

Over-winter oceanographic profiles in Jones Sound, Canadian Arctic Archipelago, November 1961 - June 1962: Temperature, salinity, oxygen and nutrients

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ABSTRACT

Vertical profiles of temperature, salinity, dissolved oxygen and inorganic nutrients (nitrate, phosphate and silicate) were measured at five depths (2, 10, 25, 50 and 80 m) beneath the ice through the winter of 1961-1962 off the southern shore of Jones Sound, north of Devon Island. Additional data were collected from the north side of the sound off Grise Fiord, Ellesmere Island, on 13 May 1962 and 12 May 1969. The over-winter data set is used here to characterize the autumn-to-late-spring and early-summer transition of Arctic waters. Minimum temperatures ($<-1.8^{\circ}\text{C}$) and maximum salinities (>33.2) were reached in late winter and early spring. Oxygen levels declined over the same fall-to-late-spring period, and increased markedly in June. Nitrate, phosphate and silicate concentrations all increased from their lowest values in fall to overall highest values in late spring, after which each nutrient showed evidence of biological uptake. A deep pycnocline, between 50 and 80 m, persisted from November to February, isolating a bottom-water layer that showed evidence of microbially-mediated silicate regeneration (silicate concentrations increased, phosphate decreased and nitrate concentrations were variable). In early spring (19 March to 1 May) nitrate concentrations dropped abruptly at all depths from $>10\ \mu\text{M}$ to $<7\ \mu\text{M}$, apparently in response to growth of ice algae. Based on T-S analyses there was little evidence of significant water mass replacements during the study period, but interpretations of coherent variations in nutrient concentrations, as well as slight differences in observed salinities from those expected based on ice formation, suggest otherwise. Comparison of results from north of Devon Island with those off Grise Fiord in May 1962 indicate both higher salinities and lower nutrient concentrations at the latter site; however, data collected at the same site off Grise Fiord in May 1969 showed lower salinities and more variable nutrient concentrations than in 1962.

Key words: salinity, temperature, oxygen, nutrients, circulation, nutrient ratios, interannual variability, bacteria and nutrients, ice algae and nutrients

INTRODUCTION

The purpose of this note is to record a previously unreported oceanographic study conducted in the winter of 1961-1962 from Jones Sound in the Canadian Arctic Archipelago as part of a research program of the Arctic Institute of North America (AINA) (Apollonio, 1963). The data are of interest concerning the sources, circulation and interannual variations of water in the sound. The data show interesting variations between phosphate and silicate, apparently associated with the sea bottom, for which is offered a possible explanation. They also show nutrient reductions in the water column apparently associated with the development of spring ice algae.

The main sampling site was approximately $75^{\circ}44'$, $84^{\circ}40' \text{W}$, about 3.6 km off the shore of Devon Island (Fig. 1). The depth of water at the site was just over 80 m. Sampling began in mid November 1961 by the first author when ice formation permitted setting up a small sampling hut, and continued at approximately two-week intervals until the end of June 1962. Sea ice generally covers the southern half of Jones Sound by mid November and most of the sound by early January. In 1962 it attained a thickness of about 1.9-2.0 m at the sampling site

and a maximum snow cover of 10-12 cm. The ice was snow-free by 12 June and broke up on 5 July. By comparison, in 1961 it broke up on August 1 and in 1963 on August 10. The sun is continuously below the horizon from 23 October until 8 February, and is continuously above the horizon from 20 April until early September. The mean air temperature in February was about -34°C . In addition to the time series, data from single stations at the entrance of Grise Fiord, Ellesmere Island, (approximately $76^{\circ}24'\text{N}$, $82^{\circ}58'\text{W}$), on the north side of Jones Sound, sampled on 13 May 1962 and 12 May 1969 (Apollonio, 1973), are included for comparison.

METHODS

Five depths were successively sampled on each date through the winter by a single Nansen bottle with a reversing thermometer (Kahl SICO). In Grise Fiord three depths per cast were sampled. Salinity was analyzed at the Woods Hole Oceanographic Institution (WHOI). Other parameters in 1961-1962 were measured at the research station on Devon Island. Nutrient samples from Grise Fiord in 1962 were frozen until returned to the Devon Island laboratory; those from 1969 were returned frozen to the Maine Department of Marine Resources laboratory for analyses. All analyses used standard methods at the time. Oxygen was measured by the Winkler method (Strickland, 1960). It was not possible to measure oxygen at the Grise Fiord stations. Nutrients were measured on a Klett-Summerson photoelectrical colorimeter using appropriate filters: nitrate by the method of Mullin and Riley (1955); phosphate by the ammonium molybdate method (Harvey, 1955) as modified by WHOI, and silicate by the method of Mullin and Riley (1955a). Appropriate salt factors were applied. The oxygen and nutrient data presented here are the averages of two analyses for each sample. Analytical errors are as follows: Temperature (reversing thermometer): $\pm 0.02^{\circ}\text{C}$; salinity (bench salinometer): ± 0.001 psu; dissolved oxygen (Winkler): mean of n determinations, $\pm (0.003 \text{ mg-at O}_2\cdot\text{l}^{-1})/\sqrt{n}$, which converts to $\pm 0.023 \text{ ml O}_2\cdot\text{l}^{-1}$; dissolved inorganic nutrients: mean of n determinations, $\pm 0.03 \mu\text{M}/\sqrt{n}$, or $\pm 0.021 \mu\text{M}$. Sampling errors, associated with single samples collected, are unknown; however, the general coherence of all data supports the probability of data validity.

