Outer Continental Shelf Environmental Assessment Program

Final Reports of Principal Investigators

Volume 71 November 1990

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Anchorage, Alaska

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The content of these reports has not been altered from that submitted by the Principal Investigators. In some instances, grammatical, spelling, and punctuation errors have been corrected to improve readability; some figures and tables have been enhanced to improve clarity in reproduction.

Outer Continental Shelf Environmental Assessment Program

Final Reports of Principal Investigators

VOLUME 71 NOVEMBER 1990

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BERING SEA PHYTOPLANKTON STUDIES

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Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 359

December 1981

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I. SUMMARY OF OBJECTIVES, CONCLUSIONS, AND IMPLICATIONS WITH RESPECT TO OCS OIL AND GAS DEVELOPMENT

The specific objective of this project was to determine phytoplankton standing stock, plant pigments, primary productivity, and nutrient regimes in specific areas of the Bering Sea in spring.

Specific conclusions are difficult because, although samples were collected over a wide area of the Bering Sea, for the most part, we have one-time only samples. Primary productivity was variable and was usually, but not always, highest at stations and depths where diatoms were most abundant. Pennate diatoms were dominant in the Navarin Basin in early May; diatoms were dominant in Norton Basin in early spring and microflagellates became dominant later; microflagellates were dominant in late May in the St. Matthew-Hall area and in June in the St. George Basin. Cell numbers were variable. Most abundant species included pennate diatoms (*Navicula* spp. and *Nitzschia* spp. section *Fragilariopsis*); centric diatoms (*Chaetoceros* spp. and *Thalassiosira* spp.); dinoflagellates (*Peridinium* spp. and *Gymnodinium lohmanni*); and unidentified microflagellates ranging in size from *ca.* 2-30 μm in diameter. Nitrate and phosphate concentrations were sometimes lower in the upper 20-30 m and may have been limiting at times.

The data presented here provide a small beginning toward understanding the phytoplankton community in the Bering Sea in spring. This is important because spring is the time when much biological activity occurs and carbon is being fixed by the phytoplankton which then become food for all higher trophic levels.

II. INTRODUCTION

A. General nature and scope of study

The 1979 and 1980 spring icebreaker cruises in the Bering Sea provided opportunities to study hydrography, microbiology, plankton, benthos, sea birds, and mammals at a time when conventional research vessels could not work in the area because of ice conditions. Special attention was given to the ice edge because it is an area of intense biological activity in spring.

Data reported here (Table 1) concern phytoplankton standing stock, plant pigments, primary productivity, and hydrographic conditions including temperature, salinity, and nutrient concentrations. Literature on the phytoplankton of the Bering Sea is briefly reviewed from 1883 through 1981.

B. Specific objectives

The specific objective of RU 359 was to determine the standing stock, plant pigments, primary productivity, and nutrient regimes in the Bering Sea in spring. In 1979, RU 359 also determined zooplankton standing stock and distribution (Horner and Wencker 1980).

Table 1. Number and kinds of samples collected and analyzed from the Bering Sea by RU 359, 1979, 1980.

Data Type Number Collected/Analyzed	Date 1979	1980
Number of Stations	24	60
Phytoplankton		
Standing Stock	189/189	467/331
Plant Pigments	189/189	467/465
Primary Productivity	189/189	467/467
Zooplankton[1], [2]		
Standing Stock	28/28	
Temperature	189/179[3]	463/463
Salinity	189/189	467/467
Nutrients	189/189	465/465
Secchi disk	24	58
Ice conditions	24	60

[1] Previously reported (Horner and Wencker 1980)

[2] Not taken by RU 359 in 1980

[3] Thermometers malfunctioned

C. Relevance to problems of petroleum development

Basic background information on standing stock, species composition, distribution, and primary productivity of phytoplankton communities is poorly known for major parts of the Bering Sea, including Norton and Navarin basins currently under consideration for oil and gas development. Spring, just as the ice is breaking up, is an especially critical time because of the intense biological activity that occurs for all major groups of organisms. The primary producers, ice algae and phytoplankton, bloom providing food, directly or indirectly, for all higher trophic levels. Disruptions of these communities by industrial development during this critical season could cause major problems within the Bering Sea ecosystem. It is therefore important to know what conditions are before perturbation occurs.

D. Acknowledgements

It is a pleasure to thank the captains, officers, and crews of CGC *Polar Sea* and CGC *Polar Star* who provided excellent assistance to us during the cruises. LTJG J. F. Schmied, MSTC G. Lausch, and the Marine Science Technicians from both ships were especially helpful and were willing to work at all hours. Kendra Daly collected zooplankton and provided field assistance in 1979; Deborah Wencker provided field assistance in 1980, did much of the literature review, and, with Dave Murphy, analyzed chlorophyll samples from both cruises. Marc Weinstein and Jerry Hornof helped with data processing. Carl Schrader analyzed standing stock samples from 1980 and processed the standing stock data for both cruises.

III. CURRENT STATE OF KNOWLEDGE

Motoda and Minoda (1974) reviewed early investigations concerning plankton in the Bering Sea, primarily based on summer surface community studies by Japanese scientists. They found that the surface currents circulating from the Pacific Ocean into, and the winter-cooled currents circulating within, the Bering Sea govern the distribution of plankton. This results in inshore assemblages of the *Chaetoceros-Hyalochaete* type, including *Chaetoceros debilis, Ch. decipiens,* and *Ch. radicans*, along the coasts; offshore assemblages of *Thalassiothrix longissima* and the *Chaetoceros-Phaeoceros* group, including *Chaetoceros atlanticus, Ch. convolutus,* and *Ch. concavicornis*, on the shelf, along with *Corethron hystrix, Denticula seminae,* and *Nitzschia seriata* in the surface waters of the deep basin area.

Soviet studies were reviewed by Gershanovich *et al.* (1974) and Zenkevitch (1963). The latter provided information on the northern Bering Sea community assemblages where the western half is dominated by arctic and arctic-boreal species, including *Thalassiosira nordenskioeldii, Th. gravida, Chaetoceros socialis, Ch. radicans, Porosira glacialis, Bacterosira fragilis,* and *Eucampia groenlandica.* The eastern part of the northern Bering Sea community is a mixture of boreal and brackish water neritic species, including *Actinoptychus undulatus, Rhizosolenia alata, Ditylum brightwellii, Actinocyclus ehrenbergii, Bellerochea malleus, Asterionella japonica,* and *Peridinium excentricum.*

Alexander and Cooney (1979) also reviewed previous phytoplankton studies in the Bering Sea with regard to species presence and distribution. Recent investigations not covered in their review include Ishimaru and Nemoto (1977) listing species and abundances from the western and eastern Bering Sea; Saito and Taniguchi (1978) discussing the species composition and abundance of the successional groups of ice, spring and summer diatoms in seasonally ice covered areas, and Furuya *et al.* (1979) including a species list and abundance of diatoms, dinoflagellates, and silicoflagellates from the eastern Bering Sea and north of St. Lawrence Island.

Most recent American investigations have been conducted in the southeastern Bering Sea. Alexander and Cooney (1979) applied numerical analysis techniques to their data from this area collected at discrete depths during all seasons except midwinter and they included an extensive species list. Iverson *et al.* (1978) determined that the area was highly productive, but primary production was not disproportionately higher than in other systems, suggesting that other factors were responsible for the high productivity. They theorized that a combination of frontal zones creating different food webs fractionalized the use of phytoplankton biomass and may be a factor responsible for the high productivity. OCSEAP reports provide data from southeastern (Alexander 1976) and northeastern Bering Sea (Alexander and Cooney 1979; Horner and Wencker 1980); and Cooney (1977) included phytoplankton references in his bibliography of the Bering Sea region fauna and flora.

McRoy and Goering (1974) discussed effects of the ice cover that most likely increased the total phytoplankton production of the Bering Sea with its highly productive population of ice algae and described the annual sequence of events in the spring beginning with the ice algae bloom. Primary production was greatest in the water column at the ice edge measuring as much as 89.28 mg C m^{-2} day^{-1} during investigations of production in ice covered and open water areas from February to April. Alexander and Cooney (1979) also discussed ice algae and its importance to the ecosystem.

Total annual production for the whole Bering Sea has been calculated to be 274 x 10^6 metric tons with slightly greater than 50% from the shelf, including 20% from ice algae and some from rivers and lagoons (McRoy and Goering 1976). Motoda and Minoda (1974) reported summer surface primary productivity to be highest, 5 mg C m^{-3} hr^{-1}, east of Bower's Bank; less than 1 mg C m^{-3} hr^{-1} on the northern shelf and in the western gyre; and 1-3 mg C m^{-3} hr^{-1} in the central and western shelf areas. Additional contributions to chlorophyll *a* and primary production values have been made for various regions by Taniguchi *et al.* (1976), Saino and Hattori (1977), Satake *et al.* (1977), Saito and Taniguchi (1978), Alexander and Cooney (1979), Saino *et al.* (1979); Stross *et al.* (1979), and Horner and Wencker (1980).

A summary of the literature on Bering Sea phytoplankton from 1883-1981 is given in Table 2. The references are arranged chronologically.

Table 2. Summary of phytoplankton literature from the Bering Sea, 1883-1981.

Author, Date	Region	Nature of Study, Methods	Results[1]
Cleve, 1883	Bering Sea	Surface samples, species list	Great abundance of *Thalassiothrix longissima;* also *Coscinodiscus borealis, Chaetoceros atlanticus, Rhizosolenia styliformis, R. hebetata*
Mann, 1925	65°15'N, 166°30'W	Net tow, species list	*Coscinodiscus concinnus, Melosira hyperborea, M. nummuloides*
Aikawa, 1933	western (Aleutians)	Samples collected in July, Aug.; quantitative distribution, species list, species percentages	*Chaetoceros* sp., *Nitzschia seriata, Thalassiothrix longissima, Coscinodiscus* sp., *Rhizosolenia* sp., *Denticula* sp.
Phifer, 1934	eastern	Diatoms centrifuged and settled from water samples; seasonal occurrence and distribution	Found *Denticula seminae* and *Stephanopyxis nipponica* in July, Aug.
Cupp, 1937	Aleutians	Surface water filtered through no. 25 bolting silk; seasonal abundance, species list	Arctic and temperate oceanic species: *Chaetoceros debilis, Asterionella japonica, Rhizosolenia*; Arctic and temperate neritic species: *Thalassiosira nordenskioeldii, Chaetoceros socialis* in winter and spring
Kiseleff, 1937	northern, western	Samples collected with no. 12 & 25 bolting silk nets; species list, relative abundance, distribution, relation to hydrography	*Eucampia groenlandica, Achnanthes taeniata, Amphiprora hyperborea, Peridinium* spp., *Coscinodiscus stellaris, Actinocyclus ehrenbergii, Ceratium pentagonum, Ditylum brightwelli, Chaetoceros danicus*
Aikawa, 1940	southern (Aleutians)	In Japanese; figures of cell numbers	

[1] Species names are those used in the cited reference and may no longer be correct

Table 2. (cont.)

Author, Date	Region	Nature of Study, Methods	Results
Cupp, 1943	southeast	Surface water filtered through no. 25 bolting silk, settled, cleaned; taxonomy, ecology; keys to pennate, centric diatoms.	Keys to diatoms collected from Scotch Cap, Alaska to southern California; classic taxonomic reference for diatoms
Lafond, *et al.* 1949	eastern	Collections in July, Aug. with no. 0 and 8 bolting silk Nansen nets; relative volumes, species list	Greatest volume just southeast of St. Lawrence Island; greatest bulk usually zooplankton
Motoda & Kawarada, 1955	southwest (Aleutians)	Samples collected with no. XX16 bolting silk vertically hauled from 50 m in May & June; area divided into regions by characteristic species	Maximum number of cells was $100/m^3$; dominant species: *Chaetoceros atlanticus, Ch. convolutus, Ch. debilis, Ch. decipiens, Ch. radicans, Corethron hystrix, Denticula* sp. *Nitzschia seriata, Rhizosolenia hebetata.* Six regions: two with neritic species, two with cold, oceanic species, one mixed, one purely oceanic
Marumo, 1956	southwest	Surface water collected June to Aug. centrifuged; important species identified, abundance, distribution related to temperature	Cell numbers generally 10^2-10^3 ℓ (10^2, 10^3-10^4); major species: *Chaetoceros debilis, Ch. convolutus, Corethron hystrix, Denticula* sp., *Nitzschia seriata*
Smetanin, 1956	western	Data from previous collections; phytoplankton standing crop determined by phosphate loss and related regions and hydrography	Northwest: 50-60 g C m^2 each season; northwest shelf break: 60-225 g C m^2 up to 15 June; deep inshore: 120-150 g C m^2 each season; deep open ocean: 35-55 g C m^2 each season
Fac. Fish. Hokkaido Univ., 1957	southern	Samples collected with 0.11 mm mesh net hauled vertically from 100 m	List major species collected

Table 2. (cont.)

Author, Date	Region	Nature of Study, Methods	Results
Kawarada, 1957	Bering Sea	Samples collected by "dipping the water;" list of major species, abundance, distribution, vertical distribution in June, July	Usually 10^3-10^4 (40-10^6) cells ℓ present; *Chaetoceros convolutus, Ch. compressus, Ch. constrictus, Ch. debilis, Ch. radicans, Denticula* sp., *Nitzschia closterium, N. seriata, Rhizosolenia hebetata, Thalassiothrix longissima*
Kawarada & Owada, 1957	transect along 55°N to Attu Is.	Surface water samples collected with a bucket, centrifuged, settled April - July; species list, abundance	Monthly variations in community composition, abundance; highest concentration in April and composed of cold, subarctic species
Fac. Fish. Hokkaido Univ., 1958	southern (Aleutians)	Samples collected with 0.11 and 1.01 mm double net, hauled vertically from 100 m	List major phytoplankton species found at each location
Iizuka & Tamura, 1958	southwest	Samples collected with 0.33 and 0.86 mm mesh nets hauled vertically from 150 m, June to Aug.; list of dominant species; species characteristic of water masses	Dominant species were *Thalassiothrix longissima, Chaetoceros atlanticus*
Karohji, 1958	southern, central	Samples collected with 0.112 mm mesh net hauled vertically from 50 m. major species, standing crop, distribution by region	Cold oceanic populations of *Thalassiothrix longissima, Rhizosolenia hebetata, Fragilaria* spp., *Denticula* sp. widely distributed in west; *Nitzschia seriata, Chaetoceros* Hyalochaete dominant in southwest; *Ch.* Phaeoceros in eastern part of area
Fac. Fish. Hokkaido Univ., 1959	western	Samples collected with 0.11 mm mesh net hauled vertically from 100 m in May and July	List of dominant species and abundance

Table 2. (cont.)

Author, Date	Region	Nature of Study, Methods	Results
Karohji, 1959	southern, central	Samples collected with Hardy Underway Plankton Catcher Model II, boltsilk no. XX13, in July, Aug.; major species, relative abundance	Western: *Thalassiothrix longissima, Nitzschia seriata;* Central: *T. longissima, N. seriata, Rhizosolenia hebatata;* North central, Bristol Bay, Cape Olyutorskii: *Chaetoceros* Hyalochaete group; Unimak Is: *Ch. didymus*; deep water: *Ch. furcellatus;* East: *Ch.* Phaeoceros
Takano, 1959	western (Aleutians)	Samples collected with 128 mesh/inch net vertically hauled from May-July; quantitative distribution from settled samples, species list, geographic distribution	Forty-eight species, 22 genera collected, including 39 centric and 9 pennate species
Fac. Fish. Hokkaido Univ., 1960	southern	Samples collected with a 0.11 mm mesh net hauled vertically from 100 m in June, July	Lists dominant species and abundance
Semina, 1960	western	Samples collected at various depths, May-June, Aug.-Oct., analyzed using settling techniques; biomass related to stability of mixed layers	Olyutorskii, Anadyr regions neritic, rest of area oceanic; maximum biomass in neritic zone in spring; maximum in oceanic zone in autumn, but no intensive development
Fac. Fish. Hokkaido Univ., 1961	southern	Samples collected with 0.11 mm mesh net hauled vertically from 100 m and Van Dorn bottles, June-Aug.; surface standing crop, prim prod (^{14}C)	Surface standing crop, primary productivity, major phytoplankton species
Heinrich, 1962	Bering Sea	Biomass peaks determined from previous samples	Neritic zone peak in early spring to summer; oceanic zone peak small and in summer

Table 2. (cont.)

Author, Date	Region	Nature of Study, Methods	Results
Tsuruta, 1962	northeast	Species composition, distribution, effects of temperature in early summer	Dense population drops off to south with copepod increase; dominant species: *Thalassiosira nordenskioeldii, Th. gravida, Th. condensata, Fragilaria oceanica*
Fac. Fish. Hokkaido Univ., 1963	southwest	Samples collected with 0.11 mm mesh net vertically hauled from 100 m in May-July	List dominant species in each sample
Kawamura, 1963	Bering Sea	Primary production, chlorophyll *a*, species composition, abundance from surface samples collected from June-August	Southeast: first record of arctic, neritic species *Fragilaria striatula, Gonyaulax tamarensis;* 1.14 mg C m^3 hr, 0.29 mg chl *a* m ; Northeast: 0.44 mg C m^3 hr, 0.29 mg chl *a, Fragilaria striatula, Chaetoceros concavicornis*; Western: 0.71 mg C m^3 hr, 0.62 mg chl *a* m and 70% *Denticula marina*
Ohwada & Kan, 1963	eastern, southwest	Water collected from June-August; nutrients, temperature, salinity, dominant species, abundance, community characteristics	Divided into 7 regions; southward flow of water from central Bering Sea to the Aleutians suggested from distributions of *Chaetoceros* Phaeoceros, *Corethron hystrix, Denticula marina*
Tsuruta, 1963	southwest St. Lawrence Is.-S. St. Matthew Is.	Samples collected with Nakai vertical net, GG54 gauze, hauled from bottom; species, distributions in relation to water masses	Higher phytoplankton when large copepods not present; dominant species: *Thalassiosira nordenskioeldii, Th. gravida, Th. condensata, Fragilaria oceanica*
Zenkevitch, 1963	Bering Sea	Ecological summary from previous collections	Summary of Soviet studies to date

Table 2. (cont.)

Author, Date	Region	Nature of Study, Methods	Results
Azova, 1964	Pribilofs to Bristol Bay	Primary production calculated from diurnal oxygen concentrations, April, July, Sept., Nov.	Average depth of euphotic zone was 26 m; mean primary production was 0.14 g C m^3 day, with total of 655 g C year
Meshcherya-kova, 1964	eastern	Samples collected with no. 38 silk Juday nets hauled from standard depths; chemical, physical oceano-graphy, major species distribution, biomass	Oceanic diatoms dominant from July-Sept., vigorous development of phytoplankton in Sept., but no large accumulations of peridinians
Fac. Fish. Hokkaido Univ., 1965	Bering Sea	Samples collected with 0.09 mm mesh nets hauled vertically from 100 m, June to Aug.	Lists dominant species from each sample
Koblents-Mishke, 1965	Bering Sea	History of studies prior to 1960, including volume of primary produc-tion, seasonal, geographic variations	Volume varied from 50-100 mg C m^2 day
Marumo, 1967	Bering Sea	Surface water collected, centrifuged for general distribution of species, abundance, communities in relation to water masses in summer	Generalized results for whole Bering Sea, cell counts of 10^2-10^6 ℓ, mainly cold water subarctic community: *Chaetoceros debilis, Ch. compressus, Ch. radicans, Leptocylindrus danicus* (coastal); *Fragilaria islandica, F. oceanica, Thalassiosira decipiens* in spring
Arsen'yev & Voytov, 1968	Bering Sea	Whole Bering Sea in summer, western region in winter, relative trans-parency, correlation of pattern of surface circulation to displacement of water masses	Plankton biomass inversely proportional to relative transparency

Table 2. (cont.)

Author, Date	Region	Nature of Study, Methods	Results
Fac. Fish. Hokkaido Univ., 1968, 1969	eastern, central	Samples collected with Van Dorn bottles, primary productivity (^{14}C), phaeopigments, chemical oceanography	Plant pigments, primary productivity, standing crops, chemistry data
Taniguchi, 1969	eastern	Variation of primary production regionally, chl *a* for individual species, abundance in summer	High productivity where dinoflagellates dominant, low where *Chaetoceros* domianant, medium where *Nitzschia closterium* dominant
Fac. Fish. Hokkaido Univ., 1970, 1972	southeast	Samples collected with Van Dorn bottles, primary productivity (^{14}C), phaeopigments, chemistry	Plant pigments, primary productivity, standing crops, chemical data
McRoy, 1970	eastern	Surface water samples taken with a bucket, ice algae from melted ice; primary productivity, chl *a*, ratio of particulate N to chl *a*, ice algae composition	Chl *a* 0.10-1.40 mg m^3 in open water and leads; 5-70 times greater on underside of ice; Ice algae composed of *Navicula, Synedra, Fragilaria, Chaetoceros, Coscinodiscus, Rhizosolenia* spp., dinoflagellates
Meshcheryakova, 1970a, 1970b	southeast	Samples collected with no. 38 silk Juday net; quantitative distribution, biomass, seasonal species composition, Feb. to Dec.	Phytoplankton peaks in May, June, Sept., Oct. near Bristol Bay; highest concentrations near Pribilofs; deep sea peaks in June, July, Oct.
Starodubtsev, 1970	southeast	Samples collected with Nansen bottles; primary production (^{14}C), O_2 concentrations, species; review of Russian literature	Average production was 1.46 g C m^2 day; surface was 0.089 g C m^2; 54% in spring, 33% in summer, 13% in autumn; maxima in center and south of Bristol Bay, west of Pribilofs

Table 2. (cont.)

Author, Date	Region	Nature of Study, Methods	Results
Karohji, 1972	Bering Sea	Samples collected in summer with 30 cm, XX13 mesh bolting cloth net hauled vertically from 100 m; standing crop, major species, characteristics for 7 regions; reviews literature	Standing crops large in western Aleutian, northern, eastern waters; small in central, western waters; neritic populations characterize northern, eastern shelf, western Aleutians; oceanic species found in rest of area
McRoy, *et al.*, 1972	eastern	Samples collected with large volume glass sampler in Feb., March, June, July; ^{14}C uptake, chl *a* concentrations, ^{15}N uptake measured	Surface productivity in June, July in Aleutians 2.2-165 mg C m^3 day, chl *a* 0.2-9.9 mg m^3; in ice-covered surface water C uptake was 0.17-4.09 mg C m^3 day, chl *a* was 0.53 mg m^3; population on undersurface of ice averaged 44.4 mg C m^3 day and 6.83 mg chl *a* m^3
Taguchi, 1972	central	Collections made at six light depths in June; *in situ* ^{14}C uptake experiments; average total phytoplankton production calculated	Average total production was 80 g C m^2 yr; total Bering Sea production was 894 tons C day or 3.2×10^5 tons C year
Boisseau & Goering, 1974	Norton Basin	Nutrients, primary production, chl *a* measured from water samples	Primary productivity for the whole water column was 238.7-499 mg C m^2 day; chl *a* was 9.44-12.72 mg m^2
Fukuoka & Kido, 1974	Bering Sea	Compared areas of high productivity in Atlantic and Pacific oceans	Productivity may be related to thickness of mixed layer; mixed layers in Bering Sea have lower salinity than in Atlantic and higher productivity may be related to this

Table 2. (cont.)

Author, Date	Region	Nature of Study, Methods	Results
Gershanovich, *et al.*, 1974	Bering Sea	Briefly summarizes Soviet information	Highest biomass in coastal waters of southeast Bering Sea; high abundance of nutrients and thawing of ice cover contribute to intense development of diatoms and dinoflagellates
Marumo & Minoda, 1974	Bering Sea	Review of previous work, includes species list from net collections	Species list includes 22 diatoms and 4 dinoflagellates
McRoy & Goering, 1974	Bering Sea	Primary production, chl *a*, ^{15}N uptake, hydrography, inorganic nutrients measured in ice and water column, Feb.-April	Surface water south of ice and under ice averaged 0.2-0.9 mg chl *a* m^3; at ice front, 4 mg m^3; total water column averaged 3-9 mg m^2; at ice edge, 168 mg m^2; primary productivity greatest at ice front at 89.3 mg C m^2 day, and 15-20 mg C m^2 day in the water
Minoda & Marumo, 1974	eastern	Collections made with Nansen bottles, vertical distribution of abundance and community components	Northeastern components in July were *Thalassiosira, Fragilaria, Nitzschia, Navicula; Chaetoceros diadema* and dinoflagellates indicate seasonal succession from spring to summer; *Thalassiosira* begins spring bloom
Motoda & Minoda, 1974	Bering Sea	Review of previous studies; surface samples collected with a bucket and 0.1 mm mesh net hauled vertically from 50 m; standing crop, chl *a*, primary productivity, species list	Standing crop is 10^5-10^7 cells m in early to midsummer; surface primary production east of Bowers Bank was 5 mg C m^3 hr, but < 1 mg C m^3 hr on northern shelf and western gyre, and 1-2 mg C m^3 hr in western and central areas
McRoy & Goering, 1974	Bering Sea	See McRoy and Goering, 1976	

Table 2. (cont.)

Author, Date	Region	Nature of Study, Methods	Results
Alexander, 1976	southeast	Samples collected with CTD rosette; chl *a*, nutrients, standing stock, primary productivity, ^{15}N uptake; some ice cores collected	Surface chl *a* declined 50-100 miles from ice edge; species diversity in ice was low; *Fragilariopsis* sp., *Melosira moniliformis*, choanoflagellates in ice; *Fragilariopsis* sp., *Chaetoceros socialis*, *Thalassiosira nordenskioeldii*, choanoflagellates outside
Marumo & Minoda, 1976	eastern	See Minoda and Marumo, 1974	
McRoy & Goering, 1976	Bering Sea	Breakdowns for regions and seasons; revised total annual production of organic matter from previous collections	Total production estimated to be 274 x 10^6 metric tons; slightly greater than 50% from shelf, including ice algae (20%), rivers and lagoons
Taniguchi, *et al.*, 1976	eastern	Water samples from several depths to 150 m; hydrography, species list, succession, nutrients, chl *a*, May-June	Dense concentrations of *Thalassiosira hyalina*, *Th. nordenskioeldii*, *Fragilaria*, *Navicula* on shelf in May; *Thalassiosira* spp. sink by June
Cooney, 1977	Bering Sea	Bibliography of arctic and subarctic marine flora and fauna with emphasis on pelagic community of the North Pacific and Bering Sea regions	List of references for Bering Sea
Ishimaru & Nemoto, 1977	57°N from 175-163°W, eastern	Norpac net vertical hauls from 150 m, water samples from 200 m; species list, distribution, June-Aug.	Diatoms especially abundant at western stations; *Chaetoceros convolutus*, *Denticula* sp., *Nitzschia seriata*, *Thalassiosira decipiens*, *Rhizosolenia alata*, *Rh. hebetata* widely distributed

Table 2. (cont.)

Author, Date	Region	Nature of Study, Methods	Results
Otobe, *et al.*, 1977	57°N from 175-163°W, eastern	Secchi disk used to measure underwater irradiance; particulate matter counted with Coulter counter from June-Aug.	Irradiance coefficient significantly correlated with volumes of particulate matter, not chl *a*, in euphotic zone on the eastern shelf
Saino & Hattori, 1977	57°N from 175-163°W, eastern	Surface samples filtered through netting, incubated for ^{15}N, ^{14}C uptake; volume of particulate matter, estimates of growth constants for dominant species, maximum growth constants; June-Aug.	Volumes of particulate matter from 4-64 μm correlated with PON; PON volume ranged from 0.017-.42 g ml; growth constants for *Nitzschia seriata, Thalassiosira decipiens, Rhizosolenia hebetata, Chaetoceros convolutus* were: 1.05, 0.92, 0.91, 0.83
Satake, *et al.*, 1977	57°N from 175-163°W, eastern	Water samples collected from light depths, incubated for primary production	^{14}C uptake 0.04-0.17 mg C m^3 hr in western area; 0.22-0.58 mg C m^3 hr in eastern area
Semina *et al.*, 1977	Bering Sea	Distribution in relation to water masses	*Denticula seminae* endemic to boreal zone in western, central Bering Sea; *Thalassiosira nordenskioeldii*, neritic, arctic species, found to the north
Goering & Iverson, 1978	southeast	Identified ecologically important species, described processes regulating primary production, April-June (see Iverson *et al.*, 1978)	Chl *a* maximum found running parallel to shelf break representing two fronts; productivity greater in outer front and nutrient limited in interfrontal zone
Iverson, *et al.*, 1978	southeast	Water samples from standard depths, processed for chl *a*; Utermöhl technique for identification, cell numbers; Coulter counter for particulate matter; April-June, Sept.; species list	Three fronts divide shelf into two interfrontal zones: shelf break, middle, outer fronts; spring bloom in middle zone involves *Thalassiosira aestivalis, Th. nordenskioeldii, Chaetoceros debilis;* chlorophyll maxima near bottom; *Phaeocystis* in both zones through Sept., blooms in early May

Table 2. (cont.)

Author, Date	Region	Nature of Study, Methods	Results
Saito & Taniguchi, 1978	Bering Sea	Nutrient concentrations, pigments, species composition, succession, cell numbers in early July	*Chaetoceros convolutus, Ch. debilis* dominant on shelf in summer; mixture of spring, summer, ice species in northern area
Alexander & Cooney, 1979	eastern	Review of previous investigations; samples collected with Niskin bottles; cluster analysis used to identify species assemblages; species lists; primary productivity, chl *a* distribution; historical account of hydrography; ice edge ecosystem model	Four major groups delineated by cluster analysis: ice edge, deeper water, surface layer away from ice edge, shelf break; Ice survey in Norton Sound: chl *a* 0-213.7 mg m^3 ; most intense primary productivity at ice edge just prior to breakup with surface chl > 20 mg m^3 , primary productivity 25 mg C m^3 hr
Dagg, 1979	southeast	Grazing impact of copepods on phytoplankton community	Copepod size affected what happened to the phytoplankton
Furuya, *et al.*, 1979	eastern	Samples collected with 0.1 mm mesh Norpac net hauled vertically from 150 m, water samples collected with Niskin bottles, filtered, settled, June-Aug.; species list, abundance	Diatoms 70% of standing stock, but large populations of naked flagellates, coccoids; species of diatoms, dinoflagellates, silicoflagellates identified, listed
Goering & Iverson, 1979	southeast	See Goering and Iverson 1978	
Iverson & Goering, 1979	southeast	See Goering and Iverson 1978	Primary productivity during spring bloom: outer shelf: 200 g C m^2 yr; middle shelf: 400 g C m^2 yr; inner shelf: 120 g C m^2 yr
Iverson, *et al.*, 1979	southeast	See Iverson and Goering 1978	Local nitrate minima correlate with chl *a* maxima; calculated doubling time of four days for *Phaeocystis pouchetii*

Table 2. (cont.)

Author, Date	Region	Nature of Study, Methods	Results
Saino, *et al.*, 1979	eastern	Water samples collected with Niskin bottles at light penetration depths; primary production; June-Aug.	Integrated production ranged from 11.6 mg C m^2 hr at Nunivak Is. to 80.2 mg C m^2 hr near the Pribilofs
Horner & Wencker, 1980	Norton Basin	Samples collected with Niskin bottles; temperature, salinity, plant pigments, primary productivity	Surface primary productivity 0.12-17.16 mg C m^3 hr; chl *a* 0.13-12 mg m^3
Niebauer, *et al.*, 1981	southeast	Cruises at ice edge in May-June 1975, March-April 1976, April-June 1977; hydrography; primary productivity; chl *a*	Nitrate depletion limits spring production at ice edge; increased light at ice edge as ice breaks up, but with some ice cover to reduce mixing, produces intense bloom; ice edge model
Alexander & Chapman, 1981	Norton Basin, southeast	Chl *a* in ice cores; productivity measured on brash ice collected at ice edge	Ice algae patchy on broad, narrow scales; some overlap in species composition between ice and seawater; ice algae < 1% of annual production in southeastern region, but important as concentrated food source early in season
Goering & Iverson, 1981	southeast	Water samples at discrete depths	Seasonal succession of shelf phytoplankton; factors affecting succession
Schandelmeier & Alexander (1981)	southeast	Water samples from discrete depths	Influence of ice on spring phytoplankton

IV. STUDY AREA

The study area and sampling locations for both cruises are given in Figure 1.

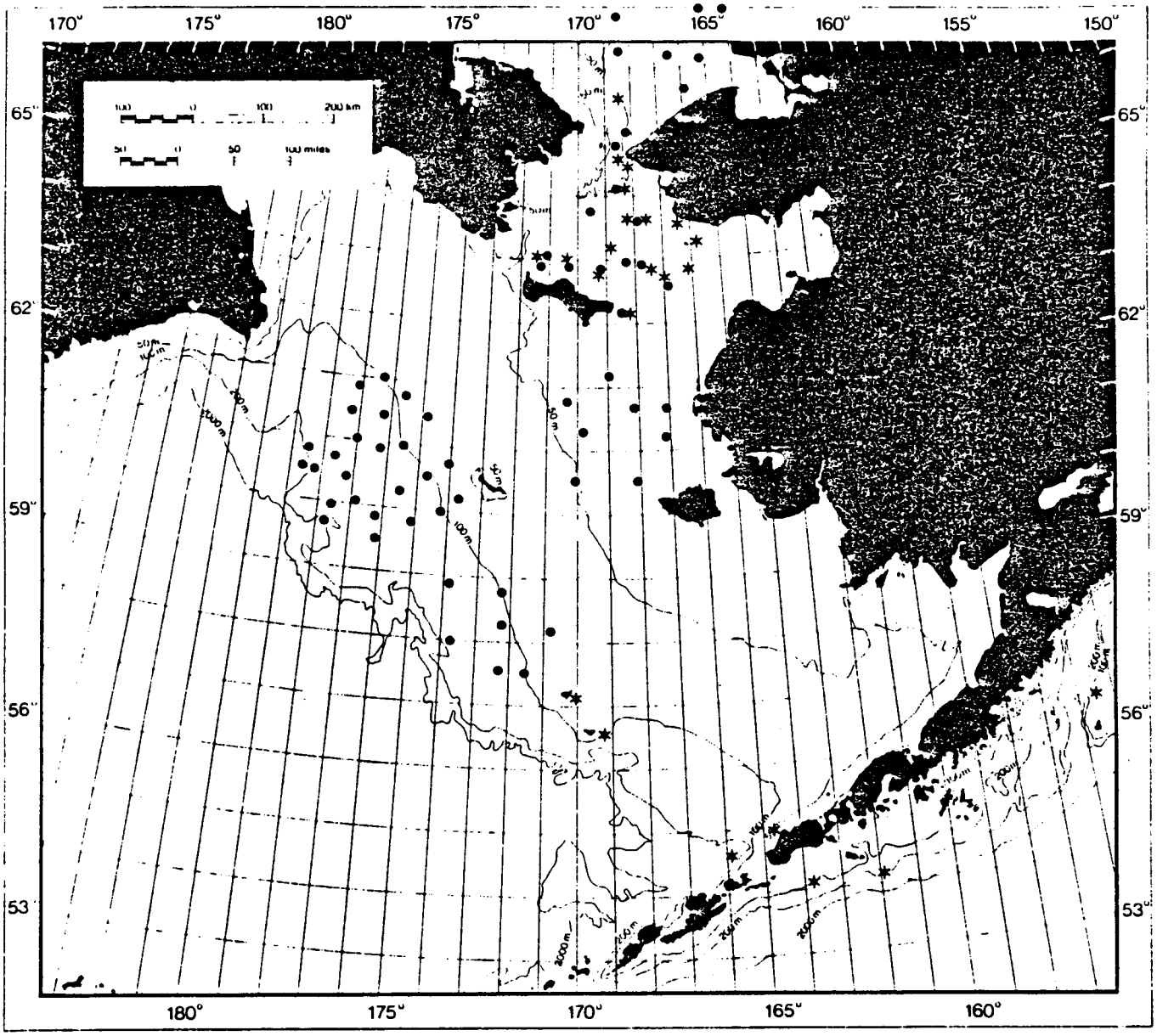


Fig. 1. Sampling locations for icebreaker cruises in the Bering Sea. * = CGC *Polar Sea*, 17 April-6 May 1979; • = CGC *Polar Star*, 4 May-24 June 1980.

V. SOURCES, METHODS, AND RATIONALE OF DATA COLLECTION

A. Sample collection

Water samples were collected with 5 ℓ Niskin bottles equipped with reversing thermometers belonging to the U.S. Coast Guard. Samples were collected from 6 or 8 depths spaced throughout the water column with the bottom bottle placed as close as possible to the sea bed. Portions of each water sample were processed for phytoplankton standing stock, plant pigments, primary productivity, and nutrient and salinity determinations.

Phytoplankton standing stock samples contained in labeled 250 ml glass jars were preserved immediately with 4-5 ml 4% formaldehyde buffered with sodium acetate.

Plant pigment samples, usually 2 ℓ, were filtered through 47 mm, 0.45 µm Millipore filters with 2 drops of a saturated solution of $MgCO_3$ added near the end of the filtration. The filters and filter towers were rinsed with a few ml filtered seawater. The filters were removed, folded into quarters, placed in labeled glassine envelopes, placed in a dessicator, and frozen.

Primary productivity experiments were run in 60 ml glass reagent bottles with 2 light and 1 dark bottle per depth. Each bottle was inoculated with 2 ml $NaH^{14}CO_3$, *ca.* 5 µCi. The dark bottle was covered with black tape and wrapped in aluminum foil and all bottles were incubated for 3-4 hr under ambient light conditions in an incubator located on the fantail of the ship. Low temperature was maintained by constantly running seawater through the system. Light was measured at the beginning and end of the incubation period with a Gossen Super Pilot photographic light meter. Following incubation, the samples were filtered onto 25 mm, 0.45 µm Millipore filters, rinsed with a few ml 0.1 N HCl and a few ml filtered seawater, and placed in scintillation vials.

Nutrient samples were taken from the plant pigment filtrate. The first 500 ml of the pigment filtrate were discarded. The nutrient sample was taken from the next quantity of water filtered and before the $MgCO_3$ was added. The nutrient samples were poured into 125 ml polyethylene bottles and frozen.

Salinity samples were put in 250 ml polyethylene bottles and stored at room temperature for 4-5 days before analysis.

Temperatures were taken with reversing thermometers attached to the Niskin bottles. Thermometers were read within an hour of being brought to the surface.

Water transparency was determined to the nearest meter with a Secchi disc lowered on a calibrated handline. This determination was always done from a location next to the hydrographic platform and while the thermometers

were equilibrating. Two people determined when the Secchi disc was no longer visible.

B. Sample analysis

1. Standing stock

These samples were analyzed using Zeiss phase-contrast inverted microscopes and 5 and 50 ml Zeiss counting chambers. Large, rare organisms (> 100 µm) were counted at 125 X magnification in 50 ml chambers, while small, abundant organisms (< 100 µm) were counted at 312 X magnification in 5 ml chambers. Usually one-eighth of each chamber was counted. In some samples, the number of small flagellates (< 10 µm diameter) was excessive and were counted in one or two fields. The number of cells per liter was calculated by multiplying the number of cells counted in the 5 ml chamber by 1600 and the number counted in the 50 ml chamber by 160. References used to identify phytoplankton included Cupp (1943), Hendey (1964), Hustedt (1930, 1959-62), Schiller (1933-37), and Hasle (1965).

2. Plant pigments

Samples were analyzed by grinding the filters in *ca.* 10 ml 90% acetone with a Teflon tissue grinder. The samples were centrifuged 3 times for a total of 30 min, and the extract was analyzed with a Turner Model 111 fluorometer.

Chlorophyll *a* and pheopigments were calculated using the equations

$$\text{Chl } a \text{ (mg m}^{-3}) = \frac{\frac{Fo/Fa_{max}}{(Fo/Fa_{max}) - 1}(K_x)(Fo-Fa)}{\text{Vol filtered}}$$

$$\text{Pheo (mg m}^{-3}) = \frac{\frac{Fo/Fa_{max}}{(Fo/Fa_{max}) - 1}(K_x)[Fo(Fo/Fa_{max})-Fa]}{\text{Vol filtered}}$$

where Fo = fluorometer reading before acidification; Fa = fluorometer reading after acidification; K = fluorometer door calibration factor; Fo/Fa_{max} = acid ratio; and vol filtered = volume of sample water filtered.

3. Primary productivity

Radioactive uptake was measured using liquid scintillation techniques in a Packard Tri-Carb Scintillation spectrometer. Aquasol (New England Nuclear, Boston, MA.) was the scintillation cocktail.

Carbon uptake was calculated using the equation

$$\text{Ps (mg C m}^{-3}\text{ hr}^{-1}) = \frac{(L - D) \times W \times 1.05}{R \times T}$$

where L = light bottle disintegrations per minute; D = dark bottle disintegrations per minute; W = carbonate carbon present in the water; 1.05 = isotope factor for ^{14}C; R = activity of the ^{14}C added to each sample; T = incubation time (Strickland and Parsons 1968).

4. Nutrient concentrations

Nitrate, nitrite, ammonia, phosphate, and silicate concentrations were determined by the University of Washington, Department of Oceanography Chemistry Laboratory using autoanalyzer techniques (Pavlou 1972).

5. Salinity

Samples were analyzed using a Bissett Berman Model 6220 induction salinometer using standard seawater to calibrate the instrument. The salinometer was standardized at the beginning and end of a run and after 30-40 samples if more than that were analyzed at one time.

6. Temperature

In 1979, uncorrected thermometer readings were sent to the U.S. Coast Guard Oceanographic Unit, Washington, D.C., for correction. The 1980 thermometer readings were corrected using calibration factors provided by the Coast Guard and following procedures outlined in U.S. Naval Oceanographic Office Publ. 607 (1968).

VI. RESULTS

Temperature, salinity, plant pigment concentrations, primary productivity, nutrient concentrations, and ice cover for 1979 are given in Tables 3-4; vertical profiles of temperature-salinity and carbon-chlorophyll *a* are shown in Fig. 2. Kite diagrams of phytoplankton abundances are shown in Fig. 3. Integrated carbon uptake and chlorophyll *a* values are in Table 5. A list of phytoplankton species found in the Bering Sea in 1979 and 1980 is given in Table 6.

In 1979, at stations 1-18 in Norton Basin and Bering Strait, temperature was isothermal and < -1.0°C, while salinity was isohaline, ranging from 31.43-32.57°/$_{oo}$. Temperature and salinity at 8 stations south of the Pribilof Islands, south of Unimak Island, and in Shelikof Strait were also usually isothermal and isohaline, but temperatures were positive, ranging from 2.64-5.12°C and salinity ranging from 31.70-34.98°/$_{oo}$.

Ice cover was variable with stations west of *ca.* 167°30' and north of 64°N having relatively heavy ice cover, although a tongue of open water was present extending from *ca.* 167°30'-168°30'W and north to about 64°30'N. Some ice was also present at the station off Gambell on the northwest tip of St. Lawrence Island. No ice was present south of St. Lawrence Island.

Primary productivity was variable, with integrated production ranging from *ca.* 6 mg C m^{-2} hr^{-1} at station 17 north of St. Lawrence Island to 398

Table 3. Summary of station locations, hydrography, ice cover, chlorophyll *a* and phaeopigment concentrations, and primary productivity, CGC *Polar Sea* cruise, Bering Sea, 17 Apr - 6 May 1979.

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Phaeo (mg m^{-3})	Prim Prod (mg C m^{-3} hr^{-1})
01	000	0644	19 Apr	64°15.5'	165°51.9'	8	2	*	31.842	1.68		8.23
	003							-1.67	31.845	1.92		7.29
	006							-1.69	31.887	2.32		9.82
	009							-1.68	31.886	1.28		7.00
	012							-1.68	31.877	1.36		7.25
	015							-1.69	31.800	1.36		8.26
	018							-1.71	31.820	2.72		10.31
	021							-1.72	31.929	2.64		11.82
02	000	1622	19 Apr	63°46.1'	166°03.2'	0	4	-1.51	31.675	4.48		0.12
	003							-1.52	31.652	5.76		3.67
	006							-1.52		Bottle didn't trip		
	009							-1.53	31.653	5.04		2.84
	012							-1.53	31.654	5.76		3.35
	015							-1.54	31.665	7.56	0.36	3.44
	018							-1.56	31.684	10.44	0.36	2.12
	021							-1.54	31.693	11.16		2.79
03	000	0612	20 Apr	63°32.95'	166°52.78'	0	4	-1.62	31.559	4.66		9.19
	004							-1.63	31.554	3.36	0.42	10.51
	008							-1.64	31.550	1.34	1.83	7.88
	012							-1.63	31.555	3.90	0.26	7.63
	016							-1.64	31.557	3.22	0.40	6.41
	020							-1.64	31.559	2.94	0.28	8.09
	024							-1.65	31.553	3.80	0.44	5.32
	028							-1.64	31.556	2.10	0.28	4.58

* Where no temperature is present, both thermometers on the bottle malfunctioned.

