influence of decomposing salmon on water chemistry
David C. Brickell, John J. Goering

THE INFLUENCE OF DECOMPOSING SALMON ON WATER CHEMISTRY

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Completion Report

by

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I. INTRODUCTION

The Pacific salmon (Oncorhynchus sp.) is a valuable source of food energy from the sea and its potential is not yet fully realized. The two most highly evolved species of the genus, O. gorbuscha and O. keta, are true marvels of efficiency from the anthropomorphic vista. Upon hatching in the gravels of coastal streams and rivers each spring, the salmon fry of these two species migrate immediately to the sea to harvest the productivity of the ocean waters. Their migrations extend over vast areas of the Central North Pacific.

After one year of residence in the ocean these salmon are compelled by instinct to return to their natal waters. This homeward migration results in the transfer of millions of pounds of organic matter, once widely distributed in the open ocean, to the coastal waters where salmon spawn. Thus, the vast primary productivity of the open ocean, which is currently too diffuse to harvest economically, is brought within man's grasp. This directed biomass transfer is sufficiently large to be considered a "biological current" originating in the Central North Pacific and terminating in the freshwater streams of the coast.

In addition to the large commercial harvest, of which a portion, about 20% by weight, is returned to the ocean as waste from processing plants, millions more salmon enter freshwater streams to spawn and inevitably to die and decompose. The fate and distribution of this organic matter has previously received little attention.

Although the decomposition of salmon carcasses in the marine environment is a natural phenomenon, the possibility that localized accumulations of seafood waste products, as might occur in the vicinity of processing plants, may stress the marine environment beyond its capacity to maintain stability must be considered.

Our interest in the fate of organic matter associated with seafood processing waste was stimulated by a Bering Sea cruise of the R/V ACONA, cruise number 066, in June 1968. In samples taken off the coast of Alaska in areas of significant seafood processing, namely in the area of Kodiak, Alaska and Unalaska, Alaska, we observed a water layer with extraodrinarily high concentrations of ammonium. Near the processing plants toxic ammonium concentrations approaching 25 μg-atom NH_4^+-N/liter were observed while lower yet distinctly elevated concentrations were observed over tens of square miles of ocean in the area.

Other cruises of the R/V ACONA in the fjords of Southeast Alaska have revealed moderately high concentrations of ammonium at about 20-30 m. Evidence suggests that the origin of this ammonium is within the estuary rather than from the sea. Since the streams of Southeastern Alaska are abundant with salmon, the observed concentrations of ammonium may represent the results of carcass decomposition within the estuary.

To increase our knowledge of the biological and chemical effects of the decomposition of seafood material, we have initiated a study of the decomposition of salmon carcasses in a natural system in southeastern Alaska (i.e. Little Port Walter estuary). The Pacific salmon migrates through this estuary when returning to its natal stream to spawn. Following spawning the fish die and the carcasses are eventually carried to the estuary where they sink to the bottom. During periods of low stream flow, the dead carcasses may remain in the stream itself until higher stream flows transport them to the estuary. In years of large escapements, the density of fish in the spawning stream can be very high. In the system chosen for our work, spawning densities greater than six fish per m^2 have been recorded although at the time the current study was conducted the spawning density was slightly more than two fish per m^2. Since our system involves primarily pink salmon (O. gorbuscha), the average weight of the fish can be assumed to be 2-3 kilograms.

Thus, our study is concerned with the fate and distribution of some 75 metric tons of organic matter in the form of salmon carcasses in one small estuary in Southeastern Alaska. We are particularly interested in determining: (1) the effects of the salmon carcass decomposition on the nitrogen chemistry of the water in which the decomposition occurs; (2) the form and distribution of the organic matter which is returned to the marine system; and (3) the rate at which remineralization occurs. This paper presents the results of our initial investigations.

II. METHODS

The system selected for study included a pink salmon spawning stream, Sashin Creek, and its associated estuary, Little Port Walter, on Baranof Island, Southeastern Alaska. Another small estuary in the vicinity, Toledo Harbor, was used as a control for the estuarine studies as it did not support a salmon run.

Sashin Creek flows some 3,000 m from Sashin Lake to the Little Port Walter estuary. A high waterfall prevents further upstream migration of the salmon, and hence spawning is limited to the lower 1,200 m. The stream area above the waterfall was used as a control for the stream studies since this area revealed seasonal variations in water chemistry but was not influenced by salmon. A permanent weir for counting fish entering the stream is located at high tide level.

The U.S. Bureau of Commercial Fisheries has maintained a research station at Little Port Walter since 1934 for the purpose of collecting information on the freshwater ecology of pink salmon. These studies have resulted in the definition of 3 distinct ecological areas of the stream: an upper, middle and lower area. To maintain integrity with existing data, we observed the same sampling boundaries in the stream. The total area of Sashin Creek available for spawning is about 13,600 m^2. The width of the stream varies between 12 and 24 m. Stream discharge data for Sashin Creek has been collected since 1951 and ranges of 8.0 to 700 cubic feet per second with a mean of 80 c.f.s.

The Little Port Walter estuary is small, consisting of an inner and outer bay with a constriction between the two. The distance from the mouth of Sashin Creek at high tide to the entrance to the outer bay is approximately 1.5 km, and the maximum width is about 0.4 km. The maximum depth at low tide is 44 m for the outer bay and 21 m for the inner bay. The connecting channel is 27 m wide and about 6 m deep at low tide. Tidal variations range to 4.6 m. A detailed description of the oceanography of Little Port Walter estuary is given by Powers (1962).

Toledo Harbor, about 3 km south of Little Port Walter, has dimensions approximately the same as the inner bay of Little Port Walter. The fresh water stream entering the harbor has a waterfall just above high tide level and does not therefore support a salmon run.

a. Stream Studies

Prior to the arrival of the salmon, surface water samples were collected weekly in Sashin Creek above the waterfall and at the lower end of each of the three designated ecological areas of the stream. Analyses for NO_2^--N, NO_3^--N, NH_4^+-N, dissolved organic -N and inorganic phosphate were performed. Nitrite was determined by the Griess method as applied to seawater by Strickland and Parsons (1965). Nitrate was determined by conversion to nitrite in a cadmium-mercury reduction column based on a method by Grasshoff (1964) and determined as nitrite. Ammonium was measured using the recent method of Solórzano (1969). This method is specific for ammonium and does not measure labile amino nitrogen. The ammonium method of Richards and Kletsch (1964) was used to obtain the Bering Sea ammonium values. This method is not specific for ammonium -N but measures a considerable fraction of labile amino nitrogen as well. Dissolved organic nitrogen was determined by converting it to nitrate by ultra-violet light oxidation in the presence of oxygen according to the method outlined by Armstrong, Williams and Strickland (1966). Reactive phosphorus was determined by the method of Murphy and Riley (1962). Samples were collected weekly beginning in August and continuing into November, about 2 months beyond spawning.

b. Estuary Studies

In the estuary weekly samples were collected at selected depths in both Little Port Walter and Toledo Harbor. The same chemical analyses and procedures were employed as were used in the stream studies.