RESULTS

The data from off the north shore of Devon Island are shown in Table 1 and Figure 2. They show gradually cooling temperatures with increasing salinities, decreasing oxygen, and generally increasing nutrient concentrations through the winter. Temperatures and salinities reached their winter minima and maxima in mid March and mid April, respectively. Temperatures at 80 m remained relatively warm (-1.0° to -1.6°C) until early February, after which the water column was essentially isothermal at about -1.8°C . Slight warming is apparent in early May with definite warming in mid June. Salinities increased steadily from about 32.4 in November to about 33.2 early in April. Surface salinities just under the ice in February and into early May show evidence of enrichment as salt was extruded from growing sea ice, as appears to be the case also for the data from Grise Fiord (Tables 2, 3). Some decrease in salinity occurred after early May and notably in early June.

Oxygen at 80 m varied irregularly between 6.7 and 7.2 ml l^{-1} until late May, but oxygen at shallower depths declined from about 7.8 to about 6.6 ml l^{-1} . Increases in oxygen at all depths are apparent in June.

Nutrients appear to have reached their maximum annual values in late May and early June. Nitrate concentrations were most variable, ranging from 4.13 to 11.9 μM , and were quite irregular in their increase. Like salinity, there is a suggestion of slight nitrate enrichment in the shallowest layer (2 m) just under the ice from January into May. Phosphate concentrations increased rather steadily from 0.9 to about 1.4 μM , and silicate generally increased from 10.6 to about 30.2 μM by the end of May; both phosphate and silicate showed declines in early May followed by maximum annual values in late May. All nutrients declined in late June 1962.

Table 2 shows the data from a station off Grise Fiord in mid May 1962 where the bottom depth was 262 m. It appears that this station was somewhat warmer and definitely more saline in the shallower depths than that on the south side of Jones Sound off Devon Island. It also shows lower levels of nitrate, phosphate and silicate than the data from the south side of Jones Sound sampled at about the same time.

Table 3 shows data from Station 8 off Grise Fiord on 12 May 1969, which was typical of three stations at that time and location (Apollonio, 1973). The depth of the bottom at Station 8 was about 230 m. Temperatures at depths from 3 to 75 m were colder than those at depths from 100 to 225 m. Salinities increased markedly between 100 and 225 m. Nitrate increased uniformly from 3 to 225 m, while phosphate was nearly uniform from 3 to 125 m, and was notably less from 150 to 225 m. Silicate showed no clear pattern of increase or decrease with depth, subject to the uncertainty of analysis of previously frozen silicate samples noted elsewhere (Apollonio 1973).

DISCUSSION

The differences of all parameters in 1961-1962 from the north and south sides of Jones Sound, under intact snow cover and sea ice and unaffected by the dilution of snow and sea ice melt (except for the June data), are consistent with concepts of water mass origins and circulation in Jones Sound (Barber and Huyer, 1977). The observed conditions throughout the winter off Devon Island may be explained by movements of water masses entering Jones Sound and by diffusion of nutrients within the water column. Water with lower salinities and higher nutrients, considered to be derived from Pacific water in the Canada Basin of the Arctic Ocean (Jones and Coote, 1980), flows through Hell Gate and Cardigan Strait at the western end of Jones Sound and along the southern half of the sound. Water flows from the east through Glacier Strait with higher salinities and lower nutrients, and is found in the northern part of the sound. In addition, the ratio of nitrate to phosphate of all data (7.89) appears to be lower on the south side of Jones Sound compared to the higher ratio (10.24) off Grise Fiord. The ratios for nitrate to silicate are 0.33 for the south shore and 0.43 for Grise Fiord. The lower ratios are indicative of Pacific water, which has higher silicate levels, and the higher ratios are indicative of water with a component of Atlantic water (Jones et al., 2003; Michel et al., 2006). These winter data indicate that winter circulation may be similar to summer circulation (Jones and Coote, 1980). It is of interest, however, that three stations taken off Grise Fiord in May 1969 were all noticeably fresher than those of 1962 and with an intermediate N/P ratio of 9.52, primarily because of higher phosphate than in 1962. Average near-surface (2-75 m) salinity data for the three sets of samples are: Devon, 33.20; Grise Fiord 1962, 33.45; Grise Fiord 1969, 33.12. These data suggest interannual variabilities.