Table 3. (continued)

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Phaeo	Prim Prod (mg C m^{-3} hr^{-1})
04	000	1237	20 Apr	63°56.7'	167°35.9'	5-6	4	-1.62	31.933	0.91		2.45
	004							-1.64	31.927	1.44		2.60
	008							-1.63	31.928	0.81	0.15	1.71
	012							-1.67	31.939	1.63	0.14	2.44
	016							-1.65	31.935	1.14	0.09	1.72
	020							-1.69	31.938	1.14	0.23	3.02
	024							-1.73	31.937	1.29	0.31	1.85
	028							-1.73	31.944	1.56	0.28	2.50
05	000	0537	21 Apr	64°30.3'	166°23.3'	6-7	4	-1.67	31.240	2.89		3.10
	003							-1.66	31.225	1.56		7.20
	006							-1.68	31.457	3.20	0.19	3.88
	009							-1.66	31.438	1.28		4.13
	012							-1.68	31.490	1.93		3.61
	015							-1.72	31.456	1.68	0.06	6.16
	018							-1.71	31.456	0.83		5.51
06	000	0956	22 Apr	66°36.26'	168°25.40'	7-8	4	-1.29	31.587	0.25	0.94	0.97
	005								31.689	0.26	0.99	1.30
	010							-1.66	31.715	0.14	0.95	0.84
	015							-1.70	31.716	1.17		1.25
	020								31.740	0.35	0.59	0.81
	025							-1.69	31.760	1.07	0.22	1.19
	030							-1.71	31.763	0.12	1.42	0.77
	035							-1.72	31.760	1.00	0.40	1.26

Table 3. (continued)

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Temp (°C)	S°/$_{oo}$	Chl *a* (mg m^{-3})	Phaeo	Prim Prod (mg C m^{-3} hr^{-1})
09	000	1222	24 Apr	65°36.6'	168°35.6'	7-8	2	-1.64	31.684	0.35	1.40	1.59
	005							-1.69	31.726	0.98	0.14	1.60
	010							-1.70	31.723	0.94	0.08	1.33
	015							-1.72	31.714	0.82	0.18	1.27
	020							-1.70	31.723	0.91	0.27	1.56
	025							-1.71	31.723	0.93	0.21	1.21
	035							-1.73	31.722	1.16	0.27	1.01
	045							-1.72	31.719	1.16	0.38	1.07
10	000	1222	25 Apr	65°29.89'	168°06.11'	7-8	3	-1.30	31.437	0.62	0.08	8.66
	005							-1.39	31.432	0.52	0.07	11.24
	010							-1.63	31.442	0.53	0.09	5.93
	015							-1.37	31.444	0.41	0.03	10.42
	020							-1.39	31.443	0.48	0.09	6.84
	025								31.448	0.54	0.11	7.73
	030							-1.33	31.458	0.50	0.09	6.02
11	000	0625	26 Apr	65°01.8'	168°15.7'	7-8	3		32.312	0.49	0.42	0.53
	005							-1.38	32.308	0.39	0.27	0.52
	010							-1.49	32.308	0.26	0.33	0.33
	015							-1.44	32.311	0.26	0.23	0.42
	020								32.306	0.39	0.20	0.46
	025							-1.51	32.323	0.36	0.27	0.44
	030							-1.42	32.345	0.46	0.31	0.62
	040								32.359	0.40	0.40	0.60

Table 3. (continued)

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Phaeo (mg m^{-3})	Prim Prod (mg C m^{-3} hr^{-1})
12	000	0634	27 Apr	64°29'64'	167°40.10'	0	2	-1.11	31.568	10.00	2.00	12.27
	004							-1.18	31.569	8.50	2.00	15.94
	008							-1.21	31.572	10.00	1.50	15.07
	012							-1.21	31.569	12.00	0.50	17.05
	016							-1.22	31.573	3.50		13.24
	020							-1.21	31.571	9.50	2.00	14.75
	024							-1.23	31.568	9.00	2.00	8.63
	028							-1.23	31.563	4.60	4.40	17.16
13	000	1337	27 Apr	64°37.82'	168°25.67'	< 1	2	-1.49	32.191	1.00	0.50	0.94
	004							-1.57	32.189	0.80	0.40	1.60
	008							-1.58	32.191	0.50	0.30	1.06
	012							-1.60	32.195	0.60	0.30	1.70
	016							-1.60	32.192	0.70	0.30	1.15
	020							-1.61	32.193	0.70	0.35	1.14
	024							-1.63	32.196	0.70	0.40	1.12
	030							-1.63	32.200	0.55	0.40	1.19
14	000	0602	28 Apr	64°12.66'	168°57.44'	4-5	4	-1.69	32.371	0.17	0.14	0.23
	004							-1.73	32.376	0.17	0.14	0.30
	008							-1.75	32.368	0.17	0.16	0.29
	012							-1.76	32.368	0.16	0.15	0.28
	016							-1.74	32.377	0.17	0.17	0.31
	020							-1.77	32.406	0.16	0.14	0.26
	026							-1.77	32.433	0.15	0.19	0.33
	032							-1.78	32.499	0.14	0.20	0.21

Table 3. (continued)

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Phaeo (mg m^{-3})	Prim Prod (mg C m^{-3} hr^{-1})
15	000	0611	29 Apr	63°50.91'	170°26.03'	0	3	-1.40	32.029	0.13	0.11	0.38
	004							-1.53	32.032	0.17	0.12	0.44
	008							-1.54	32.028	0.18	0.10	0.36
	012							-1.54	32.031	0.16	0.10	0.33
	016							-1.53	32.025	0.15	0.10	0.32
	020							-1.54	32.035	0.18	0.10	0.39
	024							-1.54	32.037	0.14	0.12	0.33
	030							-1.56	32.034	0.17	0.12	0.32
16	000	1307	29 Apr	64°00.6'	171°25.5'	1-3	4	-1.52	31.978	0.38	0.11	0.71
	004							-1.64	31.980	0.30	0.06	0.54
	008							-1.66	31.979	0.39	0.09	0.90
	012							-1.69	31.980	0.40	0.06	0.77
	016							-1.68	31.979	0.27	0.24	0.83
	020							-1.68	31.976	0.38	0.11	0.63
	024							-1.69	31.966	0.37	0.08	0.71
	028							-1.70	31.980	0.35	0.10	0.75
17	000	0600	30 Apr	63°44.83'	169°12.32'	0	5	-1.58	32.261	0.16	0.10	0.28
	002							-1.61	32.282	0.21		0.21
	006							-1.58	32.398	0.15	0.11	0.22
	010							-1.59	32.299	0.14	0.09	0.21
	014							-1.56	32.348	0.13	0.11	0.23
	018								32.316	0.12	0.10	0.18
	024							-1.63	32.346	0.11	0.11	0.22
	030							-1.68	32.434	0.12	0.13	0.16

Table 3. (continued)

Sta	Depth (m)	Time (Local	Date	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Phaeo	Prim Prod (mg C m^{-3} hr^{-1})
18	000	1343	30 Apr	63°17.83'	168°20.07'	0	4	-1.16	31.449	1.40	0.25	2.02
	004							-1.19	31.450	1.20	0.30	2.02
	008							-1.20	31.456	1.35	0.30	2.04
	012							-1.23	31.455	1.30	0.30	2.70
	018							-1.27	31.457	1.35	0.30	1.76
	024							-1.32	31.461	1.80	0.35	2.38
	030							-1.34	31.459	1.40	0.30	3.44
	036							-1.33	31.462	1.80	0.40	3.67
19	000	0552	2 May	57°06.89'	170°00.7'	0	3-4	2.68	32.583	1.05	0.35	2.13
	005							1.56	32.542	1.35	0.50	2.19
	010							2.67	32.540	1.05	0.35	2.47
	015							2.64	32.538	1.65	0.60	3.20
	020							2.67	32.664	1.05	0.45	1.69
	025							2.67	32.585	0.95	0.40	2.53
	030							2.66	32.583	1.05	0.25	2.35
	042							2.66	34.977	0.85	0.70	3.58
20	000	1255	2 May	56°27.50'	169°25.06'	0	12	3.91	32.546	0.28	0.15	0.54
	010								32.514	0.28	0.11	0.81
	020							3.55	32.504	0.29	0.16	1.08
	030							3.49	32.485	0.24	0.11	1.07
	040							3.50	32.468	0.25	0.17	0.70
	050								32.444	0.25	0.17	0.85
	060							3.48	32.410	0.25	0.14	0.82
	080							3.48	32.379	0.28	0.14	0.93

Table 3. (continued)

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Temp (°C)	S°/$_{oo}$	Chl *a* (mg m^{-3})	Phaeo	Prim Prod (mg C m^{-3} hr^{-1})
23	000	0657	3 May	54°34.07'	165°58.64'	0	~ 7	4.49	32.808	4.00	0.80	6.18
	010							4.57	32.788	3.30	0.70	10.42
	020							4.57	32.785	2.80	0.70	14.05
	030							4.40	32.785	1.90	0.30	7.99
	045							4.40	32.800	1.70	0.45	5.90
	060							4.35	32.808	1.55	0.40	5.55
	075							4.32	32.829	1.60	0.55	8.74
	100							4.09	32.977	0.65	0.40	2.15
24	000	1423	3 May	54°58.7'	164°36.2'	0	~ 7	4.81	32.240	1.15	0.35	5.18
	005							4.76	32.235	0.95	0.25	5.19
	010							4.74	32.239	1.10	0.20	5.75
	015							4.70	32.252	1.10	0.30	5.60
	020							4.72	32.303	1.25	0.45	2.58
	025							4.52	32.318	0.70	0.35	4.45
	035							4.44	32.380	0.85	0.30	2.42
	045							4.41	32.424	0.55	0.40	0.98
25	000	0658	4 May	54°10.36'	163°47.78'	0	8	4.72	31.704	0.85	0.20	2.71
	010							4.69	31.709	0.80	0.30	2.45
	020							4.70	31.718	0.90	0.25	2.74
	030							4.54	31.812	1.60	0.45	3.23
	040							4.53	31.875	1.25	0.35	3.10
	050							4.47	31.923	0.90	0.60	1.91
	060							4.21	31.974	0.55	0.50	0.71
	075							4.04	32.170	0.09	0.32	0.20

Table 3. (continued)

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Phaeo (mg m^{-3})	Prim Prod (mg C m^{-3} hr^{-1})
26	000	1605	4 May	54°14.7'	161°52.5'	0	> 12	4.62	31.789	0.45	0.30	1.34
	005							4.60	31.798	0.50	0.20	1.25
	010							4.59	31.794	0.75	0.20	1.33
	020							4.47	31.805	0.55	0.20	1.43
	030								31.822	0.45		0.59
	040							4.15	31.953	0.13	0.27	0.15
	050							3.97	32.138	0.14	0.10	0.12
	060							4.03	32.250	0.07	0.22	0.08
27	000	1506	5 May	56°21.44'	155°30.78'	0	> 10	5.07	32.194	3.60	0.60	15.14
	005							5.00	32.192	3.40	0.60	16.23
	010							4.77	32.192	3.90	0.50	14.25
	015							4.55	32.205	3.10	0.40	7.91
	020							4.53	32.194	3.30		8.94
	030							4.47	32.199	2.25	0.40	5.47
	040							4.49	32.230	1.85	0.50	3.73
	050							4.64	32.323	1.25	0.65	3.49
28	000	0659	6 May	59°07.07'	152°54.38'	0	> 10	5.12	32.099	3.40	0.60	22.33
	010							4.98	32.044	3.70	0.60	19.80
	020							4.89	32.100	4.80	0.80	18.78
	030							4.71	32.144	3.10	0.70	13.47
	040							4.72		2.80	0.80	10.66
	050							4.70	32.142	3.10	1.00	9.27
	060							4.69	32.136	2.30	0.70	8.53
	070							4.68	32.138	2.60	0.90	8.88

Table 4. Hydrographic data, CGC *Polar Sea* cruise, Bering Sea, 17 Apr - 6 May 1979.

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Sonic Depth (m)	Secchi Depth (m)	Temp (°C)	S°/₀₀	PO_4	SiO_4 (µg at ℓ)	NO_3	NO_2	NH_3
01	000	0644	19 Apr	64°15.5'	165°51.9'	22	2	*	31.842	1.04	23.61	2.90	0.04	1.09
	003							-1.67	31.845	0.85	19.63	2.23	0.03	2.53
	006							-1.69	31.887	0.76	14.79	1.76	0.02	2.28
	009							-1.68	31.886	0.79	17.11	2.29	0.03	3.69
	012							-1.68	31.877	0.77	13.72	1.66	0.03	2.28
	015							-1.69	31.800	1.05	24.52	3.08	0.04	0.64
	018							-1.71	31.820	0.86	18.21	2.30	0.02	0.95
	021							-1.72	31.929	1.12	24.52	3.29	0.06	0.66
02	000	1622	19 Apr	63°46.1'	166°03.2'	26	4	-1.51	31.675	0.44	5.66	0.08	0.00	1.04
	003							-1.52	31.652	0.40	5.79	0.09	0.00	0.93
	006							-1.52	Bottle didn't trip					
	009							-1.53	31.653	0.51	6.94	0.12	0.00	0.65
	012							-1.53	31.654	0.44	7.18	0.21	0.00	1.60
	015							-1.54	31.665	0.35	4.97	0.09	0.00	1.07
	018							-1.56	31.684	0.52	7.93	0.09	0.00	0.50
	021							-1.54	31.693	0.43	6.64	0.09	0.00	0.79
03	000	0612	20 Apr	63°32.95'	166°52.78'	31	4	-1.62	31.559	1.15	16.69	5.06	0.22	1.24
	004							-1.63	31.554	1.12	16.70	5.17	0.23	1.23
	008							-1.64	31.550	1.13	16.32	5.17	0.19	1.08
	012							-1.63	31.555	1.13	16.32	5.11	0.19	1.12
	016							-1.64	31.557	1.15	16.71	5.08	0.21	1.07
	020							-1.64	31.559	1.11	16.33	5.11	0.24	1.19
	024							-1.65	31.553	1.11	16.41	5.17	0.20	1.11
	028							-1.64	31.556	1.12	16.41	5.08	0.19	0.99

* Where no temperature is present, both thermometers on the bottle malfunctioned.

Table 4. (continued)

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Sonic Depth (m)	Secchi Depth (m)	Temp (°C)	S°/₀₀	PO_4	SiO_4	NO_3	NO_2	NH_3
										(µg at ℓ)				
04	000	1237	20 Apr	63°56.7'	167°35.9'	32	4	-1.62	31.933	1.50	27.88	9.57	0.14	1.46
	004							-1.64	31.927	1.52	28.36	9.70	0.15	1.59
	008							-1.63	31.928	1.55	28.45	9.73	0.14	1.58
	012							-1.67	31.939	1.56	28.35	9.61	0.13	1.33
	016							-1.65	31.935	1.56	28.54	9.70	0.14	1.49
	020							-1.69	31.938	1.56	28.54	9.77	0.14	1.46
	024							-1.73	31.937	1.49	28.44	9.77	0.14	1.34
	028							-1.73	31.944	1.54	28.53	9.83	0.14	1.44
05	000	0537	21 Apr	64°30.3'	166°23.3'	22	4	-1.67	31.240	1.11	20.80	4.15	0.08	1.21
	003							-1.66	31.225	1.12	20.64	4.15	0.09	1.26
	006							-1.68	31.457	1.14	21.06	4.25	0.09	1.08
	009							-1.66	31.438	1.10	20.23	4.04	0.08	0.99
	012							-1.68	31.490	1.10	20.73	4.35	0.15	1.25
	015							-1.72	31.456	1.12	20.90	4.27	0.08	1.10
	018							-1.71	31.456	1.12	20.32	4.25	0.09	1.21
06	000	0956	22 Apr	66°36.26'	168°25.40'	40	4	-1.29	31.587	1.28	25.85	6.49	0.10	2.03
	005								31.689	1.29	26.22	6.54	0.11	2.32
	010							-1.66	31.715	1.26	26.12	6.57	0.11	2.41
	015							-1.70	31.716	1.07	20.75	5.23	0.07	2.29
	020								31.740	1.00	16.41	4.32	0.06	2.91
	025							-1.69	31.760	1.00	17.47	4.45	0.05	2.39
	030							-1.71	31.763	1.00	16.93	4.28	0.05	2.32
	035							-1.72	31.760	1.33	26.47	6.60	0.06	1.95

Table 4. (continued)

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Sonic Depth (m)	Secchi Depth (m)	Temp (°C)	S°/₀₀	PO_4	SiO_4 (µg at ℓ)	NO_3	NO_2	NH_3
09	000	1222	24 Apr	65°36.6'	168°35.6'	55	2	-1.64	31.684	1.49	26.09	8.71	0.14	1.97
	005							-1.69	31.726	1.50	26.55	8.72	0.21	1.90
	010							-1.70	31.723	1.55	26.45	9.24	0.38	2.19
	015							-1.72	31.714	1.54	26.08	8.72	0.12	2.10
	020							-1.70	31.723	1.54	26.35	9.01	0.11	2.26
	025							-1.71	31.723	1.46	24.06	8.03	0.09	2.25
	035							-1.73	31.722	1.54	25.97	8.75	0.10	2.16
	045							-1.72	31.719	1.55	26.43	8.73	0.10	2.07
10	000	1222	25 Apr	65°29.89'	168°06.11'	40	3	-1.30	31.437	0.89	14.58	0.82	0.05	0.98
	005							-1.39	31.432	0.91	14.93	0.90	0.05	0.70
	010							-1.63	31.442	0.90	15.44	1.38	0.18	1.25
	015							-1.37	31.444	0.91	14.78	1.06	0.06	0.70
	020							-1.39	31.443	0.90	15.44	1.30	0.05	0.84
	025								31.448	0.63	9.43	0.69	0.11	1.16
	030							-1.33	31.458	0.93	15.95	1.06	0.02	0.70
11	000	0625	26 Apr	65°01.8'	168°15.7'	44	3		32.312	1.49	30.00	10.90	0.17	2.10
	005							-1.38	32.308	1.86	38.08	13.52	0.20	1.82
	010							-1.49	32.308	1.48	28.44	9.93	0.15	2.38
	015							-1.44	32.311	1.54	31.35	11.25	0.13	2.38
	020								32.306	1.57	31.32	11.07	0.12	2.16
	025							-1.51	32.323	1.32	26.41	9.46	0.10	2.11
	030							-1.42	32.345	1.38	24.80	8.99	0.12	2.49
	040								32.359	1.39	28.17	10.08	0.11	2.41

Table 4. (continued)

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Sonic Depth (m)	Secchi Depth (m)	Temp (°C)	S°/₀₀	PO_4	SiO_4 (µg at ℓ)	NO_3 (µg at ℓ)	NO_2	NH_3
12	000	0634	27 Apr	64°29.64'	167°40.10'	36	2	-1.11	31.568	1.02	12.68	2.37	0.17	0.47
	004							-1.18	31.569	1.05	13.15	2.21	0.18	0.40
	008							-1.21	31.572	1.01	12.95	2.25	0.14	0.51
	012							-1.21	31.569	1.04	13.22	2.25	0.19	0.31
	016							-1.22	31.573	1.03	13.22	2.18	0.13	0.33
	020							-1.21	31.571	1.05	12.95	2.35	0.11	0.33
	024							-1.23	31.568	1.02	13.50	1.99	0.12	0.20
	028							-1.23	31.563	1.02	12.34	1.91	0.10	0.34
13	000	1337	27 Apr	64°37.82'	168°25.67'	35	2	-1.49	32.191	1.90	37.39	14.09	0.23	1.04
	004							-1.57	32.189	1.94	38.45	14.09	0.17	1.08
	008							-1.58	32.191	1.92	38.81	14.31	0.16	0.94
	012							-1.60	32.195	1.92	38.93	14.22	0.20	0.98
	016							-1.60	32.192	1.60	37.04	13.50	0.19	1.66
	020							-1.61	32.193	1.60	38.81	14.53	0.18	1.40
	024							-1.63	32.196	1.90	38.69	14.00	0.20	0.94
	030							-1.63	32.200	1.83	37.98	13.79	0.23	0.94
14	000	0602	28 Apr	64°12.66'	168°57.44'	36	4	-1.69	32.371	2.05	43.88	17.25	0.20	0.80
	004							-1.73	32.376	2.06	43.83	17.25	0.16	0.71
	008							-1.75	32.368	2.09	44.97	17.25	0.11	1.08
	012							-1.76	32.368	2.06	45.24	17.25	0.12	1.03
	016							-1.74	32.377	2.05	45.38	17.36	0.12	0.88
	020							-1.77	32.406	2.00	45.94	17.30	0.12	1.01
	026							-1.77	32.433	2.10	46.22	17.36	0.12	1.15
	032							-1.78	32.499	2.10	47.36	17.70	0.14	1.07

Table 4. (continued)

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Sonic Depth (m)	Secchi Depth (m)	Temp (°C)	S°/₀₀	PO_4	SiO_4	NO_3	NO_2	NH_3
										(µg at ℓ)				
15	000	0611	29 Apr	63°50.91'	170°26.03'	34	3	-1.48	32.029	2.04	44.01	16.76	0.17	0.87
	004							-1.53	32.032	2.05	45.24	16.98	0.14	0.78
	008							-1.54	32.028	2.04	45.24	16.92	0.13	0.80
	012							-1.54	32.031	2.05	44.97	17.03	0.20	0.82
	016							-1.53	32.025	2.05	44.69	16.71	0.12	0.72
	020							-1.54	32.035	2.04	45.24	17.03	0.11	0.86
	024							-1.54	32.037	2.04	45.24	17.08	0.12	0.82
	030							-1.56	32.034	2.05	44.56	16.92	0.13	1.26
16	000	1307	29 Apr	64°00.6'	171°25.5"	32	4	-1.52	31.978	1.95	42.63	16.28	0.11	0.43
	004							-1.64	31.980	1.99	43.43	16.48	0.12	0.45
	008							-1.66	31.979	2.03	44.10	16.74	0.13	0.63
	012							-1.69	31.980	2.00	43.31	16.43	0.10	0.40
	016							-1.68	31.979	2.00	43.32	16.42	0.10	0.34
	020							-1.68	31.976	1.99	43.46	16.47	0.09	0.40
	024							-1.69	31.966	1.99	44.01	16.57	0.10	0.34
	028							-1.70	31.980	2.00	44.15	16.68	0.10	0.53
17	000	0600	30 Apr	63°44.83'	169°12.32'	36	5	-1.58	32.261	2.08	44.71	17.26	0.20	0.74
	002							-1.61	32.282	2.09	46.24	17.26	0.15	0.75
	006							-1.58	32.298	2.09	46.82	17.42	0.14	0.79
	010							-1.59	32.299	2.10	46.68	17.59	0.18	0.73
	014							-1.56	32.348	2.09	46.84	17.31	0.14	0.71
	018								32.316	2.08	46.99	17.53	0.14	0.85
	024							-1.63	32.346	2.12	47.72	17.81	0.15	0.91
	030							-1.68	32.434	2.13	48.61	18.22	0.16	0.94

Table 4. (continued)

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Sonic Depth (m)	Secchi Depth (m)	Temp (°C)	S°/₀₀	PO_4	SiO_4	NO_3 (µg at ℓ)	NO_2	NH_3
18	000	1343	30 Apr	63°17.83'	168°20.07'	42	4	-1.16	31.449	1.41	25.26	7.86	0.13	2.19
	004							-1.19	31.450	1.66	29.35	9.88	0.13	1.78
	008							-1.20	31.456	1.53	26.57	9.60	0.11	1.51
	012							-1.23	31.455	1.53	25.17	9.47	0.17	1.52
	018							-1.27	31.457	1.48	25.95	9.44	0.13	1.57
	024							-1.32	31.461	1.48	28.10	9.98	0.11	1.39
	030							-1.34	31.459	1.55	28.13	9.95	0.10	1.32
	036							-1.33	31.462	1.44	24.80	8.92	0.10	1.63
19	000	0552	2 May	57°06.89'	170°00.7'	46	3-4	2.68	32.583	1.77	48.02	22.01	0.24	0.80
	005							1.56	32.542	1.77	48.91	22.00	0.21	0.78
	010							2.67	32.540	1.78	49.22	22.24	0.21	0.86
	015							2.64	32.538	1.77	48.94	22.08	0.21	0.89
	020							2.67	32.664	1.77	48.95	22.32	0.21	0.96
	025							2.67	32.585	1.80	49.71	22.32	0.21	0.97
	030							2.66	32.583	1.80	50.02	22.49	0.23	1.07
	042							2.66	34.977	1.79	49.88	22.40	0.21	1.03
20	000	1255	2 May	56°27.50	169°25.06'	93	12	3.91	32.546	1.75	48.20	22.58	0.24	0.68
	010								32.514	1.79	50.00	22.74	0.24	0.73
	020							3.55	32.504	1.82	50.31	23.17	0.23	0.82
	030							3.49	32.485	1.80	50.94	23.16	0.24	0.69
	040							3.50	32.468	1.79	51.26	23.51	0.24	0.77
	050								32.444	1.79	51.27	23.60	0.25	0.83
	060							3.48	32.410	1.82	51.91	23.51	0.24	0.82
	080							3.48	32.379	1.78	49.92	22.74	0.24	0.88

Table 4. (continued)

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Sonic Depth (m)	Secchi Depth (m)	Temp (°C)	S°/₀₀	PO_4	SiO_4	NO_3	NO_2	NH_3
										(µg at ℓ)				
23	000	0657	3 May	54°34.07'	165°58.64'	437	∿ 7	4.49	32.808	0.87	14.75	9.04	0.14	1.00
	010							4.57	32.788	1.29	28.22	16.54	0.29	0.47
	020							4.57	32.785	1.29	28.15	16.76	0.27	0.54
	030							4.40	32.785	1.49	32.50	18.41	0.24	1.06
	045							4.40	32.800	1.51	34.62	18.77	0.25	1.07
	060							4.35	32.808	1.54	35.09	19.35	0.25	1.13
	075							4.32	32.829	1.52	35.46	19.35	0.25	1.13
	100							4.09	32.977	1.78	43.94	23.68	0.29	1.03
24	000	1423	3 May	54°58.7'	164°36.2'	55	∿ 7	4.81	32.240	1.27	32.54	14.32	0.23	0.79
	005							4.76	32.235	1.32	34.87	14.63	0.23	0.86
	010							4.74	32.239	1.30	35.12	14.73	0.21	0.87
	015							4.70	32.252	1.33	35.83	14.96	0.21	0.87
	020							4.72	32.303	1.38	36.90	16.49	0.22	1.11
	025							4.52	32.318	1.38	37.27	17.03	0.22	1.17
	035							4.44	32.380	1.47	37.89	17.87	0.23	1.55
	045							4.41	32.424	1.50	38.39	18.35	0.21	1.51
25	000	0658	4 May	54°10.36'	163°47.78'	86	8	4.72	31.704	0.78	26.29	5.32	0.21	1.37
	010							4.69	31.709	0.78	27.18	5.27	0.17	1.32
	020							4.70	31.718	0.80	27.20	5.29	0.15	1.66
	030							4.54	31.812	0.91	28.19	6.71	0.16	1.66
	040							4.53	31.875	1.06	28.81	10.47	0.16	2.11
	050							4.47	31.923	1.12	30.04	10.64	0.15	2.08
	060							4.21	31.974	1.29	32.35	13.25	0.19	2.13
	075							4.04	32.170	1.50	36.36	17.45	0.26	2.61

Table 4. (continued)

Sta	Depth (m)	Time (Local)	Date	Latitude (N)	Longitude (W)	Sonic Depth (m)	Secchi Depth (m)	Temp (°C)	S°/₀₀	PO_4	SiO_4 (µg at ℓ)	NO_3 (µg at ℓ)	NO_2 (µg at ℓ)	NH_3 (µg at ℓ)
26	000	1605	4 May	54°14.7'	161°52.5'	71	> 12	4.62	31.789	0.65	14.33	3.78	0.08	2.89
	005							4.60	31.798	1.04	25.85	6.61	0.12	2.21
	010							4.59	31.794	1.03	25.95	6.71	0.10	2.26
	020							4.47	31.805	1.03	25.97	6.59	0.10	2.22
	030								31.822	1.03	25.89	6.71	0.11	2.20
	040							4.15	31.953	1.20	29.75	10.99	0.14	2.16
	050							3.97	32.138	1.42	34.81	15.78	0.19	0.95
	060							4.03	32.250	1.45	36.17	16.65	0.20	0.84
27	000	1506	5 May	56°21.44'	155°30.78'	60	> 10	5.07	32.194	0.92	21.53	10.27	0.17	0.43
	005							5.00	32.192	0.93	22.39	10.44	0.23	0.50
	010							4.77	32.192	0.94	22.58	10.44	0.15	0.67
	015							4.55	32.205	0.98	22.76	11.33	0.15	1.03
	020							4.53	32.194	0.93	22.00	11.16	0.14	0.82
	030							4.47	32.199	1.05	23.68	12.01	0.14	1.63
	040							4.49	32.230	1.13	25.38	12.47	0.15	1.97
	050							4.64	32.323	1.21	27.33	13.28	0.15	2.39
28	000	0659	6 May	59°07.07'	152°54.38'	81	> 10	5.12	32.099	0.82	19.80	9.24	0.16	0.44
	010							4.98	32.044	0.89	20.62	9.90	0.19	0.66
	020							4.89	32.100	0.96	21.87	10.83	0.15	0.76
	030							4.71	32.144	1.07	23.95	12.32	0.16	1.16
	040							4.72		1.08	24.48	12.52	0.15	1.21
	050							4.70	32.142	1.12	24.93	12.72	0.15	1.30
	060							4.69	32.136	1.12	24.93	12.73	0.15	1.28
	070							4.68	32.138	1.13	24.38	12.90	0.15	1.29

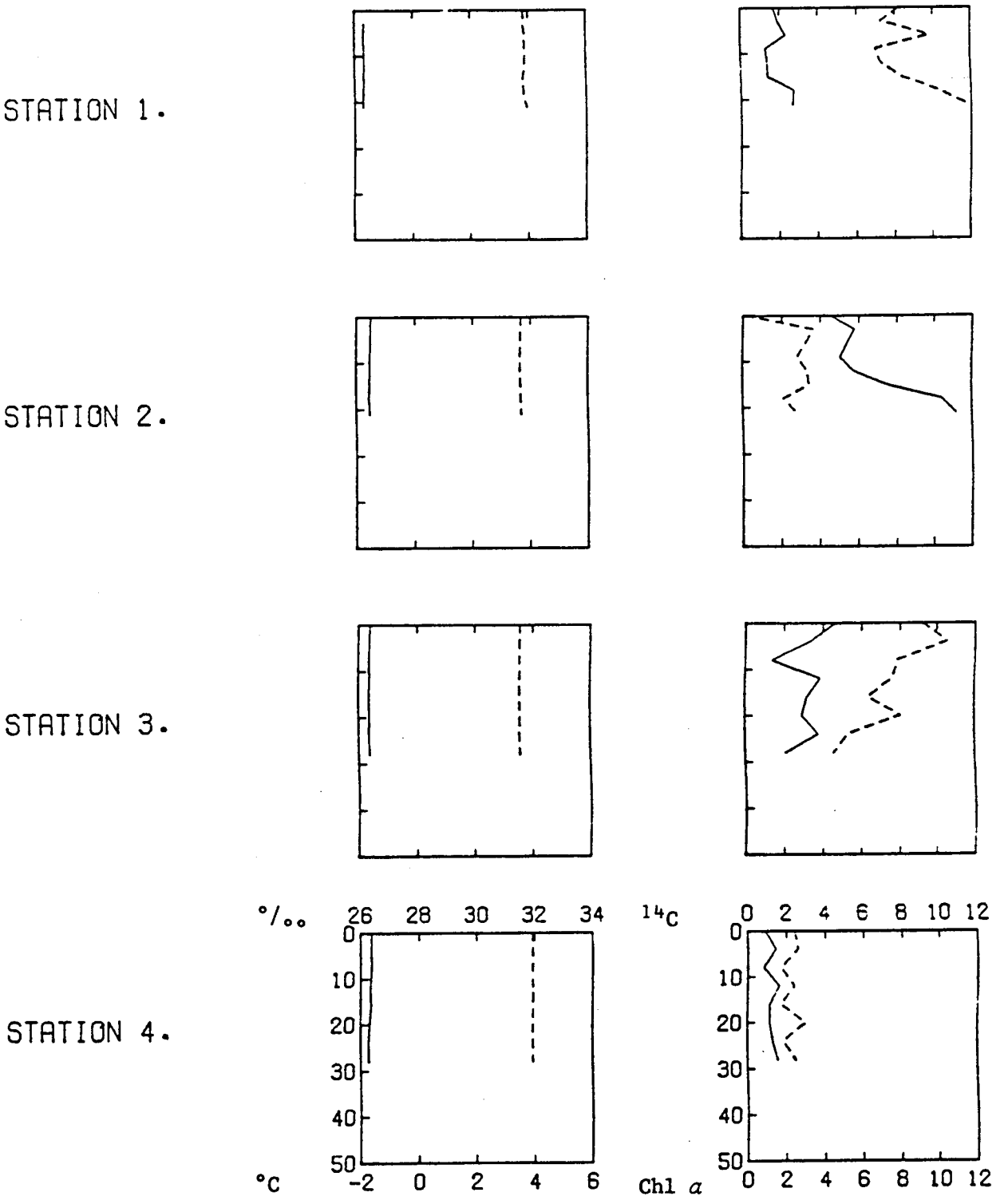


Fig. 2. Depth profiles of temperature-salinity and chlorophyll *a*-primary productivity in the Bering Sea and Shelikof Strait, 17 Apr-6 May 1979. Salinity (°/₀₀) ---; temperature (°C) ___; primary productivity (mg C m^{-3} hr^{-1}) ---; chlorophyll *a* (mg m^{-3}) ___.

STATION 5.

STATION 6.

STATION 9.

STATION10.

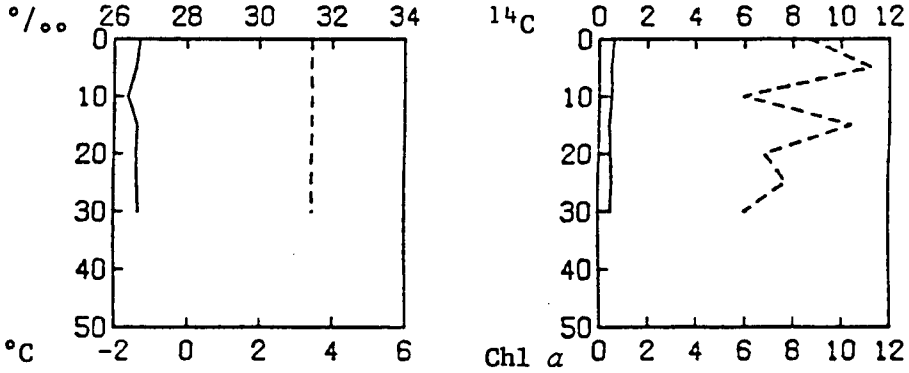


Fig. 2. (continued)

STATION11.

STATION12.

STATION13.

STATION14.

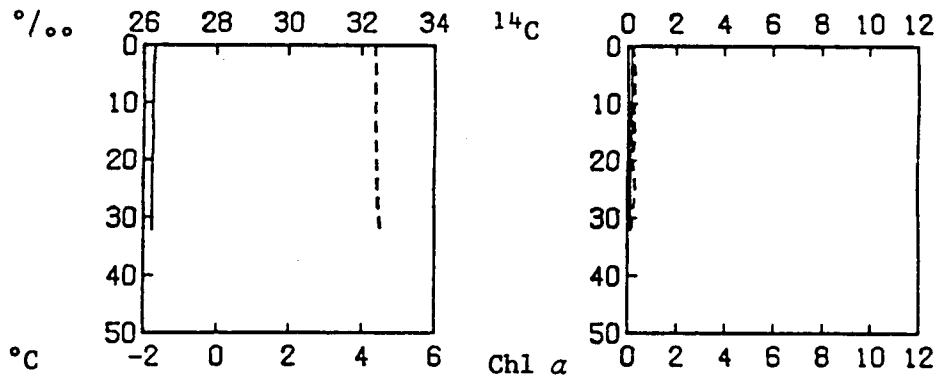


Fig. 2 (continued)

STATION15.

STATION16.

STATION17.

STATION18.

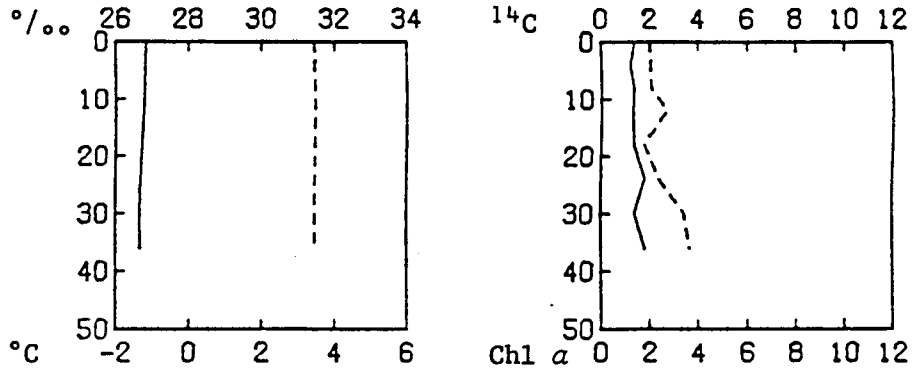


Fig. 2. (continued)

STATION19.

STATION20.

STATION23.

STATION24.

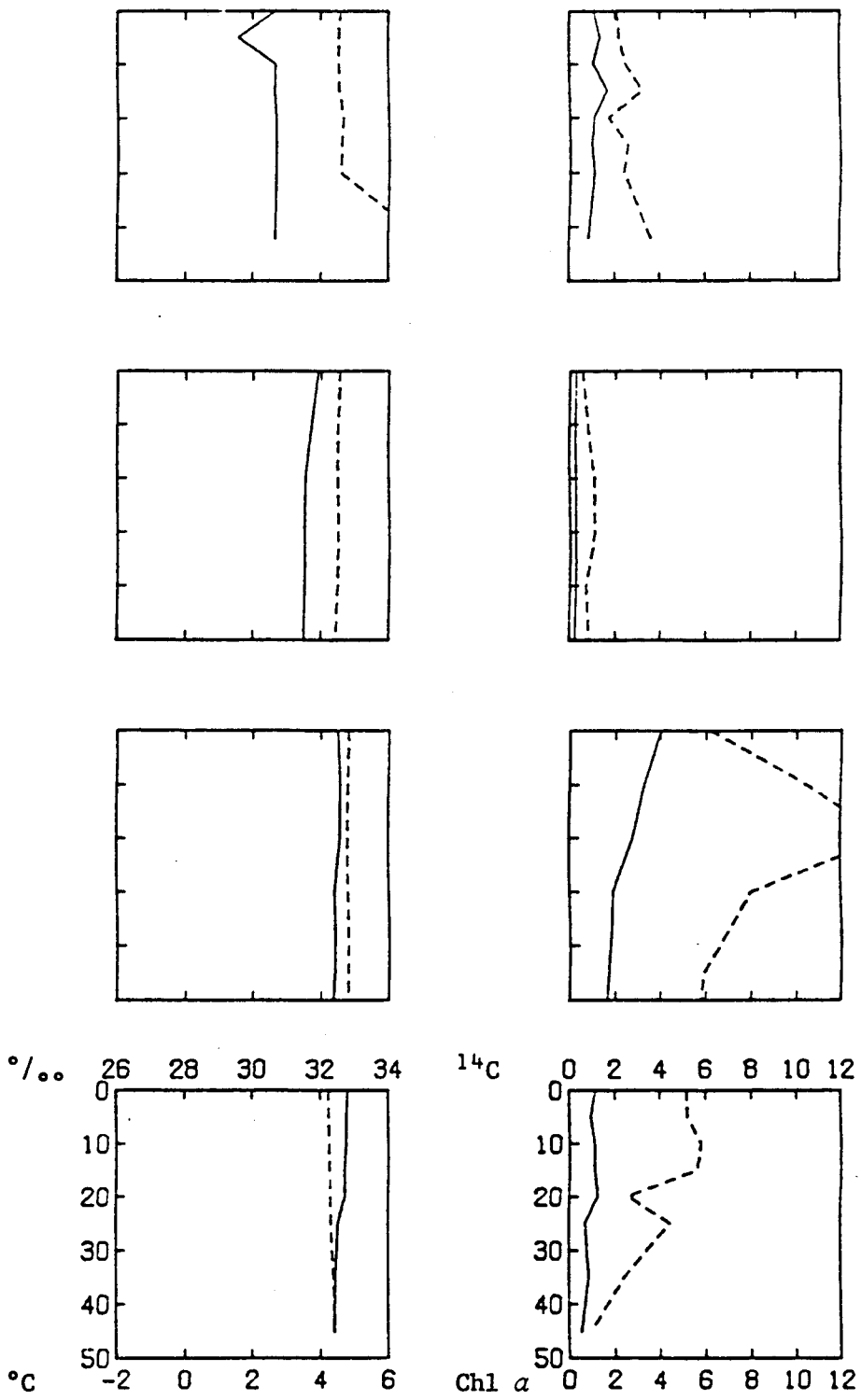
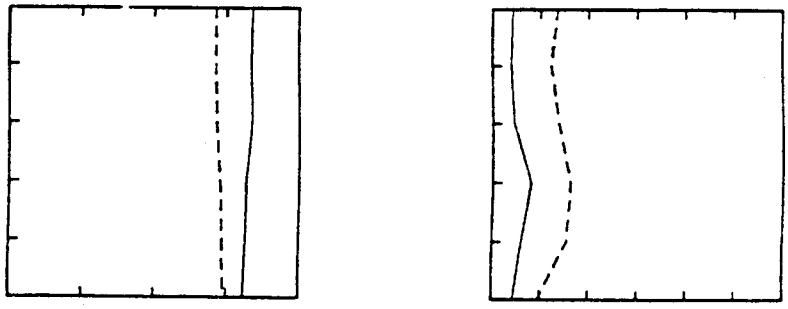
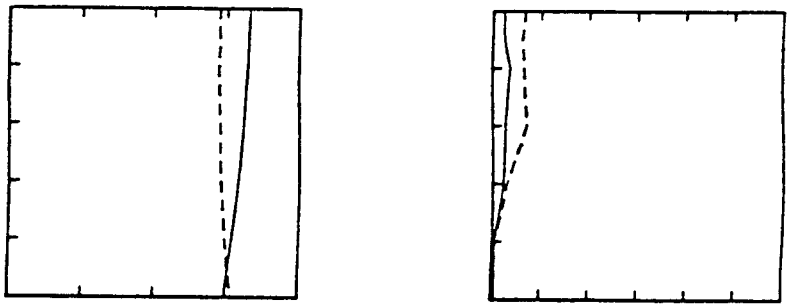


Fig. 2. (continued)

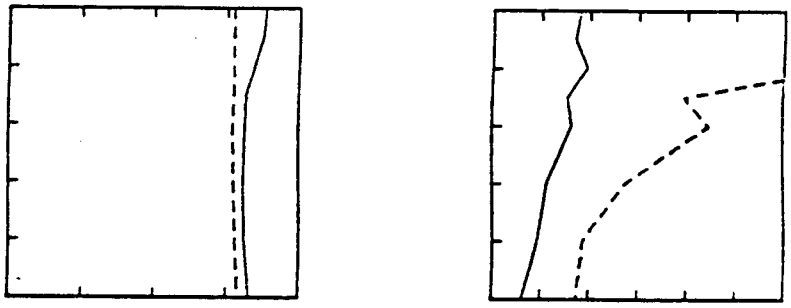
STATION25.



STATION26.



STATION27.



STATION28.

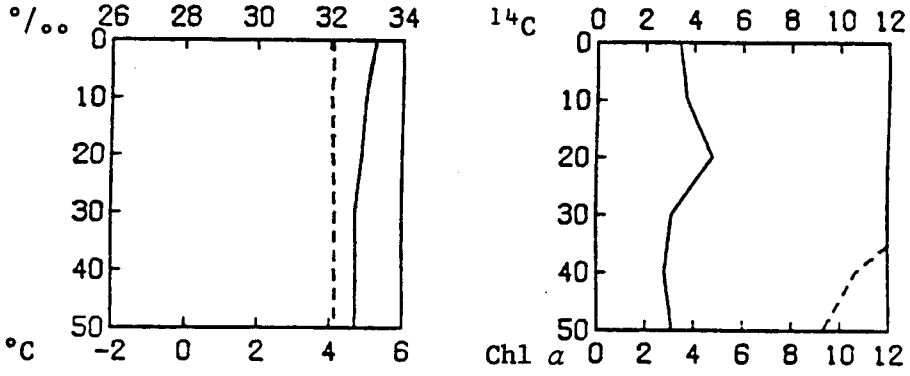


Fig. 2. (continued)

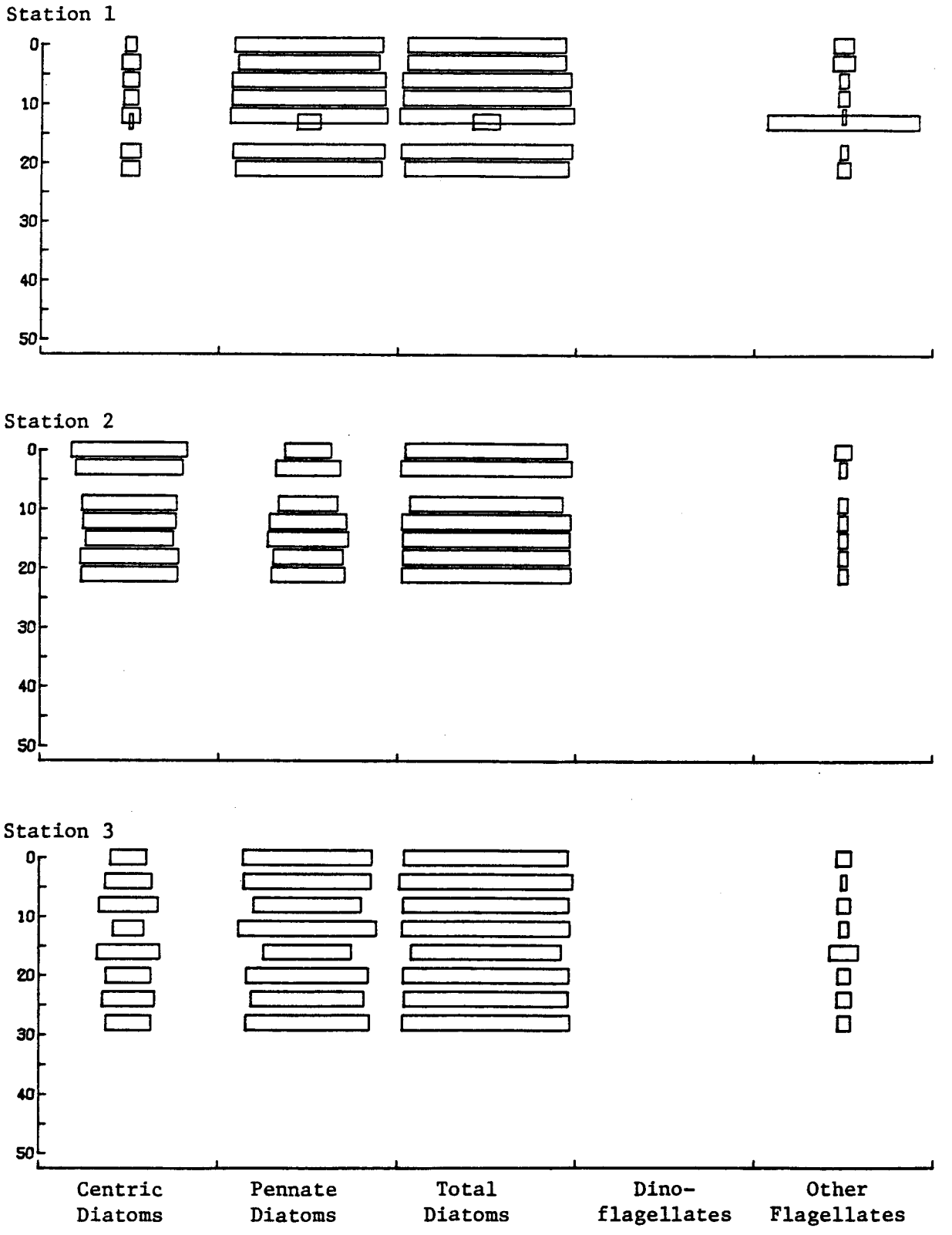


Fig. 3. Kite diagrams showing depth distribution of major categories of phytoplankton in the Bering Sea, 17 April-6 May 1979.

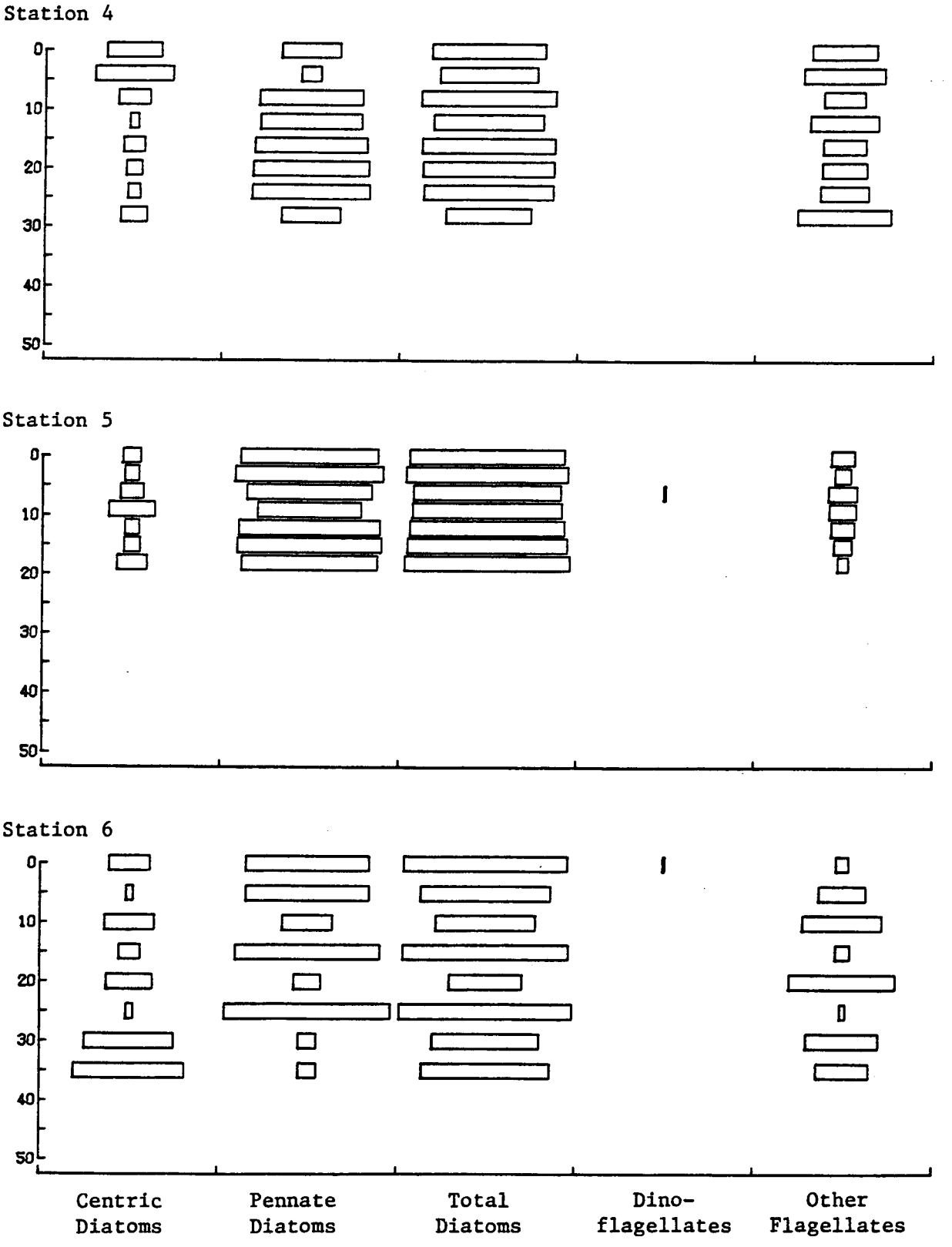

Station 4
0
10
20
30
40
50
Station 5
0
10
20
30
40
50
Station 6
0
10
20
30
40
50
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 3. (cont.)