III. RESULTS

a. Iliuliuk Bay and Bering Sea Studies

The locations of sampling stations and seafood processing plants on Amaknak and Unalaska Islands, which are located near Unimak Pass in the Aleutian chain, are shown in Figure 1. The oceanographic parameters observed in the area on cruise 066 indicated that during our sampling period in June 1968 the tidal current entered the area from the northwest and exited toward the northeast. The temperature-salinity-oxygen characteristics in the Captain's Bay area where station 2349 is located suggested an open ocean environment little affected by the waste of the processing plants, while those stations to the northeast of the processing plants revealed rather marked chemical alteration. Table 1 presents the chemical and physical parameters obtained at all stations. Station 2349, indicative of the water entering the area of seafood processing, had a normal open ocean ammonium concentration of approximately 1μg-atom NH_4^+-N/liter at 25 m while the ammonium concentration at 25 m at station 2341 was 23.8μg-atom NH_4^+-N/liter, which is an extraordinarily high concentration för sea water. Station 2351, further seaward, exhibits the chemical characteristics which result after the water from Iliuliuk Bay has mixed with Bering Sea water. The ammonium values obtained in this study of Iliuliuk Bay were determined using the method of Richards and Kletsch. This method does not distinguish ammonium -N from labile amino -N. Because of the highly organic nature of the seafood waste a considerable fraction of the nitrogen reported here as ammonium -N could be amino -N.

Figure 2 presents a plot of the ammonium and oxygen concentrations with depth at stations sampled in Iliuliuk Bay. The results show a drastic increase in the ammonium concentration of the waters while in residence in Iluiliuk Bay. Whereas that water entering the bay from Captains Bay has an ammonium concentration of approximately 1μg-atom NH_4^+-N/liter, the concentration of ammonium in the bottom waters within the bay increases to almost 25μg-atom NH_4^+-N/liter. Likewise, the oxygen concentration of the bottom waters is lowered. The ammonium concentrations are high at intermediate depths, 5 - 10 μg-atom NH_4^+-N/liter at 15 m, but the most significant increase in ammonium and decrease in oxygen occurs between 15 and 25 m. Since the 25 m sample is near the bottom, the substantial increase in ammonium at this depth probably results from decomposition of organic matter which has accumulated on the bottom.

The data for station 2351 indicate a well mixed water column with the ammonium distributed rather uniformly through the column from the surface to 50 meters. Other seaward stations displayed decreasing but elevated ammonium concentrations suggesting that ammonium originating in Iliuliuk Bay has an influence on the nitrogen economy of the surrounding ocean.

b. Stream Studies

After evaluating the data from the Iliuliuk Bay and Bering Sea study we decided to examine a natural phenomenon which results in the accumulation of organic matter in the marine environment similar to the situation observed in the vicinity of seafood processing sites. Salmon inevitably die following spawning. This results in the accumulation of salmon carcasses both in the freshwater stream where spawning occurs and in the receiving estuary. This natural system was selected for study because it represents a cyclic phenomenon which can be followed from beginning to end with little external influence.

About 30,000 pink salmon spawned in the 1200 m of Sashin Creek in 1969. After spawning and death many of these carcasses remained in the stream for a period of time before being washed into the estuary. Some of these were scavenged, but the majority of the carcasses were deposited on the bottom of the Little Port Walter estuary. In following the chemistry of salmon carcass decomposition we were particularly interested in the nitrogen chemistry. Since fish flesh contains much protein we felt that the various forms of nitrogen would be excellent indices of the rates of biological decomposition of salmon carcasses.

Surface water samples were collected and analyzed weekly from four different sites in the stream; above the waterfall which prevented further upstream migration of the spawners, Area 0, and at the lower boundary of each of the three defined ecological areas. These boundaries were as follows: Area I, waterfall - 430 m downstream; Area II, 430 - 730 m downstream; and Area III, 700 - 1200 m downstream. The first 300 m of stream below the waterfall is not favorable for spawning and hence only a few carcasses are deposited here.

Since the water at each sampling area downstream had been exposed to more carcasses we expected a systematic increase in the concentrations of metabolites resulting from carcass decomposition as we moved progressively downstream.

Water samples collected prior to entrance of the fish into the stream showed little variation in water chemistry from above the falls to the mouth of the stream. On August 31, the NH_4^+-N concentration above the fall was 0.32 µg-atom N/liter while at the stream mouth the concentration was 0.46 µg-atom N/liter. Similarly the dissolved organic nitrogen concentration above the falls on that date was 3.3 µg-atom N/liter while at the stream mouth an organic nitrogen concentration of 3.8 µg-atom N/liter was observed.

Spawning activity commenced in late August and by early September dead carcasses began to appear in the stream. The first noticeable chemical effects of decomposition were observed in the stream on September 14. On this date, the ammonium concentration above the falls was 0.40 μg-atom N/liter while at 1200 m downstream the concentration increased to 1.73 μg-atom N/liter. Likewise the dissolved organic nitrogen concentration increased from 4.0 μg-atom N/liter to 7.4 μg-atom N/liter during the traverse. As the number of carcasses increased, the downstream increase in ammonium nitrogen and dissolved organic nitrogen became greater. On September 29 we observed the greatest difference in stream chemistry between the control area and the lower end of the stream. The ammonium concentration increased from 1.66 μg-atom N/liter above the falls to 7.80 μg-atom N/liter at 1200 m downstream. Dissolved organic nitrogen increased from 5.7 μg-atom N/liter to 17.7 μg-atom N/liter. The concentration of NH_4^+-N and dissolved organic -N observed at each sampling site and date are presented in Table 2 and in Figure 3 and 4.

c. Estuary Studies

Water samples in the Little Port Walter estuary and in the control estuary, Toledo Harbor, were collected weekly at 1, 4, 8 and 12 m. Dissolved organic nitrogen proved to be the most valuable index of the salmon carcass decomposition phenomenon. The dissolved organic nitrogen concentrations observed in Little Port Walter and Toledo Harbor appear in Table 3. Figure 5 compares graphically the dissolved organic nitrogen of the surface waters of the two estuaries. Figure 6 is a comparison of their organic nitrogen concentrations at 12 m.