In addition to nutrient variations reported here that may be attributed to horizontal water mass movements and vertical diffusions, two other kinds of variations are apparent in Table 1 and Figures 2 and 3. The first concerns variations of phosphate and silicate values at 80 m that were inversely correlated until 5 March, after which they were directly correlated. Figure 3 shows how silicate co-varies with phosphate over the first seven sample periods through 18 February. The negative correlation ($r^2 = 0.81$) for those dates is shown in Figure 4. The positive correlation is less clear for the two remaining data clusters, 18 February to 25 May and 12-29 June. After 18 February the two nutrients track one another, with each nutrient clearly increasing to maximum concentrations in late May. During the fall, the concentrations of silicate were highest in the 80 m depth sample, and generally increased by some 20 μM between 13 November and 21 January (Fig. 2). The dense bottom layer (80 m) was effectively isolated from water layers above, and we suspect that the deep layer was accumulating regenerated silicate from diatom frustules. The data from 50 m suggest similar variations, but less clearly than those at 80 m. There is apparently similar though less clearly marked variations between nitrate and silicate values at 80 m. These data suggest that the phenomenon is associated with the bottom.

Arctic ice algae and phytoplankton often sink rapidly from the euphotic zone. In Jones Sound, Longhurst and Head (1989) found that large zooplankton consumed less than 1% of the phytoplankton standing stock daily, and concluded that large proportions of the phytoplankton are not consumed and sink out of the surface layers and may accumulate on the bottom where regeneration of their nutrients may occur. The decrease in deep water phosphate over that same time interval would suggest microbial activity, as the removal by microbes of the organic film coating on diatom frustules is required before the biogenic silica can dissolve (Hecky et al., 1973). The present data from 80 m are consistent with the possibility that reduction of phosphate is indicative of microbial action making possible dissolution of silicon shells with concomitant increases of silicate in bottom waters. Presumably this process was completed by early March after which time both phosphate and silicate were regenerated concurrently. Unfortunately, nitrate data for the first two sample dates are not available, but its concentrations were also highest in the deep layer from 24 December to 23 January, which might reflect nitrification in the deep layer.

The second kind of nutrient variations of interest is apparent most clearly in nitrate reductions in April and early May (Fig 2). The abrupt decrease in nitrate at all sample depths after 19 March was accompanied by a general leveling off in silicate, which had been increasing in concentrations immediately prior to that date, and a leveling off or a decline in concentrations of phosphate (Fig. 2). The depth-averaged nitrate concentration on 19 March was about 11.2 μM , and dropped to about 7.2 μM on 1 May, which would correspond to an apparent biological uptake of approximately 4 μM . Phosphate decreased by only 0.05 μM over the same period. If we assume, however, that both nitrate and phosphate were continuing to increase in concentration, reflecting regenerative processes for the period before the abrupt nitrate decline to the time of the highest concentrations of each nutrient in late May and early June, then the apparent uptake of nitrate would be just over 4 μM and that of phosphate about 0.25 μM . This assumption is consistent with a biological uptake of nitrate and phosphate corresponding to the Redfield Ratio of 16 N:1P, which would lead us to surmise that the period between 19 March

and late May-early June is one of a growing ice algae population (Apollonio, 1965). Similar declines of nitrate and silicate to 100 m between April and June in Barrow Strait, Lancaster Sound, were reported by Welsh and Bergmann (1989) and by Cota et al. (1990). Harrison and Cota (1991) suggested those declines were related to growth of ice algae. In each of these three data sets nutrients increased near the expected end of the growing season for ice algae, but declined again with the onset of phytoplankton production. By 26 May in Jones Sound, nitrate, phosphate and silicate were each replenished to their highest levels, most likely the result of a water mass replacement, although there was no evidence of such in our T-S analyses.

Temperature and salinity data pairs were plotted (as T-S diagrams) for the overwinter time series, color-coded by sample dates (Fig. 5). As revealed by the contour lines of constant density on the T-S diagram, (density anomaly, or σ_t , in g kg^{-1}), changes in density are controlled principally by even slight changes in salinity, with temperature having only a minor influence, even on 13 November, the first sample date, and when the broadest range in temperatures were observed. The densest water is at the bottom on that date (sample depth 80 m). This pattern of the bottom water being the saltiest, warmest and densest continues through late winter and early spring, with each successive sample period reflecting steadily increasing salinities at all depths, as a partial result of the exclusion of salt as the surface ice thickens, and decreasing temperatures. The T-S pairs for the sample dates 3 February to 26 May cluster together in a fairly tight envelope, which would indicate that this is a period of only slight changes of ice cover, while in fact, it is more likely that the ice continued to thicken until about 16 April. The last two sample dates, 12 and 29 June, reveal decreasing salinities and warming temperatures, thus marking a period of significant ice melt.