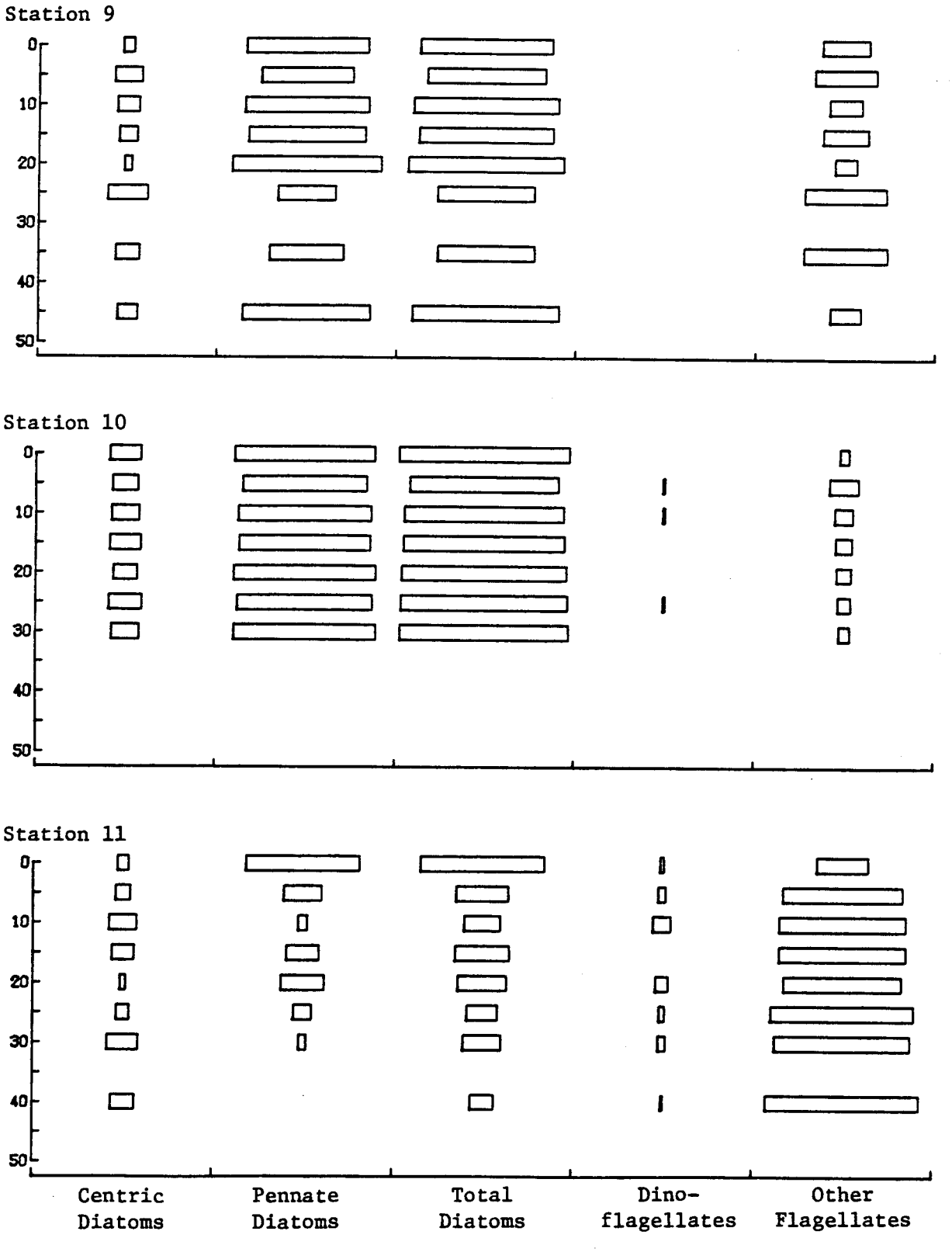

Station 9
0
10
20
30
40
50
Station 10
0
10
20
30
40
50
Station 11
0
10
20
30
40
50
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 3. (cont.)

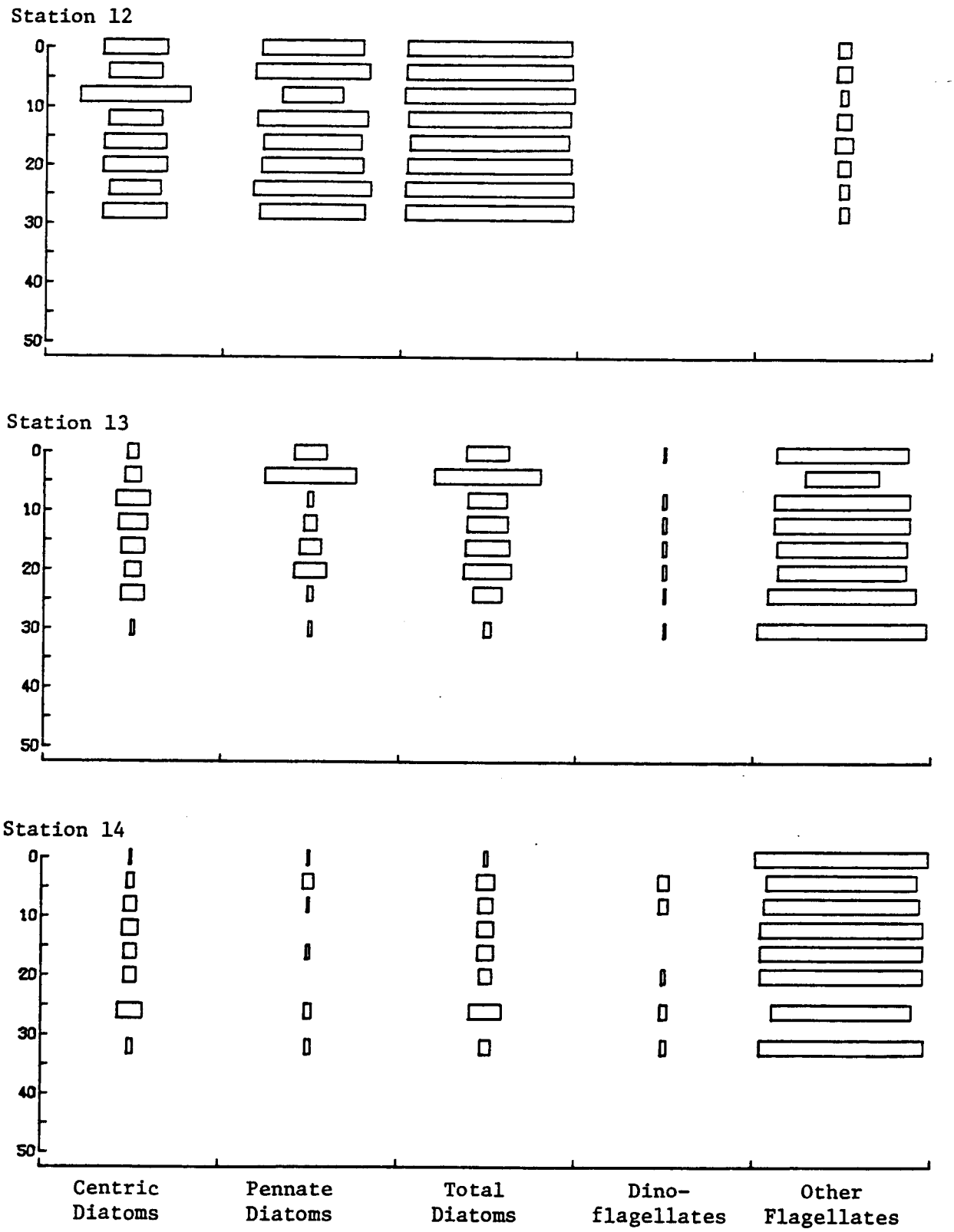

Station 12
0
10
20
30
40
50
Station 13
0
10
20
30
40
50
Station 14
0
10
20
30
40
50
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 3. (cont.)

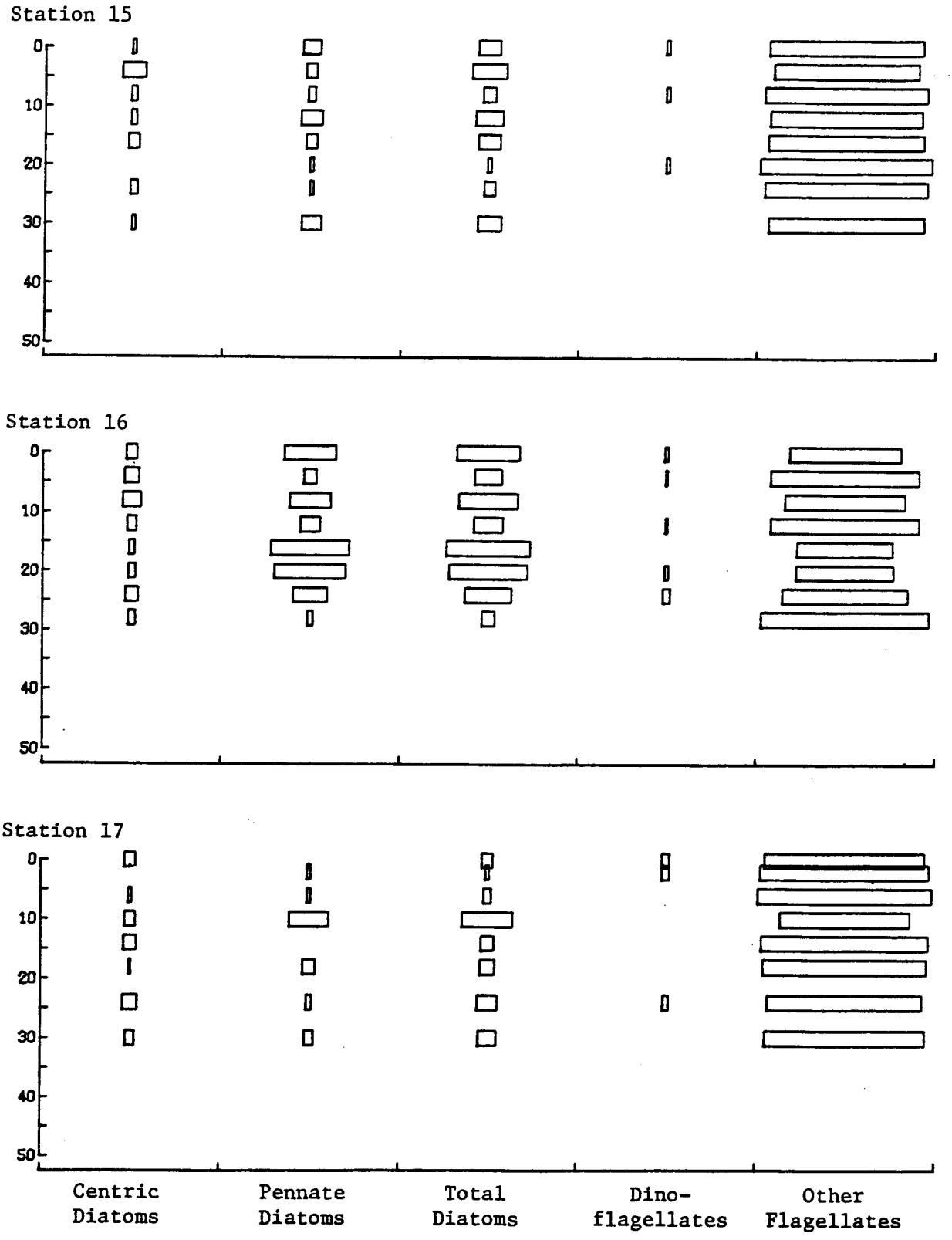

Station 15
0
10
20
30
40
50
Station 16
0
10
20
30
40
50
Station 17
0
10
20
30
40
50
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 3. (cont.)

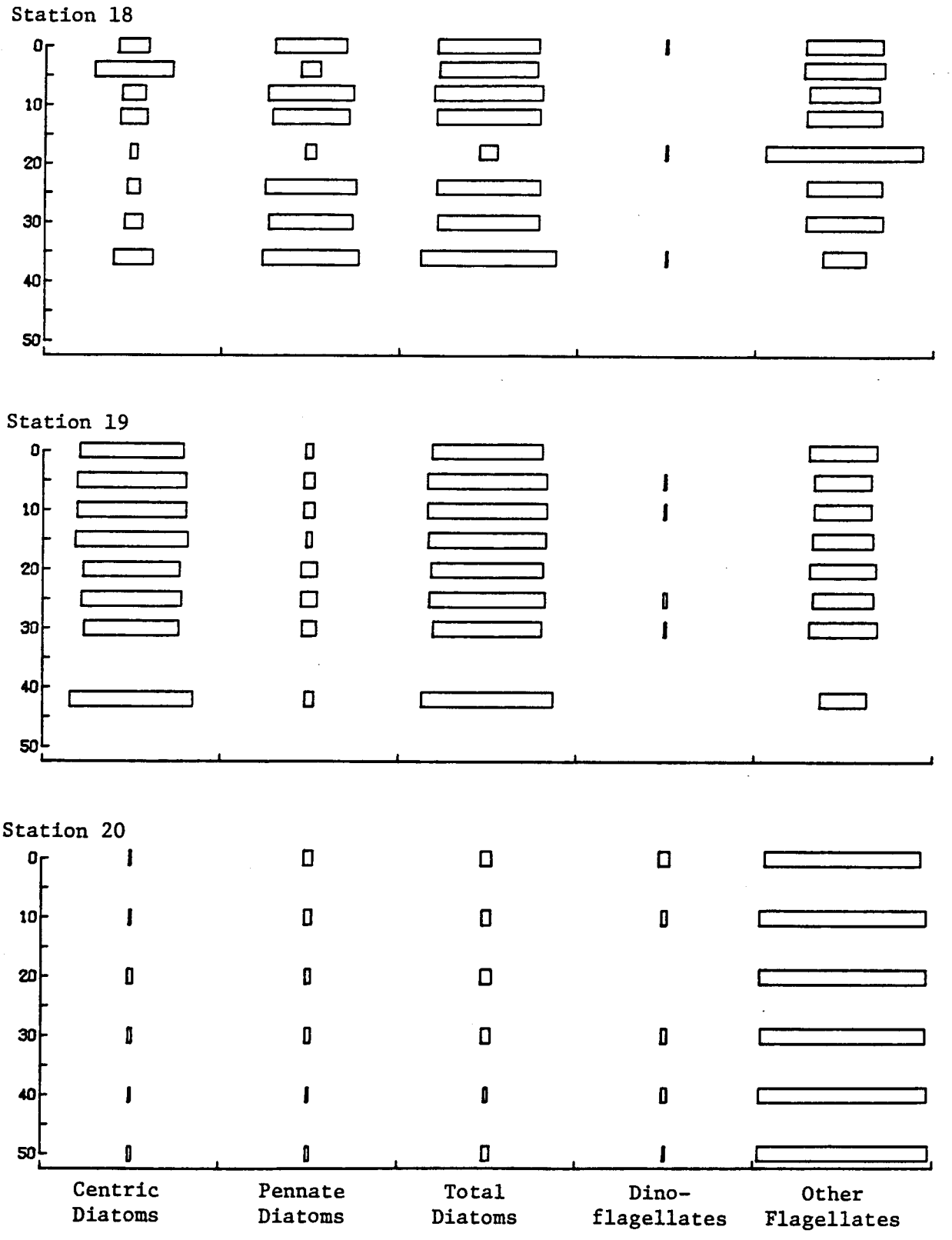

Station 18
0
10
20
30
40
50
Station 19
0
10
20
30
40
50
Station 20
0
10
20
30
40
50
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 3. (cont.)

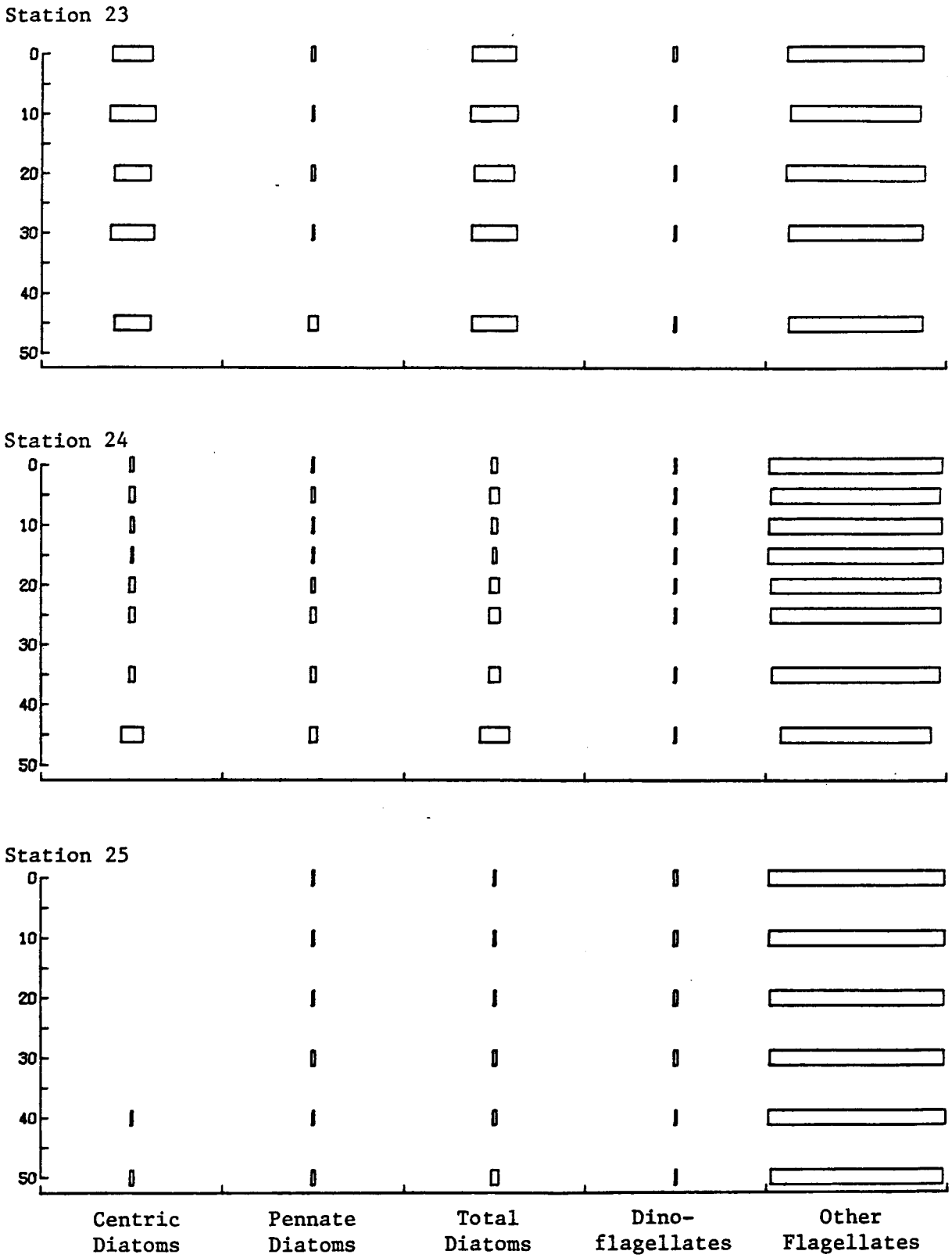

Station 23
0
10
20
30
40
50
Station 24
0
10
20
30
40
50
Station 25
0
10
20
30
40
50
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 3. (cont.)

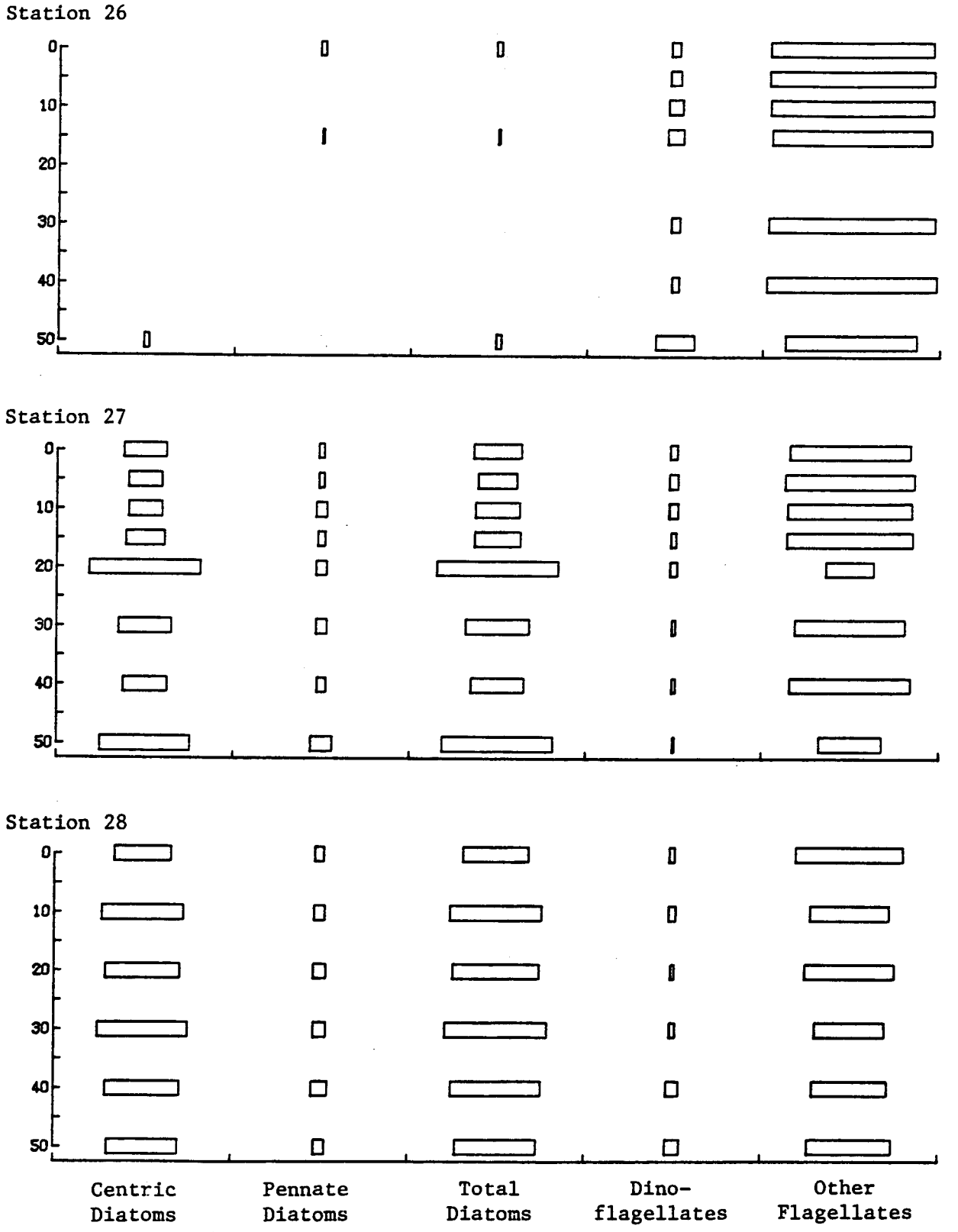

Station 26
0
10
20
30
40
50
Station 27
0
10
20
30
40
50
Station 28
0
10
20
30
40
50
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 3. (cont.)

Table 5. Integrated chlorophyll *a* and primary productivity in the Bering Sea, CGC *Polar Sea*, 17 Apr - 6 May 1979.

Sta	Chl *a* (mg m^{-2})	Prim Prod (mg C m^{-2} hr^{-1})
1	39.36	179.86
2	143.34	60.39
3	85.65	211.91
4	34.74	63.26
5	34.53	87.86
6	18.68	36.38
9	43.50	57.30
10	15.20	247.50
11	14.98	19.83
12	239.20	397.58
13	20.35	37.65
14	5.14	9.09
15	4.83	10.73
16	9.90	20.44
17	4.09	6.25
18	52.20	90.27
19	46.90	107.18
20	21.05	69.40
23	193.63	748.90
24	41.38	171.02
25	66.30	158.23
26	22.30	42.87
27	133.00	406.30
28	228.00	961.15

Table 6. List of phytoplankton species found in the Bering Sea, spring 1979 and 1980. Not all species were found both years or in all areas.

Bacillariophyceae
Centrales
Actinoptychus sp.
Bacterosira fragilis Gran
Biddulphia aurita (Lyngb.) Bréb. & God.
Chaetoceros atlanticus Cleve
Chaetoceros cinctus Gran
Chaetoceros compressus Laud.
Chaetoceros concavicornis Mang.
Chaetoceros convolutus Castr.
Chaetoceros debilis Cleve
Chaetoceros decipiens Cleve
Chaetoceros furcellatus Bail.
Chaetoceros gracilis Schütt
Chaetoceros septentrionalis Østr.
Chaetoceros similis Cleve
Chaetoceros socialis Laud.
Chaetoceros subsecundus (Grun.) Hust.
Chaetoceros spp.
Corethron criophilum Castr.
Coscinodiscus curvatulus Grun.
Coscinodiscus oculus-iridis Ehrenb.
Coscinodiscus radiatus Ehrenb.
Coscinodiscus spp.
Ditylum brightwelli (West) Grun.
Eucampia zoodiacus Ehrenb.
Lauderia borealis Gran
Leptocylindrus danicus Cleve
Melosira sol (Ehrenb.) Kütz.
Melosira sulcata Rabh.
Melosira spp.
Porosira glacialis (Grun.) Jørg.
Rhizosolenia hebetata (Bail.) Gran
Rhizosolenia styliformis Brightw.
Rhizosolenia spp.
Skeletonema costatum (Grev.) Cleve
Thalassiosira antarctica Comber
Thalassiosira decipiens (Grun.) Jørg.
Thalassiosira gravida Cleve
Thalassiosira hyalina (Grun.) Gran
Thalassiosira lacustris (Grun.) Hasle
Thalassiosira nordenskioeldii Cleve
Thalassiosira polychorda (Gran) Jørg.
Thalassiosira spp.

Pennales
Achnanthes taeniata Grun.
Achnanthes spp.

Table 6. (cont.)

Amphiprora spp.
Asterionella kariana Grun.
Cylindrotheca closterium (Ehrenb.) Reimann & Lewin
Gomphonema spp.
Gyro-Pleurosigma spp.
Navicula directa (W. Sm.) Ralfs
Navicula distans (W. Sm.) Ralfs
Navicula pelagica Cleve
Navicula spicula (Hickie) Cleve
Navicula transitans Cleve
Navicula spp.
Nitzschia cylindrus (Grun.) Hasle
Nitzschia delicatissima Cleve
Nitzschia frigida Grun.
Nitzschia grunowii Hasle
Nitzschia seriata Cleve
Nitzschia spp., Section *Fragilariopsis*
Nitzschia spp.
Stauroneis quadripedis (Cleve-Euler) Hendey
Synedra spp.
Thalassionema nitzschioides Grun.

Pyrrophyta
Actiniscus pentasterias (Ehrenb.) Ehrenb.
Amphidinium spp.
Ceratium lineatum (Ehrenb.) Cleve
Ceratium spp.
Cladopyxis sp.
Dinophysis norvegica Clap. & Lachm.
Dinophysis spp.
Gymnodinium lohmanni Paulsen
Gymnodinium spp.
Protoperidinium belgicum (Wulff) Balech
Protoperidinium bipes (Pauls.) Balech
Protoperidinium brevipes (Pauls.) Balech
Protoperidinium conicum (Gran) Balech
Protoperidinium depressum (Bail.) Balech
Protoperidinium grenlandicum (Wolosz.) Balech
Protoperidinium pallidum (Ostenf.) Balech
Protoperidinium spp.
Prorocentrum baltica (Lohm.) Loeblich III
Scrippsiella trochoidea (Stein) Loeblich III

Chrysophyceae
Calycomonas gracilis Lohm.
Calycomonas ovalis Wulff
Dinobryon balticum (Schütt) Lemm.
Dinobryon petiolatum Willén
Pelagococcus subviridis Norris

Table 6. (cont.)

Euglenophyceae
Unidentified spp.

Cryptophyceae
Unidentified spp.

Craspedomonadales
Parvicorbicula socialis (Meun.) Defl.
Unidentified spp.

Dictyochales
Distephanus speculum (Ehrenb.) Haeckel

mg C m^{-2} hr^{-1} at station 12 just south of the ice edge. No ice was present at either station. Station 10, located off Cape Prince of Wales in 7-8 oktas of ice had integrated productivity of 248 mg C m^{-2} hr^{-1}. Nutrient concentrations at station 17 were high with phosphate *ca.* 2 µg-at ℓ^{-1} and nitrate slightly more than 17 µg-at ℓ^{-1} (Table 4). Chlorophyll *a* concentrations were low, only about 0.15 mg m^{-3} at all depths. Phytoplankton standing stock was low, generally being < 1 x 10^5 cells ℓ^{-1} and with small flagellates comprising > 80% of the population. At station 12, phosphate concentration was *ca.* 1 µg-at ℓ^{-1} and nitrate was *ca.* 2 µg-at ℓ^{-1}. Chlorophyll *a* concentrations were high, ranging from 3.5 mg m^{-3} at 16 m to 12.0 mg m^{-3} at 12 m. Phytoplankton standing stock was high with more than 1 x 10^6 cells ℓ^{-1} at all depths. Diatoms comprised *ca.* 90% of the population at all depths.

Nutrient concentrations at station 10 were relatively low with phosphate < 1.0 µg-at ℓ^{-1} and nitrate < 1.4 µg-at ℓ^{-1} suggesting nutrient utilization. Phytoplankton standing stock was also high at station 10 with more than 1 x 10^6 cells ℓ^{-1} at nearly all depths. Diatoms were the most abundant organisms being *ca.* 85% of the population at all depths.

Station 2 just south of the ice edge had only moderate integrated productivity, *ca.* 60 mg C m^{-2} hr^{-1}, but had high chlorophyll *a* concentration at 143 mg m^{-2}, and the highest cell counts of all the northern stations, up to 3.9 x 10^6 cells ℓ^{-1} at 3 m. Diatoms comprised more than 90% of the population at all depths.

At stations south of the Pribilof Islands and in Shelikof Strait, integrated productivity ranged from *ca.* 43 mg C m^{-2} hr^{-1} at station 26 south of Unimak Island to 961 mg C m^{-2} hr^{-1} at station 28 in the north end of Shelikof Strait. Chlorophyll *a* concentration was also low at station 26, 22 mg m^{-2}, and high at station 28, 228 mg m^{-2}.

For the two stations close to the Pribilofs, the number of cells per liter was somewhat higher at station 19 being near 4 x 10^5, with about 60% of the cells being diatoms, while at station 20, the number of cells per liter was generally between 2 x 10^5 and 3 x 10^5, with 85-95% of the cells small flagellates that may or may not have been photosynthetic. Primary productivity and chlorophyll *a* values reflect the cell composition with moderate productivity, 107 mg C m^{-2} hr^{-1}, at station 19, and low productivity, 69 mg C m^{-2} hr^{-1}, at station 20. Chlorophyll *a* was 47 mg m^{-2} at station 19 and 21 mg m^{-2} at station 20.

Of the four stations close to Unimak Island, stations 23, 24, and 25 had high phytoplankton standing stocks, from 1-3 x 10^6 cells ℓ^{-1}, but 70-95% of the cells were small flagellates. Station 23 had high integrated productivity at 749 mg C m^{-2} hr^{-1}, while stations 24 and 25 were considerably lower at 171 and 158 mg C m^{-2} hr^{-1}. Integrated chlorophyll *a* for these stations was 194 mg m^{-2} at station 23, 41 mg m^{-2} at station 24, and 66 mg m^{-2} at station 25. Station 26 had much lower standing stock with 0.1-0.8 x 10^6 cells ℓ^{-1} and 80-95% of the cells were small flagellates. Primary productivity at this station was 43 mg C m^{-2} hr^{-1} and chlorophyll *a* was 22 mg m^{-2}.

The two stations in Shelikof Strait had productivities of 406 and 961

mg C m^{-2} hr^{-1} and chlorophyll *a* concentrations of 133 and 228 mg m^{-2}. At station 27, cell numbers were near 1 x 10^6 cells ℓ^{-1} in the upper 15 m with about 70% small flagellates. Below 15 m, cell numbers dropped about 50% and the number of small flagellates was 30-70%. Cell numbers at station 28 ranged from about 0.5 x 10^6 to 1.4 x 10^6 with the highest numbers occurring in the upper 20 m; 40-60% of the cells were small flagellates.

Dominant species throughout the area were similar. Among the diatoms, species of *Chaetoceros, Nitzschia,* and *Thalassiosira* were common. In the Norton Basin, *Asterionella kariana, Porosira glacialis,* and *Melosira sulcata* were often present, but usually not in large numbers. Unidentified pennate diatoms were present, but also not in large numbers. Among the dinoflagellates, *Gymnodinium lohmanni* was probably the most abundant of the large identifiable species. Other species of *Gymnodinium* were present, along with species of *Peridinium* and *Amphidinium*. Athecate, small dinoflagellates were common, but could not be identified. Unidentifiable small flagellates, < 10 μm in diameter, were common at all stations and were often the dominant group of organisms. It is not known if these organisms were photosynthetic.

At stations north of St. Lawrence Island where diatoms were abundant, pennate diatoms were usually more numerous than centric diatoms, station 2 being the exception. At stations 12-17, small flagellates were the most abundant organisms, while at station 18 diatoms and flagellates were present in more or less equal numbers. Stations 19 and 20 near the Pribilof Islands had quite different species compositions with diatoms, primarily centric species, the most abundant organisms at station 19 and small flagellates dominating at station 20. Flagellates were most abundant at the four stations near Unimak Island. Dinoflagellates were more abundant at station 26 than at any other station during the cruise. Diatoms, primarily centric species, and small flagellates were about equally numerous at the two stations in Shelikof Strait.

Temperature, salinity, plant pigment concentrations, primary productivity, nutrient concentrations, and ice cover in 1980 are given in Tables 7-8; vertical profiles of temperature-salinity and carbon-chlorophyll *a* are shown in Fig. 4. Kite diagrams of phytoplankton abundance are shown in Fig. 5. Integrated carbon uptake and chlorophyll *a* concentrations are given in Table 9.

Four separate areas of the Bering Sea were sampled in 1980: Navarin Basin, St. Matthew-Hall, Norton Basin, and St. George Basin. These will be discussed separately. There will be some discrepancy with regard to station numbers in the Norton Basin because grab samples only were collected at some stations for the National Marine Fisheries Service Marine Mammal Division and all stations including the grabs only ones were numbered consecutively, so it might appear that we are reporting only selected stations.

Stations 1-25 were taken in the Navarin Basin from 59°31'N to 62°00'N and from 173°45'W to 178°39'W (Fig. 1). Ice cover was heavy in the southern and western parts of the area in early May when the cruise started necessitating an early change in our sampling program because of the difficulties in sampling in nearly solid ice and mechanical problems with the ship that occurred before we boarded.

Table 7. Summary of station locations, ice conditions, Secchi disc depths, temperature, salinity, plant pigment concentrations, and primary productivity in the Bering Sea, CGC *Polar Star*, 4 May - 24 June 1980.

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo (mg m^{-3})	Prim Prod (mg m^{-3} hr^{-1})
1	4 May	0817	59°31.1'	176°06.2'	6-7			000	-1.71	31.72	2.20	0.31	35.27
								010	-1.65	31.70	1.44	0.24	19.22
								020	-1.63	31.67	5.66	1.30	16.71
								030	0.06	32.46	0.99	0.47	0.93
								045	-0.61	32.70	0.20	0.23	0.51
								060	*	32.78	0.29	0.20	0.19
								075			Bottle didn't trip		
								130			Bottle didn't trip		
2	5 May	1540	59°44.9'	177°44.7'	6-7	4	157	000	-1.76	31.89	2.47	0.54	15.88
								010	-1.71	31.89	2.78	0.59	14.02
								020	-1.45	31.90	2.53	0.60	18.42
								030	-1.69	32.65	4.93	0.84	26.92
								045	-0.64	31.91	0.87	0.37	0.66
								060			Bottle didn't trip		
								075			Bottle didn't trip		
								145			Bottle didn't trip		
3	6 May	0107	59°50.8'	177°29.2'	7	6	135	000	-1.74	31.87	1.80	0.32	26.39
								010	-1.56	31.87	4.95	0.56	16.36
								020	-1.66	31.88	3.32	0.62	14.78
								030	-1.54	31.89	2.09	1.02	21.96
								045	-1.45	32.58	1.82	0.32	2.11
								060		33.03	0.31	0.20	0.06
								075	-1.67	33.02	0.10	0.11	0.02
								125	-1.60	33.03	0.21	0.15	0.04

* Where there is no temperature, both thermometers on the bottle malfunctioned
† Indicates dark bottle value greater than light bottle uptake value

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo (mg m^{-3})	Prim Prod (mg m^{-3} hr^{-1})
4	6 May	1557	60°27.0'	178°16.4'	7	16	165	000	-1.76	32.15	0.29	0.10	3.42
								010	-1.67	32.15	1.14	0.43	4.41
								020	-1.69	32.13	1.71	0.25	1.93
								030	-1.68	32.15	1.02	0.17	2.21
								045	-0.98	32.36	1.27	0.38	2.29
								060		33.01	0.17	0.12	0.14
								075	1.10	33.08	0.11	0.11	0.09
								145	1.72	33.13	0.06	0.11	0.05
5	7 May	0232	60°38.21'	178°38.67'	7	14	194	000	-1.71	32.24	2.75		3.77
								010	-1.62	32.24	1.65	0.36	5.23
								020	-1.65	32.26	1.50	0.68	2.69
								030	-1.66	32.25	2.20	0.31	1.96
								045	-1.56	32.30	2.07	0.19	2.55
								060		33.06	0.23	0.11	0.14
								075	2.14	33.12	0.08	0.10	0.05
								100	1.69	33.13	0.32	0.07	†
6	7 May	1628	60°48.4'	178°24.63'	8	14	168	000	-1.69	32.20	1.64	0.48	3.84
								010	-1.69	32.24	1.64	0.13	3.75
								020	-1.68	32.24	2.18	0.15	3.60
								030	-1.68	32.17	2.10	0.22	3.78
								045	0.41	32.83	0.51	0.20	0.51
								060	0.65	33.10	0.13	0.12	0.23
								075	1.73	33.16	0.05	0.10	†
								145			Bottle didn't trip		
7	8 May	1643	60°43.8'	177°37.6'	7	6	145	000	-1.33	31.98	7.64	1.13	14.91
								010	-1.66	31.93	9.56	1.26	19.12
								020	-1.70	31.96	8.52	0.99	18.15
								030	-1.68	31.96	8.74	0.52	12.93

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo (mg m^{-3})	Prim Prod (mg m^{-3} hr^{-1})
								045	-1.70	32.07	3.74	0.89	9.16
								060	-2.06	32.92	0.85	0.24	2.10
								075	0.94	33.06	0.15	0.21	0.13
								125			Bottle didn't trip		
8	9 May	0127	60°25.62'	177°15.72'	6-7	6	150	000	-1.63	31.85	8.33	1.48	29.75
								010	-1.90	31.84	14.26	3.34	31.13
								020	-2.22	31.85	12.11	2.47	23.32
								030	-1.68	31.87	16.91	2.13	18.94
								045	-1.53	31.99	1.79	0.67	14.49
								060	-0.18	32.88	0.34	0.26	0.33
								075	0.91	32.93	0.17	0.17	0.29
								125			Bottle didn't trip		
9	9 May	1535	59°47.9'	176°12.3'	4	6	143	000	-1.63	31.66	20.66	2.58	9.83
								010	-2.53	31.62	9.36	1.11	12.05
								020	-1.62	31.69	6.93	1.55	16.84
								030	-1.68	31.78	8.48	1.19	7.57
								045	0.20	32.48	1.39	0.39	1.64
								060	-0.10	32.75	0.38	0.26	0.02
								115	0.96	32.96	0.13	0.18	0.02
								125	1.36	32.96	0.10	0.19	0.06
10	10 May	0128	60°04.40'	176°54.27'	0	6	137	000	-1.68	31.55	15.64	2.20	23.83
								010	-1.38	31.54	15.85	1.77	21.76
								020	-1.46	31.58	12.32	1.31	20.03
								030	-1.64	31.67	6.04	1.97	16.63
								045	0.40	32.61	0.95	0.58	17.62
								060	0.68	32.70	0.74	0.40	18.20
								075	1.02	32.82	0.34	0.34	23.39
								125	1.36	32.94	0.21	0.25	7.38

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo	Prim Prod (mg m^{-3} hr^{-1})
11	10 May	1541	59°44.7'	175°00.4'	1	5	119	000	-1.48	31.53	14.99	0.57	3.92
								010	-1.43	31.53	7.03	0.48	0.37
								020	-1.46	31.58	14.03	0.93	0.14
								030	-1.55	31.68	7.98	0.66	29.15
								045	0.97	32.61	17.13	0.84	19.40
								060	1.40	32.76	0.50	0.12	19.48
								075	1.38	32.79	0.52	0.37	15.89
								100	1.34	32.77	0.44	0.29	11.80
12	10 May	2310	59°59.3'	174°12.42'	0	6	102	000	-1.51	31.66	5.28	1.12	1.28
								010	-1.50	31.69	6.43	0.25	0.17
								020	-1.56	31.72	8.68	0.99	†
								030	-1.66	31.90	2.46	0.16	11.20
								045	-1.67	31.91	1.94	0.16	12.77
								060	-1.66	31.94	2.61	0.18	23.61
								075	0.22	32.29	0.51	0.16	22.33
								095	0.24	32.31	0.47	0.15	6.57
13	11 May	1528	60°15.20'	173°45.24'	0	5	82	000	-1.52	31.63	4.75	0.65	0.48
								005	-1.47	31.63	9.15	1.10	0.42
								010	-1.47	31.64	7.14	0.49	0.09
								020	-1.51	31.99	1.84	0.33	24.42
								030	-1.60	32.01	0.86	0.15	25.84
								045	-1.58	32.07	1.19	0.27	22.26
								060	-1.36	32.11	0.61	0.19	24.54
								075	-1.38	32.11	0.58	0.23	4.98
14	12 May	0013	60°42.67'	174°04.66'	7	5	88	000	-1.33	31.80	4.27	0.63	0.52
								005	-1.18	31.80	5.41	0.83	10.16
								010	-1.28	31.83	4.34	0.54	0.97
								020	-1.16	31.92	3.32	0.51	0.75

Table 7. (cont.)

Sta	Date	Time (GMT)	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo	Prim Prod (mg m^{-3} hr^{-1})
								030	-1.29	31.93	3.52	0.33	0.22
								045	-1.57	32.06	1.97	0.83	0.12
								060	-0.62	32.29	0.56	0.17	16.76
								075	-0.21	32.34	0.47	0.16	18.64
15	12 May	1530	60°31.11'	174°46.84'	0	5	101	000	-1.34	31.80	4.66	0.83	9.27
								010	-1.30	31.91	2.75	0.62	10.77
								020	-1.30	31.91	4.71	0.74	15.57
								030	-1.43	31.92	6.27	0.68	0.89
								045	-1.68	31.97	4.35	0.60	0.74
								060	-0.56	32.25	1.77	0.35	0.42
								075	0.56	32.49	0.27	0.18	18.79
								095	0.73	32.54	0.21	0.17	10.81
16	12 May	2357	60°13.53'	175°29.56'	0	6	115	000	-1.29	31.64	3.18	0.41	13.98
								010	-1.25	31.63	3.47	1.05	3.84
								020	-1.24	31.64	15.67	1.61	7.07
								030	-1.38	31.73	10.67	0.67	3.70
								045	-0.29	32.29	7.45	0.68	0.38
								060	1.06	32.64	0.86	0.18	0.52
								075	1.15	32.74	0.17	0.18	33.58
								100	1.16	32.80	0.85	0.27	27.40
17	13 May	1555	60°55'	176°16'	0	7	117	000	-1.45	31.92	5.46	0.22	17.04
								010	-1.58	31.91	4.51	0.68	3.42
								020	-1.58	31.92	5.83	0.39	1.11
								030	-1.62	31.97	3.79	0.42	0.77
								045	-1.69	32.15	3.23	0.21	0.70
								060	-1.65	32.18	0.63	0.37	0.86
								075	0.93	32.68	0.40	0.21	14.83
								100	0.96	32.70	0.10	0.15	18.60

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo	Prim Prod (mg m^{-3} hr^{-1})
18	14 May	0001	60°59.95'	175°30.1'	0	6	104	000	-1.30	31.98	6.91	0.98	14.21
								010	-1.24	31.97	8.75	1.52	14.02
								020	-1.44	31.97	9.34	1.45	14.54
								030	-1.30	31.98	9.68	1.30	2.41
								045	-1.34	32.12	0.58	0.24	0.09
								060	-1.44	32.19	0.46	0.24	0.67
								075	0.26	32.57	0.96	0.25	0.23
								095	0.24	32.53	2.75	0.45	0.12
19	14 May	1556	61°29.6'	174°44.1'	0	5	82	000	-0.78	32.05	11.19	0.59	27.61
								005	-1.22	32.05	13.58	1.74	29.01
								010	-1.22	32.06	14.84	0.77	26.74
								020	-1.15	32.10	13.78	2.99	22.72
								030	-1.23	32.19	9.05	0.90	20.20
								045	-1.56	32.42	1.14	0.20	1.64
								060	-1.73	32.50	0.44	0.13	1.62
								075	-1.74	32.54	1.05	0.28	0.78
20	14 May	2330	61°43.42'	175°32.00'	0	10	93	000	-1.27	32.09	2.98	0.21	8.19
								005	-1.21	32.09	3.63	0.13	10.45
								010	-1.26	32.09	3.60	0.05	8.22
								020	-1.36	32.11	4.31	0.47	12.64
								030	-1.30	32.25	4.44	0.08	13.24
								045	-1.30	32.40	0.30	0.11	0.66
								060	-1.68	32.45	0.61	0.19	1.00
								075	-1.61	32.53	0.33	0.19	0.21
21	15 May	1525	61°31.12'	176°15'	0	8	106	000	-1.24	32.00	3.69	0.22	8.20
								010	-1.18	32.01	4.01	0.26	7.52
								020	-1.39	32.02	4.64	0.17	8.14
								030	-1.37	32.05	2.74	0.19	3.04

Table 7. (cont.)