The first effects of salmon carcass decomposition on the water in Little Port Walter estuary, as evidenced by increases in dissolved organic nitrogen, were not observed until about 15 days after increases were first observed in the stream. Heavy rains in late September resulted in flushing most of the carcasses from the stream into the estuary where they sank to the bottom. The dissolved organic nitrogen concentration in the surface water of Little Port Walter estuary began to increase on September 22 and reached a peak of 10.3 μg-atom N/liter on October 28 (Figure 5) while the surface concentration in Toledo Harbor remained almost steady at about 5.4 μg-atom N/liter throughout this period.

The data on ammonium concentrations for the two estuaries did not reflect the immediate effect of carcass decomposition. The concentrations in fact declined during the fall months from a summer high. The ammonium concentrations observed at 12 m depth in the two estuaries is presented in Figure 7.

IV. DISCUSSION

The surprisingly large concentrations of NH_4^+-N and the oxygen depletions observed in Iliuliuk Bay indicate that the decomposition of seafood material in a restricted body of water can influence the nitrogen chemistry of the estuarine environment. The organic waste matter resulting from sea food processing plants located on Iliuliuk Bay is emptied into the estuary rather continuously. Thus the highest observed concentrations of NH_4^+-N at station 2341, 23.8 μg-atom N/liter, may well represent the remineralization of organic material that has accumulated over a long period of time. It would appear that such extremely high concentrations of ammonium are potentially toxic to fish (Ball, 1967) and to other forms of life. Other effects of decomposition such as oxygen depletion are also probably detrimental to the organisms residing in the bay.

It is important to determine whether elevated concentrations of ammonium as were observed in Iliuliuk Bay occur naturally in the marine environment. It appeared from the knowledge available on the nitrogen chemistry of the sea that it is unlikely that such high concentrations of NH_4^+-N would occur naturally, and that the observed situation was therefore the result of industrial stress on the environment. We felt that the phenomenon of salmon carcass decomposition most closely duplicated the industrial situation, and we were therefore interested in determining what level of nitrogen compounds are present in systems where salmon are decomposing.

It is difficult to compare the Richards and Kletsch (1964) ammonium values for Iliuliuk Bay to those obtained by the Solórzano (1969) technique in Little Port Walter since it is uncertain what fraction of the organic nitrogen was recorded by the Richards and Kletsch method as ammonium. Our investigations in Little Port Walter suggest that dissolved organic nitrogen is the initial decomposition product and organic nitrogen (i.e., labile amino-N) may have contributed heavily to the ammonium measured in Iliuliuk Bay. If the ammonium -N and dissolved organic -N for Little Port Walter are summed, a combined dissolved organic -N - ammonium -N concentration of 18.2 μg-atom N/liter occurred near the bottom on 10/16/69. This approximates the value of 23.8 μg-atom of NH_4^+-N/liter observed in Iliuliuk Bay and indicates that high concentrations of ammonium and organic nitrogen are not restricted to waters receiving waste from seafood processing.

The ammonium and dissolved organic nitrogen concentrations observed in Sashin Creek indicate that decomposing salmon carcasses have a significant influence on stream chemistry. It has been observed that survival of salmon eggs in the Sashin Creek spawning beds is significantly lower in the lower area of the stream, Area III, than in the upper areas. Several reasons have been presented by McNeil (personal communication) to explain this phenomenon. The chemical parameter normally associated with survival of eggs in the spawning bed is dissolved oxygen, but we feel that ammonium or other products of carcass decomposition might have a significant influence on egg survival, especially when stream flow is low.

The large dissolved organic nitrogen concentrations observed in the surface waters of Little Port Walter undoubtedly reflect the decomposition of salmon carcasses occurring in the stream and in the intertidal zone. The bottom of the estuary received most of the carcasses and it is here that final decomposition occurs. Sediment samples of the Little Port Walter estuary bottom showed a gelatinous quality even for samples taken prior to the arrival of the fish, suggesting that the sediment may act as a nutrient sink. This gelatinous nature probably results from the long term accumulation of fish carcasses. All sediment samples from Toledo Harbor were granular.

The apparent increase in the concentration of dissolved organic nitrogen observed in the control estuary, Toledo Harbor, between September 22 and September 29 is probably the reflection of heavy rains, wind and heavy cloud cover which resulted both in high runoff from the land and death of plankton in the water column.

It is evident that this brief study is only a beginning in our understanding of the fate of organic matter deposited, naturally or by industry, in the marine environment. Our attempts to follow the decomposition of salmon carcasses employing nitrogen chemistry was rewarding in that effects were clearly demonstrable. Since nitrogen comprises only a small proportion of the organic matter, and since remineralization rates are slow, it is evident that more sophisticated techniques must be utilized to obtain a clear understanding of the process. Possibly, remineralization of the organic matter resulting from carcass decomposition does not occur within the confined body of water where the carcasses are deposited. The early stages of decomposition might result in the production of soluble complex organic compounds which are transported from the local area before remineralization occurs.

ACKNOWLEDGEMENTS

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Table 1. Chemical and physical characteristics of water in Iliuliuk Bay at stations 2327 - 2349 near seafood processing sites and at station 2351 further seaward.

Station number and location	Depth in meters	Temp. C	Salinity °/°°	Oxygen ppm	PO_4^{-3}-P µg-atom/liter	NH_4^+-N	NO_2^--N µg-atom/liter	NO_3^--N µg-atom/liter
2349	0	5.70	32.051	7.91	1.08	0.4	0.17	5.8
53°51.8'N 166°33.3'W	5	5.63	32.005	7.97	1.10	0.4	0.16	6.0
	10	5.01	32.237	7.67	1.35	0.8	0.19	7.8
	15	4.81	32.266	6.90	1.44	0.8	0.19	11.2
	20	4.34	32.294	7.14	1.69	1.0	0.20	13.1
	30	3.70	32.360	6.84	2.12	0.9	0.20	18.3
	40	3.30	32.343	5.60	2.45	1.0	0.22	20.9
2347	0	7.35	24.906	6.78	1.22	5.2	0.19	0.9
53°52.8'N 166°32.7'W	5	5.52	32.171	7.17	1.78	8.1	0.26	5.1
	10	5.20	32.223	7.39	1.50	5.7	0.23	6.6
2341	0	6.71	30.782	7.98	0.51	1.8	0.06	0.2
53°52.8'N 166°31.5'W	5	5.98	31.667	8.05	0.87	3.4	0.11	2.2
	10	5.39	32.202	7.82	1.21	4.6	0.15	4.7
	15	5.03	32.366	7.35	1.47	5.9	0.16	6.4
	25	3.83	32.373	4.30	5.03	23.8	0.33	9.2
2337	0	5.95	31.788	8.07	0.84	2.4	0.12	3.0
53°53.2'N 166°31.1'W	5	5.86	31.820	8.08	0.88	2.3	0.14	3.0
	10	5.47	32.265	8.10	0.98	2.2	0.12	4.5