The temporal progression of these T-S properties does not reveal obvious intrusions of water masses with markedly different T-S properties, but the total changes in salinities might suggest otherwise. Depth-averaged salinities increased from 32.61 on 13 November to about 33.21 for the period 5 March to April 16, an increase of 0.60. Assuming that 90% of the salt is extruded from first-year sea ice (Grainger, 1977), and that the ice grew about 1.7 m (to 2 m, starting at about 0.3 m on 13 November), the salinity should have increased to about 33.24. This slight difference, if significant, would suggest a dilution of waters at the study site by an influx of lower salinity waters throughout the fall and winter. One possibility for such an influx is a cross-isobath exchange between the relatively shallow waters in the immediate vicinity of the study site and the deeper waters of the Sound; all else being equal, those deeper waters would remain fresher throughout the winter, experiencing proportionately less of a salinity increase than shallower waters as a result of ice formation. It is also possible that some of the fresher waters resulted from an influx of lower salinity Pacific waters into Jones Sound.

While we expect that advective processes are important throughout the winter in Jones Sound, the horizontal length scales of water properties are sufficiently great that the continuous exchange of waters beneath our sampling station was not reflected in the T-S properties, only in changes in depth-averaged salinity as compared with changes in ice thickness. Dissolved inorganic nutrient fields are less conservative, however, and are constantly changing throughout the time series as nutrients (nitrate, phosphate and silicate) are regenerated, lost by way of possible sediment denitrification (nitrate loss), and taken up by benthic microbes and ice algae. Such appears to be the case for the sudden uptake of nitrate in between 19 March and

1 May, and its replenishment by 26 May (Fig. 2) which we suspect is the result of a water mass exchange.

CONCLUSIONS

This report presents a record of hydrographic, oxygen, and nutrient data taken in Jones Sound at roughly two-week intervals from mid November until early June, 1961-1962. The data show three patterns of particular interest: 1) the changes in physical properties and nutrient concentrations that would be expected from circulation and water mass exchanges in Jones Sound; 2) an inverse relation between phosphate and silicate concentrations close to the bottom (80 m until 5 March), perhaps because of microbial activity and regeneration of silica from diatom frustules, and 3) a spring reduction of nutrients because of growth of ice algae, followed by an increase near the end of that growth. Transition from ice formation to ice-out is a time of continuous recharge of nutrient loads reflecting regenerative processes in the water column and near the bottom, and later spring uptake and with likely patchy nutrient distributions in and out of the sampling site.

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Table 1. Oceanographic data from Jones Sound off the north shore of Devon Island

Depth (m)	Temp. (°C)	Salinity	Oxygen ml l ⁻¹	Nitrate	Phosphate µM	Silicate
13 Nov. 1961						
1	-1.75	32.439	7.82	-	0.89	10.6
10	-1.73	32.465	7.78	-	0.93	11.9
25	-1.74	32.484	7.75	-	0.93	11.8
50	-1.74	32.621	7.30	-	1.01	14.3
80	-1.00	32.955	6.88	-	1.20	18.4
27 Nov. 1961						
1	-	32.613	7.34	-	0.95	16.5
10	-	32.642	7.31	-	1.01	15.7
25	-	32.652	7.29	-	0.95	17.6
50	-	32.681	7.19	-	1.03	17.0
78	-	33.003	6.68	-	1.15	26.9
24 Dec. 1961						
1	-	32.850	7.40	4.13	0.93	17.4
10	-1.76	32.833	7.38	4.94	0.95	17.4
25	-1.75	32.851	7.35	4.25	0.93	17.4
50	-1.46	32.924	7.12	5.50	1.00	20.9
78	-1.05	33.093	6.71	9.65	0.93	28.4
9 Jan. 1962						
2	-1.75	32.897	7.22	6.38	0.84	22.0
10	-1.75	32.908	-	6.82	0.84	24.7
25	-1.76	32.925	7.20	7.62	0.91	24.7
50	-1.74	32.923	7.12	6.25	0.98	23.8
80	-1.36	33.052	6.79	11.48	1.02	24.7
21 Jan. 1962						
2	-1.74	32.953	7.18	8.00	1.00	27.9
10	-1.74	32.981	7.21	7.30	1.12	20.9
25	-1.76	32.988	7.20	9.90	0.87	28.4
50	-	33.011	7.10	8.39	0.95	27.5
80	-1.62	33.040	7.10	10.01	0.74	36.2
3 Feb. 1962						
2	-	33.054	7.13	7.28	1.02	24.1
10	-1.79	33.053	7.12	6.82	1.09	22.9
25	-1.74	33.079	-	8.77	1.09	22.4
50	-1.71	33.144	6.80	8.00	1.14	27.9
80	-1.60	33.185	6.71	10.85	1.19	29.4