Sta	Date	Time (GMT)	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo (mg m^{-3})	Prim Prod (mg m^{-3} hr^{-1})
								045	-1.66	32.12	0.76	0.15	0.93
								060	-1.09	32.22	0.73	0.16	0.37
								075	0.34	32.67	0.15	0.13	0.19
								095	0.38	32.68	0.05	0.16	0.10
22	16 May	0128	61°01.5'	177°01'	< 1	8	123	000	-0.95	31.97	4.96	0.23	12.02
								010	-1.25	32.04	5.44	0.22	17.53
								020	-1.38	32.05	4.38	1.14	18.90
								030	-1.34	32.06	5.00	0.53	12.56
								045	-1.31	32.08	4.50	1.01	9.02
								060	1.05	32.73	2.63	0.87	6.40
								075	0.96	32.87	0.21	0.26	0.36
								100	0.90	32.96	0.27	0.24	0.10
23	16 May	1530	61°29.9'	177°24.2'	3-4	9	123	000	-1.64	32.03	3.44	0.51	5.59
								010	-1.58	32.04	3.93		5.66
								020	-1.58	32.10	3.94	0.04	6.37
								030	-1.57	32.10	2.52	0.25	2.99
								045	-1.57	32.12	1.58	0.49	1.91
								060	-0.22	32.78	0.37	0.18	0.53
								075	0.98	32.84	0.15	0.15	0.23
								100	1.04	33.02	0.08	0.18	0.07
24	17 May	0239	61°54.4'	177°04.5'	2		114	000	-1.70	32.06	1.84	0.54	3.49
								010	-1.61	32.06	2.32	0.24	3.32
								020	-1.64	32.03	1.96	0.38	4.22
								030	-1.62	32.05	2.24	0.35	3.76
								045	-1.63	32.08	2.00	0.45	3.61
								060	-1.51	32.11	1.19	0.35	3.04
								075	-0.86	32.35	1.35	0.41	2.46
								100	-1.02	32.96	0.20	0.22	0.04

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo (mg m^{-3})	Prim Prod (mg m^{-3} hr^{-1})
25	17 May	1539	62°00.5'	176°17.8'	0	8	100	000	-1.57	32.19	5.99	0.73	13.74
								010	-1.44	32.19	3.05	0.14	12.47
								020	-1.44	32.19	4.73	0.17	15.57
								030	-1.42	32.19	2.95	0.25	13.30
								045	-1.69	32.36	1.15	0.12	1.42
								060	-1.52	32.41	1.21	0.19	1.67
								075	-0.52	32.41	0.08	0.23	0.17
								090	-0.32	32.66	0.15	0.21	0.17
26	22 May	2307	62°10.3'	168°59.1'	0	7	38	000	0.98	31.33	0.46	0.16	1.92
								003	0.51	31.33	0.34	0.64	2.20
								006	0.52	31.34	0.62	0.62	2.98
								009	0.58	31.33	0.81	0.21	2.65
								012	0.49	31.34	0.91	0.15	3.32
								018	0.56	31.35	0.86	0.22	3.98
								023	-1.26	32.14	3.91	0.81	19.94
								028	-1.29	32.14	4.37	0.64	16.04
27	23 May	1546	61°45.1'	170°22.6'	0	5	47	000	-0.16	31.31	4.60	0.61	21.03
								003	-0.06	31.31	3.56	1.04	20.06
								006	-0.06	31.31	4.13	1.33	15.65
								009	-0.11	31.31	5.61	1.19	15.03
								012	-0.26	31.31	4.98	1.13	12.69
								018	-0.11	31.32	6.20	2.10	19.79
								027	-1.59	31.81	2.69	1.21	6.02
								040	-1.57	31.82	2.28	0.62	4.37
28	23 May	2310	61°17.77'	169°50.59'	0	6	46	000	0.01	31.23	3.31	1.12	14.08
								003	0.07	31.22	3.53	1.39	10.25
								006	0.05	31.23	3.28	1.26	14.02
								009	0.08	31.23	3.58	1.16	15.20

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo	Prim Prod (mg m^{-3} hr^{-1})
								015	0.05	31.23	4.02	1.24	11.12
								024	-0.31	31.34	8.02	1.38	24.44
								030	-094	31.38	7.52	1.66	18.48
								040	-0.97	31.39	7.54	0.58	20.22
29	24 May	1520	61°47.5'	168°09.5'	0	6	31	000	-0.16	31.42	0.91	0.23	1.03
								003	-0.07	31.42	0.90	0.18	1.67
								006	-0.10	31.42	0.94	0.23	1.60
								009	-0.10	31.42	0.93	0.15	2.08
								012	0.15	31.44	0.95	0.14	2.02
								015	-0.12	31.42	0.97	0.26	2.71
								020	-0.40	31.45	1.12	0.26	2.32
								025	-0.14	31.55	1.07	0.37	2.64
30	24 May	2127	61°44.09'	167°07.5'	0	9	27	000	1.12	31.46	0.33	0.09	0.70
								003	1.27	31.46	0.37	0.08	0.64
								006	1.16	31.46	0.33	0.08	0.58
								009	1.34	31.46	0.30	0.08	0.59
								012	1.35	31.48	0.35	0.10	0.71
								015	1.06	31.50	0.21	0.08	0.69
								018	0.87	31.49	0.17	0.40	0.71
								021	0.85	31.49	0.38	0.08	0.80
31	25 May	1521	61°14.96'	167°08.32'	0	8	26	000	1.16	31.37	0.19	0.14	0.51
								003	1.60	31.37	0.23	0.17	0.50
								006	1.60	31.37	0.27	0.19	0.55
								009	1.68	31.33	0.27	0.14	0.58
								012	1.66	31.38	0.23	0.16	0.54
								015	1.74	31.38	0.22	0.17	0.61
								018	1.55	31.38	0.19	0.17	0.50
								021	1.53	31.39	0.19	0.15	0.47

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo (mg m^{-3})	Prim Prod (mg m^{-3} hr^{-1})
32	25 May	2332	60°31.9'	168°13.1'	0	5	31	000	1.24	31.08	0.63	0.48	1.23
								003	1.25	31.08	0.58	0.49	1.17
								006	1.23	31.08	0.51	0.43	1.37
								009	1.20	31.08	0.62	0.61	1.27
								012	1.39	31.08	0.66	0.61	1.46
								015	1.53	31.08	0.65	0.56	1.23
								018	1.18	31.08	0.22	1.00	2.02
								025	1.18	31.07	0.92	0.75	2.96
33	26 May	1635	60°32.11'	170°01.8'	0	6	51	000	0.20	31.46	3.87	0.55	12.98
								005	0.24	31.46	4.13	0.75	15.16
								010	0.26	31.46	5.88	1.65	9.85
								015	0.28	31.47	2.54	0.30	13.10
								020	0.46	31.46	2.41	0.56	11.03
								030	0.29	31.47	3.56	0.88	14.88
								040	1.42	31.56	8.16	1.44	27.17
34	4 Jun	1540	63°11.8'	168°28.2'	0	4	46	000	0.14	31.53	3.56		18.79
								005	0.14	31.52	2.98	0.38	14.96
								010	-0.09	31.55	3.89	0.82	25.97
								015	-0.11	31.66	8.76	1.08	29.01
								020	-0.58	32.21	4.54	0.36	12.89
								025	-0.32	32.36	2.21	0.62	5.46
								030	-1.14	32.36	1.43	0.46	4.23
								040	-1.15	32.37	1.65	0.41	5.31
35	4 Jun	2310	63°33.5'	166°55.5'	0	10	29	000	3.50	30.93	0.19	0.05	0.39
								003	3.50	30.93	0.18	0.05	0.44
								006	3.56	30.93	0.16	0.05	0.38
								009	3.56	30.93	0.13	0.05	0.42
								012	3.52	30.93	0.14	0.04	0.34

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo	Prim Prod (mg m^{-3} hr^{-1})
								015	3.51	30.94	0.16	0.04	0.38
								018	0.22	31.53	0.16	0.11	0.51
								024	0.27	31.96	0.45	0.38	0.73
36	5 Jun	1525	63°52.21'	167°40.52'	0	3	37	000	0.24	31.27	3.89	0.55	14.20
								003	0.30	31.26	3.03	0.61	10.19
								006	0.14	31.36	3.80	0.64	15.41
								009	-0.33	32.16	6.77	1.21	21.21
								012	-0.30	32.22	4.72	0.87	8.07
								015	-0.24	32.27	2.70	0.83	8.56
								021	-1.13	32.28	3.23	0.92	5.68
								030	-1.12	32.29	3.57	1.23	6.88
37	6 Jun	0223	63°57.7'	168°22.92'	8	5	40	000	-0.33	30.86	4.93	1.00	28.31
								005	-1.30	31.56	7.77	1.63	23.36
								010	-1.16	31.83	6.97	1.07	23.48
								015	-0.98	32.07	6.57	0.63	21.34
								020	-0.61	32.34	7.82	1.22	21.23
								025	-0.96	32.99	4.99	1.06	14.08
								030	-1.71	33.10	1.63	0.71	7.44
								035	-2.27	33.22	1.12	0.64	2.39
41	6 Jun	2112	64°28.64'	167°51.92'	8	3	35	000	-0.55	30.47	2.47	0.40	11.27
								005	-1.10	31.42	8.39	1.12	29.74
								010	-1.23	31.57	7.70	0.92	23.70
								015	-1.34	31.96	6.04	1.18	16.10
								020	-1.06	31.15	6.37	1.23	18.27
								025	-1.18	32.29	3.91	1.28	10.52
								030	-1.16	32.31	3.85	1.23	8.42

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Phaeo (mg m^{-3})	Prim Prod (mg m^{-3} hr^{-1})
47	8 Jun	0201	65°59.87'	168°17.92'	8	4	55	000	-0.39	30.56	1.32	0.41	3.48
								005	-1.09	31.24	2.40	0.34	5.15
								010	-1.32	31.53	3.16	0.38	9.20
								015	-1.40	32.15	5.03	0.39	10.28
								020	0.77	32.37	6.06	0.80	13.35
								030	-1.14	32.39	4.88	0.73	11.57
								045	-1.02	32.40	6.02	1.21	19.54
48	9 Jun	0212	66°35.5'	165°58.6'	0	8	20	000	-0.06	31.02	0.72	0.10	2.91
								003	-0.33	31.14	1.21	0.26	5.95
								006	-0.65	31.21	1.64	0.26	9.55
								009	-0.33	31.42	2.42	0.32	7.54
								012	-0.27	31.64	3.52	0.81	12.05
								015	-0.90	31.67	4.86	0.46	11.29
								018	-0.86	31.75	4.75	0.76	12.49
49	9 Jun	1554	67°07.98'	165°12.45'	8	8	33	000	1.04	30.32	0.35	0.10	1.31
								003	0.16	30.91	0.49	0.09	2.41
								006	-1.02	31.32	1.62	0.25	5.80
								009	-0.21	31.88	4.17	0.13	26.00
								012	-1.26	31.91	3.96	0.92	17.63
								015	-1.07	31.98	7.67	1.24	30.27
								020	-1.30	32.18	8.46	0.16	23.04
								025	-1.64	32.59	0.85	0.14	8.08
50	12 Jun	0215	66°48.3'	165°01.5'	0	7	27	000	2.06	31.14			0.43
								003	1.02	31.51	0.28	0.08	2.25
								006	-1.52	31.84	1.37	0.30	4.66

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Phaeo (mg m^{-3})	Prim Prod (mg m^{-3} hr^{-1})
								009	-0.22	31.93	1.76	0.33	10.24
								012	-0.27	32.05	2.27	0.32	10.97
								015	-0.82	32.06	2.73	0.40	31.81
								018	-0.92	32.08	4.28	0.80	17.73
								024	-0.94	32.13	2.84	0.41	25.88
51	12 Jun	1538	66°48.2'	164°00'	0	9	26	000	1.33	30.36	0.53	0.06	0.71
								003	0.19	31.39	0.47	0.20	1.24
								006	-0.28	31.44	0.93	0.27	2.31
								009	-0.45	31.48	0.76	0.19	1.41
								012	-0.99	31.54	0.48	0.23	0.90
								015	-0.72	31.77	1.24	0.28	2.79
								018	-0.83	31.88	2.18	0.57	4.37
								021	-0.98	32.29	4.70	0.42	8.36
52	13 Jun	1611	66°21.2'	166°36'	0	7	18	000	-0.36	29.56	0.46	0.12	0.59
								003	-0.18	29.74	0.44	0.12	0.76
								006	-0.41	30.20	0.79	0.24	2.34
								009	-0.66	30.33	1.39	0.24	2.20
								012	-0.45	30.57	1.41	0.27	2.76
								015	-1.38	31.64	3.16	0.53	12.04
54	15 Jun	1526	66°45.8'	168°33"	3	6	38	000	0.02	26.07	0.14	0.07	0.84
								005	-0.64	31.52	1.05	0.26	2.55
								010	-0.14	31.94	0.86	0.29	2.40
								015	-0.74	32.20	2.37	0.83	5.15
								020	-0.24	32.20	2.53	1.13	6.30
								025	-0.82	32.22	3.15	1.15	4.98
								030	-0.86	32.23	3.08	1.10	9.06
								035	-0.84	32.23	3.37	1.14	7.73

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Phaeo (mg m^{-3})	Prim Prod (mg m^{-3} hr^{-1})
55	15 Jun	2328	66°19'	168°36'	0	10	57	000	1.58	31.49	0.18	0.05	0.59
								005	1.69	31.83	0.15	0.06	0.66
								010	-0.26	32.16	1.42	0.49	4.26
								015	-0.86	32.21	3.44	0.85	7.79
								020	-0.88	32.21	3.38	1.09	7.84
								030	-0.81	32.33	3.73	0.29	9.00
								040	-0.89	32.22	3.60	1.20	13.83
								050	-0.88	32.22	4.33	1.42	11.05
56	16 Jun	1523	65°45.0'	168°35.3'	0	10	53	000	1.63	32.15	0.21	0.04	0.64
								005	2.85	32.26	0.45	0.08	1.38
								010	0.34	32.32	6.21	1.60	7.00
								015	-0.34	32.29	3.20	0.74	6.24
								020	-0.51	32.29	2.76	0.72	5.52
								030	-0.47	32.28	2.64	1.21	7.26
								040	-0.56	32.31	1.43	0.48	7.89
								050	-0.55	32.31	1.76	0.17	11.34
57	16 Jun	2314	65°06.2'	168°36.6'	0	10		000	2.92	32.44	0.23	0.07	0.90
								005	2.94	32.44	0.24	0.07	0.85
								010	2.14	32.44	0.38	0.08	1.65
								015	0.38	32.46	3.58	0.90	16.13
								020	0.25	32.46	3.02	1.28	9.42
								025	0.27	32.45	2.74	1.42	9.28
								035	0.10	32.48	1.79	0.77	11.85
								045	0.66	32.76	0.78	1.26	1.41
60	17 Jun	1533	64°40.0'	169°27.8'	0	5	50	000	2.83	31.89	0.97	0.25	
								005	-0.77	32.51	14.48	2.08	49.99

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo	Prim Prod (mg m^{-3} hr^{-1})
								010	-0.51	32.56	17.75	1.70	37.61
								015	-0.89	32.59	7.19	0.93	14.95
								020	-1.11	32.61	3.88	1.27	8.28
								025	-1.08	32.63	2.83	1.40	7.07
								030	-1.18	32.65	2.30	1.24	6.24
								040	-1.18	32.65	3.17	2.19	5.87
64	18 Jun	1530	64°01'	171°06'	0	9	32	000	0.68	32.42	1.61	0.52	2.77
								003	0.75	32.43	1.49	0.34	2.46
								006	0.74	32.45	1.82	0.49	3.08
								009	0.76	32.46	1.67	0.46	3.06
								012	0.75	32.47	2.30	0.53	3.41
								015	0.82	32.47	1.63	0.41	9.97
								020	0.72	32.48	2.79	0.48	3.15
								025	0.74	32.48	2.14	0.45	4.22
65	18 Jun	2225	63°51.6'	171°23'	0	10	26	000	1.51	32.36	0.84	0.35	2.19
								003	1.55	32.36	0.95	0.35	1.87
								006	1.52	32.37	1.03	0.46	2.15
								009	1.52	32.37	1.02	0.34	1.88
								012	1.51	32.38	0.96	0.34	2.15
								015	1.60	32.37	1.16	0.34	2.05
								018	1.48	32.37	0.94	0.37	2.93
								021	1.46	32.37	1.06	0.40	2.57
66	19 Jun	1544	63°52.0'	170°15.3'	0	10	42	000	1.02	31.28	0.25	0.07	0.62
								005	-0.93	31.67	0.60	0.10	1.48
								010	-0.02	32.26	3.14	0.70	5.31
								015	0.00	32.33	2.39	0.51	5.42
								020	0.03	32.34	4.70	0.99	6.66

Table 7. (cont.)

Sta	Date	Time (GMT)	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo (mg m^{-3})	Prim Prod (mg m^{-3} hr^{-1})
								025	0.11	32.34	2.93	0.58	6.15
								030	0.02	32.35	4.40	0.92	7.05
								035	0.02	32.34	4.56	0.69	6.73
68	20 Jun	0007	63°51.0'	169°08.3'	0	8	34	000	1.76	32.02	0.75	0.22	1.32
								003	1.82	32.03	0.60	0.17	1.32
								006	1.72	32.04	0.52	0.20	1.10
								009	1.89	32.05	0.57	0.18	1.44
								012	1.84	32.10	0.58	0.19	0.75
								017	1.86	32.15	0.61	0.19	1.37
								022	1.14	32.25	1.05	0.32	2.12
								027	1.60	32.28	1.52	0.45	2.79
69	21 Jun	1603	58°45'	172°20.2'	0	5	102	000	4.96	32.37	4.88	0.36	9.31
								010	4.91	32.37	4.48	0.31	10.46
								020	4.94	32.37	4.24	0.38	12.25
								030	3.17	32.39	0.65	0.29	1.36
								040	2.02	32.41	0.25	0.27	0.56
								050	1.47	32.47	0.18	0.64	0.22
								060	1.22	32.48	0.11	0.72	0.11
								075	1.22	32.47	0.17	0.97	0.13
70	22 Jun	0007	58°50'	173°58.5'	0	8	132	000	5.12	32.48	1.07	0.32	2.69
								010	5.05	32.48	0.97	0.61	3.00
								020	5.07	32.49	1.23	0.49	3.18
								030	4.08	32.53	0.87	0.14	1.48
								045	1.97	32.51	0.25	0.12	0.44
								060	1.40	32.62	0.12	0.13	0.17
								075	1.42	32.71	0.06	0.17	0.03
								100	1.80	32.82	0.07	0.22	0.03

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo	Prim Prod (mg m^{-3} hr^{-1})
71	22 Jun	1524	58°00'	173°45'	0	10	121	000	5.11	32.65	0.88	0.18	1.66
								010	5.22	32.64	0.76	0.23	1.61
								020	5.20	32.65	0.82	0.22	1.62
								030	5.20	32.66	0.73	0.22	1.53
								045	4.16	32.74	1.11	0.37	1.60
								060	3.08	32.80	0.13	0.21	0.15
								075	2.84	32.88	0.09	0.19	0.11
								100	2.92	33.04	0.04	0.16	0.05
72	23 Jun	0002	58°14.6'	172°22'	0	7	106	000	5.41	32.46	1.79	0.29	5.99
								010	5.41	32.47	1.87	0.60	6.32
								020	5.42	32.47	0.77	0.13	6.54
								030	5.41	32.47	2.03	0.06	6.18
								045	4.06	32.51	0.24	0.29	0.38
								060	2.41	32.63	0.10	0.32	0.04
								075	2.26	32.66	0.06	0.29	0.23
								100	2.26	32.67	0.06	0.30	0.09
73	23 Jun	1545	58°14.9'	170°43'	0	8	84	000	5.18	32.28	1.99	1.22	5.81
								005	5.04	32.27	2.07	1.07	6.32
								010	5.04	32.27	1.77	1.06	6.03
								020	4.97	32.27	1.99	0.95	5.77
								030	3.22	32.35	0.39	0.46	0.59
								045	1.46	32.36	0.27	0.28	0.28
								060	1.36	32.35	0.25	0.26	0.45
								075	1.36	32.36	0.24	0.31	0.36
74	23 Jun	2350	57°29.4'	171°30.2'	0	11	73	000	5.74	32.39	0.68	0.13	1.83
								005	5.80	32.38	0.70	0.11	2.09
								010	5.67	32.39	0.73	0.09	2.03

Table 7. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Ice Cover (oktas)	Secchi Depth (m)	Sonic Depth (m)	Sample Depth (m)	Temp (°C)	S°/₀₀	Chl *a* (mg m^{-3})	Pheo (mg m^{-3})	Prim Prod (mg m^{-3} hr^{-1})
								020	5.45	32.39	0.35	0.08	0.84
								030	4.12	32.33	0.22	0.22	0.50
								040	4.08	32.36	0.16	0.22	0.31
								050	4.00	32.36	0.17	0.18	0.34
								060	3.94	32.35	0.13	0.27	0.36
75	24 Jun	1526	57°30.3'	172°19.5'	0	8	110	000	5.65	32.55	1.76	0.53	4.03
								010	5.64	32.55	1.87	0.40	4.13
								020	5.56	32.58	1.24	0.34	3.30
								030	5.60	32.63	1.01	0.20	2.23
								045	4.56	32.65	0.34	0.34	0.46
								060	3.12	32.79	0.20	0.19	0.22
								075	3.06	32.93	0.10	0.12	0.05
								100	3.09	32.93	0.08	0.14	0.08

Table 8. Summary of station locations and nutrient concentrations in the Bering Sea, CGC *Polar Star*, 4 May - 24 June 1980. * indicates samples thawed before analysis and values are questionable.

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
1	4 May	0817	59°31.1'	176°06.2'		000	0.82	30.24	5.35	0.25	0.86
						010	0.82	30.90	5.52	0.25	1.06
						020	0.91	31.35	5.72	0.26	1.16
						030	2.05	50.77	24.46	0.30	1.61
						045	1.95	51.96	25.45	0.36	0.73
						060	1.74	36.03	17.22	0.36	0.97
						075		Bottle didn't trip			
						130		Bottle didn't trip			
2	5 May	1540	59°44.9'	177°44.7'	157	000	1.25	36.03	9.52	0.41	1.51
						010	1.16	36.16	9.99	0.42	1.64
						020	1.14	36.04	9.86	0.35	1.25
						030	1.16	35.43	9.70	0.29	1.38
						045	2.01	50.94	24.58	0.26	2.01
						060		Bottle didn't trip			
						075		Bottle didn't trip			
						145		Bottle didn't trip			
3	6 May	0107	59°59.8'	177°29.2'	135	000	1.22	37.92	11.97	0.30	0.89
						010	1.20	38.57	11.94	0.30	0.90
						020	1.21	38.05	11.94	0.28	0.81
						030	1.25	38.57	11.91	0.26	0.76
						045	2.03	52.49	25.19	0.27	0.88
						060	2.17	56.49	28.32	0.18	0.59
						075	2.25	58.42	28.33	0.22	0.45
						125	1.47	32.96	14.85	0.17	0.72
4	6 May	1557	60° 27.0'	178°16.4'	165	000	1.78	47.86	21.46	0.24	0.67
						010	1.83	48.50	21.62	0.26	0.53
						020	1.98	48.66	21.70	0.25	0.54

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
						030	1.76	48.66	21.62	0.21	0.48
						045	1.86	50.13	23.62	0.23	0.61
						060	2.28	56.50	28.36	0.16	0.41
						075	2.16	55.75	27.99	0.14	0.38
						145	2.25	60.45	29.68	0.17	0.24
5	7 May	0232	60°38.21'	178°38.67'	194	000	1.68	45.72	20.18	0.25	0.46
						010	1.53	45.57	19.84	0.27	0.34
						020	1.65	45.57	20.12	0.21	0.38
						030	1.68	47.88	21.58	0.21	0.27
						045	1.80	43.51	19.52	0.21	0.71
						060	2.08	56.51	27.89	0.17	0.16
						075	2.07	58.45	28.90	0.15	0.08
						100	2.08	57.28	28.39	0.13	0.14
6	7 May	1628	60°48.4'	178°24.63'	168	000	1.56	40.09	19.08	0.18	0.23
						010	1.62	41.44	19.67	0.18	0.22
						020	1.66	41.44	19.94	0.19	0.19
						030	1.49	41.17	20.14	0.17	0.21
						045	2.04	49.70	27.20	0.26	0.09
						060	2.09	52.25	28.65	0.13	0.02
						075	2.17	54.05	28.40	0.16	0.02
						145		Bottle didn't trip			
7	8 May	1643	60°43.8'	177°37.6'	145	000	1.06	32.80	10.50	0.25	0.54
						010	1.07	33.36	10.75	0.27	0.51
						020	1.15	35.22	11.65	0.27	0.50
						030	1.10	34.63	11.32	0.22	0.47
						045	1.15	36.09	10.10	0.17	1.10
						060	1.15	36.90	19.47	0.21	0.79

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
						075	1.96	51.56	26.09	0.19	0.18
						125		Bottle didn't trip			
8	9 May	0127	60°25.62'	177°15.72'	150	000	1.13	33.93	10.43	0.23	0.47
						010	1.10	33.93	10.61	0.24	0.47
						020	1.11	34.40	10.96	0.24	0.61
						030	1.11	34.40	10.92	0.24	0.46
						045	1.54	39.05	17.51	0.18	0.79
						060	2.00	48.71	25.68	0.19	0.27
						075	2.10	52.25	27.20	0.14	0.14
						125		Bottle didn't trip			
9	9 May	1535	59°47.9'	176°12.3'	143	000	0.84	29.47	5.54	0.23	0.34
						010	0.89	29.57	5.56	0.23	0.43
						020	0.92	29.57	6.82	0.24	0.42
						030	1.18	35.10	12.22	0.21	0.87
						045	1.82	42.27	21.68	0.19	0.84
						060	1.86	45.00	23.49	0.15	0.26
						115	1.90	54.23	27.55	0.15	0.25
						125	2.03	54.79	27.67	0.16	0.34
10	10 May	0128	60°04.40'	176°54.27'	137	000	0.42	15.54	0.29	0.02	0.27
						010	0.47	15.54	0.32	0.03	0.23
						020	0.58	19.86	1.87	0.08	0.23
						030	1.08	30.41	8.94	0.24	0.83
						045	1.99	46.20	24.49	0.30	0.42
						060	2.04	48.88	26.42	0.29	0.26
						075	1.87	49.04	26.20	0.25	0.30
						125	2.02	57.88	28.91	0.18	0.13

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
11	10 May	1541	59°44.7'	175°00.4'	119	000	0.44	12.23	0.26	0.05	0.11
						010	0.47	12.85	0.18	0.03	0.21
						020	0.39	13.35	0.18	0.02	0.17
						030	0.51	14.14	0.56	0.02	0.58
						045	2.01	44.41	25.17	0.25	1.97
						060	1.87	47.28	25.07	0.26	0.19
						075	1.91	49.70	26.20	0.27	0.19
						100	2.03	50.53	26.97	0.26	0.41
12	10 May	2310	59°59.3'	174°12.42'	102	000	0.80	22.60	2.26	0.09	0.29
						010	0.69	19.13	1.58	0.09	0.43
						020	0.67	16.97	1.94	0.08	0.64
						030	1.60	43.24	14.44	0.14	0.43
						045	1.37	24.01	11.54	0.19	8.38
						060	1.07	21.86	7.45	0.04	0.52
						075	1.38	29.54	11.88	0.11	0.38
						095	1.58	37.76	15.34	0.14	0.28
13	11 May	1528	60°15.20'	173°45.24'	82	000	1.13	36.48	6.44	0.19	0.39
						005	1.20	37.11	6.44	0.19	0.23
						010	1.20	38.28	6.72	0.20	0.10
						020	1.25	31.10	10.47	0.18	0.45
						030	1.71	44.87	16.68	0.12	0.34
						045	1.79	45.47	17.17	0.18	0.98
						060	1.87	45.63	17.97	0.17	0.68
						075	1.85	48.61	18.58	0.17	0.65
14	12 May	0013	60°42.67'	174°04.66'	88	000	1.14	33.42	5.09	0.22	0.21
						005	1.09	30.88	4.62	0.23	0.30
						010	1.14	32.83	5.14	0.22	0.15

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
						020	1.22	32.36	7.01	0.20	0.67
						030	1.27	34.74	8.90	0.20	0.29
						045	1.58	40.98	15.24	0.20	0.92
						060	1.97	37.24	21.31	0.24	0.27
						075	1.76	46.24	18.73	0.22	0.24
15	12 May	1530	60°31.11'	174°46.84'	101	000	0.93	28.35	3.06	0.17	0.13
						010	0.89	25.75	2.68	0.15	0.25
						020	0.94	28.89	3.35	0.18	0.14
						030	1.01	29.98	4.94	0.13	0.36
						045	1.27	34.74	12.33	0.17	0.51
						060	1.66	40.70	17.50	0.16	0.48
						075	1.97	54.65	23.97	0.16	0.17
						095	1.92	53.74	23.53	0.15	0.19
16	12 May	2357	60°13.53'	175°29.56'	115	000	0.43	14.90	0.26	0.03	0.20
						010	0.39	15.22	0.29	0.04	0.19
						020	0.44	15.47	0.38	0.04	0.29
						030	0.57	18.25	1.63	0.07	0.82
						045	1.66	43.83	18.83	0.19	1.16
						060	1.91	52.14	23.54	0.19	4.07
						075	2.00	54.83	24.27	0.13	0.29
						100	1.84	49.43	22.29	0.19	0.54
17	13 May	1555	60°55'	176°16'	117	000	0.99	33.61	8.11	0.17	0.16*
						010	1.18	30.96	10.57	0.19	0.44
						020	1.17	31.51	10.65	0.20	2.29
						030	1.26	33.19	12.47	0.15	0.30
						045	1.60	39.06	17.91	0.14	1.10
						060	1.70	40.65	19.65	0.64	1.70
						075	1.98	52.25	24.04	0.15	0.45
						100	1.94	51.20	24.42	0.14	0.42

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
18	14 May	0001	60°59.95'	175°30.1'	104	000	1.03	26.92	6.54	0.16	0.48
						010	1.09	28.95	7.11	0.18	0.58
						020	1.11	29.36	8.44	0.17	0.67
						030	1.12	28.84	8.59	0.16	1.44
						045	1.45	36.15	15.19	0.15	0.87
						060	1.58	37.64	17.85	0.17	0.73
						075	1.95	51.20	23.65	0.17	0.31
						095	1.92	50.34	22.80	0.19	1.51
19	14 May	1556	61°29.6'	174°44.1'	82	000	1.03	27.42	4.57	0.21	3.99
						005	1.14	28.84	4.75	0.22	1.19
						010	1.05	28.74	4.84	0.22	0.60
						020	1.14	29.78	5.74	0.17	0.65
						030	1.29	33.19	10.43	0.17	0.59
						045	1.84	42.03	19.43	0.18	0.76
						060	2.11	50.51	21.44	0.16	0.63
						075	1.98	44.93	19.63	0.16	0.88
20	14 May	2330	61°43.42'	175°32.00'	93	000	1.38	37.26	14.72	0.22	0.47
						005	1.41	36.76	14.95	0.22	1.02
						010	1.36	35.66	13.93	0.19	0.33
						020	1.28	34.94	13.43	0.17	0.68
						030	1.43	37.51	14.97	0.17	0.55
						045	1.85	43.60	20.55	0.18	0.96
						060	1.90	46.92	21.27	0.18	0.69
						075	2.11	50.34	21.72	0.17	0.68
21	15 May	1525	61°31.12'	176°15'	106	000	1.25	32.74	11.23	0.19	0.27
						010	1.30	37.32	12.01	0.14	0.25
						020	1.37	37.33	13.45	0.15	2.14
						030	1.53	39.20	15.93	0.10	0.25

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
						045	1.60	39.09	16.78	0.11	1.14
						060	1.68	42.08	18.80	0.09	0.49
						075	2.05	54.80	23.80	0.13	1.13
						095	2.08	56.34	24.40	0.14	0.38
22	16 May	0128	61°01.5'	177°01'	123	000	0.95	34.51	7.72	0.32	0.24*
						010	1.15	36.15	10.12	0.16	0.19*
						020	0.92	31.16	6.07	0.05	1.43*
						030	1.33	36.52	13.91	0.12	10.42
						045	1.41	38.56	14.91	0.16	0.66*
						060	1.97	52.56	24.22	0.19	1.97*
						075	1.73	46.97	18.74	0.07	1.68*
						100	1.95	52.84	24.67	0.13	4.74
23	16 May	1530	61°29.9'	177°24.2'	123	000	1.44	38.64	14.76	0.13	0.23
						010	1.53	41.33	15.40	0.14	0.71*
						020	1.49	39.53	15.07	0.16	0.47*
						030	1.52	41.33	16.50	0.11	0.39*
						045	1.34	43.75	14.99	0.19	0.36*
						060	2.02	55.35	18.16	0.07	2.02
						075	2.01	55.36	18.52	0.04	0.17
						100	2.11	60.71	26.64	0.10	0.62
24	17 May	0239	61°54.4'	177°04.5'	114	000	1.34	41.32	13.79	0.08	*
						010	1.58	44.45	17.21	0.16	3.19*
						020	1.60	43.92	18.40	0.15	0.47
						030	1.50	40.20	16.92	0.12	11.26
						045	1.52	39.70	16.28	0.08	0.35
						060	1.53	42.54	16.73	0.15	3.25*
						075	1.83	53.71	20.88	0.11	3.29*
						100	1.52	43.93	17.55	0.13	3.25*

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
25	17 May	1539	62°00.5'	176°17.8'	100	000	1.33	43.43	10.48	0.07	4.63*
						010	1.19	44.05	11.37	0.08	4.11*
						020	1.42	41.39	13.40	0.11	0.24
						030	1.39	42.99	13.04	0.18	3.62*
						045	1.68	47.25	17.02	0.21	3.22*
						060	1.64	31.65	13.36	0.11	2.22
						075	1.74	59.23	18.14	0.24	3.15*
						090	2.08	52.60	22.32	0.13	0.22
26	22 May	2307	62°10.3'	168°59.1'	38	000	0.74	2.15	0.51	0.04	3.72
						003	0.56	1.77	0.35	0.15	0.28
						006	0.50	4.71	0.15	0.09	3.21*
						009	0.51	1.14	0.14	0.02	0.55
						012	0.55	3.12		0.00	3.12*
						018	0.55	2.63		0.00	3.18*
						023	0.90	12.56	0.82	0.14	3.05*
						028	0.94	12.85	0.79	0.15	3.04*
27	23 May	1546	61°45.1'	170°22.6'	47	000	0.52	4.26	0.03	0.03	3.02*
						003	0.51	3.82	0.03	0.01	3.01*
						006	0.50	1.40	0.12	0.05	0.10
						009	0.49	3.82	0.04		3.04*
						012	0.44	1.34	0.14	0.01	0.16
						018	0.43	1.16	0.07	0.03	0.13
						027	1.36	21.20	4.00	0.22	3.00
						040	1.37	22.13	4.22	0.22	3.18
28	23 May	2310	61°17.77'	169°50.59'	46	000	0.52	2.54	0.10	0.02	0.13
						003	0.51	1.97	0.20	0.03	0.22
						006	0.55	1.52	0.08	0.02	0.14
						009	0.50	1.85	0.08	0.01	0.18

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
						015	0.52	1.67	0.11	0.02	0.73
						024	0.88	8.69	0.40	0.09	0.73
						030	0.93	10.54	0.62	0.11	0.70
						040	0.93	10.17	0.81	0.14	3.93
29	24 May	1520	61°47.5'	168°09.5'	31	000	0.54	0.91	0.07	0.01	0.15
						003	0.54	0.51	0.09	0.02	0.18
						006	0.54	0.77	0.11	0.04	5.38
						009	0.54	0.82	0.16	0.01	1.05
						012	0.54	0.62	0.08		0.32
						015	0.54	0.73	0.08		0.38
						020	0.58	0.93	0.06		0.41
						025	0.53	0.83	0.06	0.00	0.73
30	24 May	2127	61°44.09'	167°07.5'	27	000	0.34	3.51	0.04		2.98*
						003	0.26	0.64	0.09	0.03	4.65
						006	0.25	1.20	0.17	0.01	0.69
						009	0.23	0.70	0.26	0.01	0.93
						012	0.21	0.55	0.12	0.01	1.26
						015	0.25	1.11	0.16	0.00	
						018	0.31	0.76	0.67	0.08	10.22
						021	0.23	0.66	0.14	0.01	4.30
31	25 May	1521	61°14.96'	167°08.32'	26	000	0.40	4.07	0.04		3.04*
						003	0.40	3.76	0.05	0.02	3.01*
						006	0.39	4.64	0.05		2.95*
						009	0.38	4.07	0.06		3.00*
						012	0.39	3.95		0.01	2.99*
						015	0.35	4.32			2.98*
						018	0.38	4.20			2.97*
						021	0.36	1.08			0.02*

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
32	25 May	2332	60°31.9'	168°13.1'	31	000	0.39	1.29	0.06	0.01	0.02*
						003	0.37	0.48	0.05		0.13*
						006	0.40	1.08	0.07		*
						009	0.01	1.08	0.34	0.92	0.25
						012	0.44	0.48	0.07		0.01*
						015	0.43	0.53			*
						018	0.42	0.80	0.05		0.06*
						025	0.45	0.43	0.04	0.01	*
33	26 May	1635	60°32.11'	170°01.81'	51	000	0.58	4.47			*
						005	0.59	3.48			*
						010	0.56	4.18	0.03		*
						015	0.53	3.83			*
						020	0.55	3.66			*
						030	0.54	3.83			*
						040	0.75	9.79			*
34	4 Jun	1540	63°11.8'	168°28.2'	46	000	0.69	14.30	0.15	0.00	1.03
						005	0.62	14.16	0.44	0.01	1.09
						010	0.64	14.44	0.20	0.02	1.17
						015	0.79	14.72	0.34	0.01	1.23
						020	1.25	29.42	4.37	0.11	1.82
						025	1.66	41.66	9.09	0.20	2.84
						030	1.67	47.49	9.46	0.21	2.78
						040	1.71	43.48	9.53	0.21	2.86
35	4 Jun	2310	63°33.5'	166°55.5'	29	000	0.31	2.92	0.22	0.05	1.64
						003	0.34	3.03	0.07	0.02	
						006	0.33	3.57	0.12	0.02	
						009	0.33	3.30	0.08	0.01	
						012	0.32	3.31	0.18	0.02	

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
						015	0.31	3.31	0.12	0.00	
						018	0.48	2.52	0.09	0.01	
						024	0.49	2.06	0.09	0.00	
36	5 Jun	1525	63°52.21'	167°40.52'	37	000	0.49	6.94	0.11	0.03	
						003	0.48	7.12	0.10	0.02	0.01
						006	0.59	9.32	0.18	0.04	0.11
						009	1.27	32.65	4.01	0.19	0.63
						012	1.41	39.36	5.34	0.18	1.38
						015	1.49	41.86	5.61	0.17	1.51
						021	1.54	41.87	5.75	0.18	1.71
						030	1.49	39.79	5.64	0.16	1.66
37	6 Jun	0223	63°57.7'	168°22.92'	40	000	0.57	13.17	0.13	0.03	0.39
						005	0.66	13.98	0.05	0.01	0.17
						010	0.94	19.84	1.16	0.07	0.35
						015	1.24	30.69	5.96	0.14	1.23
						020	1.57	41.05	8.87	0.20	2.00
						025	2.08	57.36	16.47	0.21	2.74
						030	2.20	61.06	18.06	0.24	3.04
						035	2.25	62.62	18.92	0.24	2.85
41	6 Jun	2112	64°28.64'	167°51.92'	35	000	0.56	12.39	0.06	0.03	0.37
						005	0.86	21.30	0.84	0.27	0.21
						010	0.96	38.09	0.94	0.17	0.34
						015	1.29	34.63	3.48	0.17	0.68
						020	1.37	35.94	4.38	0.18	0.86
						025	1.42	35.95	4.82	0.19	0.96
						030	1.43	36.56	4.82	0.16	1.34

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
47	8 Jun	0201	65°59.87'	168°17.92'	55	000	0.41	8.23	0.50	0.05	0.48
						005	0.69	11.16	0.81	0.09	0.09
						010	0.88	16.35	1.53	0.12	0.22
						015	1.26	31.92	4.89	0.13	0.39
						020	1.38	36.65	5.97	0.13	0.49
						030	1.39	36.79	5.89	0.14	0.57
						045	1.40	38.64	6.42	0.12	0.45
48	9 Jun	0212	66°35.5'	165°58.6'	20	000	0.59	11.19	0.13	0.09	0.23
						003	0.62	11.65	0.25	0.06	0.20
						006	0.61	11.97	0.31	0.14	0.29
						009	0.61	10.93	0.11	0.02	0.10
						012	0.56	7.22	0.14	0.06	0.27
						015	0.63	8.64	0.14	0.04	0.17
						018	0.63	8.37	0.12	0.02	0.15
49	9 Jun	1554	67°07.98'	165°12.45'	33	000	0.55	6.38	0.12	0.05	0.13
						003	0.63	6.99	0.09	0.04	0.05
						006	0.59	8.18	0.07	0.03	0.05
						009	0.67	11.56	0.11	0.01	0.06
						012	0.70	11.84	0.13	0.01	0.05
						015	0.70	12.19	0.17	0.02	0.06
						020	0.82	14.15	0.86	0.06	0.12
						025	1.50	35.15	9.36	0.17	0.97
50	12 Jun	0215	66°48.3'	165°01.5'	27	000	0.50	7.60	0.08	0.04	0.24
						003	0.57	6.81	0.18	0.05	0.07
						006	0.53	7.68	2.45	0.26	0.11

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
						009	0.47	4.40	0.07	0.05	0.13
						012	0.45	4.58	0.11	0.06	0.27
						015	0.65	7.70	0.17	0.08	0.24
						018	0.66	7.09	0.11	0.05	0.19
						024	0.70	9.16	0.15	0.02	0.04
51	12 Jun	1538	66°48.2'	164°00'	26	000	0.41	4.50	0.06	0.03	0.03
						003	0.40	3.59	0.16	0.07	0.05
						006	0.41	3.88	0.08	0.03	0.00
						009	0.41	3.32	0.16	0.02	0.06
						012	0.44	3.95	0.11	0.01	
						015	0.52	3.96	0.07	0.02	
						018	0.56	4.48	0.07	0.01	
						021	0.68	9.67	0.93	0.04	
52	13 Jun	1611	66°21.2'	166°36'	18	000	0.35	5.73	0.12	0.07	
						003	0.43	6.45	0.06	0.06	0.03
						006	0.40	7.13	0.06	0.05	
						009	0.44	7.20	0.08	0.02	
						012	0.47	7.51	0.10	0.03	
						015	0.79	17.05	1.47	0.08	0.07
54	15 Jun	1526	66°45.8'	168°33'	38	000	0.34	3.35	0.10	0.05	0.26
						005	0.61	10.97	0.24	0.06	0.11
						010	0.53	9.42	0.21	0.10	0.18
						015	0.99	21.65	2.16	0.07	0.61
						020	1.09	24.05	2.48	0.09	0.53
						025	1.11	24.59	2.61	0.08	0.70
						030	1.10	24.33	2.70	0.08	0.59
						035	1.10	24.07	2.61	0.08	0.66

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
55	15 Jun	2328	66°19'	168°36'	57	000	0.42	4.46	0.12	0.04	0.00
						005	0.38	3.45	0.02	0.02	
						010	0.90	19.35	1.32	0.06	
						015	1.06	21.12	1.96	0.07	1.85
						020	1.10	22.54	2.37	0.07	0.67
						030	1.09	21.13	2.15	0.07	0.79
						040	1.10	22.46	2.31	0.09	0.52
						050	1.10	22.04	2.16	0.08	0.50
56	16 Jun	1523	65°45.0'	168°35.3'	53	000	0.53	8.52	0.08	0.03	0.18
						005	0.44	5.76	0.05	0.03	0.11
						010	0.87	16.14	2.34	0.09	0.77
						015	1.05	20.41	3.23	0.07	0.63
						020	1.10	22.06	3.61	0.08	0.75
						030	1.10	22.48	3.58	0.07	0.72
						040	1.10	21.24	3.48	0.07	0.73
						050	1.09	21.32	3.50	0.07	0.62
57	16 Jun	2314	65°06.2'	168°36.6'		000	0.30	3.62	0.14	0.05	0.34
						005	0.31	3.54	0.03		*
						010	0.25	3.89	0.03		*
						015	0.51	7.97	0.04	0.01	0.09*
						020	0.83	8.93	2.60	0.08	1.77
						025	0.83	8.55	2.55	0.07	4.92
						035	0.99	12.22	3.57	0.07	2.28
						045	1.47	32.67	10.24	0.13	3.06
60	17 Jun	1533	64°40.0'	169°27.8'	50	000	0.26	6.97	0.17	0.09	0.07
						005	0.56	22.09	0.07	0.03	0.12
						010	1.18	23.79	6.47	0.18	0.18

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
						015	1.57	39.78	14.67	0.15	0.72
						020	1.74	40.96	16.27	0.16	1.70
						025	1.80	42.42	16.79	0.15	1.89
						030	1.74	42.30	17.00	0.16	1.90
						040	1.75	43.16	17.04	0.15	1.89
64	18 Jun	1530	64°01'	171°06'	32	000	0.65	10.15	2.05	0.13	0.16
						003	0.64	10.22	1.83	0.06	0.17
						006	0.68	11.03	2.03	0.11	1.19
						009	0.67	10.23	1.99	0.04	0.26
						012	0.65	9.57	1.81	0.04	0.35
						015	0.64	10.57	2.01	0.03	0.22
						020	0.66	10.10	2.11	0.04	0.37
						025	0.66	10.24	2.00	0.04	0.31
65	18 Jun	2225	63°51.6'	171°23'	26	000	0.57	10.29	1.09	0.05	1.50
						003	0.61	10.36	1.12	0.05	0.39
						006	0.54	10.53	0.04		0.06*
						009	0.60	10.37	1.20	0.04	0.35
						012	0.51	9.66	0.04	0.02	0.06*
						015	0.60	10.71	1.17	0.04	0.26
						018	0.60	10.51	1.24	0.04	0.33
						021	0.60	10.38	1.21	0.04	0.46
66	19 Jun	1544	63°52.0'	170°15.3'	42	000	0.33	7.48	0.07	0.04	0.12
						005	0.42	8.37	0.81	0.07	0.32
						010	0.71	14.62	1.67	0.12	0.32
						015	0.74	14.20	1.83	0.06	0.29
						020	0.54	13.60	0.03	0.01	0.05*
						025	0.60	13.60	0.03	0.01	0.05*
						030	0.73	14.34	1.86	0.06	0.30

Table 8. (cont.)

Sta	Time (GMT)	Date	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
						035	0.71	13.99	1.90	0.06	0.31
68	20 Jun	0007	63°51.0'	169°08.3'	34	000	0.42	5.47		0.02	2.80
						003	0.40	5.72		0.02	0.24
						006	0.40	5.97		0.06	0.24
						009	0.41	5.97		0.01	0.10
						012	0.42	6.04		0.02	0.21
						017	0.39	5.49		0.02	2.05
						022	0.41	5.28		0.02	2.74
						027	0.44	5.99	0.09	0.03	2.24
69	21 Jun	1603	58°45'	172°20.2'	102	000	0.71	32.54	6.25	0.12	0.29
						010	0.19	31.86	0.03	0.01	0.07*
						020	0.74	33.67	6.54	0.10	0.74
						030	1.22	37.88	12.69	0.15	1.66
						040	1.47	39.73	18.52	0.23	1.00
						050	1.70	44.02	20.21	0.21	2.33
						060	1.77	45.12	20.59	0.20	2.68
						075	1.74	45.54	20.53	0.20	2.77
70	22 Jun	0007	58°50'	173°58.5'	132	000	1.02	40.40	10.70	0.13	0.25
						010	1.02	39.90	10.33	0.12.	0.39
						020	1.01	41.05	10.81	0.11	0.17
						030	1.24	41.31	14.05	0.12	0.83
						045	1.52	42.48	19.90	0.24	0.55
						060	1.68	48.27	23.14	0.15	0.33
						075	1.84	52.80	25.62	0.11	0.15
						100	1.75	46.44	22.11	0.06	2.91
71	22 Jun	1524	58°00'	173°45'	121	000	1.17	39.21	13.68	0.16	0.65
						010	1.22	41.49	14.40	0.15	0.95

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
						020	1.20	40.85	14.32	0.14	0.64
						030	1.20	41.12	14.49	0.15	0.93
						045	1.61	46.20	21.69	0.27	0.86
						060	1.74	49.80	24.10	0.31	0.48
						075	1.78	52.39	26.27	0.15	0.10
						100	2.03	61.63	29.59	0.07	0.18
72	23 Jun	0002	58°14.6'	172°22'	106	000	1.01	37.81	11.00	0.16	0.81
						010	1.07	41.30	11.69	0.12	0.61
						020	1.05	39.78	11.33	0.12	0.80
						030	1.04	38.68	11.11	0.12	0.48
						045	1.70	51.52	23.63	0.12	0.16
						060	1.60	46.55	21.43	0.07	0.15
						075			sample missing		
						100	1.35	39.44	18.27	0.08	1.53
73	23 Jun	1545	58°14.9'	170°43'	84	000	0.60	29.13	4.25	0.21	0.61
						005	0.60	29.66	4.14	0.12	0.65
						010	0.60	29.78	4.14	0.12	0.87
						020	0.60	29.16	4.32	0.11	0.86
						030	1.54	40.61	18.28	0.23	2.25
						045	1.63	42.42	19.32	0.22	2.26
						060	1.63	42.55	19.45	0.22	2.17
						075	0.03	38.63	0.03	0.04	0.16*
74	23 Jun	2350	57°29.4'	171°30.2'	73	000	0.19	30.24	0.03	0.01	0.04*
						005	0.84	27.95	7.61	0.12	2.24
						010	0.15	30.46	0.03	0.01	0.06*
						020	0.16	30.67	0.18	0.01	0.04*
						030	1.26	35.90	14.22	0.20	1.65

Table 8. (cont.)