	15	5.19	32.313	7.83	1.20	4.9	0.15	5.6
	25	3.79	32.381	4.84	4.43	19.9	0.33	9.6
2331	0	6.70	30.781	7.88	0.48	1.7	0.06	0.5
53°53.7'N 166°30.6'W	5	5.87	32.109	8.34	0.83	2.0	0.12	3.4
	10	4.92	32.304	7.51	1.42	6.4	0.17	6.7
	15	4.64	32.347	7.36	1.80	9.3	0.21	7.7
	25	4.11	32.362	5.51	3.37	18.4	0.28	9.9
2327	0	6.02	31.777	7.93	0.70	2.7	0.09	2.3
53°54.2'N 166°30.2'W	5	5.68	32.146	7.97	0.96	3.2	0.10	3.2
	10	5.22	32.376	7.59	1.13	5.0	0.13	5.7
	15	-	32.391	7.28	1.42	6.5	0.16	7.0
2351	0	4.87	-	-	1.30	3.4	0.16	12.0
54°01.3'N 166°04.5'W	5	4.88	32.431	-	1.29	3.6	0.17	11.7
	10	4.88	32.408	-	1.25	3.2	0.18	11.5
	20	4.87	32.502	-	1.26	3.3	0.17	11.8
	30	4.88	32.412	-	1.25	3.2	0.17	11.8
	50	4.87	32.523	-	1.26	3.2	0.17	12.3

Table 2. The concentrations of ammonium -N and dissolved organic -N (D.O.N.) observed in each sampling area of Sashin Creek. Concentrations are expressed as μg-atom-N/liter.

Date	Area 0		Area I		Area II		Area III	
	NH_4^+-N	DON	NH_4^+-N	DON	NH_4^+-N	DON	NH_4^+-N	DON
8/24/69	0.20	3.04	0.60	3.18	0.62	3.27	0.68	3.67
8/31/69	0.32	3.29	0.38	3.39	0.38	3.49	0.46	3.84
9/7/69	0.32	3.38	0.64	3.64	0.92	4.84	0.98	5.39
9/14/69	0.40	4.04	0.33	5.31	1.40	6.10	1.73	7.36
9/22/69	1.31	5.83	1.44	6.44	3.22	8.22	4.17	9.71
9/29/69	1.66	5.71	4.59	7.38	6.55	12.40	7.80	17.67
10/8/69	1.56	5.23	4.48	6.72	6.62	10.52	7.66	16.8
10/16/69	1.44	5.22	4.04	6.11	6.72	8.43	7.02	10.32
10/28/69	1.63	4.84	2.46	6.02	3.88	7.02	5.63	8.64

Table 3. Dissolved organic nitrogen concentrations observed in Little Port Walter and Toledo Harbor estuaries in summer and fall of 1969. Concentrations expressed as μg-atom-N/liter.

Little Port Walter

Depth m	8/24	8/31	9/7	9/14	9/22	9/29	10/8	10/16	10/28	11/14
1	2.42	2.40	3.96	3.27	3.78	5.46	6.62	9.20	10.33	5.62
4	2.64	1.46	3.03	3.40	1.48	3.36	7.52	4.86	10.83	4.83
8	2.42	1.32	3.02	3.18	1.09	3.50	2.55	11.61	9.11	7.68
12	2.56	3.90	3.38	3.65	1.80	6.53	8.92	16.26	14.26	12.43

Toledo Harbor

Depth m	8/24	8/31	9/7	9/14	9/22	9/29	10/8	10/16	10/28	11/14
1	2.07	1.52	1.45	1.34	1.23	5.24	5.48	5.42	5.32	5.02
4	1.87	0.65	1.69	1.41	1.20	5.60	5.66	5.63	4.27	4.22
8	3.21	1.60	1.98	1.88	1.32	4.98	3.45	4.99	5.39	4.87
12	2.46	3.09	2.14	2.35	1.92	4.93	4.63	5.02	5.42	5.20