18 Feb.1962						
2	-1.78	-	7.24	11.22	1.14	25.8
10	-1.81	33.139	7.28	10.45	1.19	25.8
25	-1.78	-	7.26	8.98	1.19	24.9
50	-1.79	33.215	7.18	8.85	1.24	24.9
80	-1.79	-	7.18	10.00	1.21	24.9
5 March 1962						
2	-1.80	33.171	7.00	9.42	1.12	25.3
10	-1.81	33.168	6.95	10.85	1.19	25.8
25	-1.77	33.158	6.88	9.19	1.14	26.4
50	-1.81	33.190	6.86	10.60	1.19	26.9
80	-1.82	33.225	6.83	9.45	1.19	26.9
19 March 1962						
2	-1.82	33.173	7.03	11.22	1.12	28.8
10	-1.81	33.186	7.01	10.75	1.21	29.4
25	-1.82	33.191	7.00	10.10	1.25	29.4
50	-1.80	33.199	6.95	11.75	1.19	31.7
80	-1.76	33.208	6.92	11.90	1.24	31.7
2 April 1962						
2	-1.81	33.218	6.98	9.79	1.14	29.9
10	-1.82	33.194	7.00	9.45	1.25	29.4
25	-1.73	33.196	6.88	9.32	1.24	29.4
50	-1.80	33.208	6.86	9.45	1.25	30.8
80	-1.79	33.218	6.79	7.88	1.19	30.8
16 April 1962						
2	-1.79	33.198	6.94	7.20	1.25	30.2
10	-1.79	33.196	6.95	7.75	1.26	30.2
25	-1.79	33.197	6.84	7.19	1.26	30.2
50	-1.79	33.208	6.88	7.08	1.26	30.2
80	-1.79	33.224	6.81	7.08	1.26	32.2
1 May 1962						
2	-1.75	33.169	6.90	7.40	1.00	27.9
10	-1.71	33.143	6.87	6.70	1.14	27.9
25	-1.73	33.172	6.72	7.39	1.14	28.4
50	-1.69	33.212	6.60	6.81	1.19	29.4
80	-1.66	33.220	6.57	7.40	1.21	30.1
26 May 1962						
2	-1.73	33.073	7.06	11.85	1.41	30.2
10	-1.76	33.129	6.95	10.38	1.35	30.2
25	-1.82	33.159	6.79	11.10	1.35	30.0

50	-1.68	33.187	6.70	11.10	1.35	30.0
80	-1.63	33.228	6.68	11.84	1.54	34.1
12 June 1962						
2	-1.57	32.910	7.80	9.45	1.33	27.8
10	-1.49	33.062	7.25	11.48	1.39	28.8
25	-1.58	33.121	6.98	11.72	1.36	28.8
50	-1.58	33.148	6.90	12.05	1.38	30.7
80	-1.50	33.149	6.99	11.60	1.38	31.6
29 June 1962						
2	-0.95	30.465	9.77	-	0.84	18.1
10	-1.18	32.783	8.67	-	1.09	22.4
25	-1.27	32.933	8.05	-	1.22	25.3
50	-1.30	33.017	7.64	-	1.31	28.4
80	-1.43	33.062	7.30	-	1.39	32.3

Table 2 Oceanographic data from Grise Fiord, Ellesmere Island, 13 May 1962.

Depth (m)	Temp (°C)	Salinity	<u>Nitrate</u>	<u>Phosphate</u>	<u>Silicate</u>
				μM	
2	-1.83	33.399	9.31	1.03	27.5
10	-1.78	33.240	9.20	1.00	25.9
25	-1.76	33.370	8.26	0.88	26.4
50	-1.24	33.577	12.30	1.01	26.4
75	-1.31	33.664	9.59	1.04	22.8
100	-1.22	33.693	11.38	1.06	26.4
125	-1.33	33.768	12.40	1.12	25.9
150	-1.25	33.804	11.60	1.23	24.8
175	-1.21	33.833	13.63	1.36	24.8
200	-	-	9.92	1.37	28.4
250	-1.08	33.958	14.14	0.87	25.9

Table 3. Oceanographic data from Station 8 off Grise Fiord, 12 May 1969.

Depth (m)	Temp. °C.	Salinity	<u>Nitrate</u>	<u>Phosphate</u>	<u>Silicate</u>
				μM	
3	-1.74	33.084	9.6	1.19	18.9
6	-1.68	33.061	9.9	1.24	15.3
11	-1.69	33.058	10.1	1.20	17.6
25	-1.67	33.054	9.9	1.23	15.4
50	-1.49	33.115	10.2	1.22	16.3
75	-1.31	33.280	10.7	1.23	16.0
100	-0.99	33.455	12.0	1.24	14.0
125	-0.89	33.599	12.2	1.20	23.9
150	-0.91	33.726	11.9	1.10	29.7
175	-0.76	33.756	12.2	1.19	16.1
200	-0.55	33.879	12.9	1.08	14.8
225	-0.47	33.932	13.2	1.10	17.8

Figure legends

Figure 1. Jones Sound in the Canadian Arctic Archipelago and the locations of the principal study site north of Devon Island (●) and off Grise Fiord, Ellesmere Island (○).

Figure 2. Changes in temperature, salinity, sigma-t, oxygen, nitrate, phosphate and silicate in Jones Sound, north of Devon Island, throughout the study period 13 November 1961 to 29 June 1962. Data are plotted for each sample depth: 2, 10, 25, 50 and 80 m. No line is plotted connecting points across missing data.

Figure 3. Variations in phosphate and silicate (μM) for the bottom sample depth (80 m) throughout the sample period in Jones Sound.