Sta	Date (GMT)	Time	Latitude (N)	Longitude (W)	Sonic Depth (m)	Sample Depth (m)	PO_4	SiO_3	NO_3 ($\mu g\text{-at } \ell^{-1}$)	NO_2	NH_3
						040	0.08	33.89	0.12	0.02	0.06*
						050	0.10	30.78	0.16	0.02	0.17*
						060	0.13	31.21	0.10	0.02	0.17*
75	24 Jun	1526	57°30.3'	172°19.5'	110	000	0.06	28.58	0.09	0.01	0.05*
						010	0.01	28.58	0.09	0.02	0.12*
						020	0.01	28.07	0.09	0.02	0.11*
						030	0.08	24.31	0.12	0.02	0.14*
						045	0.01	42.79	0.12	0.04	0.16*
						060		49.16	1.70	1.65	0.03*
						075		56.22	0.02	0.03	0.08*
						100		56.80		0.03	0.15*

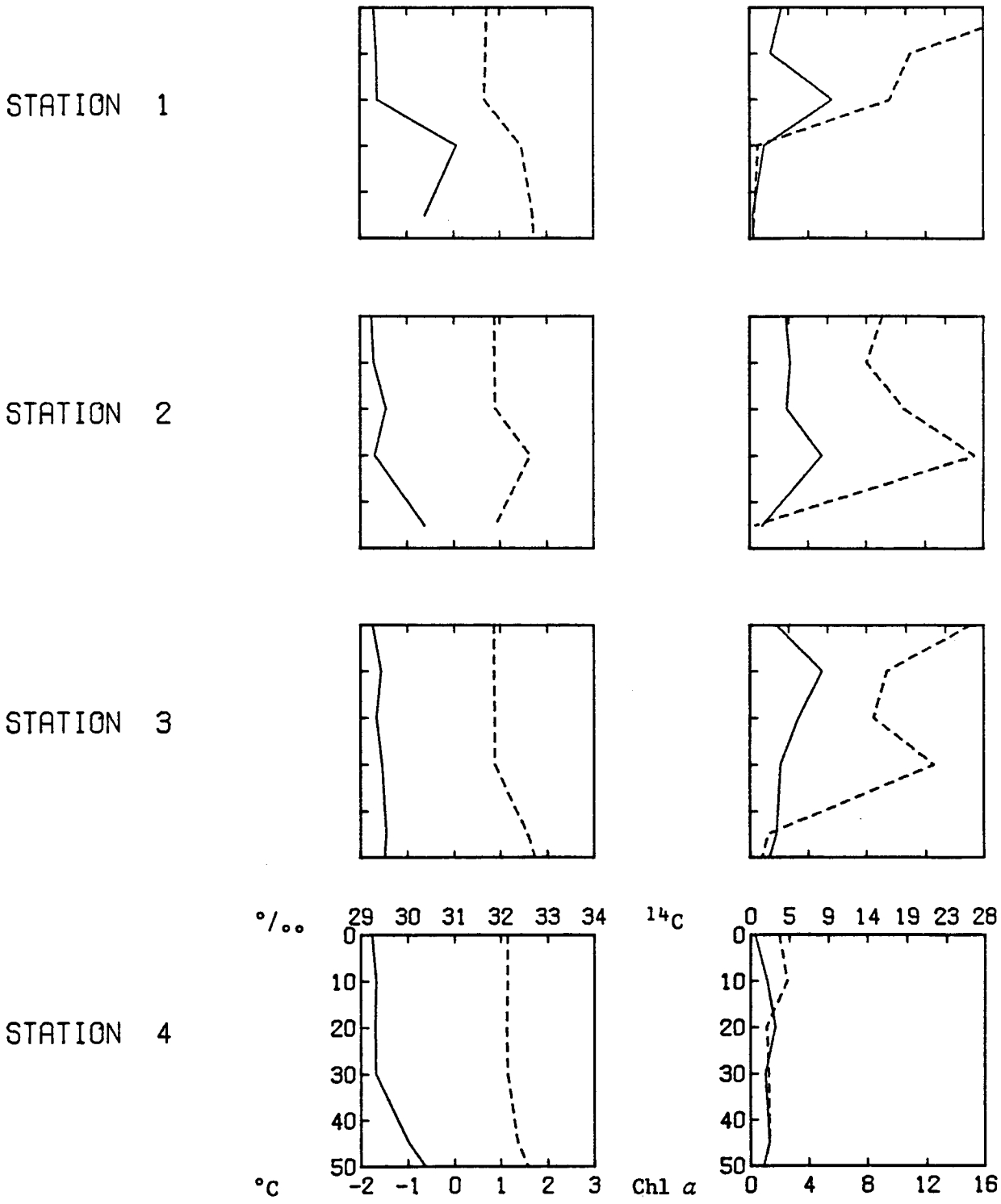
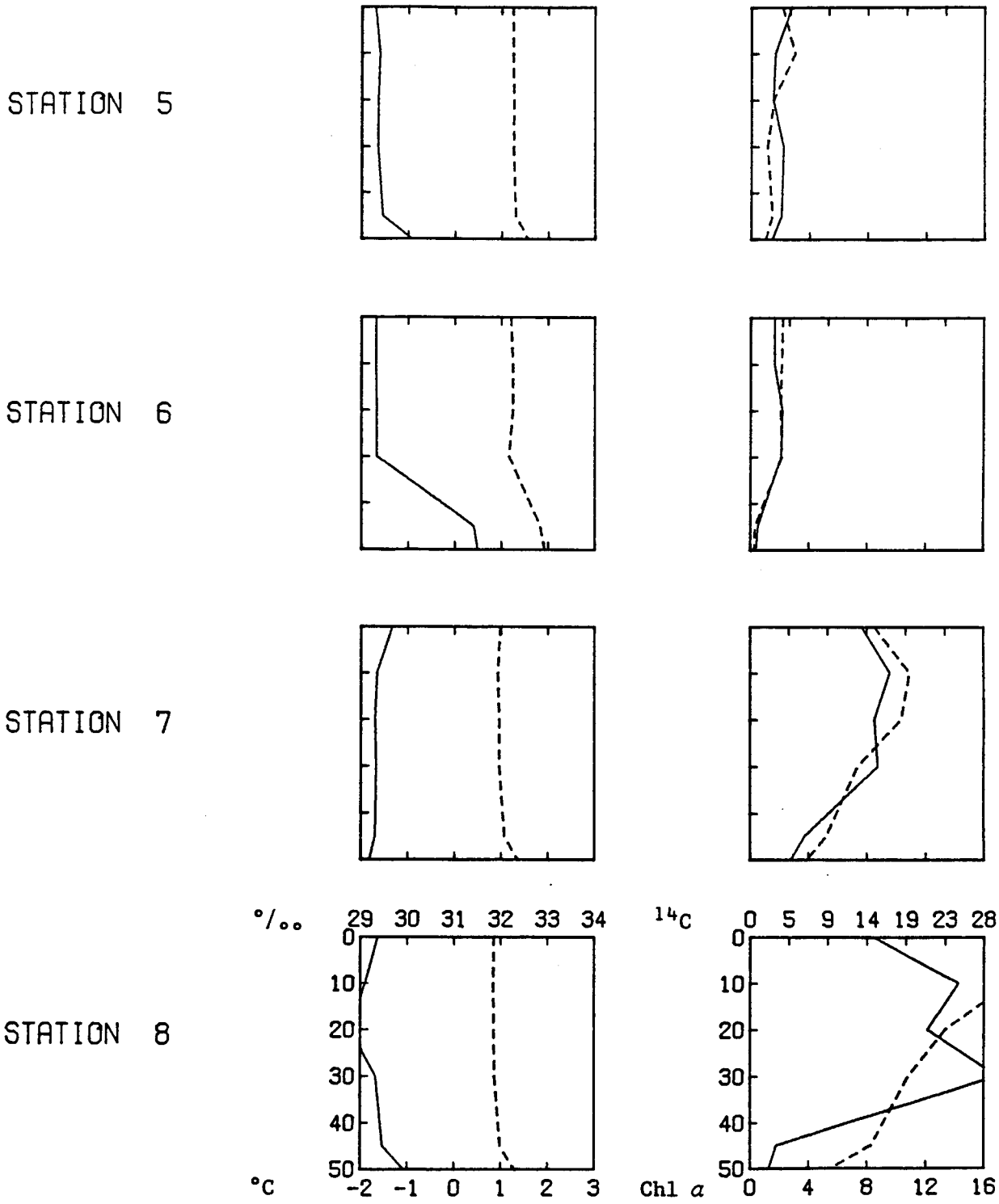


Fig. 4. Depth profiles of temperature-salinity and chlorophyll *a*-primary productivity in the Bering Sea, 4 May-24 June 1980. Salinity (°/₀₀) ---; temperature (°C) ___; primary productivity (mg C m^{-3} hr^{-1}) ---; chlorophyll *a* (mg m^{-3}) ___.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10
20
30
40
50
°C
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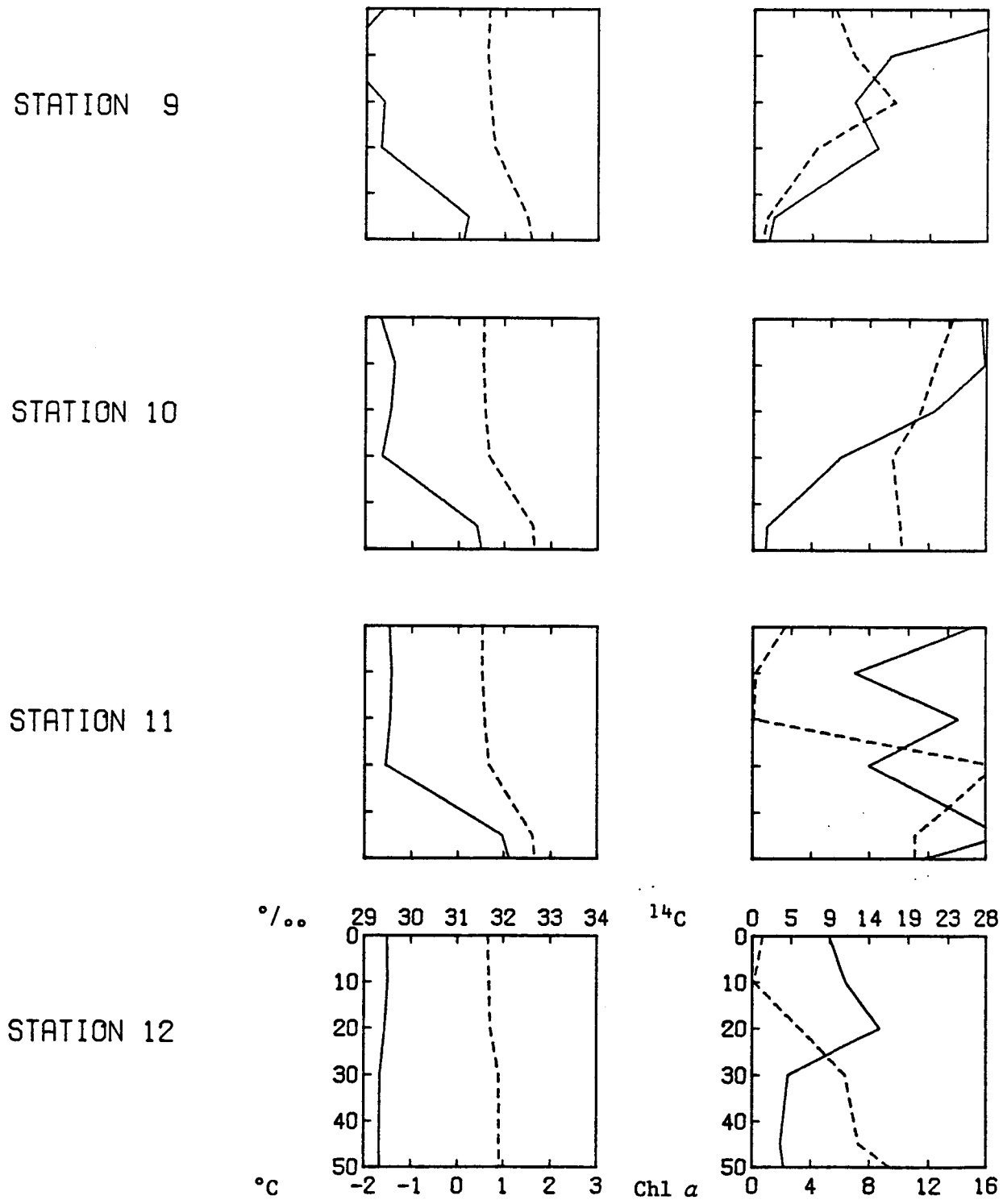
Chl a
0 4 8 12 16

Fig. 4. (cont.)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°C
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^{14}C
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Chl *a*
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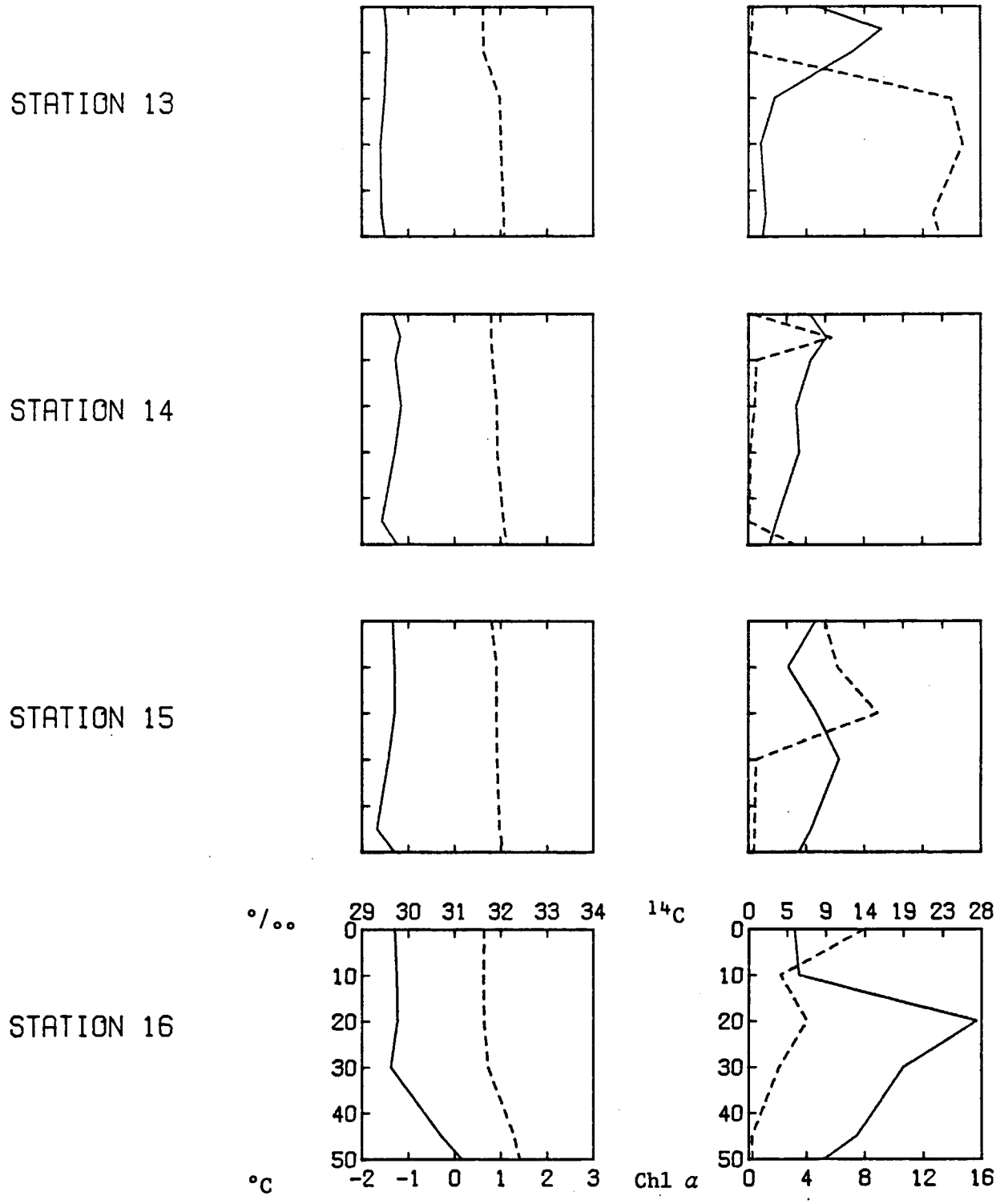
0
10
20
30
40
50

Fig. 4. (cont.)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Chl *a*
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10
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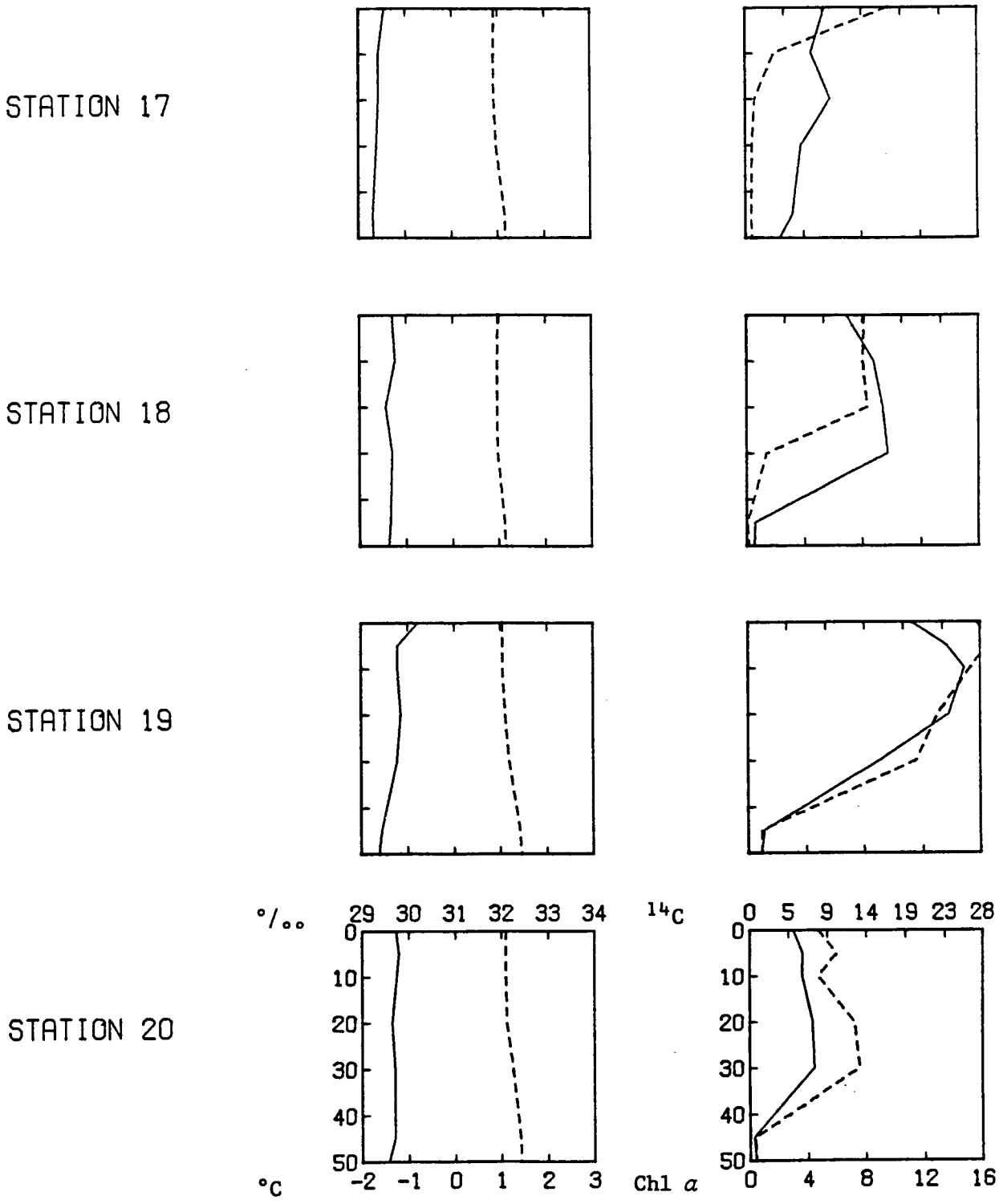
30
40
50

Fig. 4. (cont.)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STATION 19
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14C
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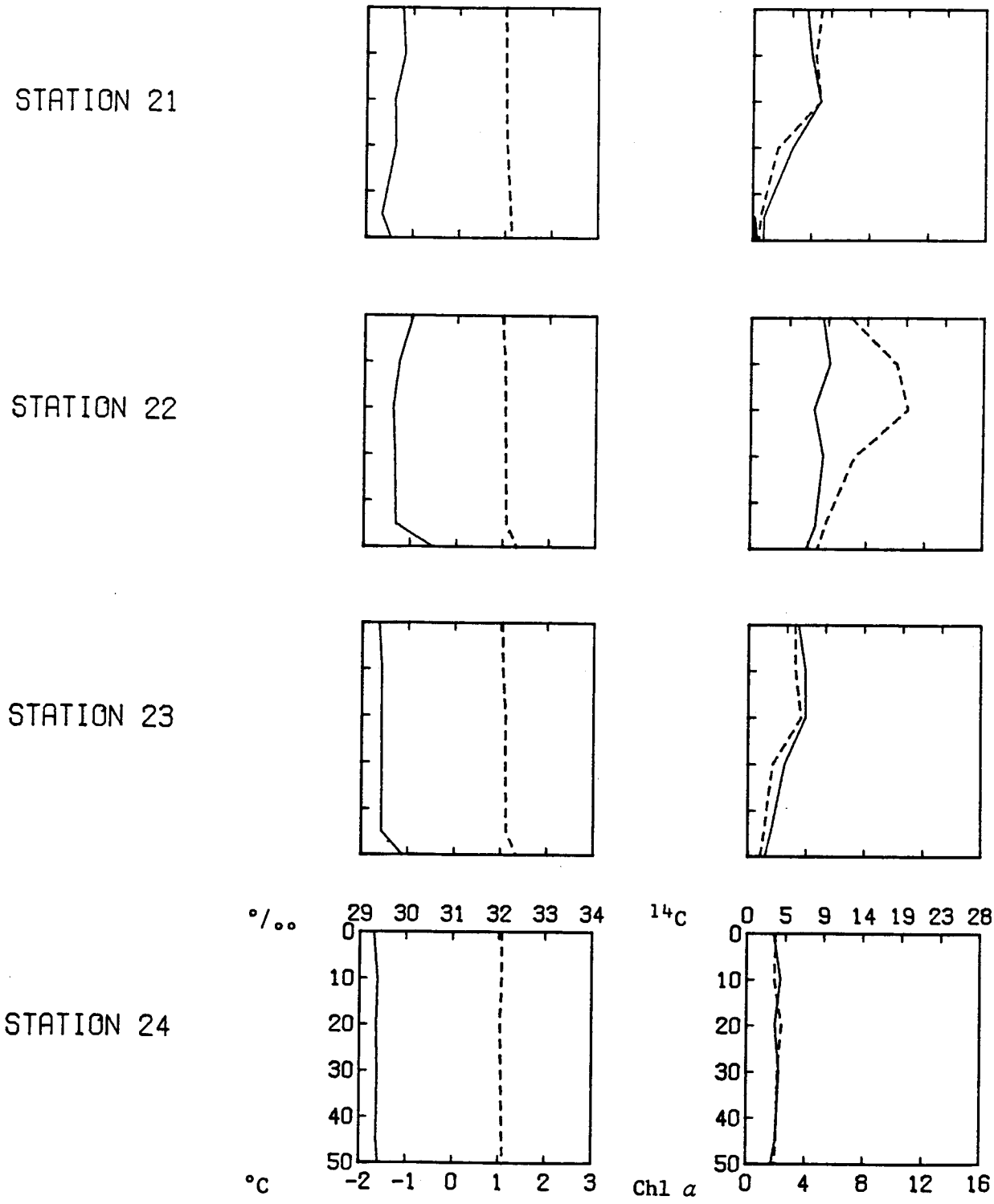
Chl a
0 4 8 12 16

Fig. 4. (cont.)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30
40
50
°C
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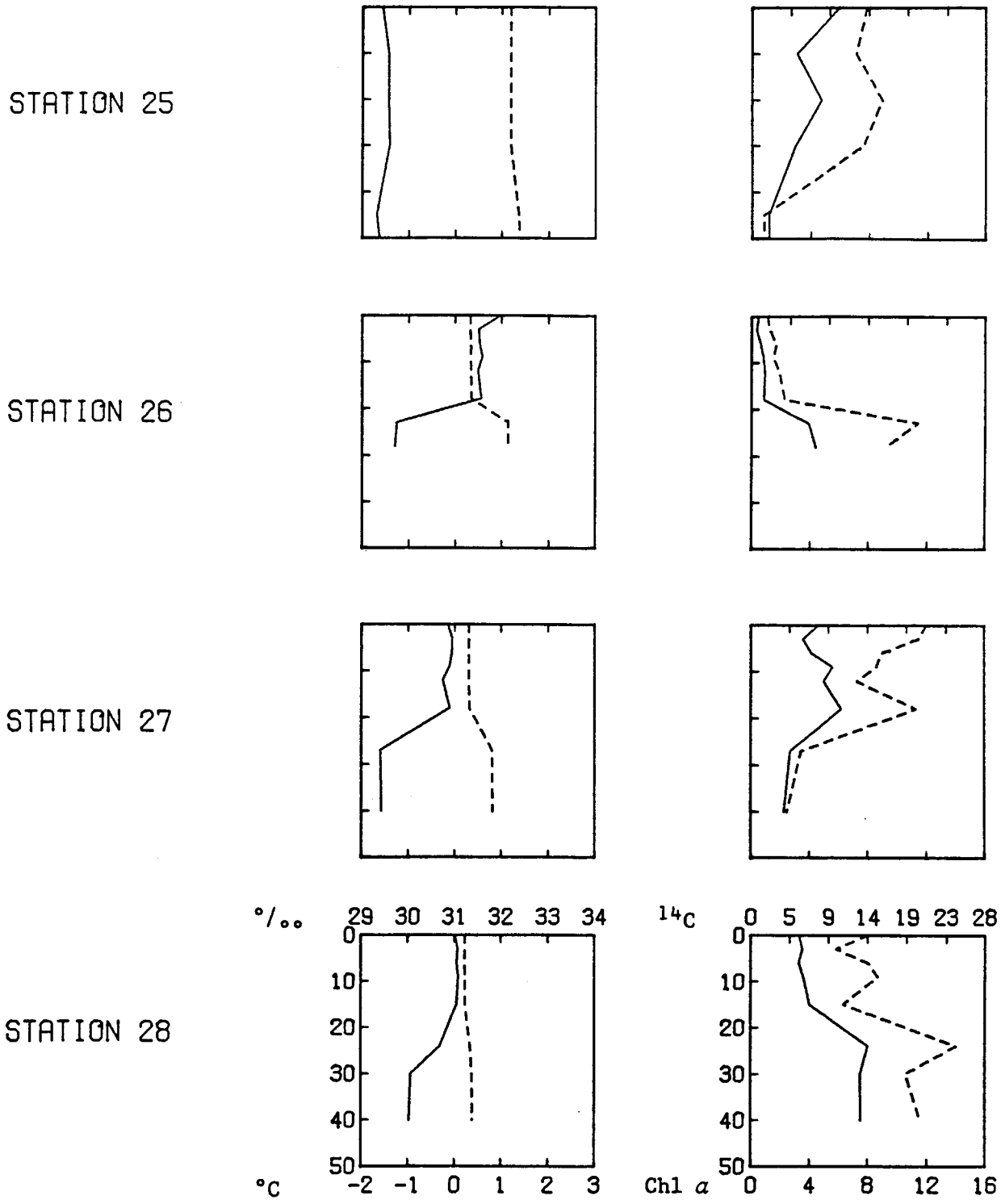
Chl *a*
0 4 8 12 16

Fig. 4. (cont.)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Chl *a*
0 4 8 12 16
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10
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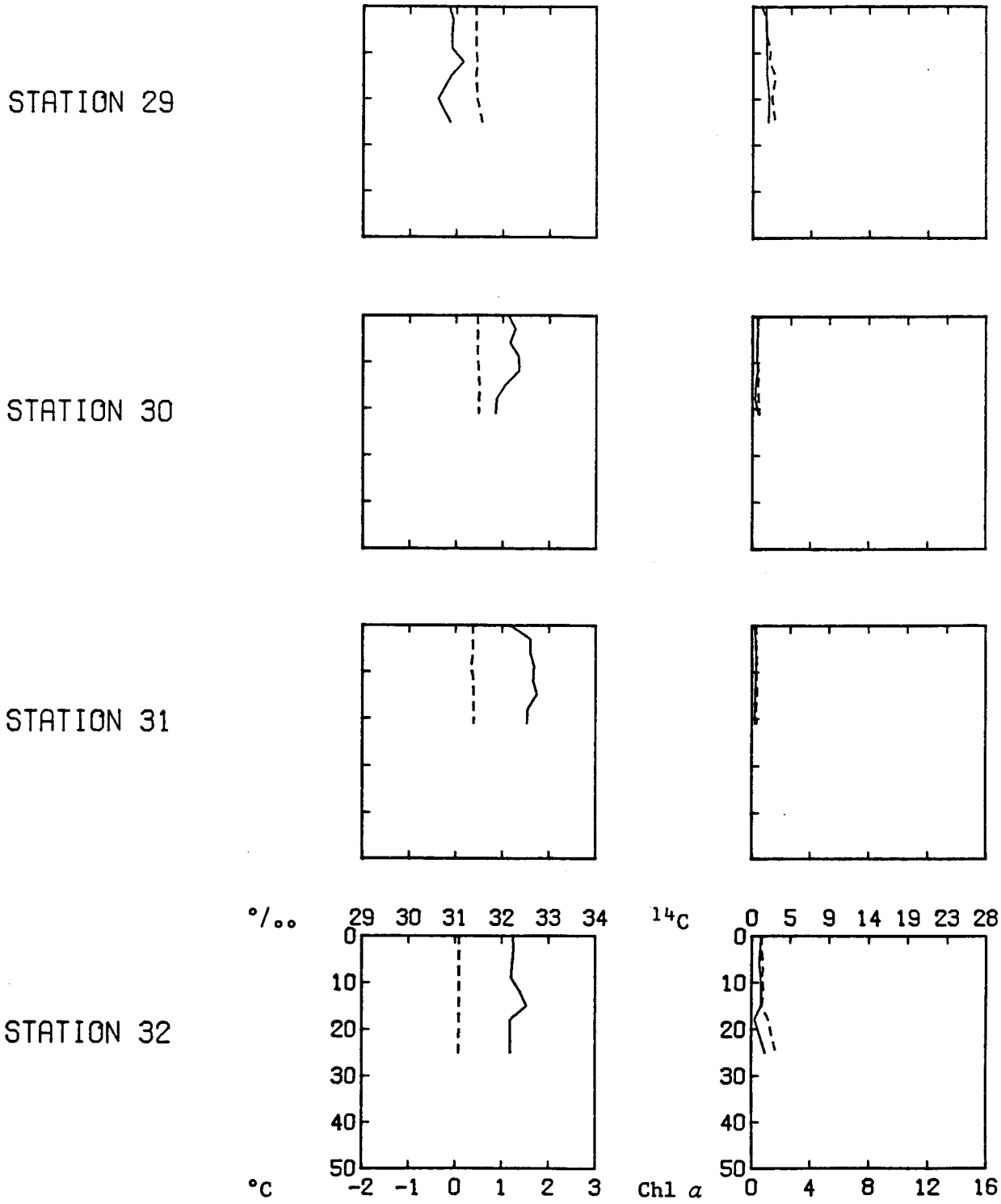
50

Fig. 4. (cont.)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STATION 31
STATION 32
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^{14}C
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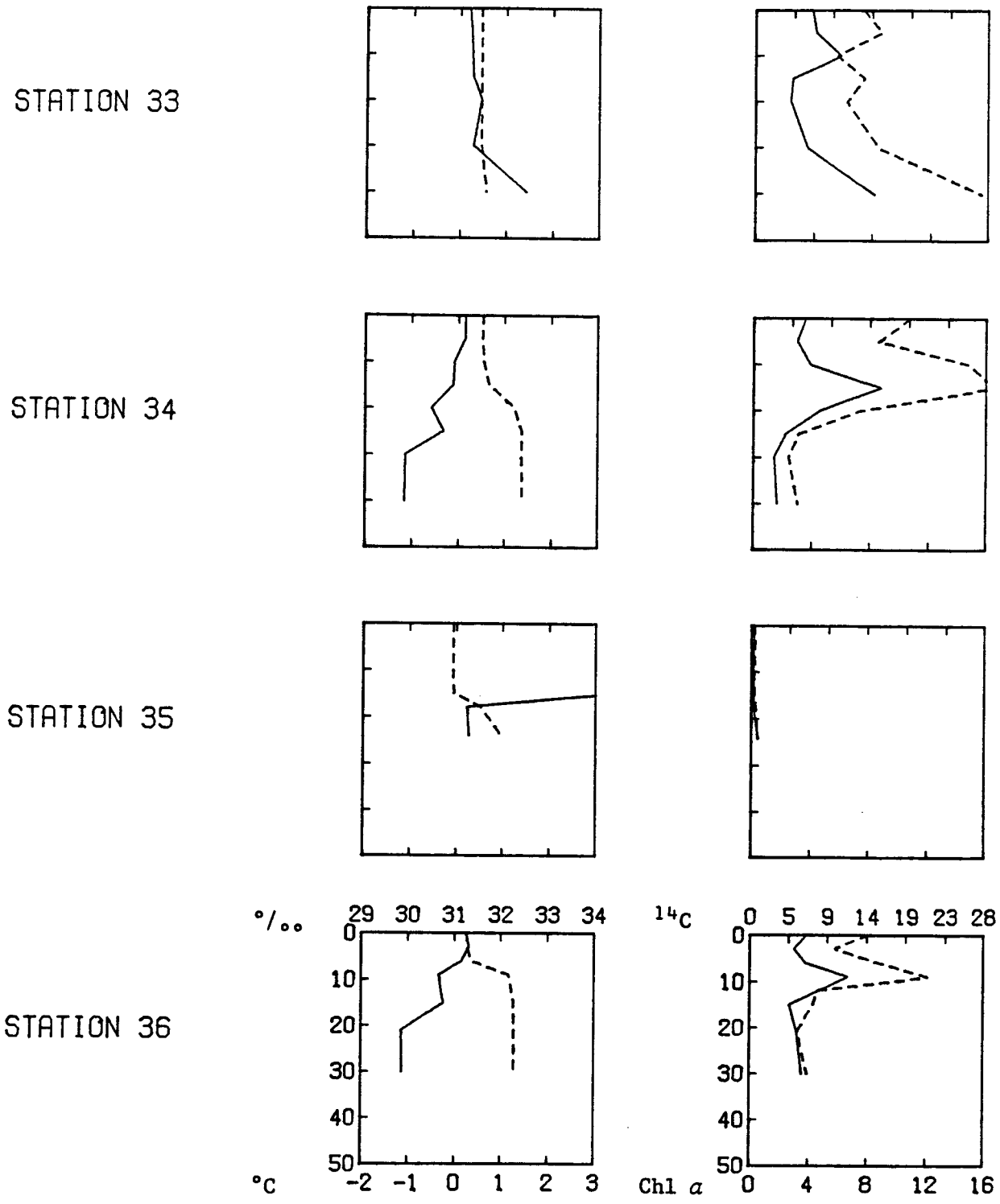
30
40
50
°C
-2 -1 0 1 2 3
Chl *a*
0 4 8 12 16

Fig. 4. (cont.)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STATION 34
STATION 35
STATION 36
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0
10
20
30
40
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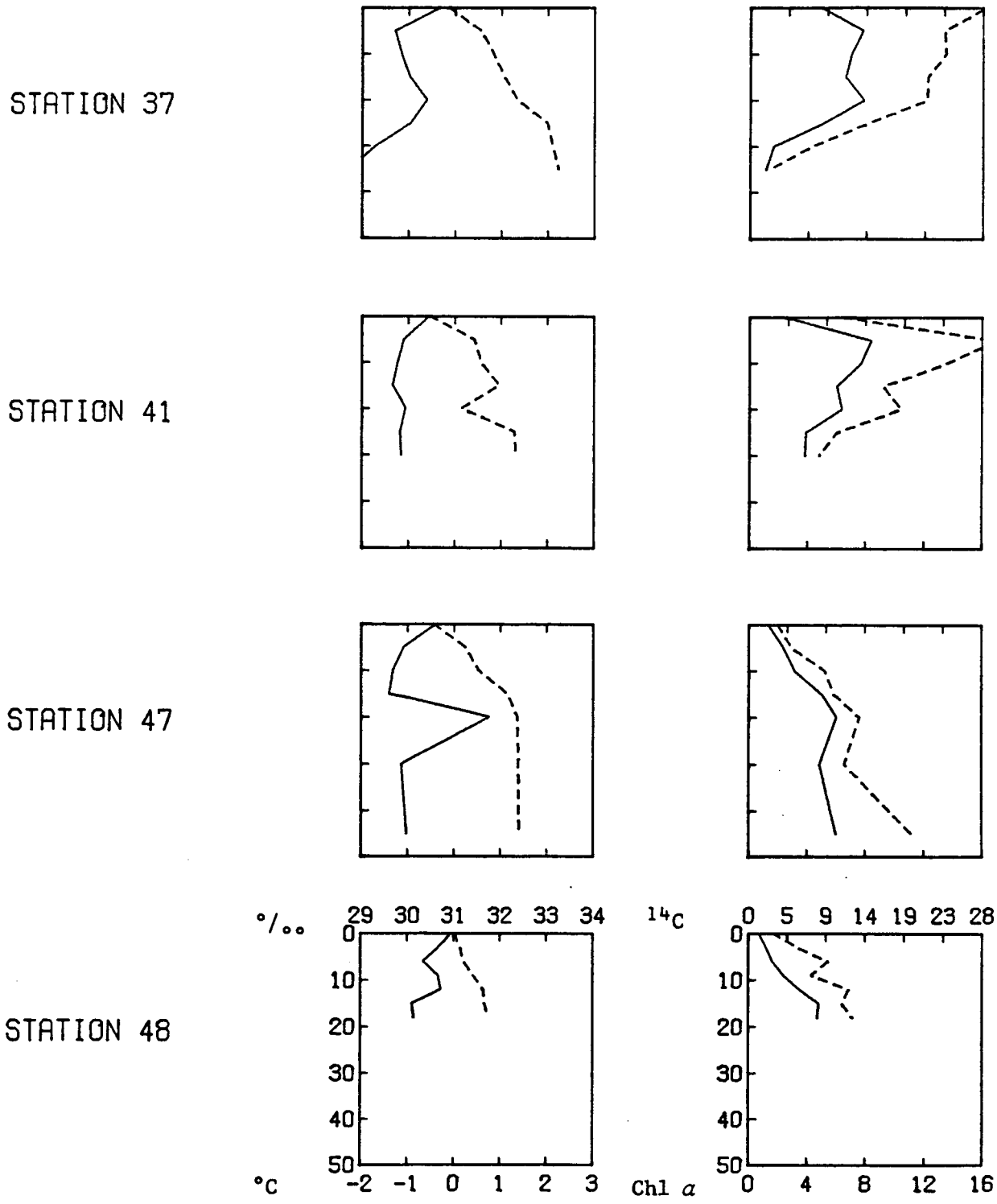
°C
-2 -1 0 1 2 3
14C
0 5 9 14 19 23 28
Chl a
0 4 8 12 16

Fig. 4. (cont.)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STATION 47
STATION 48
°/₀₀
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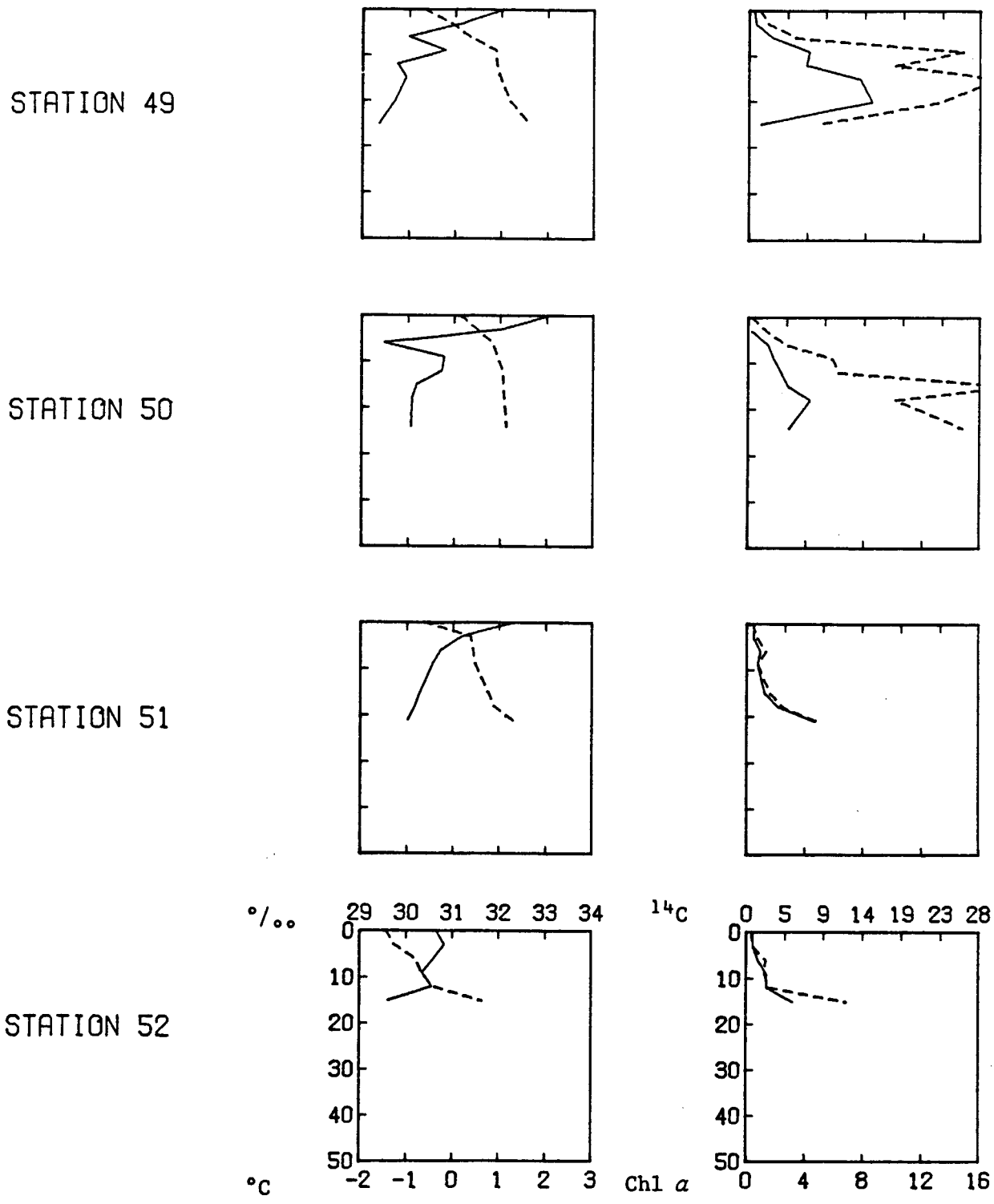
°C
-2 -1 0 1 2 3
^{14}C
0 5 9 14 19 23 28
Chl a
0 4 8 12 16
0
10
20
30
40
50

Fig. 4. (cont.)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STATION 51
STATION 52
°/₀₀
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0
10
20
30
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50
-2 -1 0 1 2 3
°C
^{14}C
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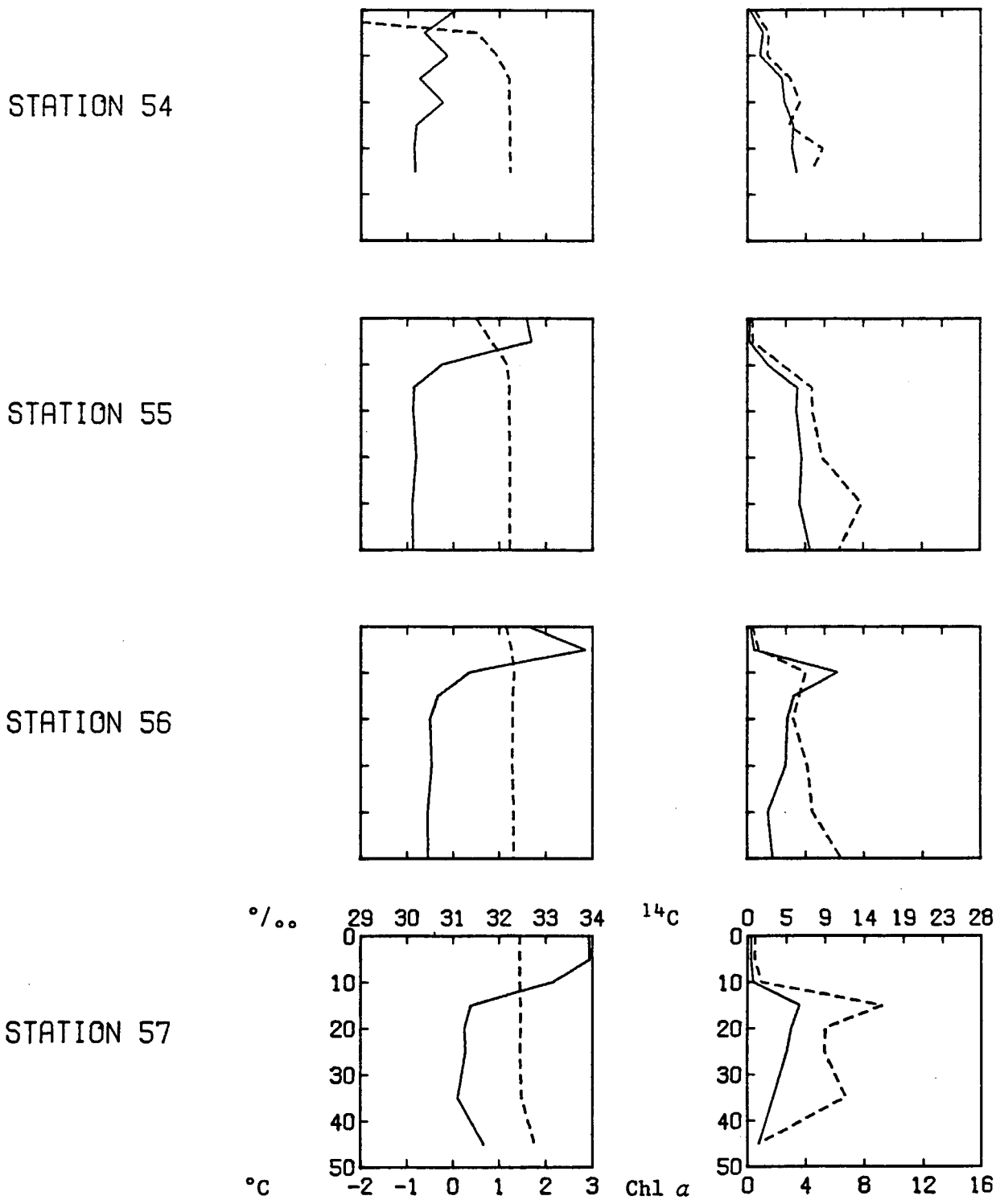
Chl *a*
0 4 8 12 16

Fig. 4. (cont.)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STATION 55
STATION 56
STATION 57
°/₀₀
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^{14}C
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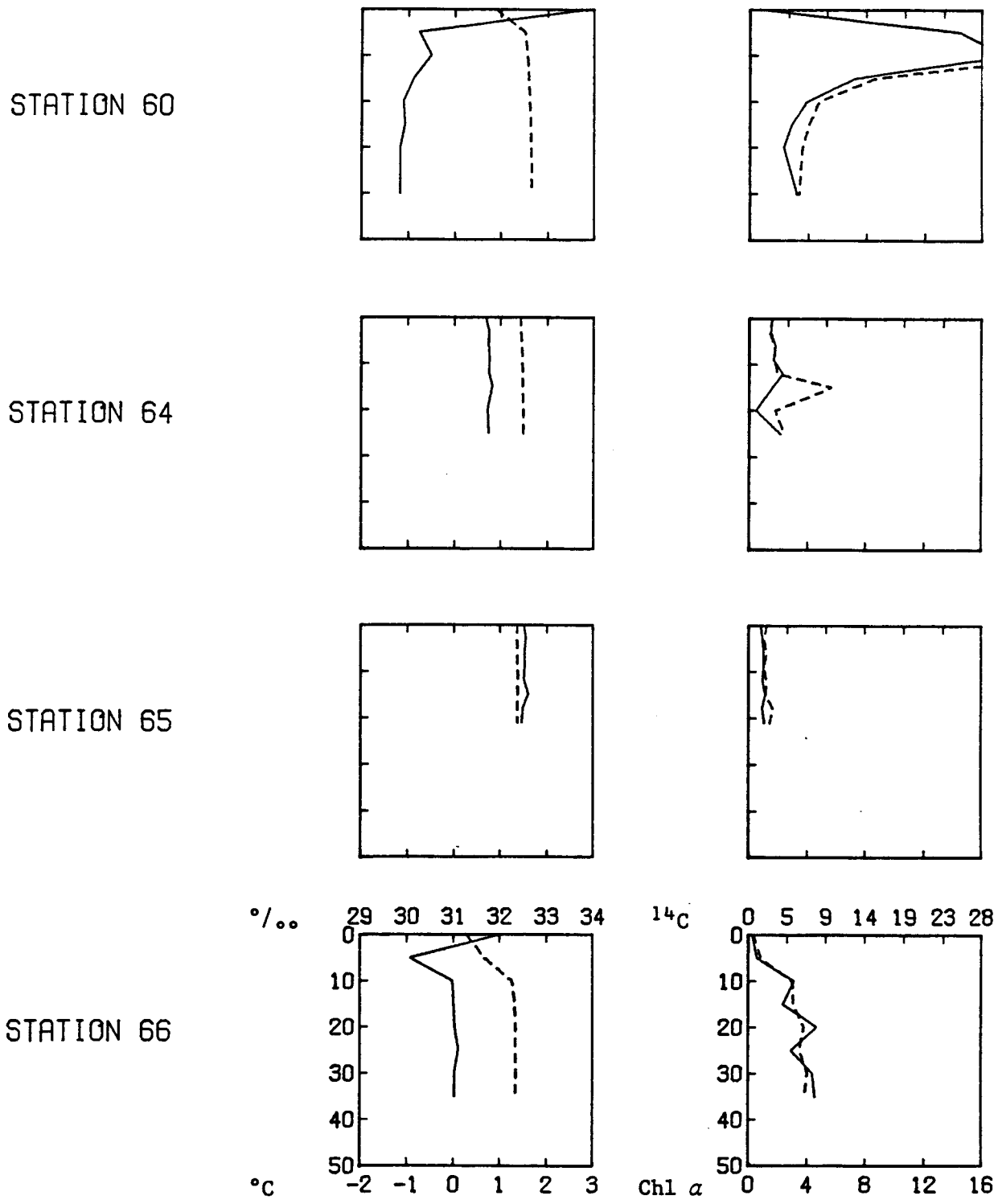
0
10
20
30
40
50
°C
-2 -1 0 1 2 3
Chl *a*
0 4 8 12 16