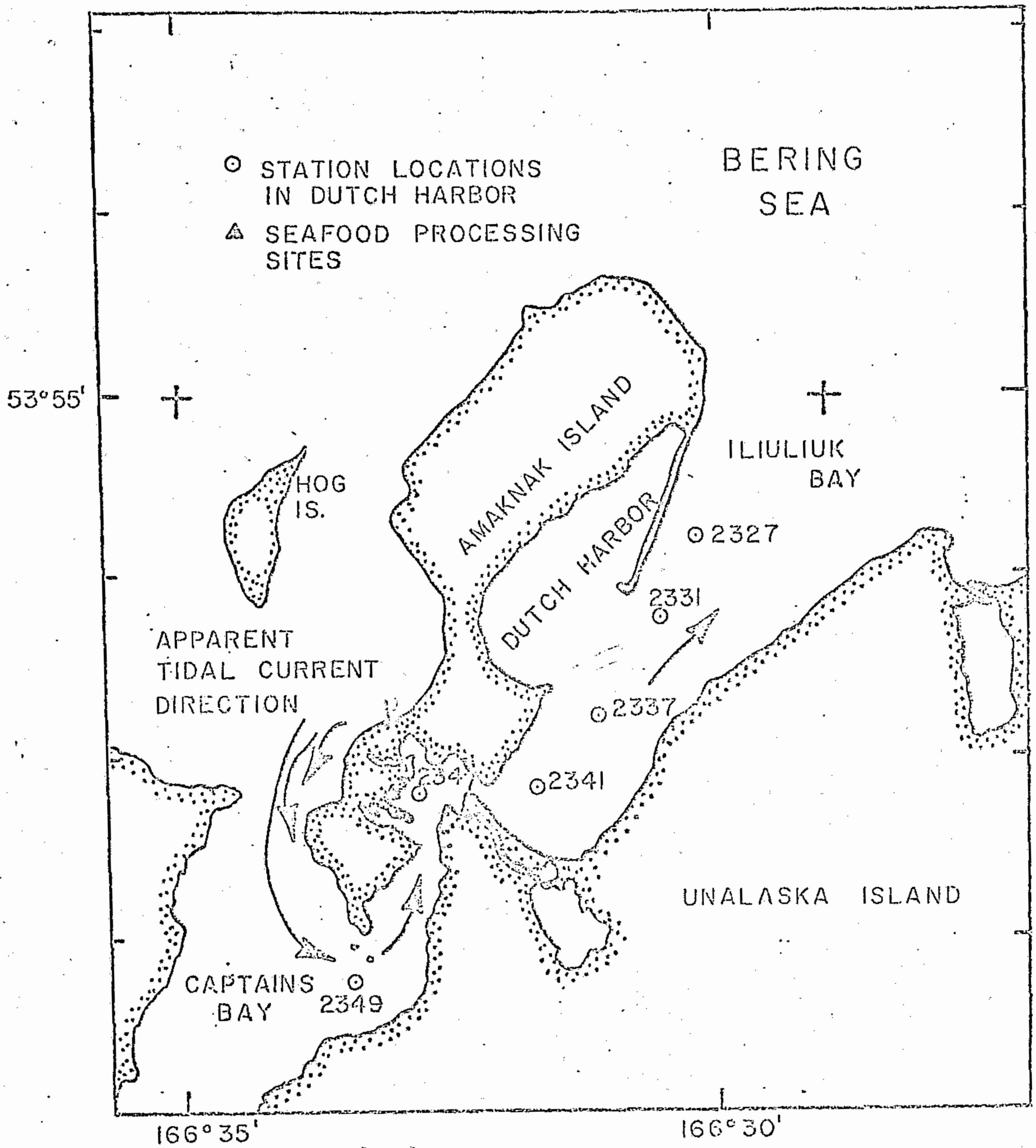

Figure 1

Iliuliuk Bay, Unalaska Island, Alaska

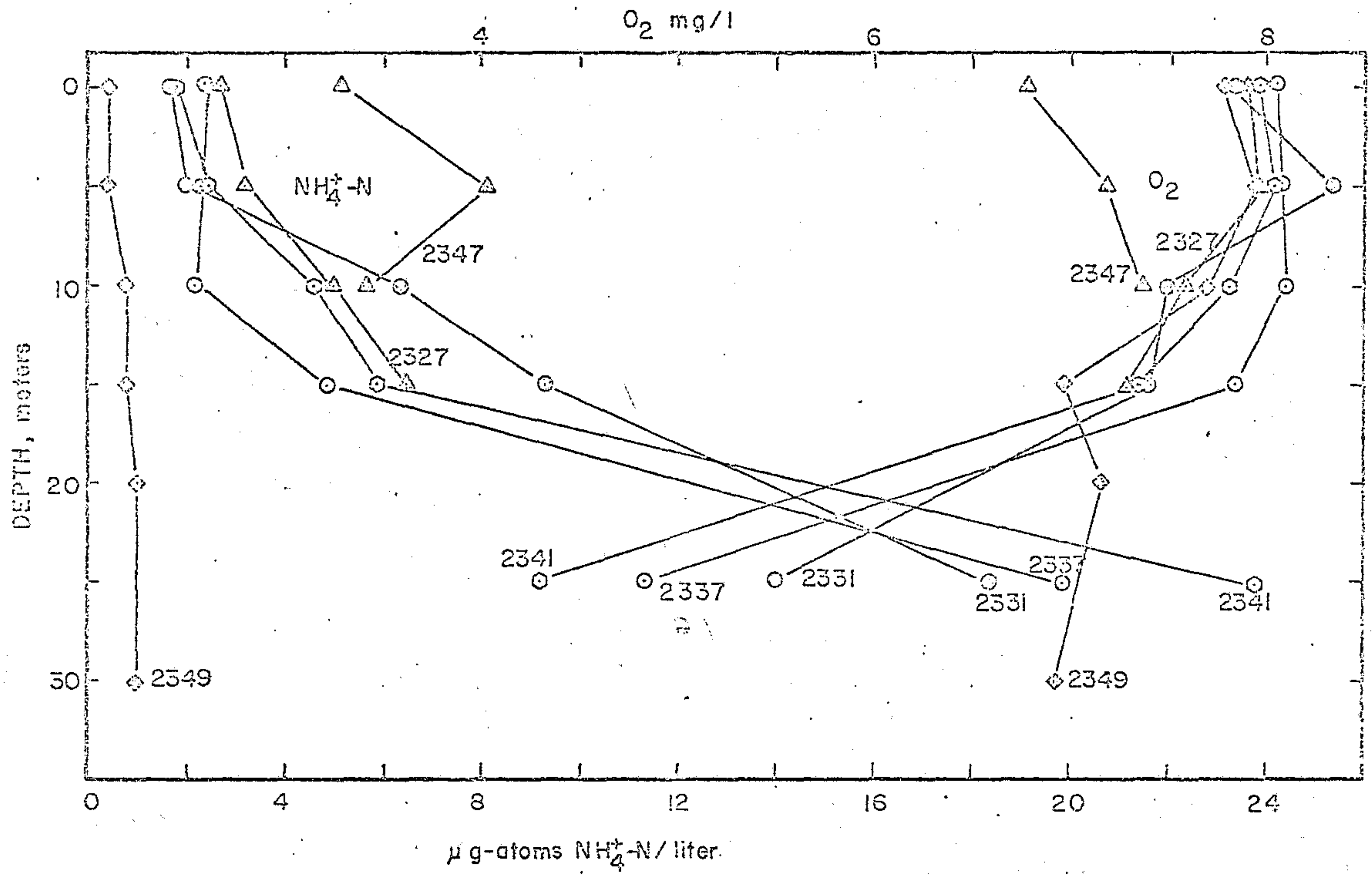

Figure 2

NH_4^+-N and Oxygen at Various Stations and Depths in Captain's Bay and Iliuliuk Bay