Figure 4. Silicate concentrations in relation to phosphate (μM) for the bottom sample depth (80 m) throughout the sample period in Jones Sound. Data are separated into three periods : 13 November to 3 February (open circles), 18 February to 26 May (filled circles) and 12 to 29 June (open diamonds). Linear regressions are given for the first two sub-periods. For the period 13 November to 3 February, $[\text{Si}(\text{OH})_4] = 58.77 \times -31.59 [\text{PO}_4]$; $r^2 = 0.81$. For the period 18 February to 26 May: $[\text{Si}(\text{OH})_4] = -32.09 \times 50.72 [\text{PO}_4]$; $r^2 = 0.28$.

Figure 5. Temperature-salinity diagram for each sample date, 13 November to June 29, in Jones Sound. The cluster of data for the sampling period 3 February to 26 May is enclosed in a dashed envelope. Density contours are given in sigma-t units (density anomaly in grams per kilogram).

Figure 1

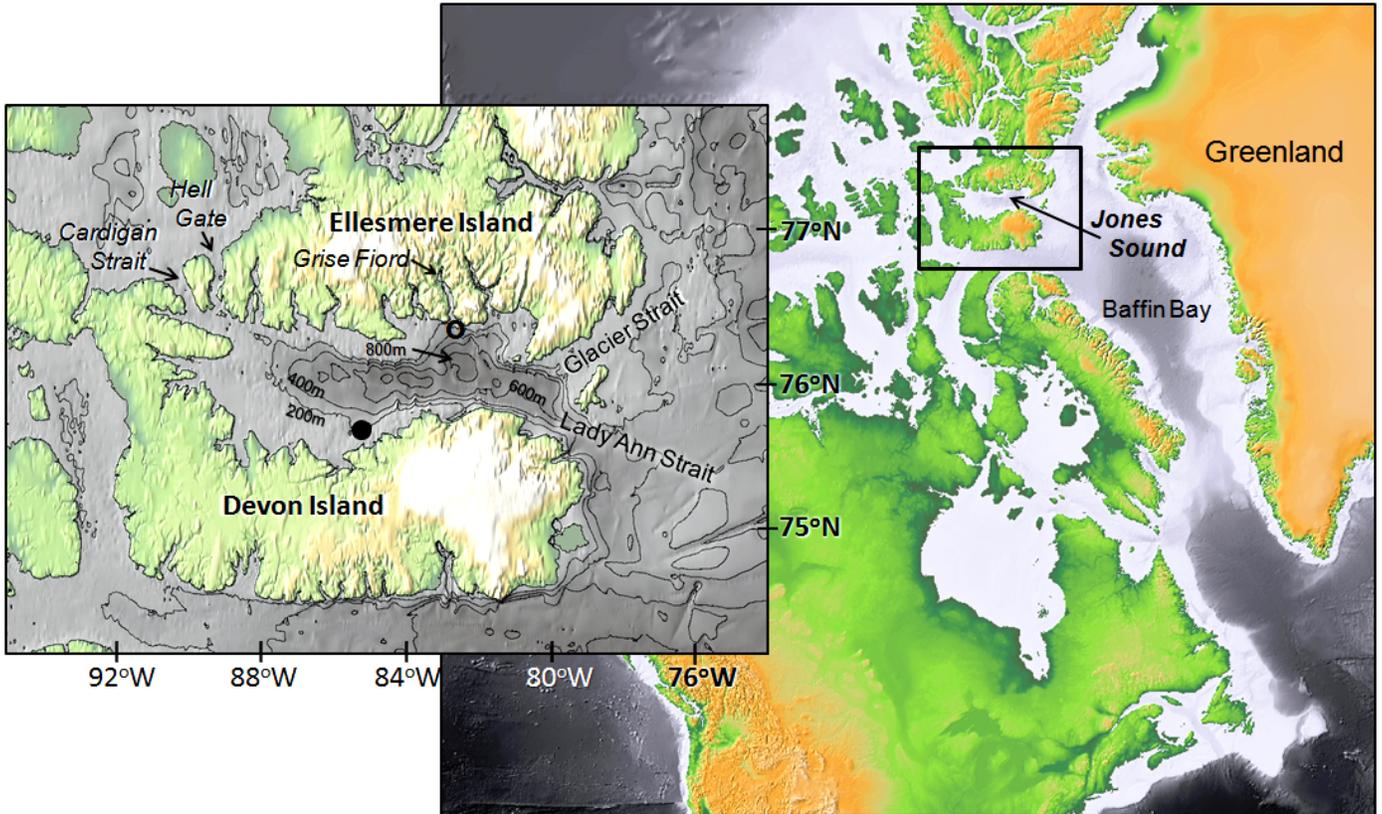


Figure 2

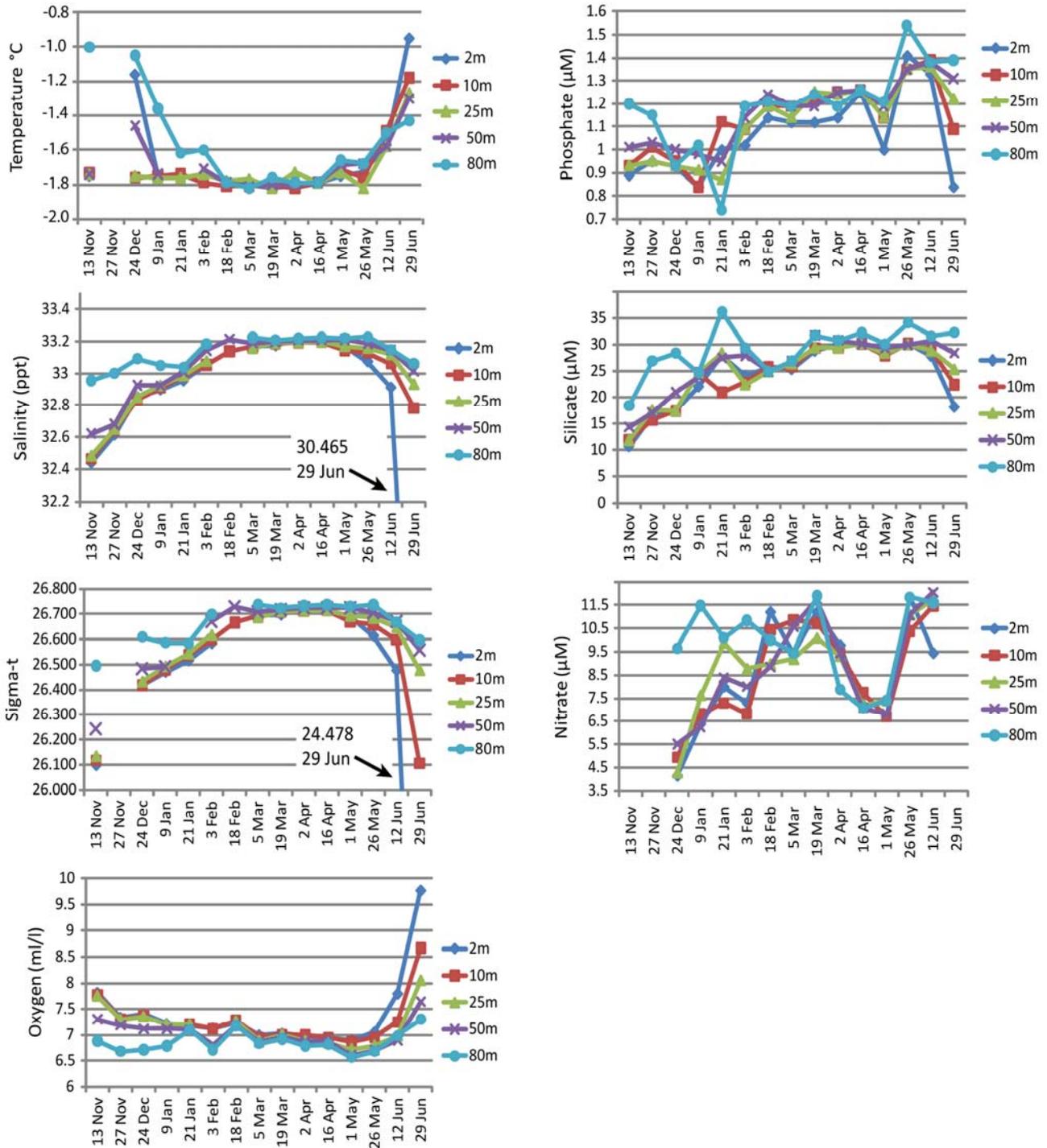


Figure 3

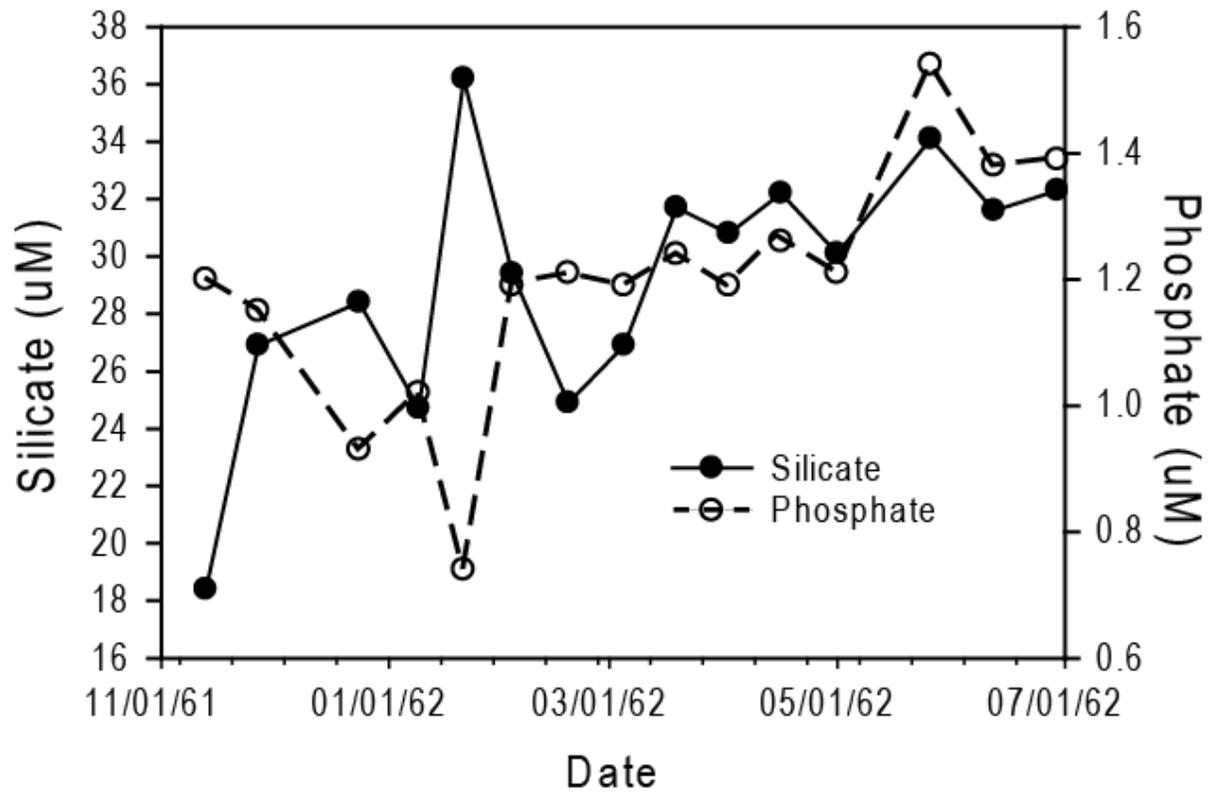


Figure 4

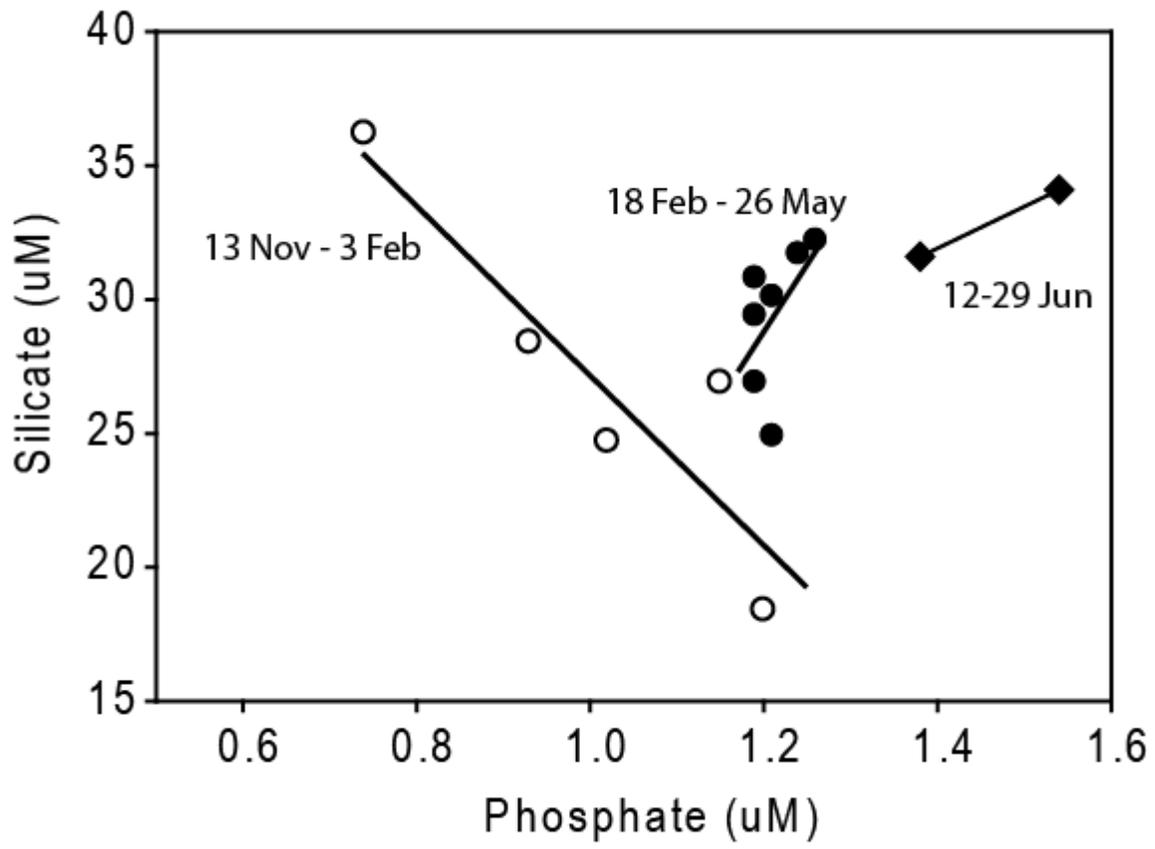


Figure 5