Fig. 4. (cont.)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STATION 64
STATION 65
STATION 66
°/₀₀
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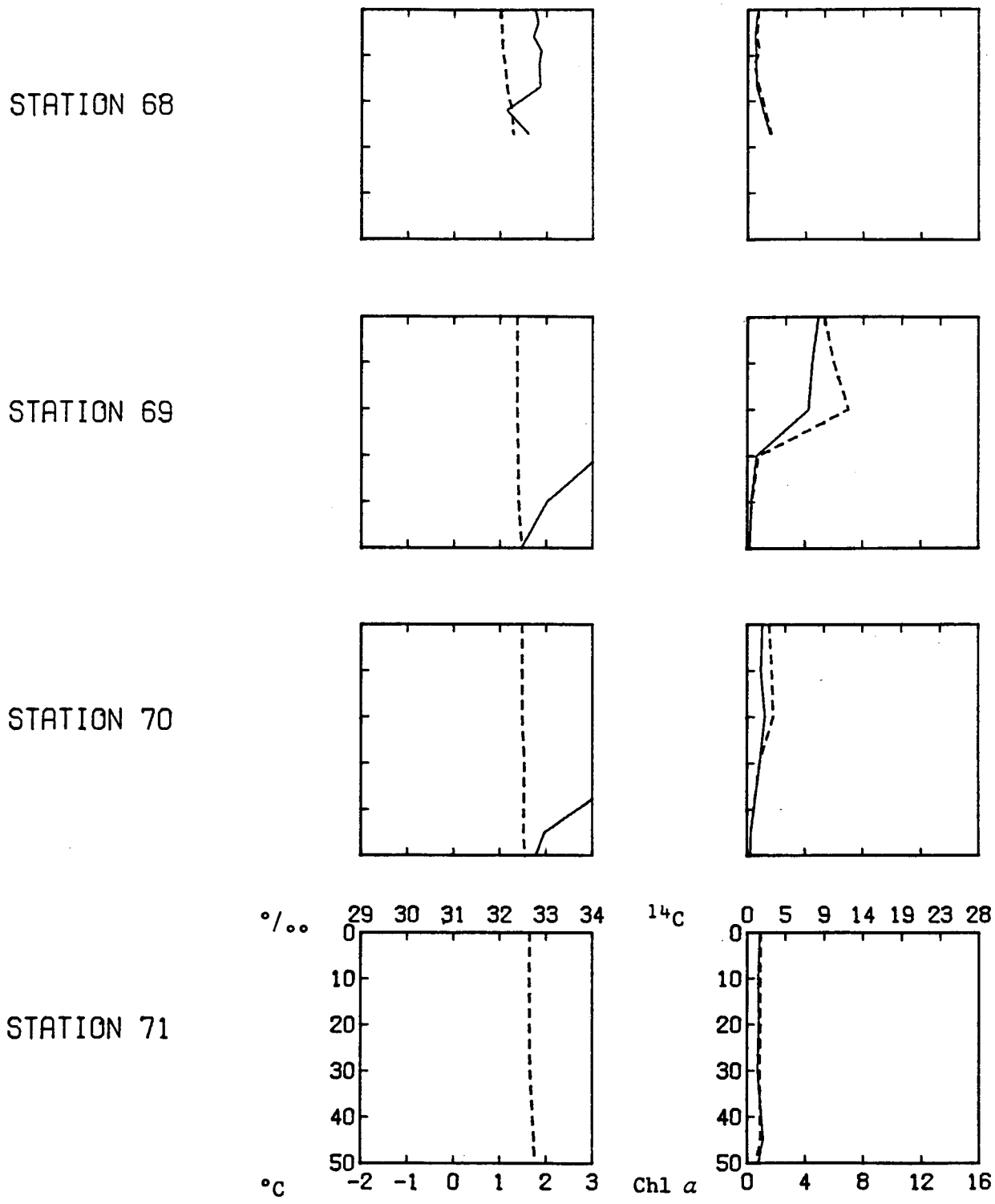
0
10
20
30
40
50
°C
-2 -1 0 1 2 3
^{14}C
0 5 9 14 19 23 28
Chl *a*
0 4 8 12 16

Fig. 4. (cont.)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STATION 71
°/₀₀
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0
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°C
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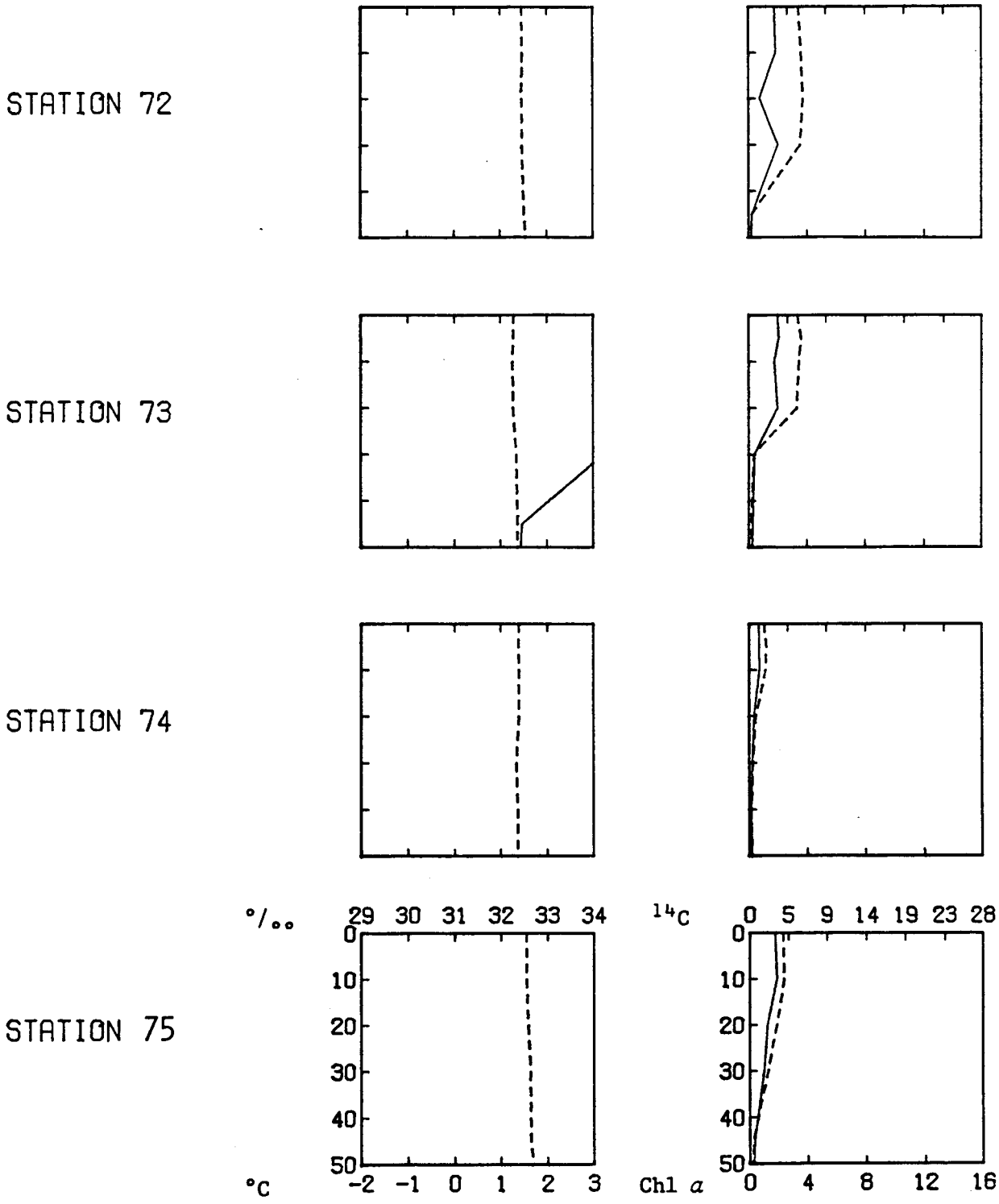
14C
0 5 9 14 19 23 28
Chl a
0 4 8 12 16

Fig. 4. (cont.)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°/₀₀
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0
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°C
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14C
0 5 9 14 19 23 28
Chl a
0 4 8 12 16

Fig. 4. (cont.)

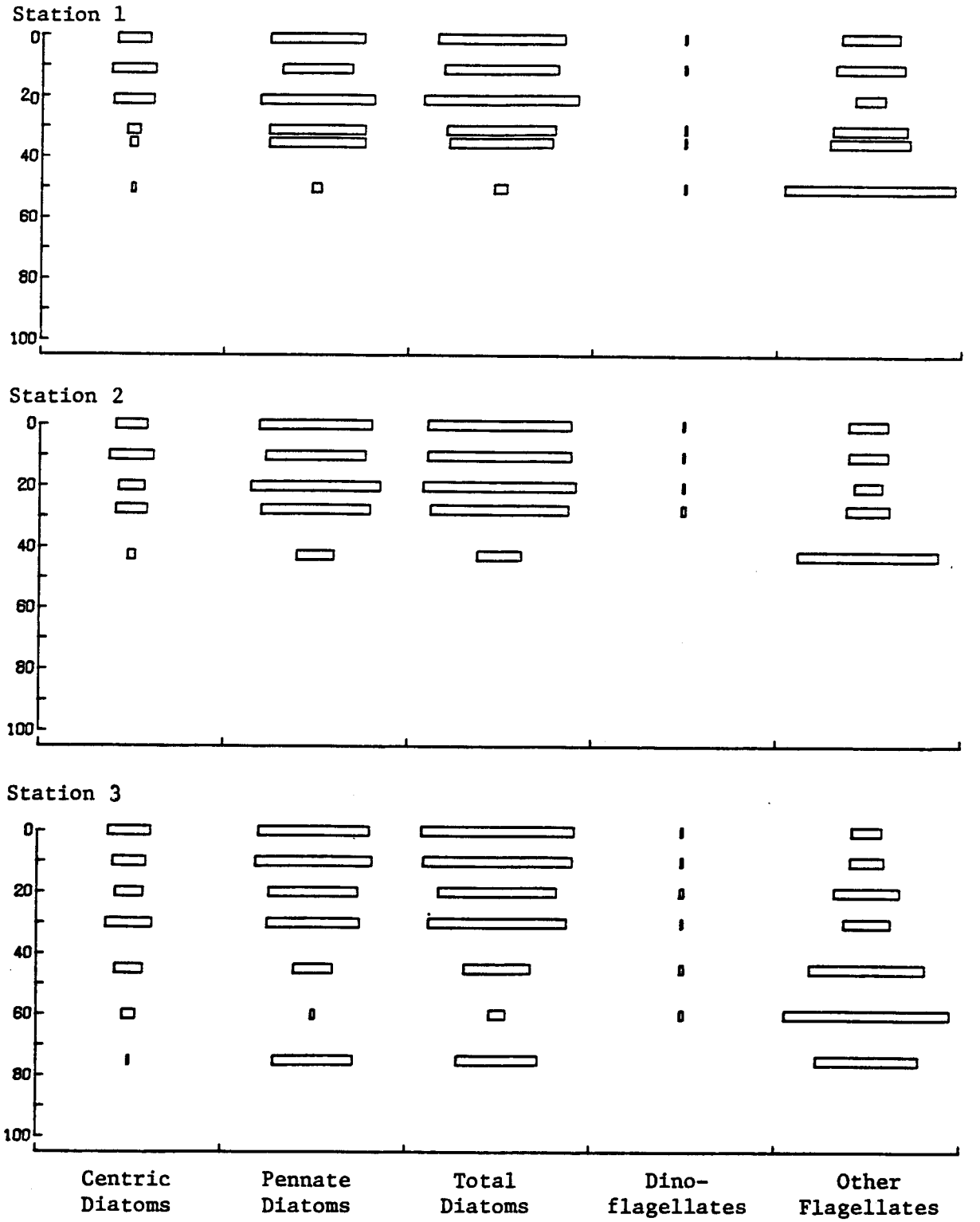
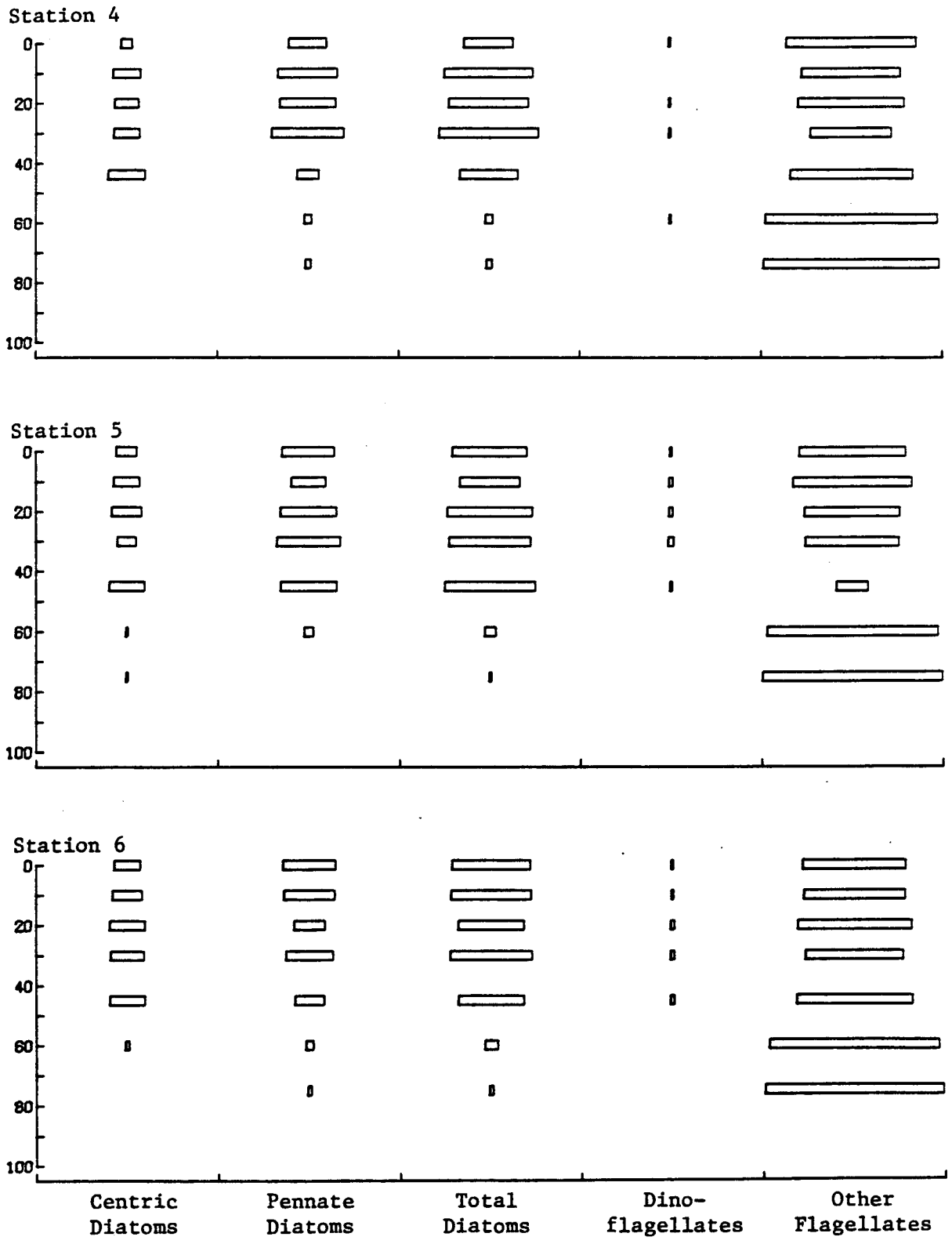


Fig. 5. Kite diagrams showing depth distribution of major categories of phytoplankton in the Bering Sea, 4 May-24 June 1980.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40
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Station 6
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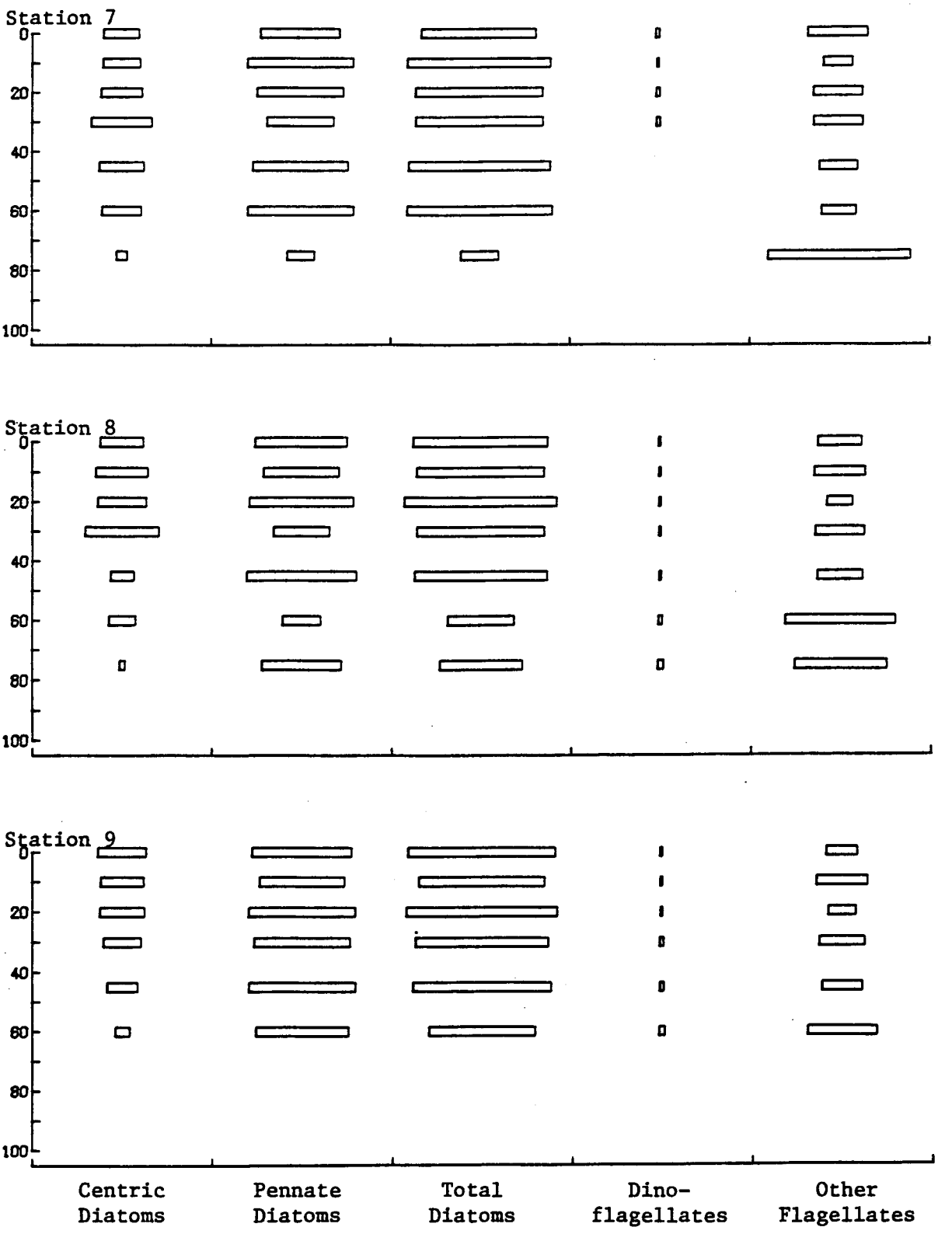
60
80
100
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)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Station 9
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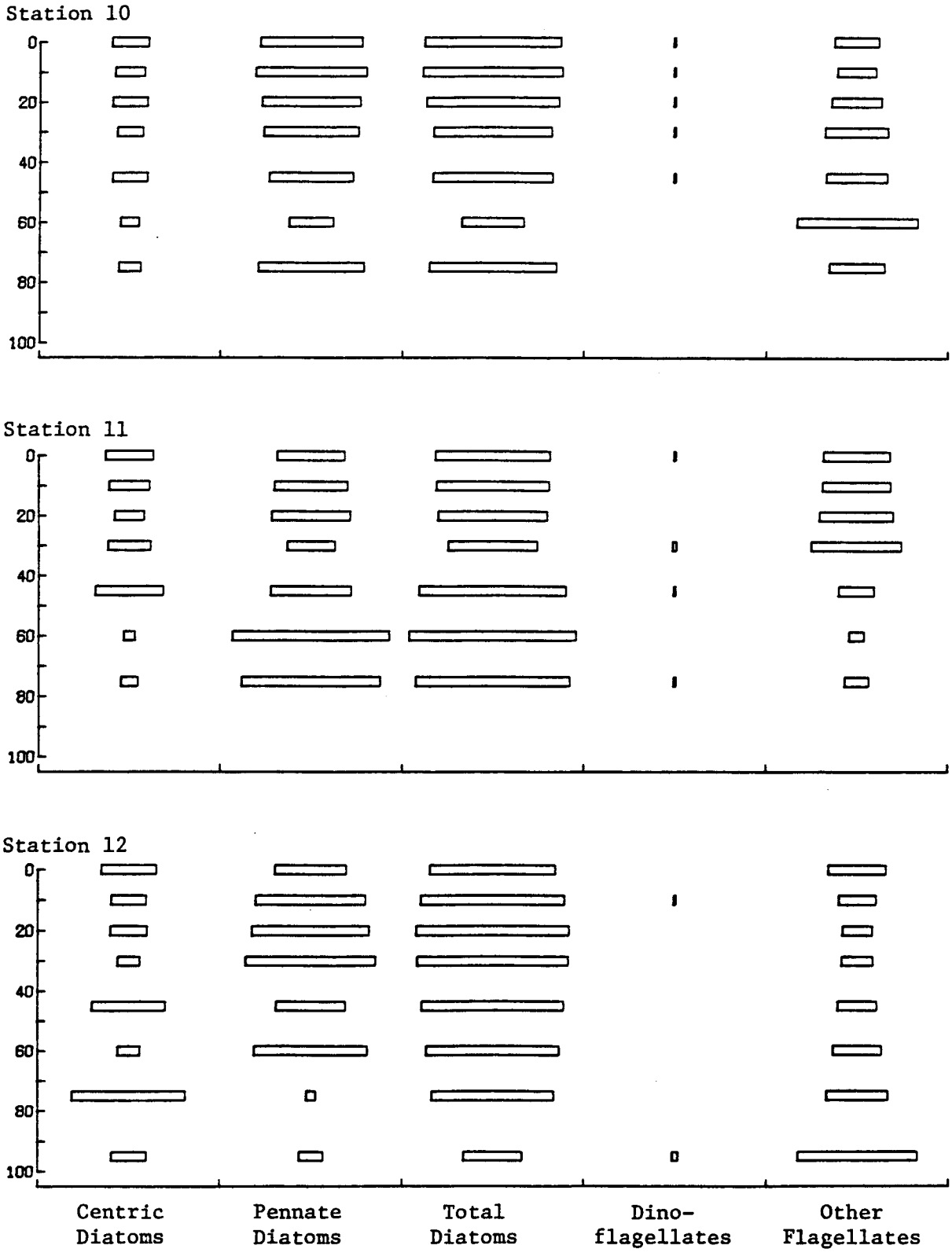
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)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Station 12
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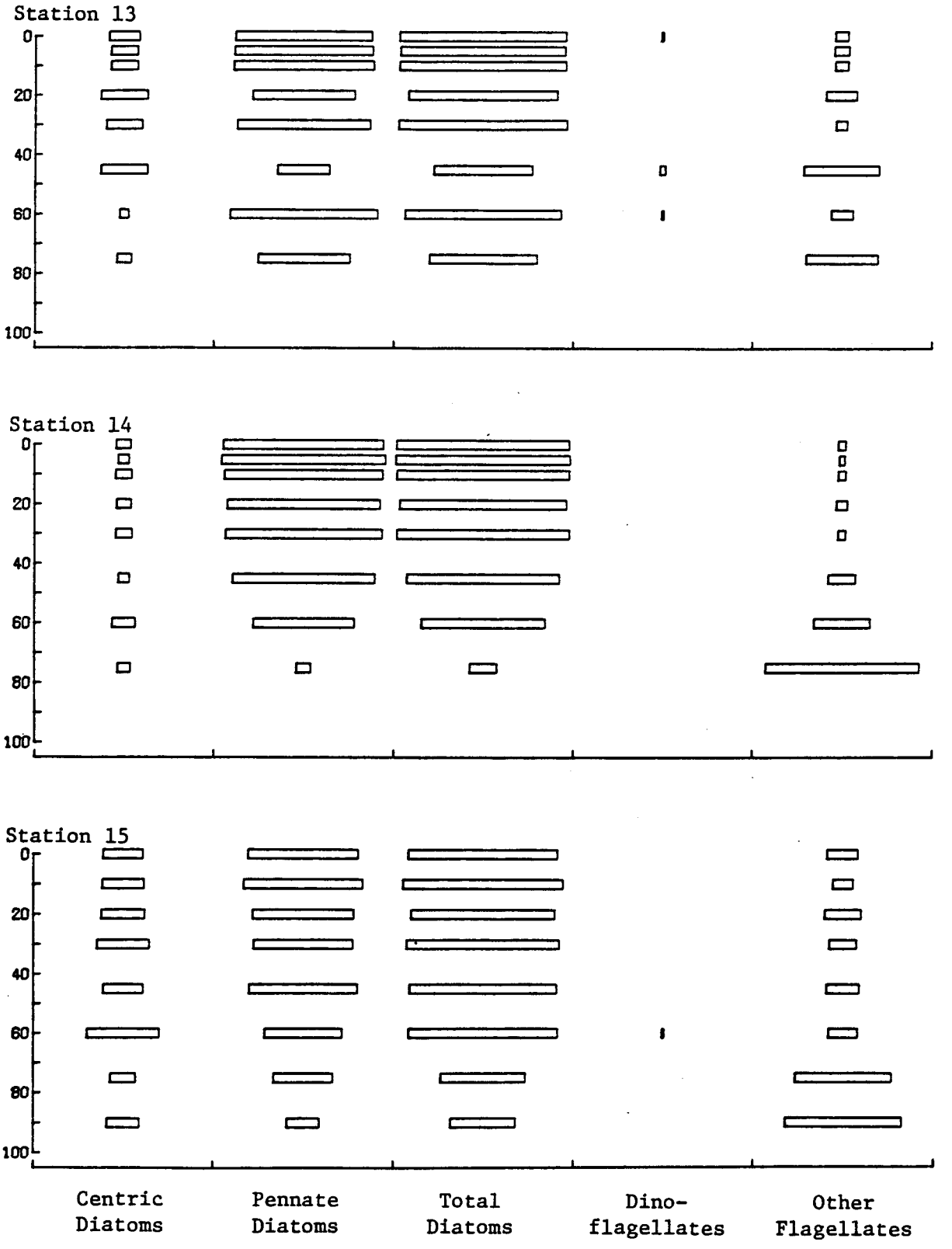
100
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)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Station 14
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Station 15
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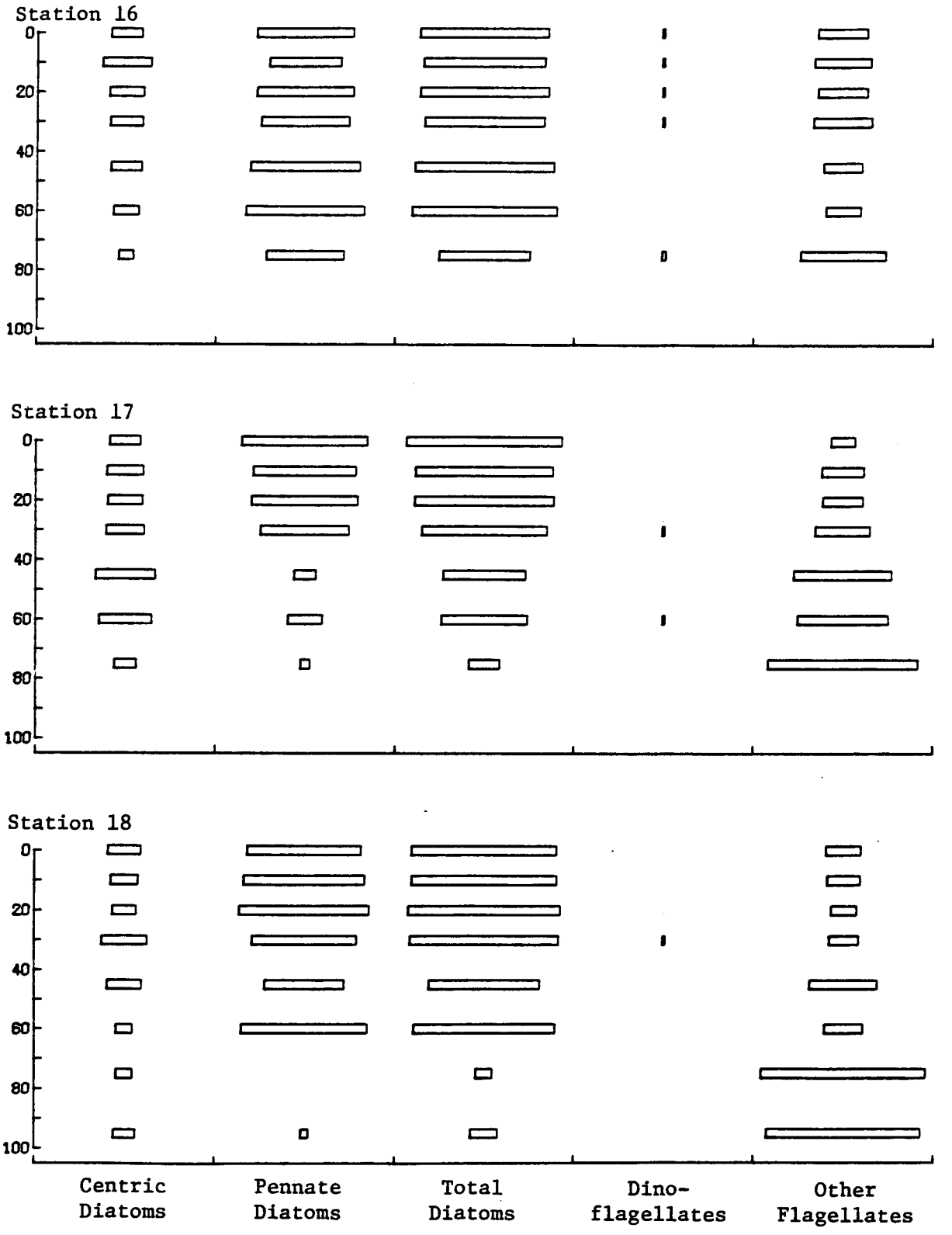
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)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Station 18
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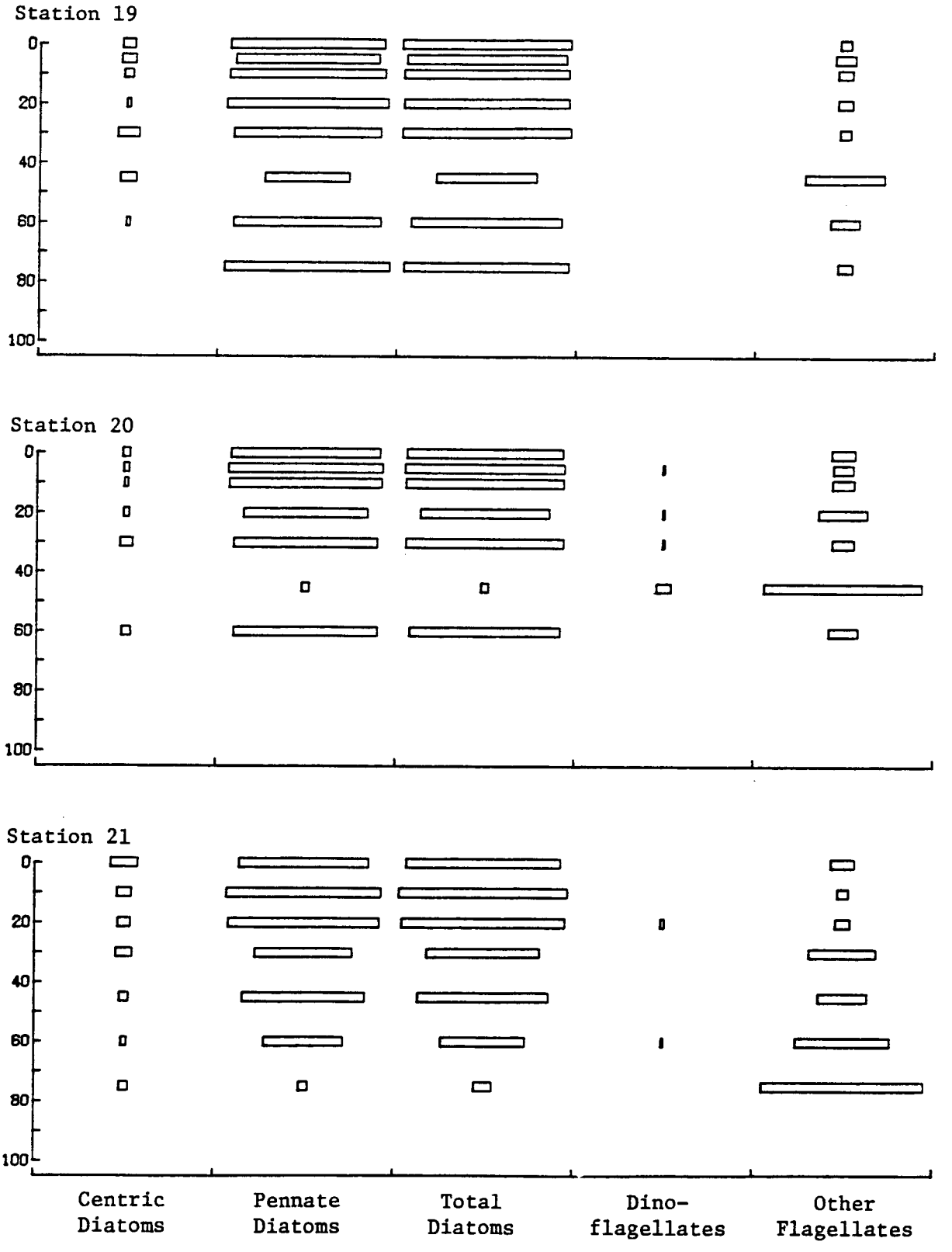
100
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)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Station 20
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80
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Station 21
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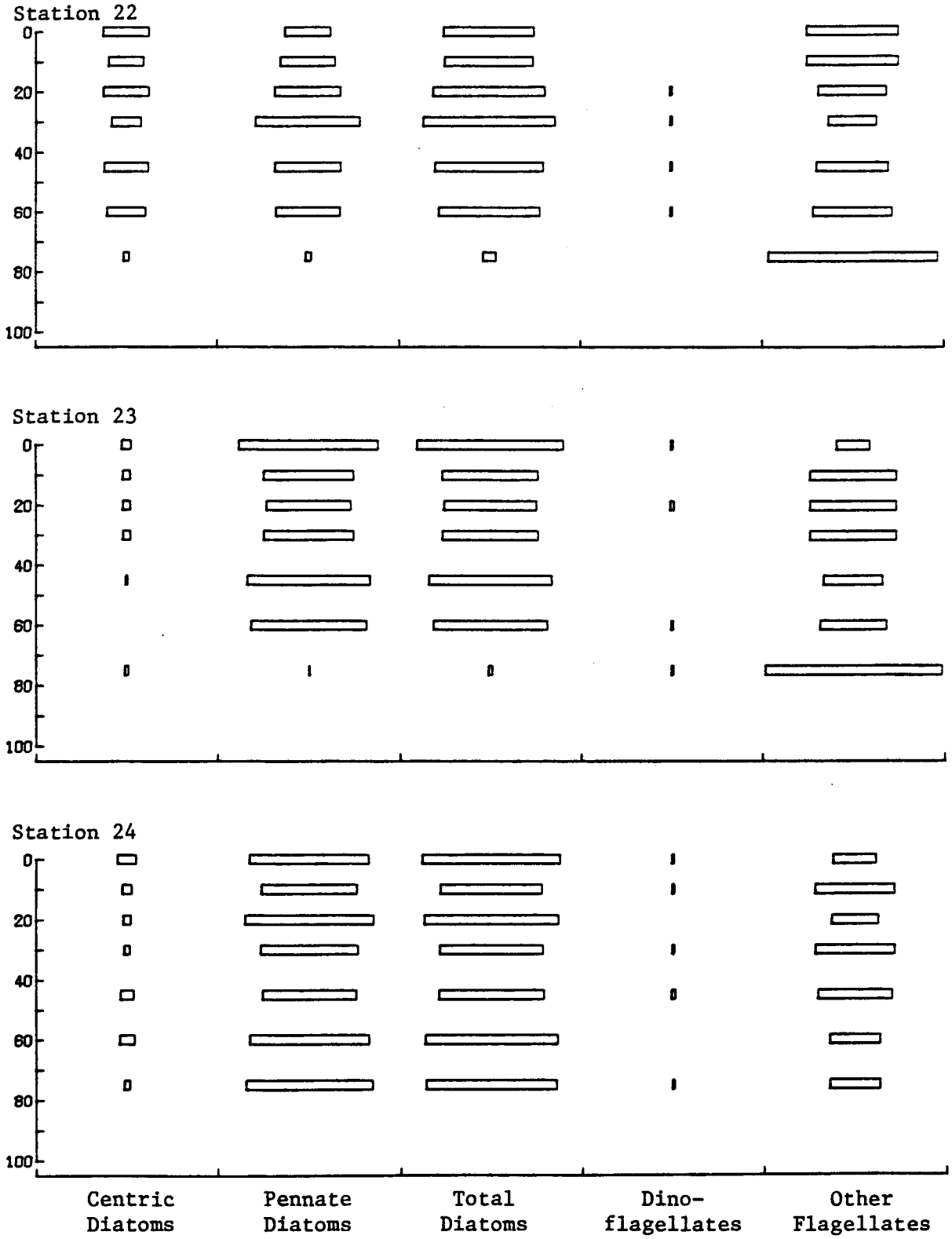
80
100
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)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Station 24
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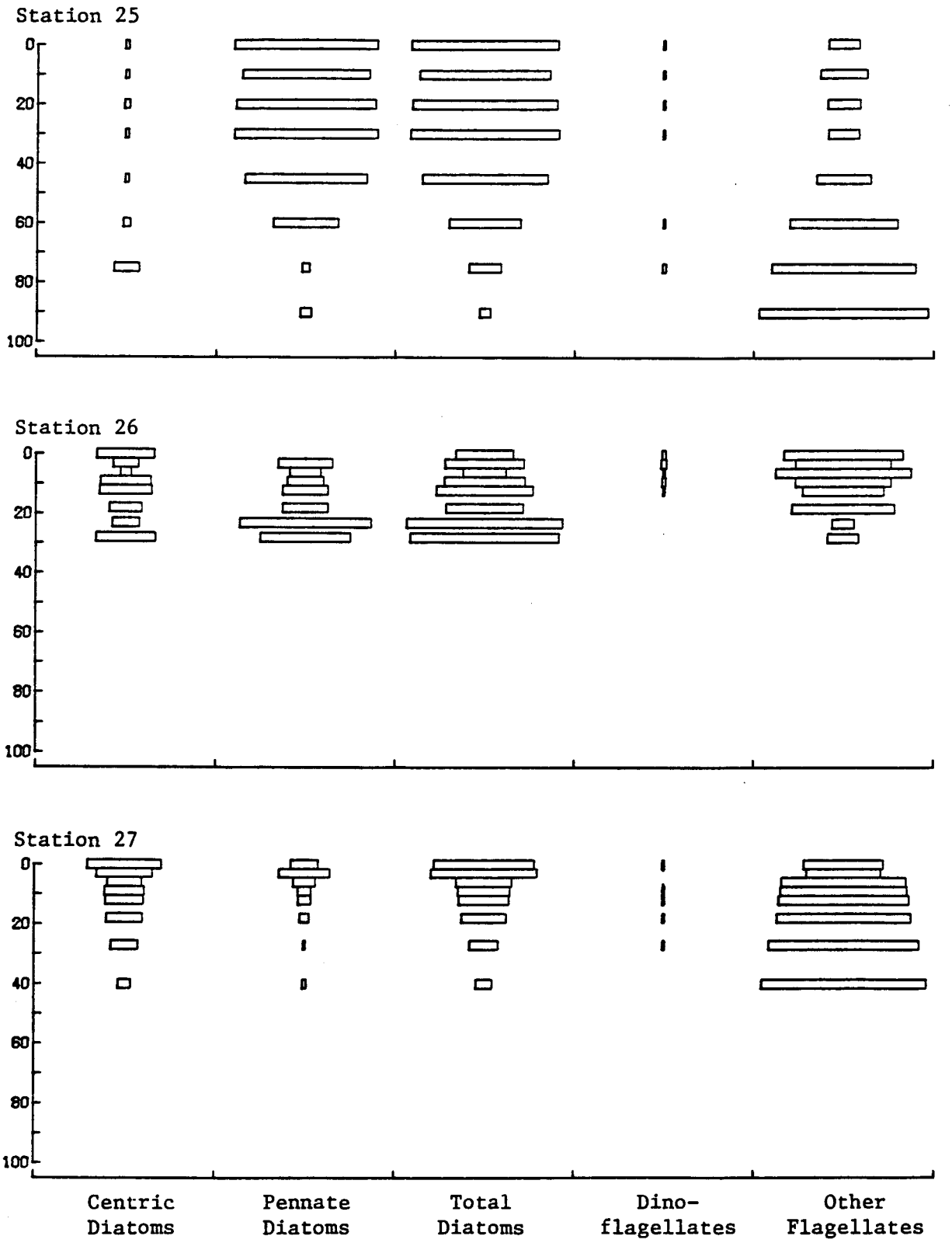
100
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)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Station 26
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80
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Station 27
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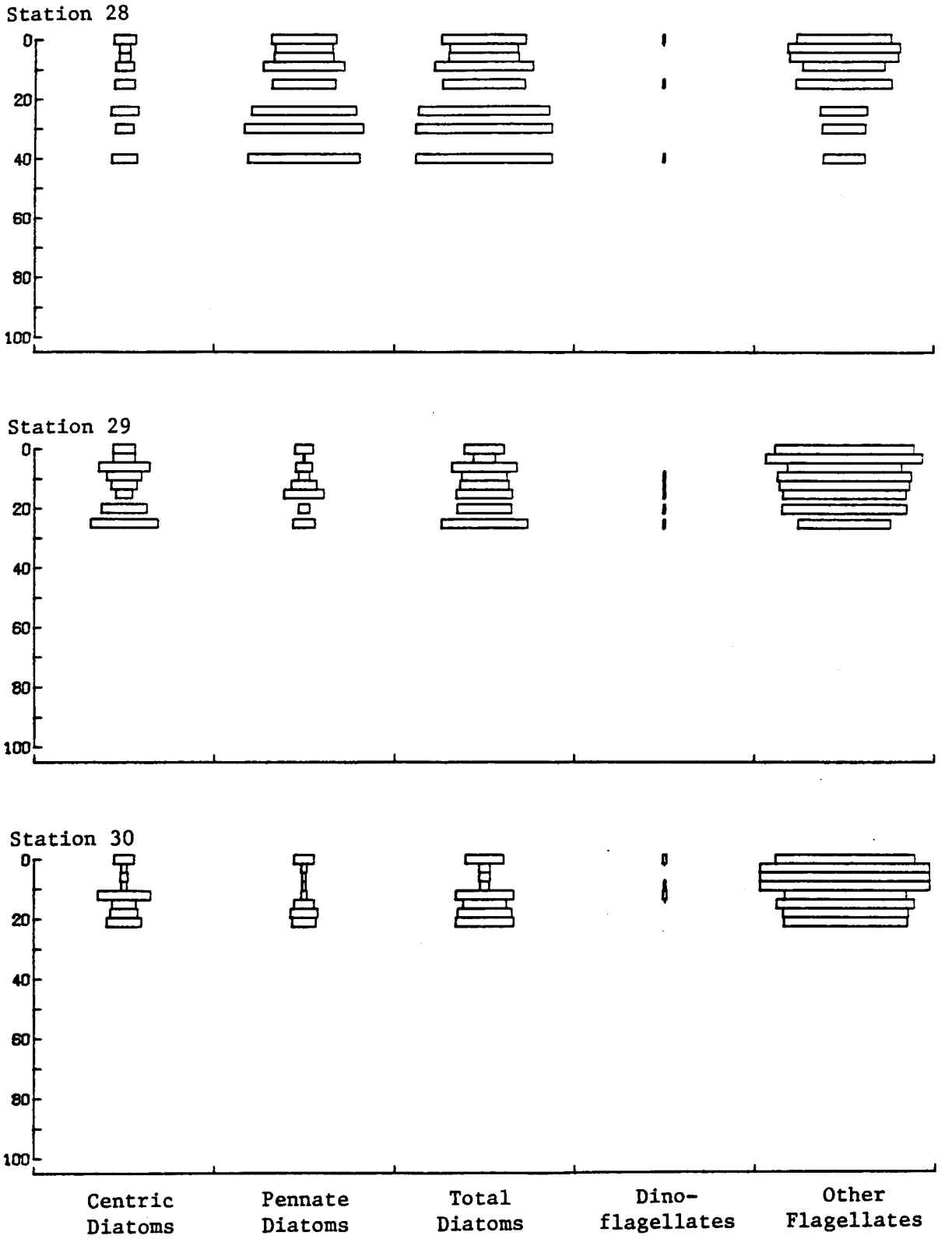
80
100
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)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Station 29
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40
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80
100
Station 30
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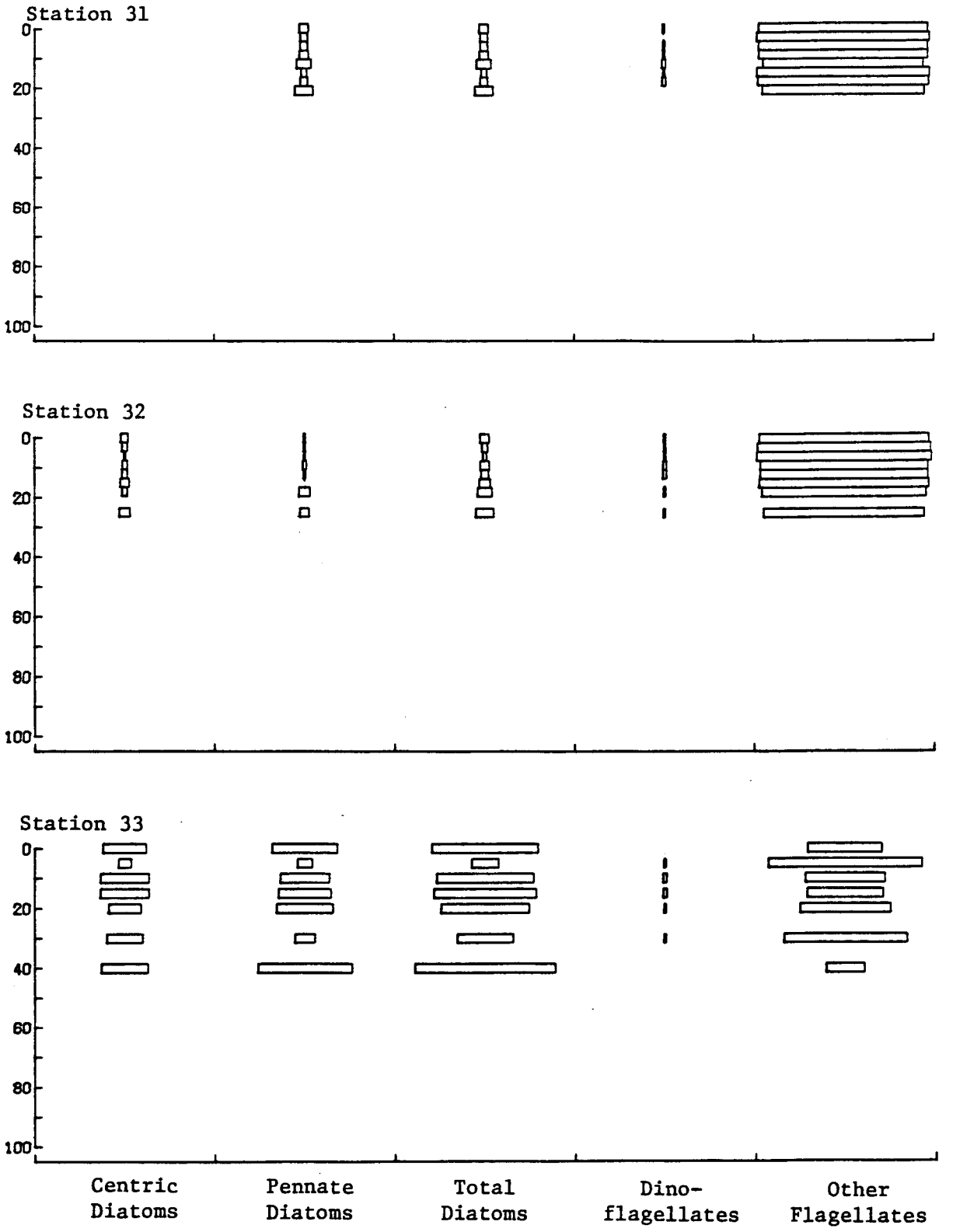
100
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)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Station 32
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60
80
100
Station 33
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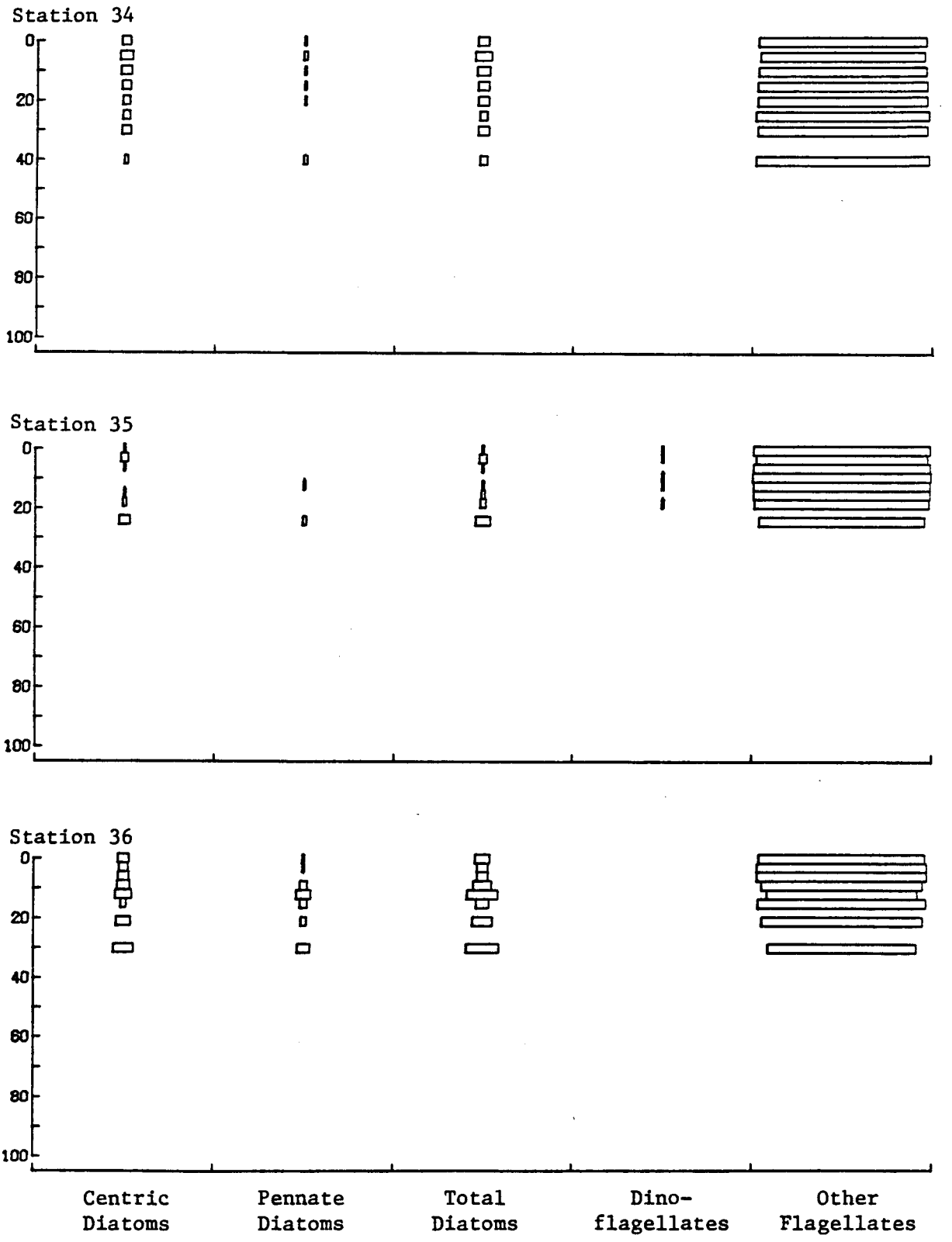
80
100
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)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Station 35
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Station 36
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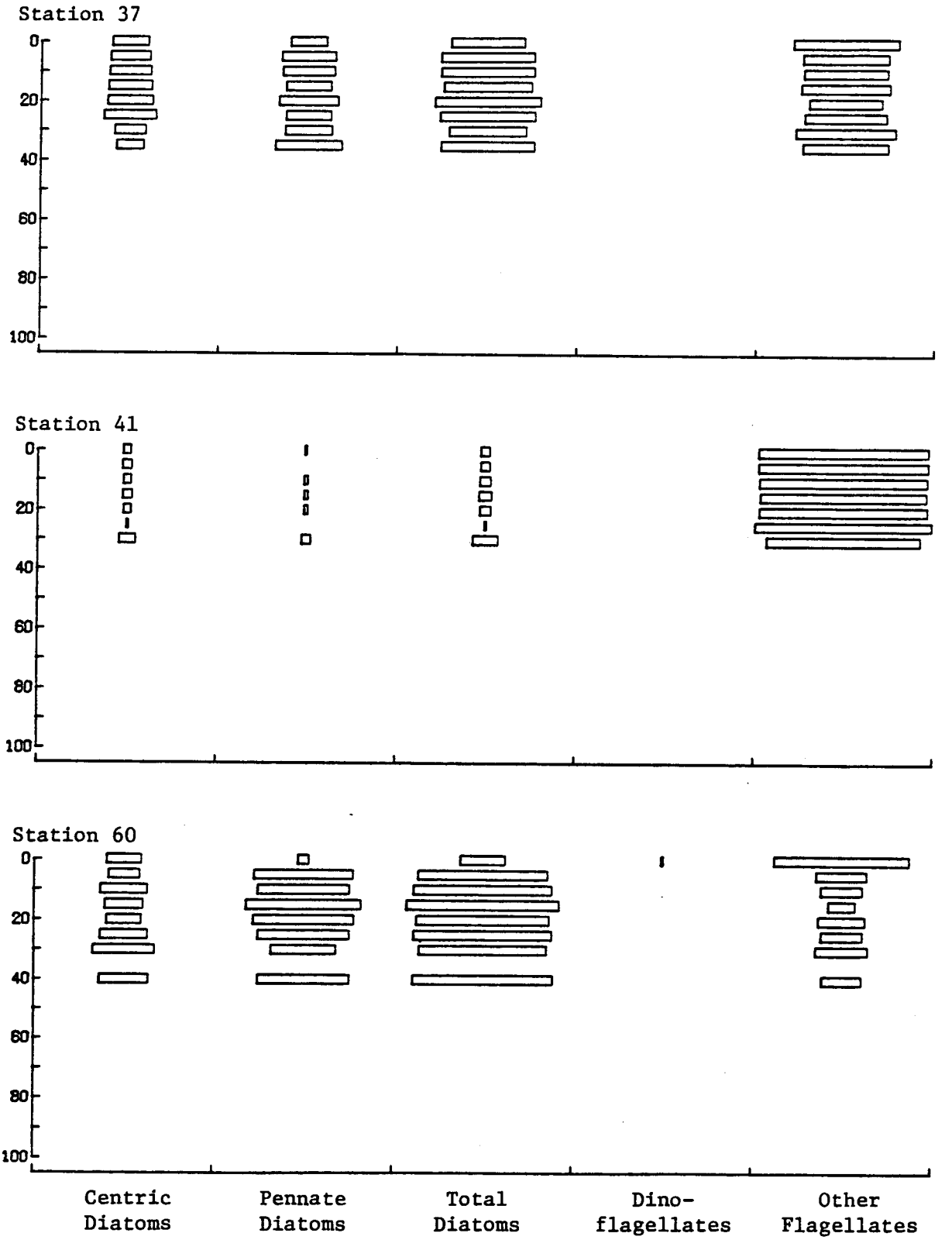
80
100
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)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Station 41
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Station 60
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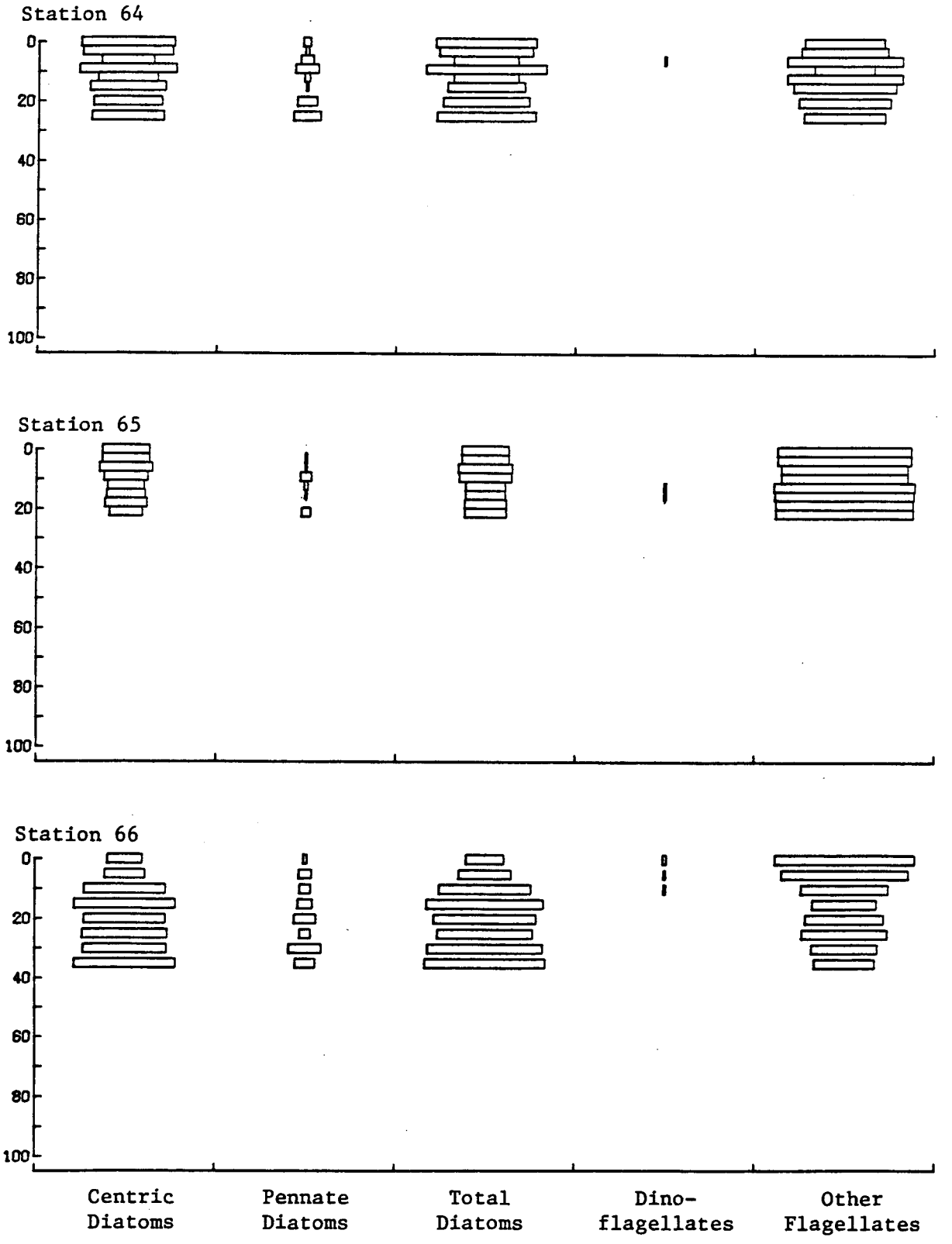
80
100
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)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Station 66
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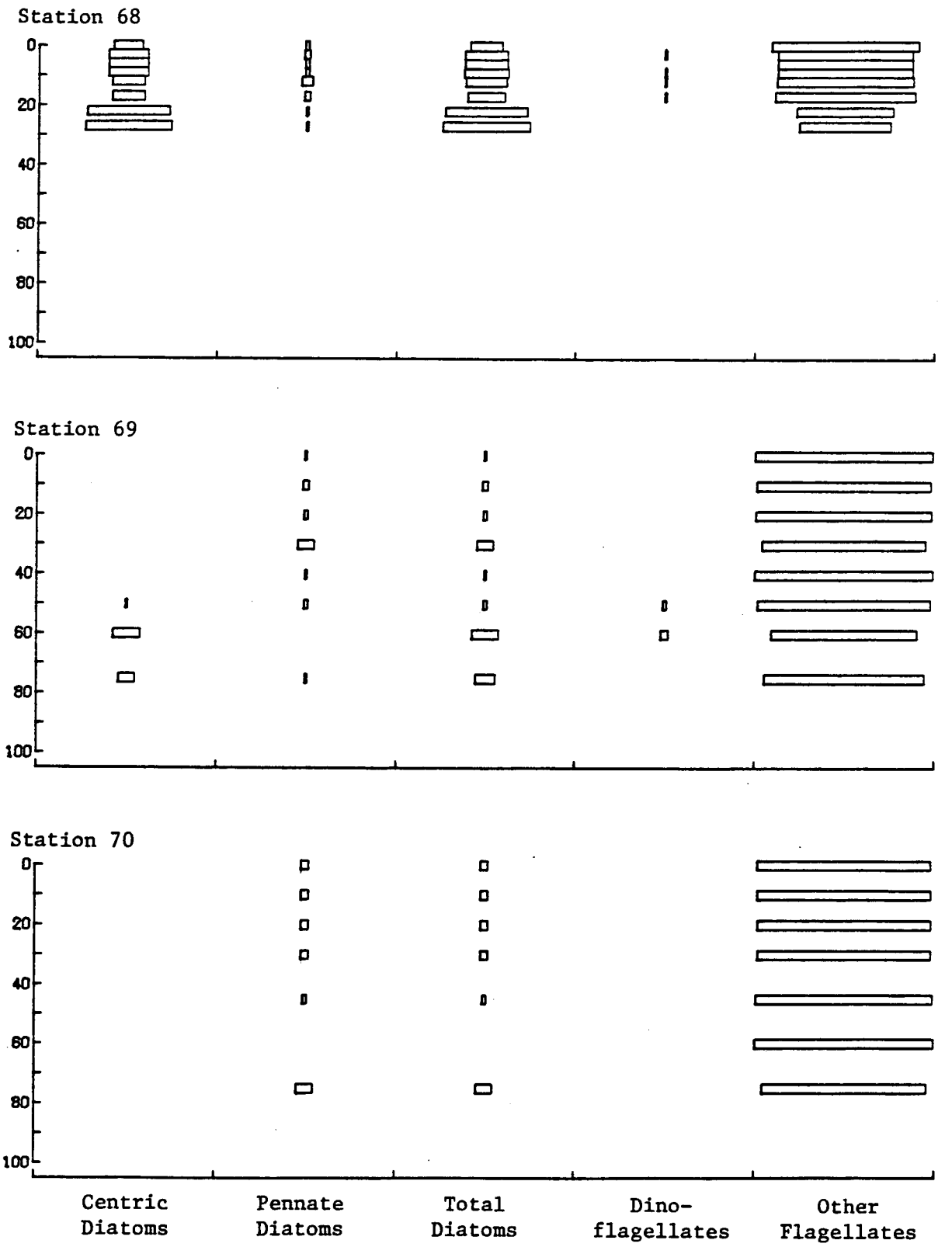
100
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)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60
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100
Station 70
0
20
40
60
80
100
Centric Diatoms
Pennate Diatoms
Total Diatoms
Dino-flagellates
Other Flagellates