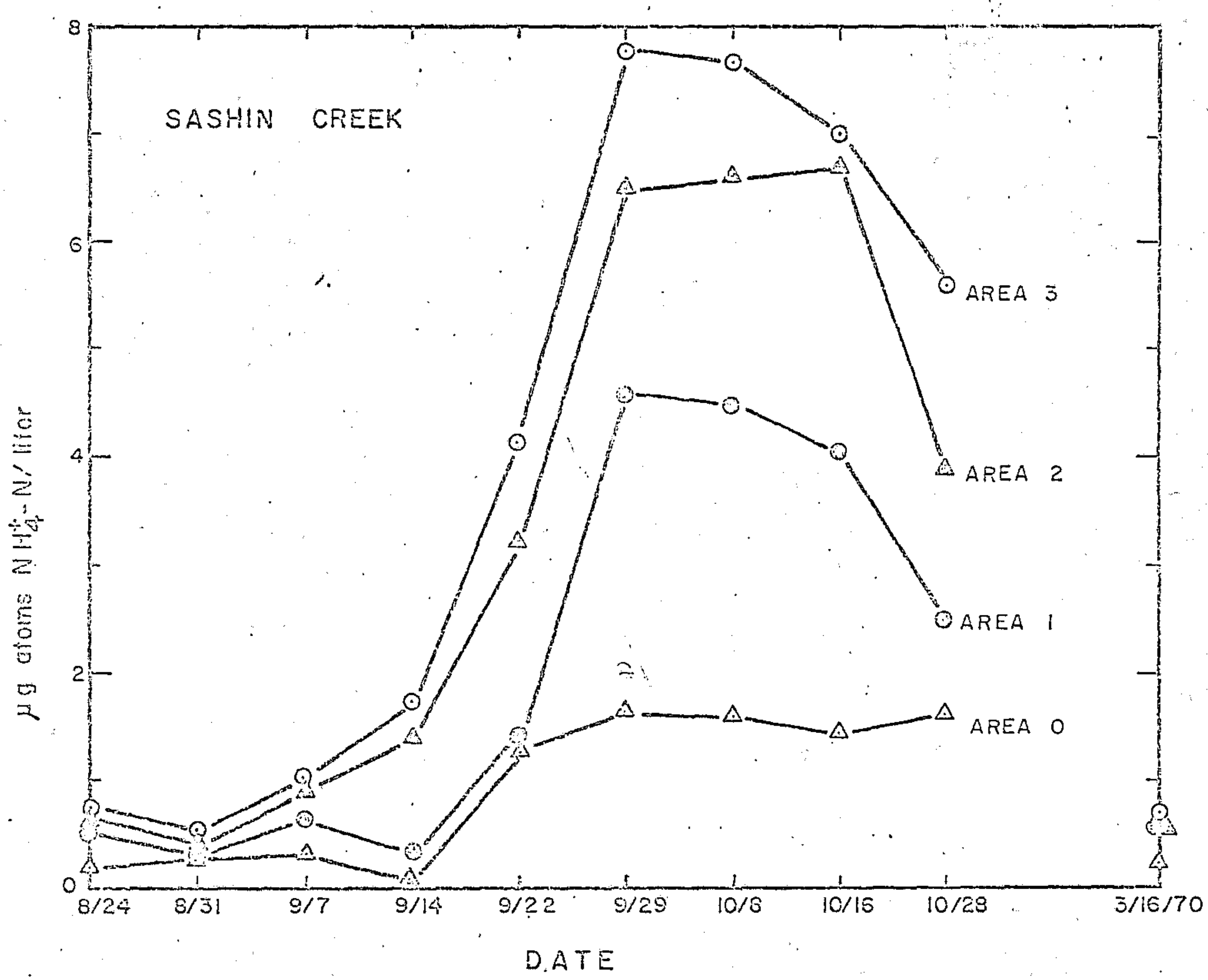

Figure 3

Concentrations of NH_4^+-N in Sashin Creek Surface Water

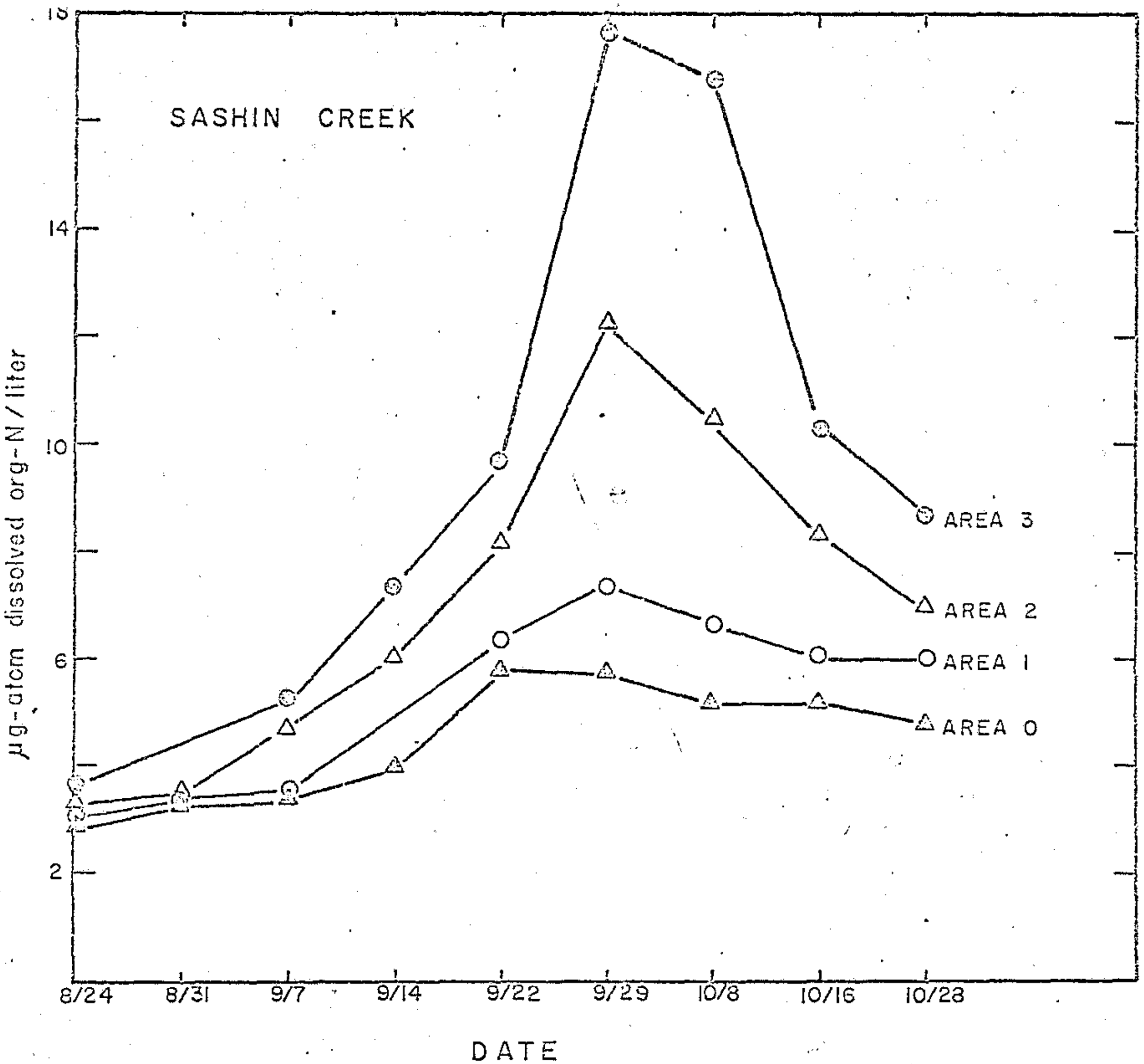

Figure 4

Concentrations of Dissolved Organic -N in Sashin Creek Surface Water

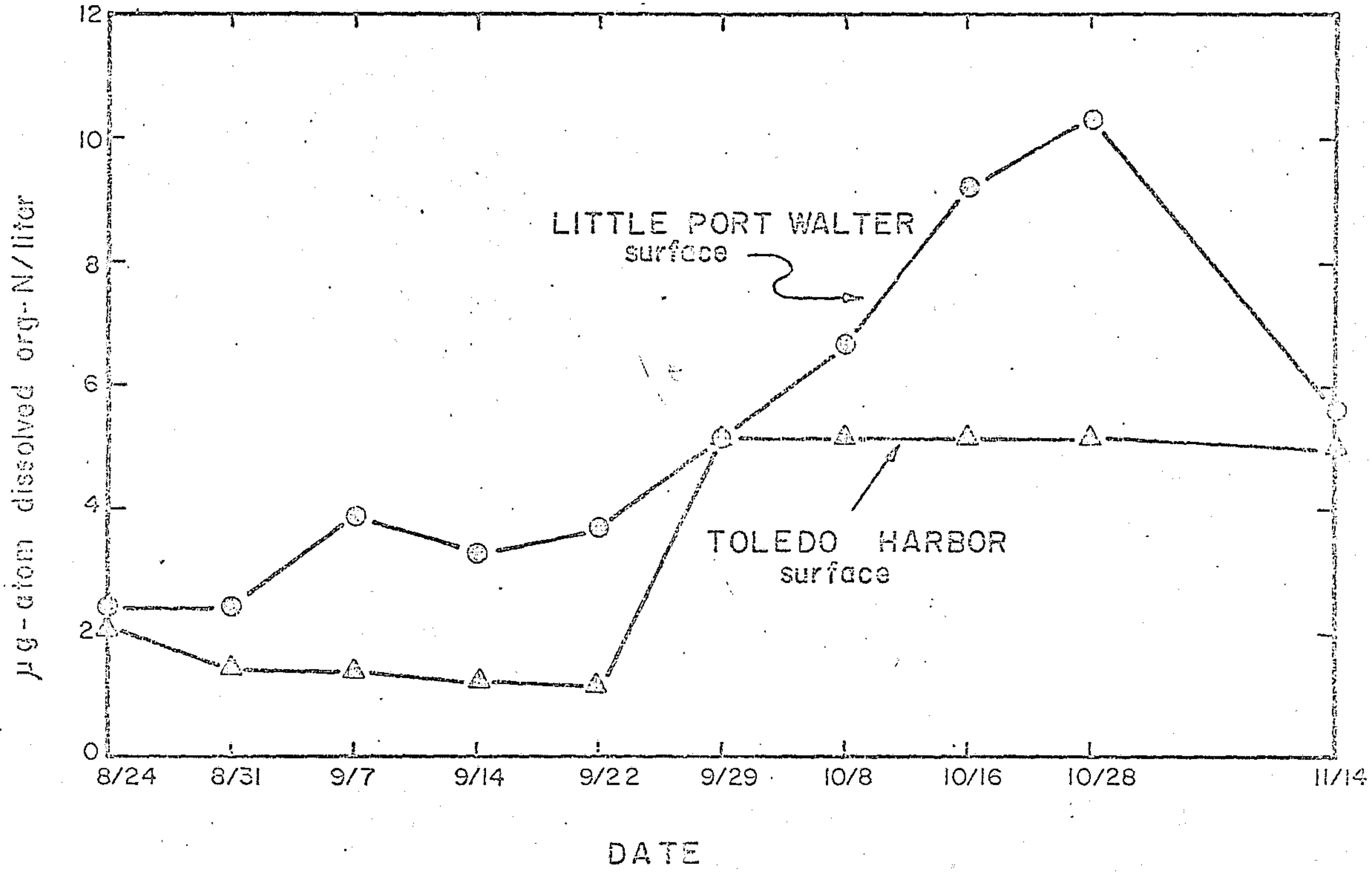

Figure 5

Concentrations of Dissolved Organic -N in Surface Water in Little Port Walter and Toledo Harbor Estuaries