Fig. 5. (cont.)

Table 9. Integrated chlorophyll *a* and primary productivity in the Bering Sea, CGC *Polar Star*, 4 May - 24 June 1980.

Sta	Chl *a* (mg m^{-2})	Prim Prod (mg C m^{-2} hr^{-1})
1	99.55	556.35
2	133.60	745.25
3	158.28	752.05
4	71.07	150.15
5	112.85	163.27
6	82.63	149.33
7	398.22	778.75
8	550.50	1154.48
9	411.07	458.93
10	477.05	2226.90
11	665.65	1437.58
12	290.12	1207.13
13	171.68	1310.53
14	188.95	462.63
15	274.90	775.20
16	479.35	1252.85
17	243.98	609.05
18	396.35	403.40
19	489.67	949.08
20	167.32	452.75
21	154.47	255.38
22	300.02	821.15
23	160.65	227.70
24	157.35	289.30
25	182.35	565.52
26	45.30	203.00
27	160.12	483.92
28	229.67	677.97
29	24.68	52.70
30	6.26	14.01
31	4.80	11.31
32	14.33	41.81
33	166.90	590.38
34	139.77	546.70
35	4.66	10.95
36	113.24	293.52
37	193.87	631.40
41	177.85	540.88
47	207.85	523.15
48	49.12	162.24
49	106.35	413.97
50	52.59	337.86
51	27.59	56.26
52	17.52	43.13
54	17.52	43.13

Table 9. (cont.)

Sta	Chl *a* (mg m^{-2})	Prim Prod (mg C m^{-2} hr^{-1})
55	145.80	407.38
56	120.02	324.30
57	79.02	337.65
60	266.17	540.67
64	38.52	106.37
65	21.03	46.23
66	102.83	178.72
68	20.61	40.99
69	125.05	297.40
70	45.85	103.88
71	50.23	88.80
72	67.77	247.82
73	62.98	170.07
74	20.33	51.95
75	63.62	134.52

Temperatures in the upper 60-75 m were generally negative. Positive temperatures were sometimes found below 75 m. Thermoclines, when present, were usually about 30 m. Salinity in the upper 20-30 m ranged from 31.53-31.98°/$_{oo}$ in the southeastern seacion (stations 1-3, 7-17), increasing to near 33°/$_{oo}$ at depth at some stations. Stations to the west (stations 4-6) and the north (stations 19-25) had salinities of 32.00-32.83°/$_{oo}$ in the upper 20-30 m, increasing to near 33°/$_{oo}$ at depth. Haloclines sometimes occurred about 30 m.

Ice cover was heavy with > 50% cover at stations 1-9, 14, and 23. Little or no ice cover was present at stations 10-13, 15-22, and 24-25. The ice edge was generally near 175°30'W.

Primary productivity values were variable, but relatively high over the whole area regardless of ice cover. Highest values were in the upper 30 m except at the easternmost stations (stations 11-14) where highest values were below 20 m and extended to 75-100 m, which was near the bottom. Integrated productivity ranged from 150 mg C m^{-2} hr^{-1} at station 4 to 227 mg C m^{-2} hr^{-1} at station 10.

Chlorophyll *a* concentrations were also relatively high, ranging from *ca.* 1-20 mg m^{-3} in the upper 30 m over the whole area. Below 30 m, the chlorophyll *a* concentration was usually < 2 mg m^{-3}. Integrated chlorophyll *a* values over the whole area ranged from 71 mg m^{-2} at station 4 to 665 mg m^{-2} at station 11.

Nutrient concentrations over the whole area were variable, but relatively high and generally with higher values occurring below 30 m. Nitrate and phosphate may have been minimal at some stations and depths.

Diatoms were the most abundant organisms at all stations except stations 4-6, the three westernmost stations where ice cover was about 90%. Microflagellates were dominant at these stations and cell numbers were low. Pennate diatoms of the genus *Nitzschia* section *Fragilariopsis* were dominant elsewhere. Also abundant were *Porosira glacialis, Navicula pelagica,* species of *Thalassiosira* and *Chaetoceros*, and choanoflagellates. Microflagellates were often abundant and were sometimes most abundant at depth. Cell concentrations were near 2 x 10^6 cells ℓ^{-1} except at stations 14, 15, 19, and 25 where cell concentrations were > 3 x 10^6 cells ℓ^{-1}. Dinoflagellates were present at most stations, but were never in large numbers.

Stations 26-33 were taken in the St. Matthew-Hall area between St. Lawrence and Nunivak islands (Fig. 1). No ice was present in the area.

Temperatures were generally positive except at stations 27 and 29 where slightly negative temperatures occurred throughout the water column and at stations 26-29 where negative temperatures were present at depth. Salinity ranged from 31.07-32.14°/$_{oo}$. The water column was relatively well-mixed in this shallow area.

Primary productivity was variable, being high at stations 27, 28, and 33 at the western edge of the area near 170°W. Stations 30 and 31, closest to shore near 167°W had lowest productivity with < 1.00 mg C m^{-3} hr^{-1} at all

depths. Stations 26, 29, and 32, located between 168 and 169°W, had productivity ranging from 1-3 mg C m^{-3} hr^{-1} except at 23 and 28 m at station 26, where productivity was 16-20 mg C m^{-3} hr^{-1}. Integrated productivity was > 480 mg C m^{-2} hr^{-1} at stations 27, 28, and 33; < 15 mg C m^{-2} hr^{-1} at stations 30 and 31; and ranged from 42-203 mg C m^{-2} hr^{-1} at stations 26, 29, and 32.

Chlorophyll *a* concentrations followed the same pattern with highest values, 2.5-7.5 mg m^{-3}, at stations 27, 28, and 33. Integrated values were > 160 mg m^{-2}. Stations 30 and 31 had low chlorophyll *a* concentrations, ranging from 0.17-0.38 mg m^{-3} with integrated values of 5-6 mg m^{-2}. Stations 26, 29, and 32 also had < 1.00 mg m^{-3}, but values ranged from 0.22-0.97 mg m^{-3}, except below 20 m at stations 26 and 29 where the chlorophyll concentration was 1-4.4 mg m^{-3}. Integrated chlorophyll values were > 14 mg m^{-2}.

Unfortunately, nutrient samples from stations 26, 27, 31-33 thawed before analysis could be done and the concentrations, though reported in Table 8, are questionable except for silicate. For samples not thawed, nutrient concentrations were low, even for silicate suggesting rapid utilization.

Microflagellates dominated at all stations in this area. Even at stations 27, 28, and 33 where productivity and chlorophyll were high, flagellates were dominant. At stations 30 and 31, closest to the coast, flagellates were 70-90% of the population. At station 31, *Cylindrotheca closterium* was the most abundant diatom, but was still less than 10% of the total population. Stations 26 and 29 had the lowest number of cells per liter, usually < 0.8 x 10^6. At station 32, cell numbers were relatively high, near 1 x 10^6 cells ℓ^{-1}, but flagellates comprised *ca.* 90% of the total population. Dinoflagellates were present at all stations, but in low numbers. The condition of the diatoms at these stations suggested that the spring bloom had occurred earlier. Many cells appeared to be unhealthy and the pennate diatoms contained large oil droplets.

Stations 34-41 and 60-68 were taken in the Norton Basin; stations 47-57 were taken in the southern Hope Basin. Ice cover in Norton Basin varied with stations 37 and 41 in heavy ice, while all other stations were ice-free. Heavy ice was encountered north of Bering Strait along the southern edge and northward into Kotzebue Sound and this limited our sampling. Because of the ice and mechanical problems with the ship (one shaft not functional), the Captain decided not to go farther north as originally planned, but to limit sampling to areas that were ice-free. This meant staying generally west of 168°30'W north of Bering Strait. Stations 57-68 were taken in open water south of 65°N.

Temperatures ranged from -2.27–+2.94 over the whole area except for the shallow station 35 at 63°35'N, 166°55.5'W, where temperature was near 3.5°C in the upper 15 m, dropping to 0.2°C at 18 and 24 m. Salinity was also lower at this station, 30.93°/$_{oo}$, as were nutrient concentrations. Perhaps this station was located in the plume of the Yukon River.

Salinity was usually above 31°/$_{oo}$ except at some surface-3 m depths where ice was present, ranging from 31.02-33.22°/$_{oo}$. Nutrient concentrations

were variable with slightly higher values often occurring at depth.

Primary productivity was relatively high at stations 34, 36, 37, 41, and 60 located generally east of 168°36'W; and with both heavy ice cover at stations 37 and 41 and no ice cover at stations 34 and 36. Integrated productivity at these stations ranged from 294 mg C m^{-2} hr^{-1} at station 36 to 631 mg C m^{-2} hr^{-1} at station 37. Integrated productivity at station 35 was only 11 mg C m^{-2} hr^{-1} and, with stations 30 and 31, south of St. Lawrence Island, was the lowest of all stations. Productivity at stations 64-68 ranged from < 1 to *ca.* 10 mg C m^{-3} hr^{-1} with lower values, closer to 2 mg C m^{-3} hr^{-1}, being more common. North of Bering Strait, productivity varied greatly from < 1 to 30 mg C m^{-3} hr^{-1} with higher values usually at depth. This correlates to some extent with higher nutrient and chlorophyll concentrations also often occurring at depth.

Chlorophyll *a* concentrations at stations 34, 36, 37, and 60 corresponded with the high productivity at these stations. Integrated chlorophyll ranged from 113-266 mg m^{-2}. Slightly lower chlorophyll concentrations occurred at stations 64-68, also corresponding to lower productivity rates. North of Bering Strait, chlorophyll concentrations were variable, ranging from 18-207 mg m^{-2}.

Microflagellates were the dominant group of organisms at all stations in Norton Basin except the most northern one (station 60) where pennate diatoms, primarily *Nitzschia* section *Fragilariopsis*, comprised *ca.* 60% of the population. Centric diatoms were the most abundant diatom group at all stations except station 60, with species of *Chaetoceros* and *Thalassiosira* being the most common.

Stations 34, 36, and 31 had highest cell numbers, near 8 x 10^6 cells ℓ^{-1}, while stations 37 and 60 had moderately high cell numbers near 2 x 10^6 cells ℓ^{-1}. Stations 64-68 generally had slightly lower concentrations, between 1-2 x 10^6 cells ℓ^{-1}. Station 35 had the lowest number of cells, usually < 1 x 10^6 cells ℓ^{-1}. About 90% of the population was microflagellates. *Dinobryon balticum*, a photosynthetic chrysophyte flagellate, was more abundant at this station than elsewhere.

Standing stock samples from stations 47-57 in southern Hope Basin were not analyzed because of funding and time constraints.

The last group of samples is from the St. George Basin. These stations were taken in late June and no ice was present. Temperatures were all positive, generally being above 4°C, except below 45 m where the temperature was usually near 1°C. As a result, temperatures do not appear for most depths in Fig. 4. Salinity was always above 32°/$_{oo}$.

Primary productivity was variable with higher productivity occurring in the upper 30-45 m. This was also true of chlorophyll. Integrated carbon and chlorophyll values are in Table 9. Nutrient concentrations were high with nitrate usually > 10 µg-at ℓ^{-1}, and phosphate near 1 µg-at ℓ^{-1}; silicate was always > 30 µg-at ℓ^{-1}.

Standing stock samples from stations 69 and 70 were the only ones analyzed for this area because of funding and time constraints. Micro-

flagellates were dominant, comprising more than 90% of the population. A small unidentified pennate diatom was usually the most abundant diatom, but still comprising only 2-3% of the population. Cell concentrations at these two stations were by far the highest at *ca.* 16 x 10^6 cells ℓ^{-1}.

VII. DISCUSSION

Other recent studies in the Bering Sea (Alexander and Cooney 1979, Goering and Iverson 1981) emphasized time series done over relatively small areas, *i.e.*, the ice edge zone and the so-called Golden Triangle in the southeastern Bering Sea. This study is considerably different because of the wide aerial coverage, *i.e.*, the Navarin Basin, St. Matthew-Hall area, Norton Sound, and the St. George Basin (Fig. 1). Only in Norton Basin were we able to repeat some stations the second year. One disadvantage of sampling a broad area as we did, is that it takes considerable time, in this case more than two months, which tends to obscure the synoptic picture.

The Navarin Basin samples (stations 1-25) were collected from 4-17 May 1981 at a time when ice cover was still heavy over much of the area. Even so, primary productivity was relatively high in the upper 30-40 m. Only at the most southwesterly stations (4-6) where ice cover was 90-100%, was productivity low, but still near 3-5 mg C m^{-3} hr^{-1}. These three stations also had the lowest cell concentrations and microflagellates were the most abundant organisms. A pycnocline, if present, was usually near 30-40 m and nutrient concentrations were generally higher below this depth. At stations 10, 11, and 16, nitrate levels in the upper 30 m were low, possibly indicating the end of the bloom in this area, although phosphate and silicate were still present in high concentrations. Pennate diatoms were the most abundant organisms.

Samples were collected in the St. Matthew-Hall area from 22-26 May 1980 when no ice was present. Microflagellates were the most abundant organisms in the area. Centric diatoms were usually more abundant than pennate diatoms. Stations closest to the coast (30 and 31) had the lowest productivity and chlorophyll in this area. Nutrient concentrations were low and cells appeared to be senescent indicating the end of the bloom.

Norton Basin samples were collected from 19-30 April 1979 and from 4-20 June 1980. Ice cover was variable, but heaviest ice was usually present west of 168°30'W and at more northerly stations. Stations located just north of St. Lawrence Island were generally ice-free both years. In 1979, productivity and chlorophyll were generally < 1 mg C m^{-3} hr^{-1} and < 1 mg chlorophyll m^{-3} at stations located west of 168°30'W where microflagellates were the dominant organisms. Much higher chlorophyll and productivity values were found at stations east of 168°30'W where diatoms were the dominant organisms. Pennate diatoms were the most abundant organisms at all the eastern stations except station 2 where centric diatoms were dominant. The pattern was not so clear for 1980 stations. Microflagellates were generally dominant at eastern stations and productivity and chlorophyll varied from very low at station 35 to relatively high at stations 34 and 41. Highest integrated productivity occurred at station 37 in the middle of the area where diatoms and microflagellates occurred in about equal numbers and

where ice cover was 100%.

Samples were collected in northwestern St. George Basin from 21-24 June 1980 and in southeastern St. George Basin from 2-3 May 1979. Productivity and chlorophyll *a* were moderately high in the northwestern area at this time. Cell concentrations were high, near 16 x 10^6 cells ℓ^{-1} with microflagellates the dominant organisms. A small, unidentified pennate diatom, *ca.* 6 µm in length, was also present and abundant. In the southeastern area, productivity and chlorophyll were high to moderate. Centric diatoms were dominant at the station between St. George and St. Paul islands, while microflagellates were dominant at the other two hydrographic stations.

These data point out a number of problems in trying to describe the seasonal phytoplankton cycle in the Bering Sea. The effect of ice cover on primary productivity was variable, but productivity was usually highest at stations where there was little or no ice and where pennate diatoms comprised the greatest percentage of cells, however there were exceptions.

In the Norton Basin in 1980, heavy ice was present only in the central area (stations 37 and 41), flagellates were most abundant and productivity was high. In 1979 when sampling was 5-6 weeks earlier, more ice was present, and productivity and cell numbers were relatively low. Diatoms, particularly pennate species, were more abundant at stations where ice was heaviest and productivity was highest. Also in 1979, flagellates were more abundant at stations closest to St. Lawrence Island where ice was light or absent. Productivity, chlorophyll *a*, and cell numbers were all low at these stations, too.

In the Navarin Basin, productivity was high at stations 1-3 where ice cover was near 90% and pennate diatoms were most common. But at stations 4-6 where ice cover was also about 90%, flagellates were more numerous at most depths and productivity was low, about one-fifth that at stations 1-3. All of these stations were taken within a three day period.

No ice was present in the St. Matthew-Hall area in 1980. Productivity and chlorophyll were variable from relatively high to very low; cell numbers were generally low and flagellates were most abundant at stations with lowest productivity, but also at some stations with relatively high productivity. The low productivity and high flagellate numbers probably indicate that most of the flagellates were not photosynthetic. Some microflagellates are photosynthetic, *i. e.*, *Platymonas* and *Dinobryon*, but many are not, and unless positive identification can be made, it is impossible to determine from preserved material whether chloroplasts are present. In our samples where flagellates were generally identified by size class, we can only speculate as to their photosynthetic capabilities.

Levels of nutrient concentrations were also variable. In Norton Basin in 1979, nutrient concentrations were relatively stable throughout the water column with no distinctly lower concentrations in the upper layers which suggests relatively strong mixing. Low concentrations of nitrate and phosphate occurred at stations 2 and 10 where productivity was high; the silica concentration was also low at station 2 where centric diatoms were most abundant and pennate diatoms were also numerous. Pennate diatoms were

more abundant at station 10. Station 2 had no ice cover and station 10 had > 90%. Station 14, with the lowest productivity in the area and dominated by flagellates, had high nutrient concentrations. In 1980, nutrient levels in Norton Basin were low in the upper 20-30 m, and were usually higher below 30 m indicating stratification of the water column.

Lower nutrient levels were also present in the upper 20-30 m in the Navarin Basin, but only at a few stations were they low enough to be considered limiting. Nutrient levels in the St. Matthew-Hall area were very low which agrees with the observation that cells appeared to be senescent and the main spring phytoplankton bloom was past. Farther south in the St. George Basin, nutrient concentrations were lower in the upper 50 m, but were probably not low enough to be considered limiting. Flagellates were the dominant organisms.

Little can be said about the relationship between the ice algae bloom and the spring phytoplankton bloom in the water column. Saito and Taniguchi (1978) list a number of species as "ice plankton," but they apparently did not sample the ice itself (Taniguchi *et al.* 1976). This category is defined as "pennate diatoms which probably have grown in the sea ice and which are common in plankton collected after the ice has melted" (Saito and Taniguchi 1978). The species they list have been reported from both sea ice and the water column.

Alexander and Chapman (1981) list species found in slush-ice, ice cores, and the water column. They found considerable overlap in species present in the slush-ice and water column which would be expected because it would be difficult to collect slush-ice without also getting some seawater. Also, slush-ice is soft as the name implies, and cells normally found in the water column could easily become stuck either to the surface of the slush-ice or in channels and eroded areas of the ice. The comparison of ice algae and phytoplankton indicates fewer common species and most of the species from the ice have been frequently reported from ice. It is probably not surprising to find *Melosira sulcata* in the ice because it is usually considered to be a benthic species and another *Melosira* species, *M. arctica*, is commonly found associated with ice at higher latitudes (Gran 1904; Horner unpubl. obs.). The *Thalassiosira* found in the ice was not identified to species, but could have been *Th. antarctica* Comber, a species often confused with *Th. gravida* and usually found associated with ice in both the northern and southern hemispheres. Because *Th. antarctica* forms resting spores, Hasle and Heimdal (1968) suggested that it might be dependent on ice or coasts for survival. Indeed, the spores are often found in ice.

Hameedi (1978) also suggested that ice algae contributed a significant amount of chlorophyll to the water column, but he did not sample the ice and did not report species composition for either the ice or the water column, therefore it would be difficult to tell if the chlorophyll came from the ice.

We collected only one ice sample during these cruises and that was between stations 5 and 6, the two westernmost 1980 stations in the Navarin Basin, and in an area where ice cover was nearly 100% and cell concentrations in the water column were low. The sample was analyzed for species present

and relative abundance. The most abundant species were *Achnanthes* spp.; *Cylindrotheca closterium; Navicula* spp.; *Nitzschia* spp., including *N. frigida* and species of the section *Fragilariopsis* that form ribbon-shaped colonies; and unidentified pennate diatoms ranging in size from < 10-100 µm in length. The only centric diatoms present were small *Chaetoceros* spp. and a few *Thalassiosira nordenskioeldii*. The list of species and taxonomic categories is longer for the ice sample than that for water samples collected at stations 5 and 6 by a factor of at least 3. There is some species overlap and most of the species found in the ice have been reported previously for ice (Horner and Schrader 1981).

We believe there is considerable overlap in the species present in the ice and in the water column in the Bering Sea, but the important factor is the relative percentage that each species contributes during the time it is present. Experience at Barrow and Prudhoe Bay has shown that there is contamination of the upper water layer under the ice when cores are cut using surface coring techniques, such as SIPRE corers. The bottom layer of ice containing the ice diatoms is soft and easily broken releasing ice algae cells into the water column. The reverse is probably also true. Cells normally found in the water could be caught on the ice surface, or perhaps be carried up into the ice in brine channels and would then be considered to be members of the ice community even though they normally do not live there. From the evidence reported in the literature and cited here, we still cannot say for sure what the contribution of the ice algae is to the spring bloom in the water column of the Bering Sea. Intensive sampling of both habitats at the same time during the spring is needed before this problem can be resolved.

VIII. CONCLUSIONS

It is difficult to come to wide-ranging conclusions concerning the phytoplankton of the Bering Sea because we covered such a large area over a relatively long time span. However, for these samples, we can say that:

1. Pennate diatoms were dominant in the Navarin Basin

2. Diatoms were dominant in the Norton Basin early in the season and microflagellates became dominant slightly later

3. Microflagellates were dominant in the St. Matthew-Hall area, the St. George Basin, and the Shumagin area

4. Microflagellates and centric diatoms were dominant at the two stations in Shelikof Strait (Cook Inlet area)

5. Primary productivity was variable, and was usually, but not always, highest at stations and depths where diatoms were abundant

6. Cell numbers were variable and the two areas, Norton and St. George basins, that were sampled both years were quite different in the upper 30-50 m (depth varied by area, but the depth interval was the same for any one area):

		1979	1980
a.	Navarin Basin		2×10^6
b.	Norton Basin	0.7×10^6	5×10^6
c.	St. Matthew-Hall		1×10^6
d.	St. George Basin	0.9×10^6	16×10^6
e.	Shumagin area	1.4×10^6	
f.	Cook Inlet	0.9×10^6	

All numbers are cells ℓ^{-1}

7. Dominant diatoms included *Navicula* spp.; *Nitzschia* spp., especially section *Fragilariopsis; Thalassiosira* spp.; and *Chaetoceros* spp. Most abundant dinoflagellates included *Peridinium* spp. and *Gymnodinium lohmanni*

8. Nutrient concentrations were varible, sometimes being lower in the upper 20-30 m. This was especially true of nitrate and phosphate, and these may have been limiting at times

9. We still cannot say with any certainty that ice algae initiate or contribute to the spring bloom in the water column

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EARLY LIFE HISTORY OF PACIFIC HERRING: 1989 PRINCE WILLIAM SOUND HERRING EGG INCUBATION EXPERIMENT

by

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ABSTRACT

In March, 1989, oil spilled from the tanker Exxon Valdez, washed onto Pacific herring, Clupea pallasi harengus, spawning beaches in Prince William Sound, Alaska. The purpose of this study was to measure the viable hatch of herring eggs spawned on oiled and non-oiled beaches of the Sound. Over 180 samples of live eggs were taken from five control transects outside of the contaminated area and 18 transects within the contaminated area. They were flown to the Vancouver Aquarium and incubated to hatch.

Fifty nine percent (SD = 0.18) of the 180 samples of eggs survived incubation and 84% (SD = 0.12) of the newly-hatched larvae were viable, giving a mean viable hatch of 50% (SD = 0.17). This is within the range of survival and viability reported in the scientific literature for natural herring spawn not contaminated by hydrocarbons.

Univariate statistics showed that oil had no significant ($P > 0.05$) effect on survival of eggs or on viability of larvae, but that it had a significantly ($P = 0.033$) negative effect on percent viable hatch, on the age of 50% hatch ($P < 0.001$), and on the frequency of the latest stage of development at hatch ($P = 0.007$). Multivariate statistics showed that the effect of oil on the vector of biological variables was significant ($0.02 < P < 0.05$). One of reasons for a weak relationship between oil and the biology of herring embryos is that the presence/absence index of oil contamination is an imprecise index of actual exposure to oil. The oil effect was also partly masked by environmental factors associated with depth that exerted a strong control over survival, age at hatch, and stage of development at hatch.

Eggs died at a constant rate of $3\% \cdot d^{-1}$ over the incubation period for both oiled and control samples. The ratio of live eggs to total eggs was significantly ($P < 0.01$) lower in oiled eggs than in control eggs and in shallow depth classes compared to deep depth classes, but this was solely a reflection of the strong influence of the schedule of hatching and not a result of differences in survival. The ratio of live to total eggs at the beginning of the experiment was an imprecise index of egg survival.

The fraction of larvae that were viable, as defined by the absence of gross morphological abnormalities, did not vary significantly with oil treatment or depth.

Only one of the six major types of deformity exhibited a significant correlation with oil treatment; missing or deformed jaws were significantly ($0.001<P<0.01$) more frequent in oiled samples than in control samples. However, since jaw deformities were only the third most common deformity, they did not affect the overall relationship between viability, oil treatment and depth.

The strongest effect of oil was an acceleration of embryo development. The presence of oil caused significant ($P<0.01$) decreases in the date of 50% hatch and in the fraction of larvae hatched in late stages of development. Early hatched larvae tended to be shorter, heavier, to carry a larger yolk sac and to be less developed than late hatched larvae. After corrections for the effects of age, small but significant ($P<0.01$) differences in size were found between viable larvae from oiled and control groups and between depth classes. Oiled larvae were 0.1 mm longer and 4 μg lighter in weight than control larvae, so their condition (WL^{-3}) was 7% lower than control larvae. Length decreased with depth, and weight increased with depth, so condition increased at a rate of about $1\%\cdot ft^{-1}$. These results suggest that oil may have stimulated metabolism and development of larvae. Water temperature during early incubation on the spawning grounds may also have played a confounding role; water temperature at control sites were always several degrees higher than temperatures at oiled sites.

Artificial variables were created from the matrix of data using factor analysis. Factor 3 was found to contain all of the information that was correlated with the presence of oil. In the absence of any other information on oil exposure, this factor was used to rank the 1989 herring spawning grounds in Prince William Sound by relative oil impact.

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*The appendices are too large to include in this volume. Readers desiring the appendices may obtain them from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

1. INTRODUCTION

On March 24, 1989, the oil tanker Exxon Valdez struck Bligh Reef and spilled 250,000 bbl of Prudhoe Bay crude oil onto the surface of Prince William Sound, Alaska. Several weeks later, Triton Environmental Consultants Ltd. was hired by the U.S. National Oceanic and Atmospheric Administration (NOAA) to assess the impact of this spill on the viable hatch of Pacific herring, Clupea harengus pallasi, eggs laid on beaches in the Sound. This is the final report of those investigations. Appendices to this report are contained in a separate volume.

The study was designed by Triton in cooperation with the Alaska Department of Fish and Game (ADF&G). ADF&G conducted a SCUBA survey of the proportion of live to dead herring eggs at 19 transects in the Sound as part of their research on the effects of the spill on herring in Prince William Sound. This survey could not measure the actual hatching success of these eggs or the viability of newly-hatched larvae, so an incubation experiment was designed to extend monitoring into the late embryo and early larval stages. Triton conducted this experiment. Its objectives were to measure egg survival, larval viability, and the mean length, weight and fitness of newly-hatched larvae. These variables were compared between oiled and non-oiled samples.

Triton also conducted a companion study in 1989 - a survey of growth, mortality and dispersal of wild herring larvae in the Sound. The results of that study are reported by McGurk et al. (1990).

2. MATERIALS AND METHODS

2.1 Study Sites

In 1989 herring spawned at four major sites in Prince William Sound: the Northeast area centered on Tatitlek Narrows, the North area centered on Fairmount Bay, the Naked Island archipelago, and the northern end of Montague Island (Fig. 1). Oil from the Exxon Valdez drifted southwest from Bligh Reef through the Naked Island archipelago, and along the eastern and western shores of Knight Island and around the western shore of Montague Island (Fig. 2). Therefore, beaches on Naked and

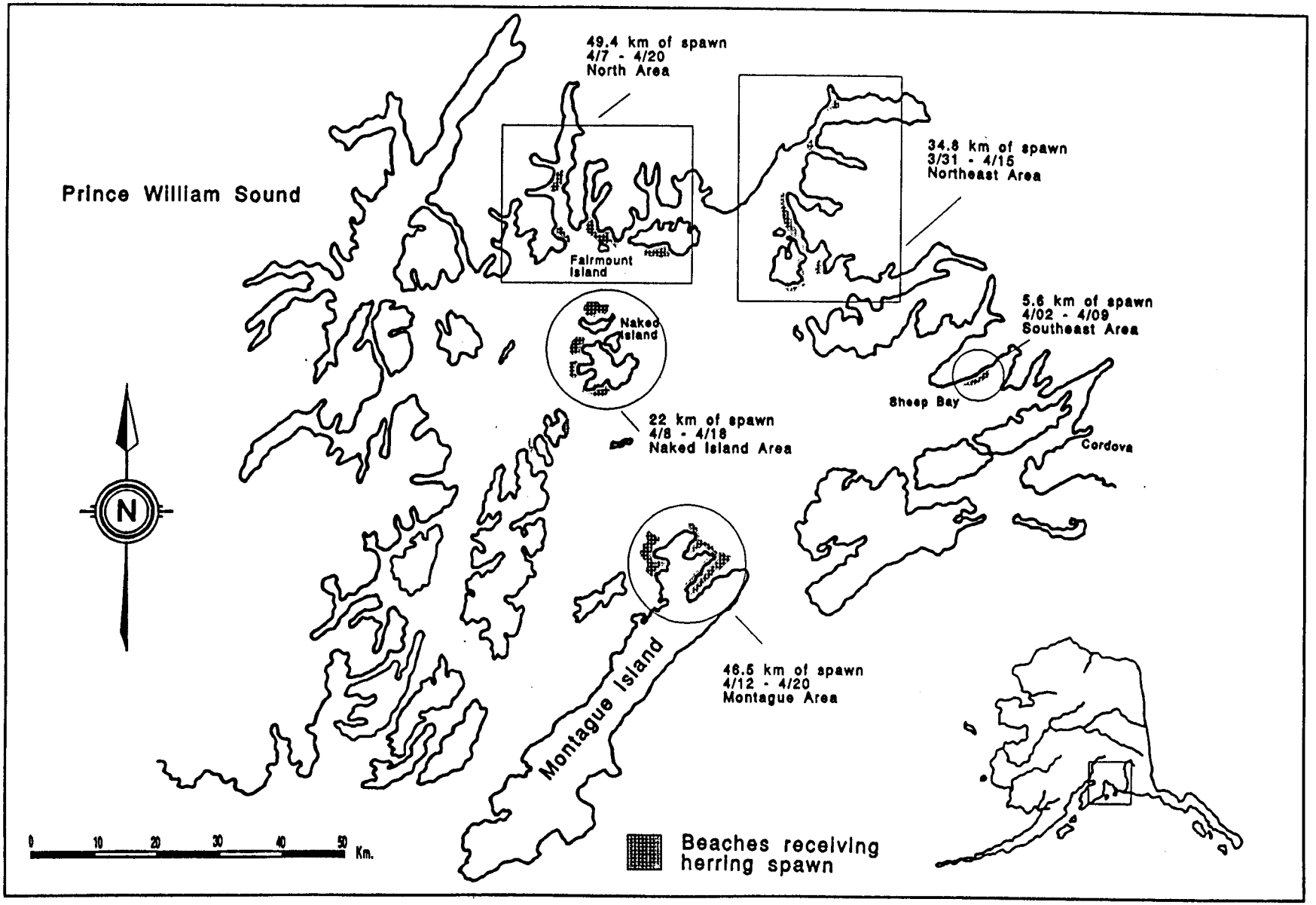

Figure 1. Map of Prince William Sound showing the four major herring spawning areas and the locations where eggs were collected for the incubation experiment.