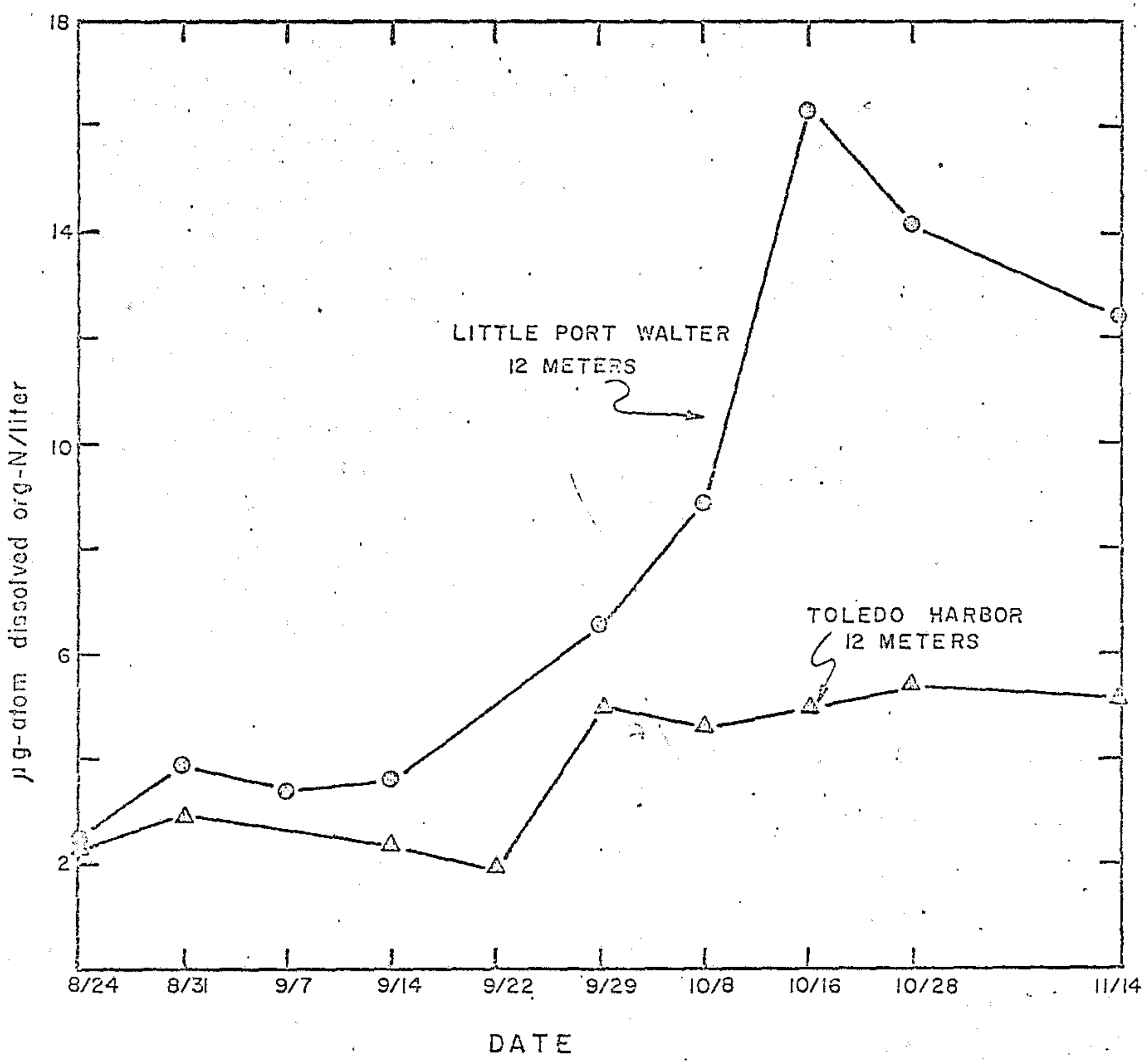

Figure 6

Concentrations of Dissolved Organic -N in 12 m Water in Little Port Walter and Toledo Harbor Estuaries

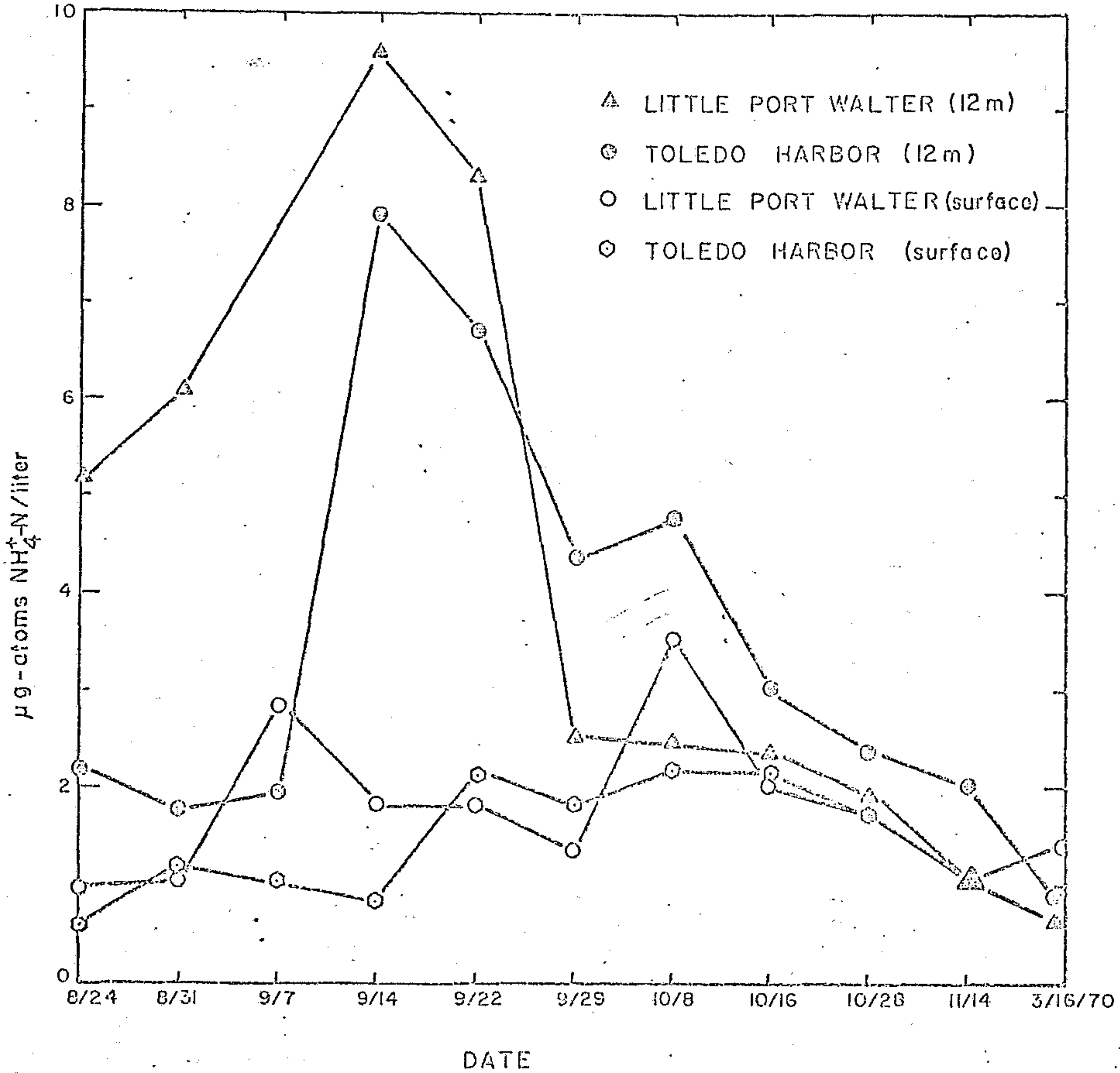

Figure 7

Con[illegible]trations of Ammonium -N at 12 m in
Littl[illegible]t Walter and Toledo Harbor Estuaries