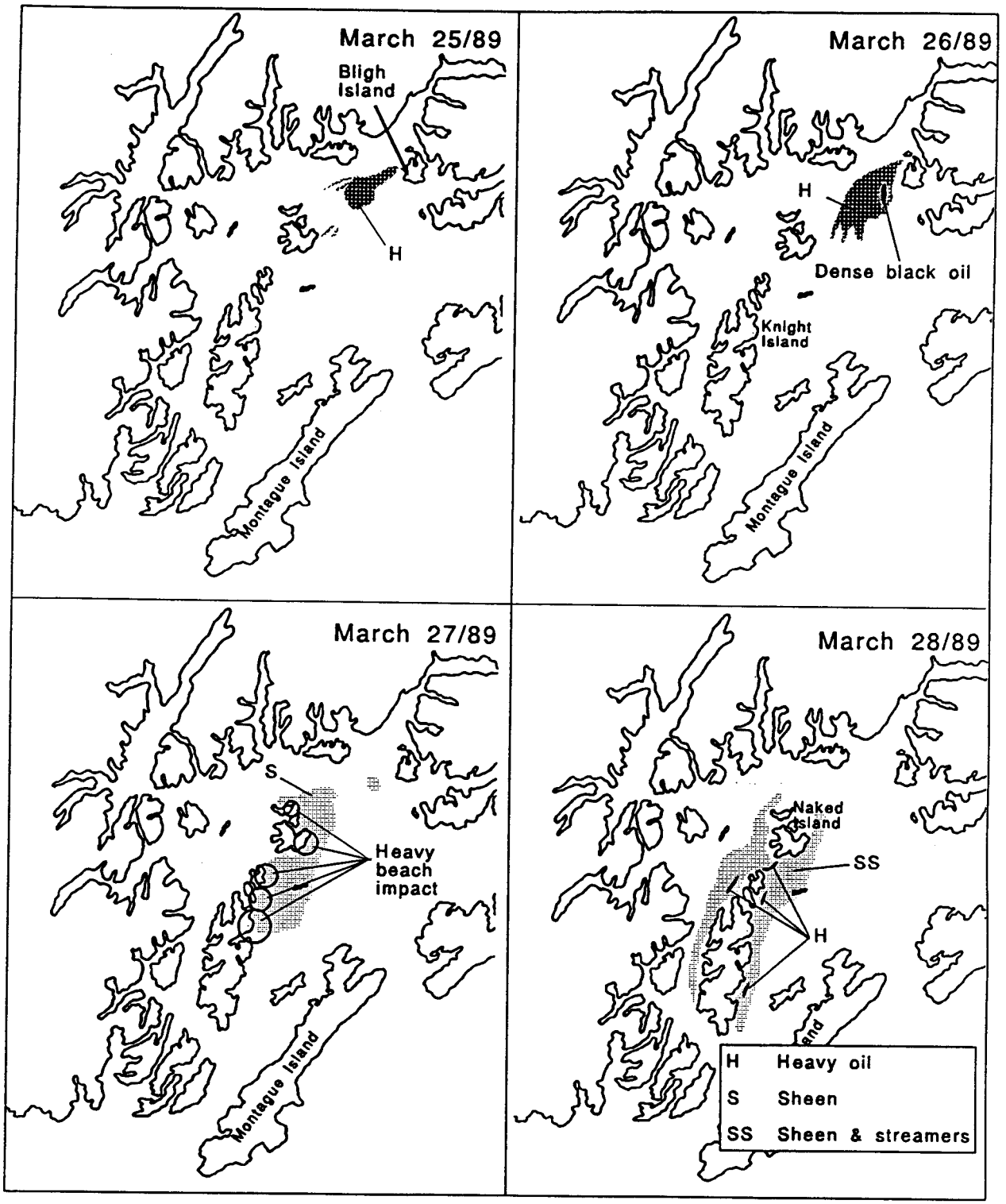

Figure 2. Seven maps of Prince William Sound showing the trajectory of oil spilled from the Exxon Valdez from March 25 to April 4, 1989.

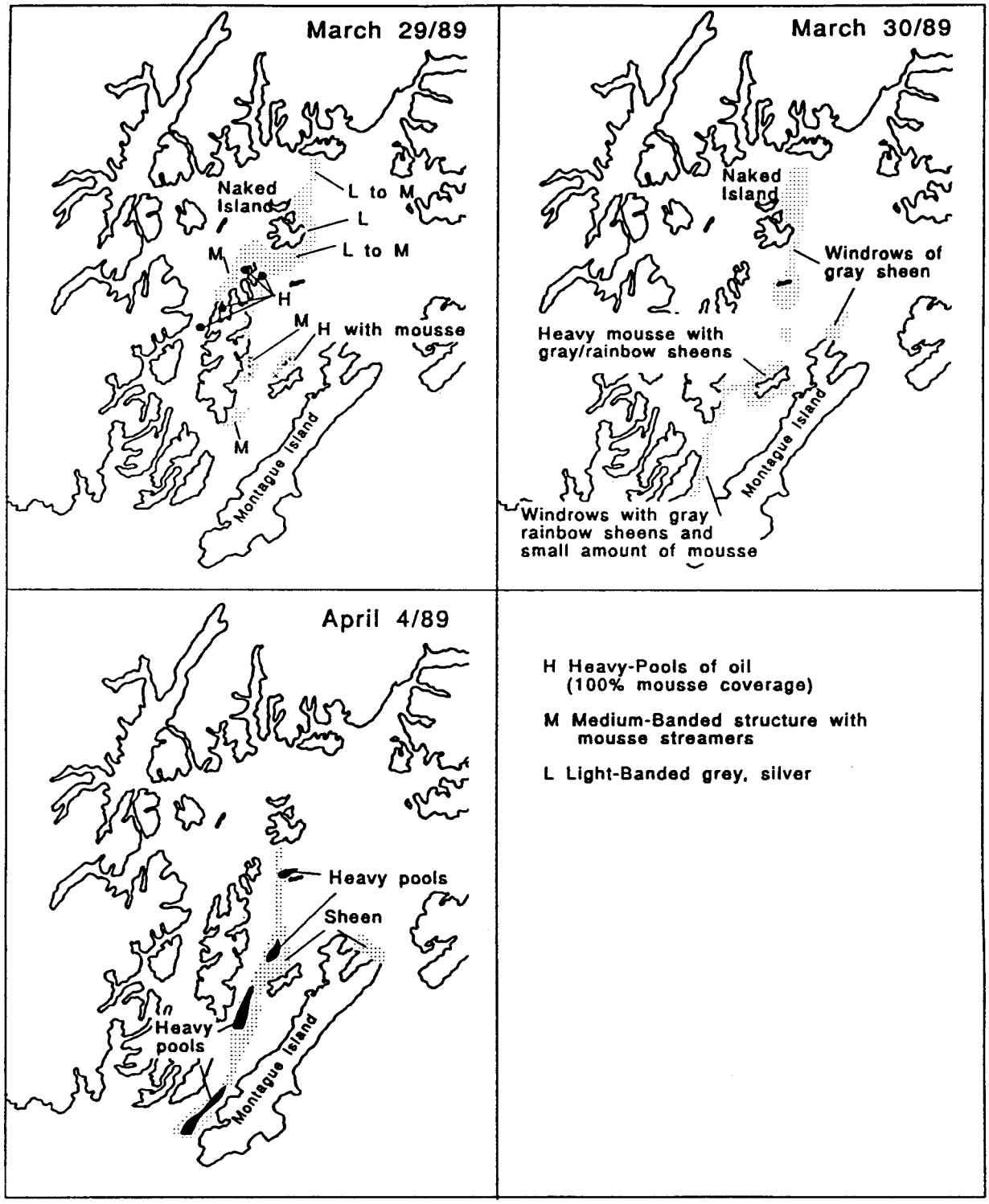

Figure 2. Seven maps of Prince William Sound showing the trajectory of oil spilled from the Exxon Valdez from March 25 to April 4, 1989.

Storey Islands and on the northern tip of Montague Island, were exposed to oil, but beaches on Fairmount Island and Tatitlek Narrows were never contaminated.

One control (non-oil-contaminated) spawning site and five potentially oil-contaminated spawning sites were chosen by ADFG biologists (Table 1). The control site was Fairmount Bay, and the five contaminated sites were: Bass Harbor, Outside Bay, and Cabin Bay on Naked Island; Storey Island north of Naked Island; and Rocky Bay on Montague Island.

It must be noted at this point that although we use the terms such as "oiled" and "oil-contaminated" in this report, we lack information on the actual concentrations of hydrocarbons. Consequently this report is really a comparison between batches of eggs that may have been exposed to oil (treatments) and batches that were apparently not exposed to oil (controls). However, the word "treatment" is just as misleading as "oiled" because it implies a planned exposure of known concentration. In the absence of any satisfactory label, we continue to use words such as "oiled" and "contaminated".

At each of these beaches SCUBA divers established between one and five transects perpendicular to the shoreline (Fig. 3). Transects were only established on spawn of medium density (two to three egg layers) so that all of the eggs collected for incubation in the laboratory came from spawn of the same egg density. Each transect was defined by a weighted rope that was anchored at its upper end by a stake that was marked by a bright red sign. Divers swam down the rope from the upper tide line to the lower edge of the zone of vegetation. At depths of 5, 0, -5 and -15 ft from mean low water (measured with depth gauges and tide tables) they laid a 0.1 m^2 frame on the substrate and took three separate handfuls of herring spawn from within the frame. Each handful of eggs was placed in its own porous paper bag, labelled according to date, beach, transect, depth, replicate number and sample number, and brought to the surface where it was immediately stored between layers of sea ice in an insulated chest. The chests were flown to Cordova, Alaska, and then to Seattle, Washington, where they were driven to the Vancouver Public Aquarium. The entire trip from the spawning beach to the Aquarium took less than 12 h. Over a 10 d period in late April, six coolers containing 180 samples were sent to the Aquarium.

Table 1. Study sites for collection of herring eggs.

Transect number	Location	Description: lat.	long.	Date of 1st survey	Water temp. (C)	Site notes/description:	Oil observations	Spawn dates
C1	Fairmount Bay	60 52.91	147 22.90	21-Apr-89	6.3	Spawn on ribbon/fucus, low tide; exposed to North	No oil	April 11-13
C2	Fairmount Isl. Area	60 53.01	147 24.16	21-Apr-89	7.2	Spawn, low; exposed to South	No oil	April 11-13
C3	Fairmount Oyster F.	60 52.45	147 23.32	21-Apr-89	7.2	Spawn, low slack; exposed from East	No oil	April 11-13
C4	Fairmount Oyster W.	60 52.60	147 24.58	21-Apr-89	7.2	Spawn on LBK, low slack; westerly exposure	No oil	April 12-15
C5	Fairmount Island W.	60 51.80	147 24.98	21-Apr-89	6.1	Spawn on mixed kelp; westerly exposure	No oil	April 12-15
O1	So. Naked Island	60 37.15	147 27.62	22-Apr-89	5.0	Spawn on mix LBK; southerly exposure	No oil evidence	April 13
O2	Inside Bass, Naked	60 37.73	147 23.15	22-Apr-89	7.2	Mixed LBK, reds, hair; SW exposure	No oil evidence	April 12-13, 15
O3	Bass Harbour Anch1	60 37.85	147 22.72	22-Apr-89	5.0	Heavy spawn under oil/boom; inside boom, protect	Heavy-med. oil	April 12-13, 15
O4	Bass Harbour Anch2	60 38.13	147 23.04	22-Apr-89	5.0	Spawn inside oil boom; SW exposure	None visible	April 13, 15, 17-1
O5	E. Bass Harbour	60 38.39	147 23.28	22-Apr-89	5.0	1015 hrs.; SW exposure, semi-protected	No oil evidence	April 13, 15, 17-1
O6	NE Bass Harbour	60 38.65	147 23.43	23-Apr-89	5.0	Spawn on fucus/LBK; SW exposure/protected	No oil evidence	April 12-13
O7	N Bass Harbour	60 38.95	147 23.10	23-Apr-89	5.0		No oil evidence	April 9, 11-13
O8	NW Bass Harbour	60 38.93	147 23.99	23-Apr-89	5.0	Spawn on fucus/reds/LBK; SE exposure/protected	No oil evidence	April 9, 11-13
O9	W Bass Harbour 1	60 38.66	147 24.49	23-Apr-89	5.0	Spawn on fucus/reds; S exposure/protected	No oil evidence	April 11-13
O10	W Bass Harbour 2	60 38.27	147 24.68	23-Apr-89	5.0	Spawn on fucus/reds; SE exposure	No oil evidence	April 11, 13
O11	N Outside Bay	60 38.69	147 26.50	24-Apr-89	5.0	Fucus/reds/LBK; W exposure/protected	No oil evidence	April 15
O12	E Outside Bay	60 39.06	147 26.23	24-Apr-89	5.0	Spawn high in intertidal zone; W exposure	No oil evidence	April 15
O13	NW Naked Island	60 40.84	147 28.87	24-Apr-89	5.0	Near rocky ptoint.; W exposure	No oil evidence	April 13
O14	W Naked Island	60 38.95	147 30.05	24-Apr-89	5.0		No oil evidence	April 15
O15	So. Storey Island	60 42.90	147 24.26	26-Apr-89	5.0	Spawn on fucus/eelgrass; S exposure/protected	Tar balls/Lt. Sheens	April 12-13
O16	No. Storey Island	60 44.04	147 24.95	26-Apr-89	5.0	Spawn on mixed kelp; N exposure	Spots of tar/beach	April 11-13
O17	Rocky Bay	60 19.32	147 59.38	29-Apr-89	5.0	Spawn on LBK; visible pools of oil	Visible oil pools	April 13-15, 17-18
O18	Rocky Bay	60 19.43	147 02.46	30-Apr-89	5.0	Spawn on mixed kelp; tar on beach	Tar balls on beach	April 14-15, 17-18
O19	Rocky Bay	60 20.72	147 01.22	30-Apr-89	5.0	Spawn on mixed kelp; windrows of loose eggs on	Strong smell of oil	April 14-15, 17-18

Notes

1. LBK = long brown kelp; ribbon , red , Fucus and hair are all categories of kelp.

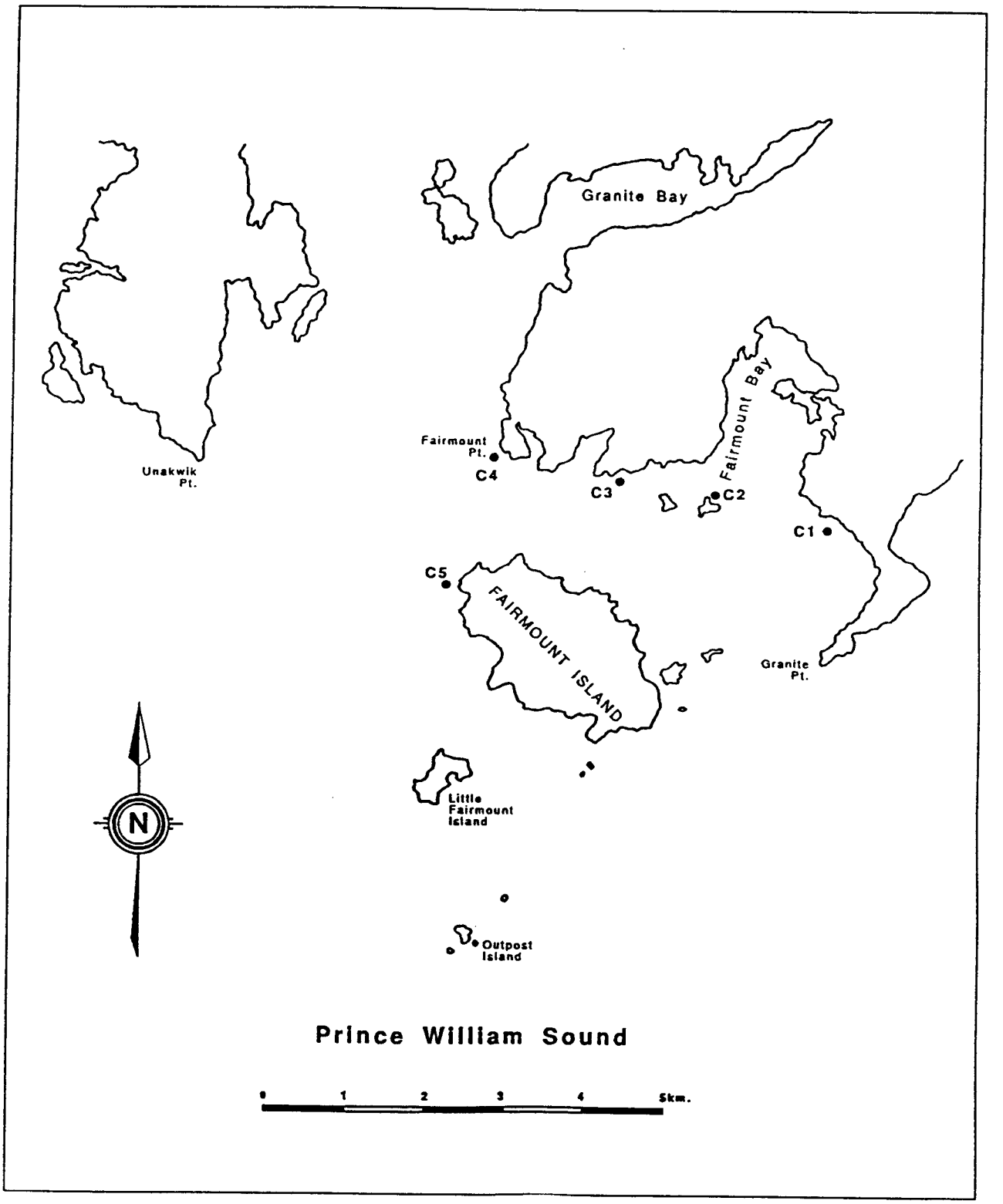

Figure 3A. Map of the Fairmount Island area in Prince William Sound showing control transects C1 to C5 where eggs were collected. See Fig. 1 for location of Fairmount Island.

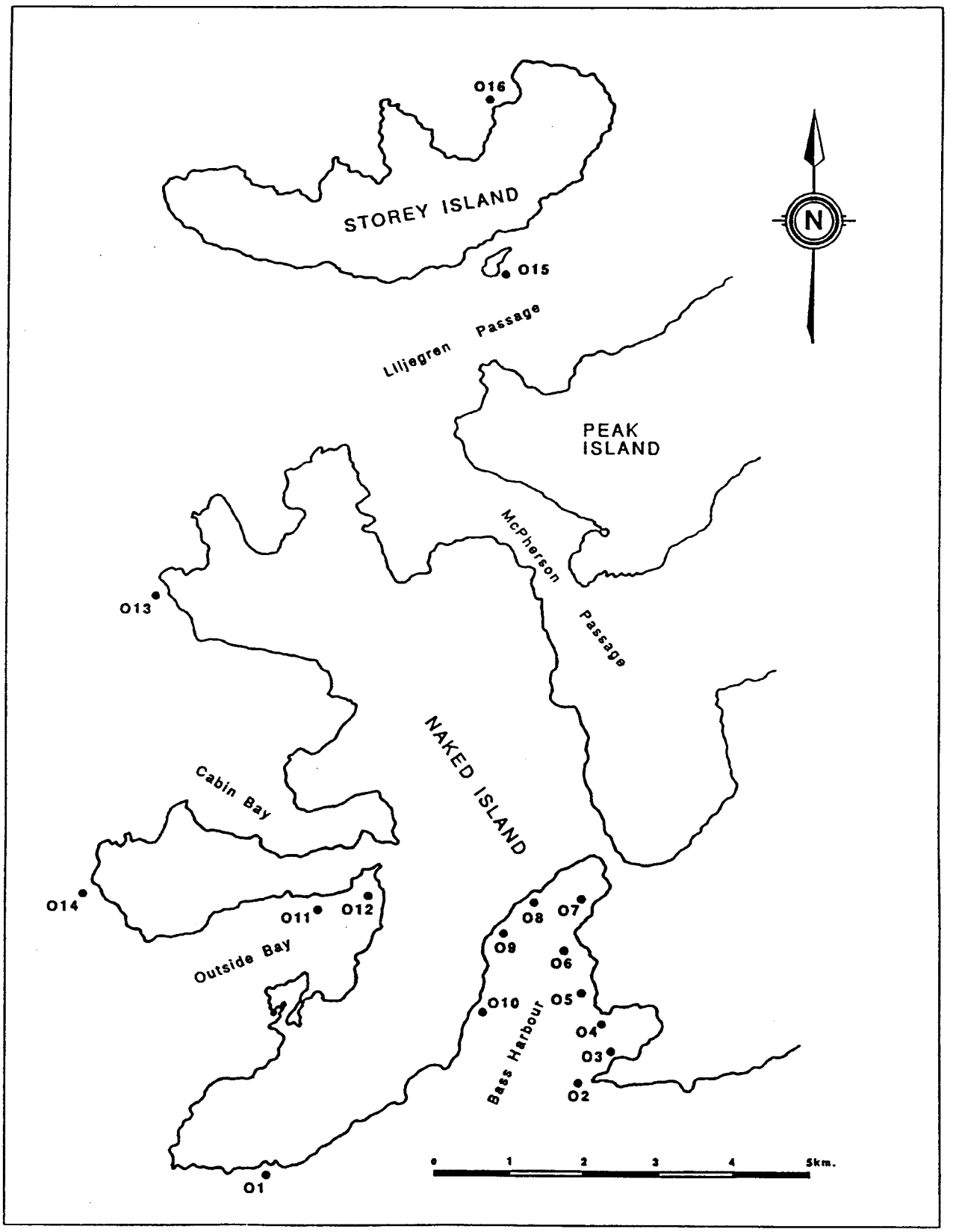

Figure 3B. Map of the Naked Island archipelago in Prince William Sound showing oiled transects O1 to O16 where eggs were collected. See Fig. 1 for location of Naked Island archipelago.

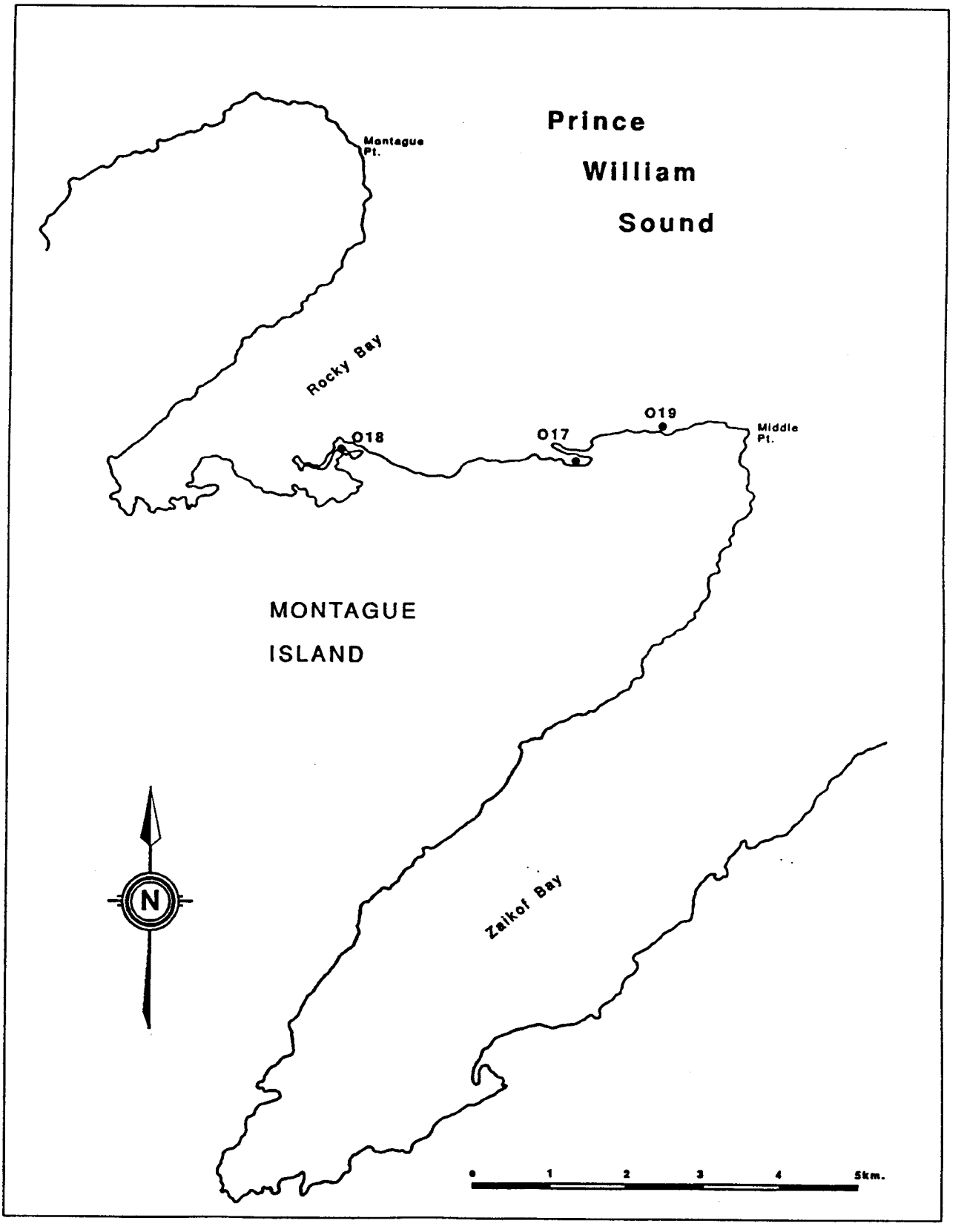

Figure 3C. Map of Rocky Bay on Montague Island in Prince William Sound showing oiled transects O17 to O19 where eggs were collected. See Fig. 1 for location of Montague Island.

2.2 Incubation

The incubation experiment was run "blind" by assigning each sample a new randomly-chosen code number which was marked on the incubation bottle. The list that cross-referenced the ADF&G sample number and the new code number was locked away until the end of the data collection period.

The samples contained too many eggs to be counted easily when they first arrived in the laboratory, so all samples were cut down to about 300 eggs each. All counts of live eggs and larvae began after the date of cut-down.

Twelve tubs each capable of holding 16 bottles were available in the laboratory (Fig. 4). As the samples arrived they were scattered among the tubs so that each contained a mixture of different beaches, transects and depths. This prevented confounding the results of the experiment with any possible "tub" effect caused by the location of the tubs in relation to each other and to sources of light and vibration in the laboratory.

Each oval tub had sides 64 x 64 cm long and a depth of 43 cm. A constant flow of freshwater into the tubs cooled the incubation bottles. The depth of freshwater was maintained at 10 cm by an elevated drainpipe in the center of each tub. Each day at 1000, 1300 and 1500 h local time three tubs were chosen at random and the water temperatures in the three tubs were measured. Thus, nine temperature measurements were taken each day.

Incubation bottles rested on the floor of the tubs (Fig. 5). They were 15 cm high with a volume of 1 L. They were filled with seawater taken from the recirculating seawater system of the Aquarium. The seawater in each bottle was replaced daily with fresh seawater. The seawater in the Aquarium's recirculating system was pumped into a reservoir from a depth of 12 m in Burrard Inlet, which is several hundred meters from the Aquarium. The salinity of the reservoir water was recorded every morning by the engineering staff of the Aquarium.

Each sample of herring eggs was contained inside a cone of Vexar mesh (Fig. 6). An airstone was attached to the bottom of each mesh cone with insulated copper wire. The exposed ends of the wire were sealed with inert silicone gel. The stream of air

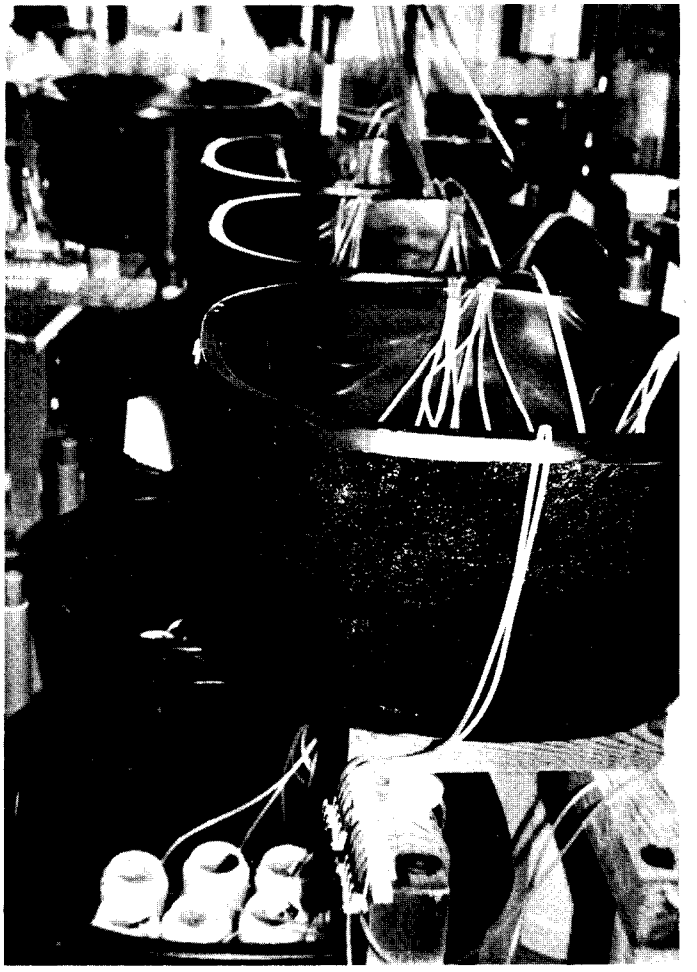

Figure 4. Incubation tubs in the larval fish laboratory of the Vancouver Public Aquarium.

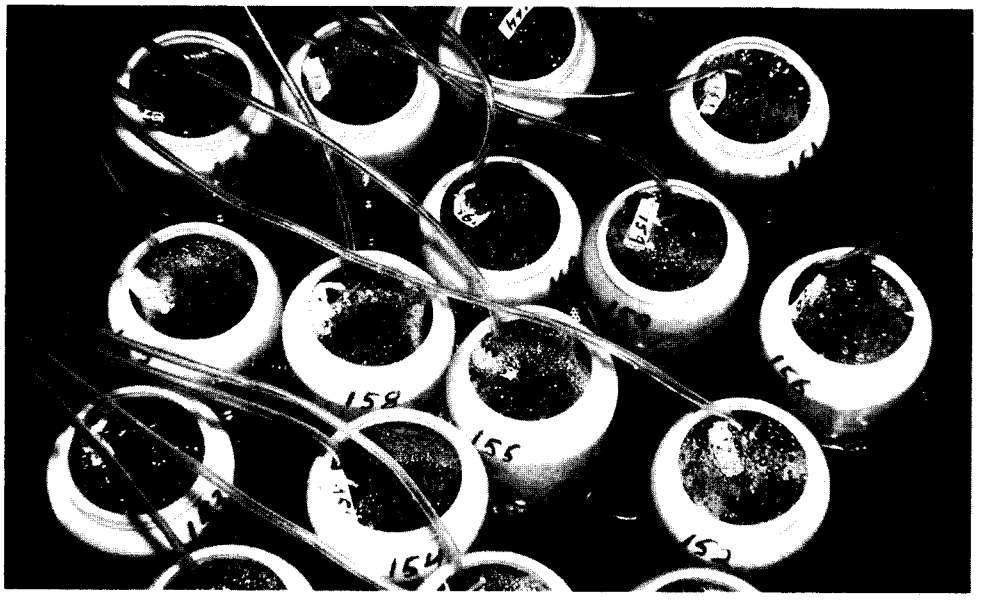

Figure 5. Incubation bottles with air hoses.

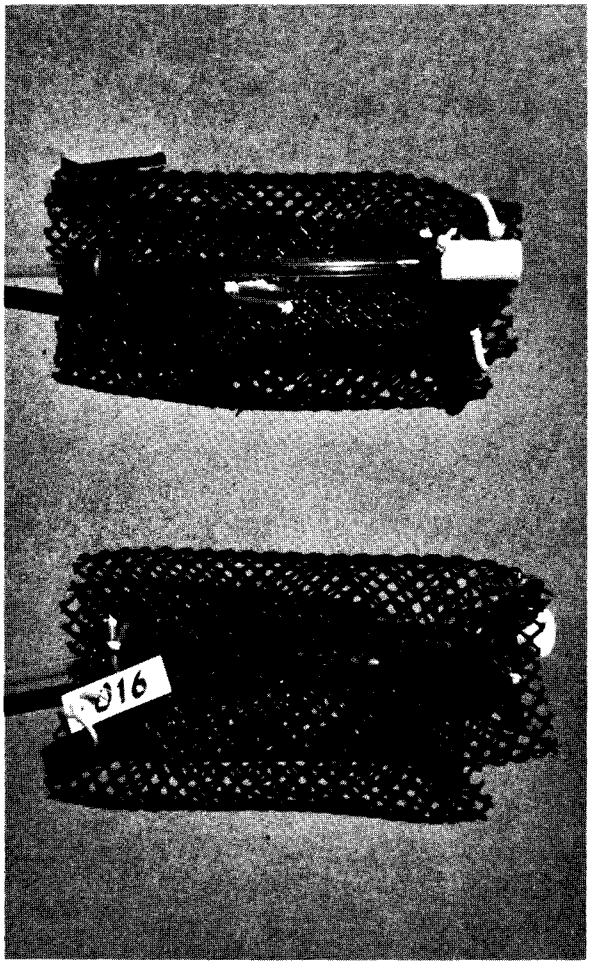

Figure 6. The mesh cone with attached airstone in an open position and enclosing a sample of spawn. The tag shows Triton sample number 16.

bubbles from an airstone travelled the length of the mesh cone and provided continuous aeration of the egg mass.

2.3 Data Collection

Each sample bottle was examined every 1 to 2 d during the experiment. The seawater in each bottle was emptied into a glass dish and all newly-hatched larvae were captured with a pipette, anaesthetized in a solution of MS222, and then preserved in a solution of 3.3% formalin and 13.4 ppt seawater. Then, the mesh cone was removed from the bottle and the numbers of live and dead eggs in the sample were counted with a dissecting microscope. Live eggs were clear and the embryo was visible in late-stage eggs; moribund eggs were tinged with white, and dead eggs were completely opaque. Fig. 7 shows three live eggs. Counting took approximately 5 to 10 min, after which the egg mass was placed back in its mesh cone, and the bottle was filled with fresh seawater and placed back in its tub.

The incubation period was over when all samples contained only egg shells, dead eggs and vegetation. At this time, the technicians began to record data from the preserved larvae. The larvae from each bottle on each date were sorted into normal and deformed groups and the number of fish in each group was counted. The developmental stage of each normal larva was recorded using Doyle's (1977) morphological staging system for the development of Atlantic herring, Clupea harengus harengus, larvae.

After the larvae were examined for deformities, a sub-sample of 10 normal fish was chosen at random, the length of each fish was measured and then it was assigned a developmental stage. The length and height of the yolk sac was measured and the larva was then rinsed in freshwater, dried at 60°C for 24 h, and stored in a dessicator until it was weighed to the nearest μg with an electrobalance.

2.4 Data Analysis

Mean age of eggs was used as an index of their state of development. Age was calculated as the number of days elapsed from the midpoint of the range of dates of spawning as recorded by ADF&G aerial surveys in 1989 and shown in Table 1. The

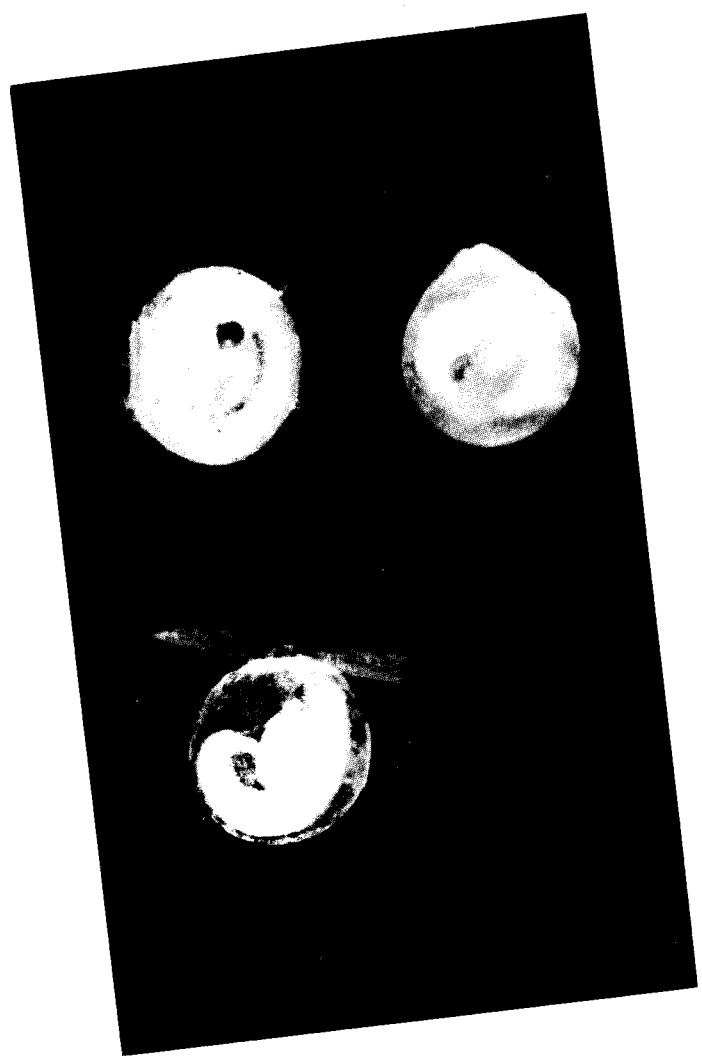

Figure 7. Three live herring eggs showing late-stage eyed embryos.

duration of spawning at a site varied from 2 to 5 d with a mean of 2 (SD = 2, n = 24) d.

Two kinds of indices of oil contamination were examined. The simplest was a division of the samples into oiled and non-oiled; Fairmount Island samples were non-oiled and all others were oiled. An attempt was also made to divide the oiled class into subclasses based on observations made by the SCUBA divers at the time the eggs were collected. These observations are recorded in Table 1. Very Light Oil was assigned to eggs from transects O-3 to O-14 from Naked Island because no oil was seen by the divers, but oil was known from aerial surveys to have been in the area before herring spawned. Light Oil was assigned to transects O-1, O-2, O-15 and O-16 because small amounts of oil were seen by divers. Medium oil was assigned to transects O-17, O-18 and O-19 in Rocky Bay because significant quanties of oil, including oil pools and tar pools, were seen by the divers. However, this second index was not used in the final analysis of this report because we found that population parameters, e.g. survival, hatching schedule etc., did not vary with treatment level, indicating that the four subclasses did not correspond to real differences in oil exposure.

The number of eggs surviving to age t, s(t), was

$$(1)\quad s(t) = [E_l(t) + \sum^{t} N(t)]/E(t_0)$$

where $E_l(t)$ = number of live eggs at age t, $N(t)$ = cumulative number of larvae at age t, and $E(t_0)$ = the total number of eggs (live and dead) in the incubation bottle at the age of cut-down, t_0. Egg and larval numbers are shown in Appendix B. Survival is synonymous with other terms that have been used in the scientific literature such as percent hatching and hatching success. It is the opposite of terms such as pre-hatching mortality.

The fraction of live eggs at age t, f(t), was

$$(2)\quad f(t) = E_l(t)/[E_l(t) + E_d(t)]$$

where $E_d(t)$ = number of dead eggs at age t.

The cumulative fraction of hatched larvae at age t, h(t), was

$$(3)\quad h(t) = \sum_{1}^{t} N(t) / N(t_n)$$

where $N(t_n)$ = the total number of larvae hatched at the end of the incubation period.

The change in s(t), f(t) and h(t) with age was analysed using the "accelerated time to failure" model of Chambers and Leggett (1989). This is a Weibull distribution modified to include auxiliary variables. For example,

$$(4a)\quad f(t) = \exp\left[-\left(\frac{t}{a}\right)^{y} \exp(b_1 z + b_2 x + b_3 xz)\right]$$

where f(t) = fraction of live eggs at age t (d), y = scale parameter of Weibull distribution, a = location parameter of the Weibull distribution, z = depth (ft) from which eggs were collected, x = dummy variable with a value of 1 for control eggs and 0 for oiled eggs, and b_1, b_2 and b_3 = coefficients for depth, oil treatment, and their interaction, respectively. Age was shifted for s(t) and h(t) using a threshold of 15 d, the minimum age for all observations. This improved the fits of the models to these data. Age was not shifted for f(t) because it reduced the fit of the model. The models were fit to the data after double ln-transformation, e.g.

$$(4b)\quad \ln\{-\ln[s(t)]\} = -y\ln(a) + y\ln(t-15) + b_1 z + b_2 x + b_3 zx$$

$$(4c)\quad \ln\{-\ln[f(t)]\} = -y\ln(a) + y\ln(t) + b_1 z + b_2 x + b_3 zx$$

with stepwise multiple regression. Only variables whose coefficients were significant at the 0.05 level were retained. Ln-transformation meant that all extreme values of a response variable, i.e. 0 and 1, were removed from the data before analysis.

This report uses a great number of fractions. In the biometrical literature fractions are often normalized with the $\arcsin(P)^{0.5}$ transformation before entering analysis of variance (Sokal and Rohlf 1981), but fractions were not transformed in this

report because normalization was most often achieved using a Weibull distribution. For those fractions that were not normalized with a Weibull function extensive preliminary analysis showed that none of the findings were changed by arcsin transformation. Therefore, for the sake of clarity we present all fractions without arcsin transformation.

Herring larvae lose length and weight upon fixation in formalin. We adjusted the post-preservation lengths and weights for fixation shrinkage in order to make our results comparable to those of live herring larvae. This was only possible because the relationships between fixation shrinkage of herring larvae and the concentration of formalin and seawater in the preservative have been extensively investigated by Hay (1982, 1984).

Hay (1982: Fig. 5) showed that 2 wk old herring larvae preserved for 10 d in 10% formalin and 27 ppt seawater shrank by an amount equal to 0.564 + 0.016L, where L = live length (mm). This means that percent shrinkage is equal to 1.6 + 56.4/L. This equation was corrected for the differences in formalin concentration and salinity between his results and the present incubation experiment (3.3% formalin and 13.4 ppt salinity) using Hay's (1982) multiple regression of percent shrinkage on salinity, formalin concentration and temperature. This equation predicted that our preservative would produce only 77.9% of the shrinkage produced by 10% formalin and 27 ppt salinity, so percent shrinkage was 0.779(1.6 + 56.4/L) or 1.2 + 43.9/L. Therefore, we corrected preserved lengths to live lengths using the rearranged equation

(5) $L = 0.444 + 1.012X$

where X = preserved length (mm).

Hay (1984) reported that the mean percent loss in dry weight of yolk sac herring larvae preserved in 4% formalin decreased from -36.2% in freshwater (0 ppt) to -21.3% at a salinity of 15 ppt, which implies an extra 1.0% increase in fixed dry weight for every 1 ppt increase in salinity. Therefore, at an average salinity of 13.4 ppt, the weight loss was calculated to be -22.9%, i.e. -36.2% + 1.0%/ppt x 13.4ppt, and live weight was equal to fixed weight/(1-0.229) or fixed weight x 1.297.

Yolk sac volume was calculated from the equation for an ellipsoid (Hourston et al. 1984)

$$(6) \quad V = \frac{4}{3}\pi\left(\frac{L_y}{2}\right)^2\left(\frac{H}{2}\right)$$

where V = volume (mm^3), L_y = length (mm) of yolk sac, and H = height (mm) of yolk sac. Neither L_y or H were corrected for fixation shrinkage.

Condition of larvae was calculated as

$$(7) \quad CF = W/L^3$$

where CF = condition factor ($\mu g \cdot mm^{-3}$), W = live dry weight (μg) and L = live length (mm).

3. RESULTS

3.1 Incubation Temperature and Salinity

Temperature of the incubation tubs rose from 8.0°C over the first three days of May to a mean of 9.2°C on May 16 (Fig. 8, Appendix A). The trend was not linear with time, so polynomial regression was used to describe the trend. Dummy variables for the three times of the day at which temperatures were taken were included in the regression model in order to determine if temperatures varied during a day as well as between days. The model that explained the most variance (r^2 = 0.55, n = 54) with all-significant parameters ($P < 0.05$) was

(8)	T =	-78.29 +	1.276D -	$4.466 \times 10^{-3} D^2$ -	0.2056g
	(SE)	(25.91)	(0.394)	(1.498×10^{-3})	(0.0937)
	(P)	(0.004)	(0.002)	(0.003)	(0.003)

where T = temperature (°C), D = Julian date, and g = a dummy variable with a value of 1 for 1000 h and zero for the other two times of day. This model shows that the temperature of the incubation water was 0.2°C lower in the morning than it was in the afternoon at all dates (Fig. 8). It suggests that water temperature followed a

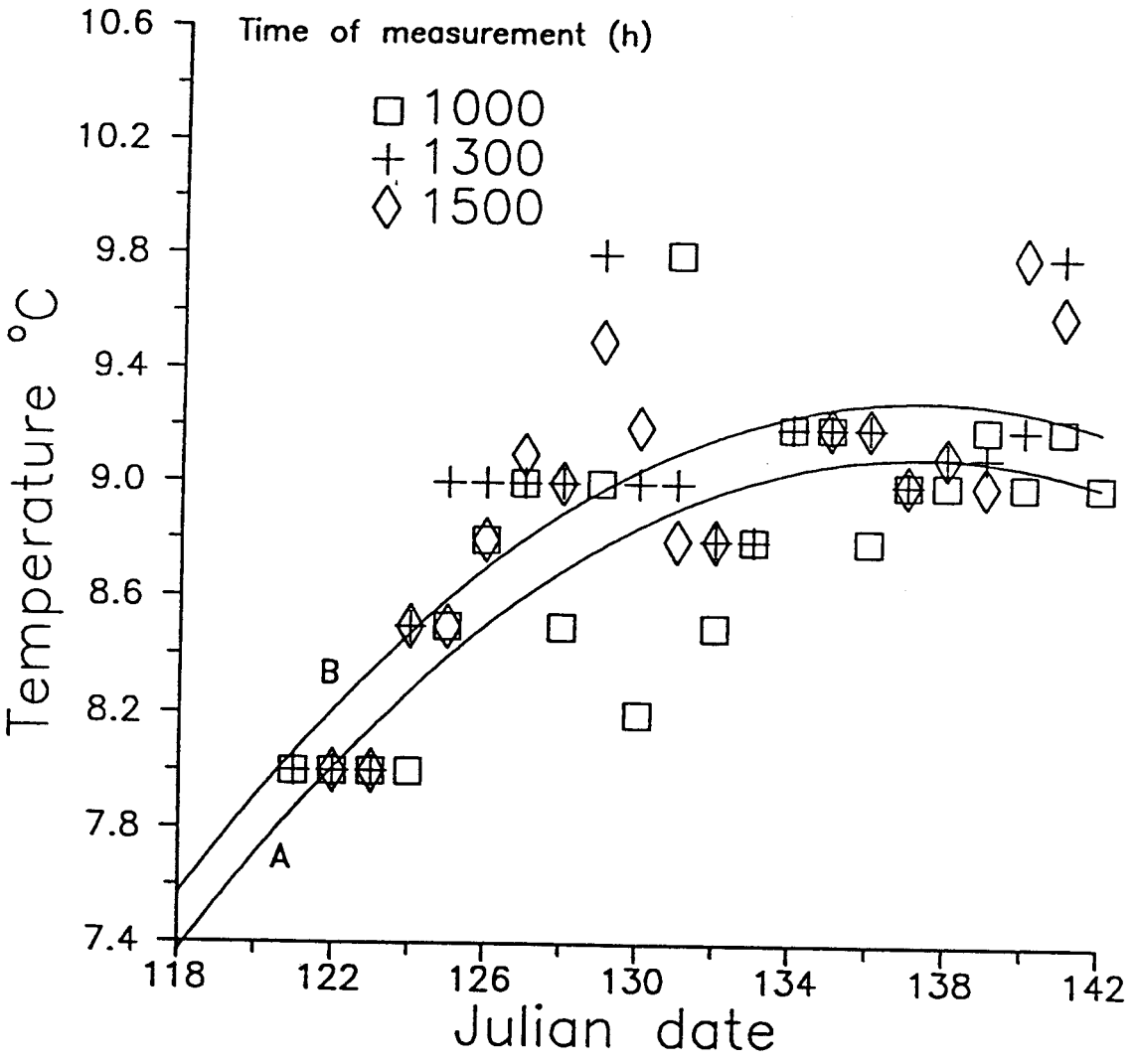

Figure 8. Temperature of incubation water, showing that water was 0.2°C cooler at 1000 h than at 1300 and 1500 h. Curve A describes temperature at 1000h and curve B describes temperature at 1300 and 1500 h. Both curves were calculated from equation (8).

daily cycle: low at night rising in the morning to a maximum in the afternoon, and then falling to an overnight low.

Fig. 9 shows that the salinity of the seawater system varied cyclically with date about a mean of 26.8 ppt (SD = 0.6, n = 24). A periodogram showed that the average cycle time was 4 d. The cause of the cycle is not known; it was not caused by the pumping of fresh seawater into the Aquarium's reservoir because at least 300 gal were pumped into it every half hour (John Rawle, Vancouver Public Aquarium, Vancouver, B.C., pers. comm.).

3.2 Egg Survival

Total Survival

The fraction of eggs that survived incubation and hatched larvae ranged from 0.071 to 0.999 with a grand mean of 0.592 (SD = 0.177, n=180) (Table 2). A two-way analysis of variance (ANOVA) showed that survival varied significantly ($P<0.001$) with depth, but not with oil treatment ($P>0.05$) or with the interaction of depth and oil treatment ($P>0.05$). Multiple regression showed that the greatest amount of variance in survival ($r^2 = 0.10$, n = 180) was explained by a quadratic regression on depth

(9)

variable	coefficient	SE	P
constant	0.6058	0.0148	<0.0001
depth	-0.0159	0.0037	<0.0001
$depth^2$	-0.0013	0.0003	<0.0001

The predicted survival is shown in Fig. 10A. It was maximal near a depth of -5 ft.

Age Trajectory of Survival

In contrast to the results for total survival, a Weibull model showed that survival at age, s(t), decreased at a constant rate of about $3\%\cdot d^{-1}$ in all depth-treatment cells and there was no significant effect of depth or oil treatment. The parameters of the model are shown in Table 3 and the predicted s(t) is shown in Fig. 11. Examination of Fig. 11 shows that this model overestimates s(t) for the oiled/5 ft class. This

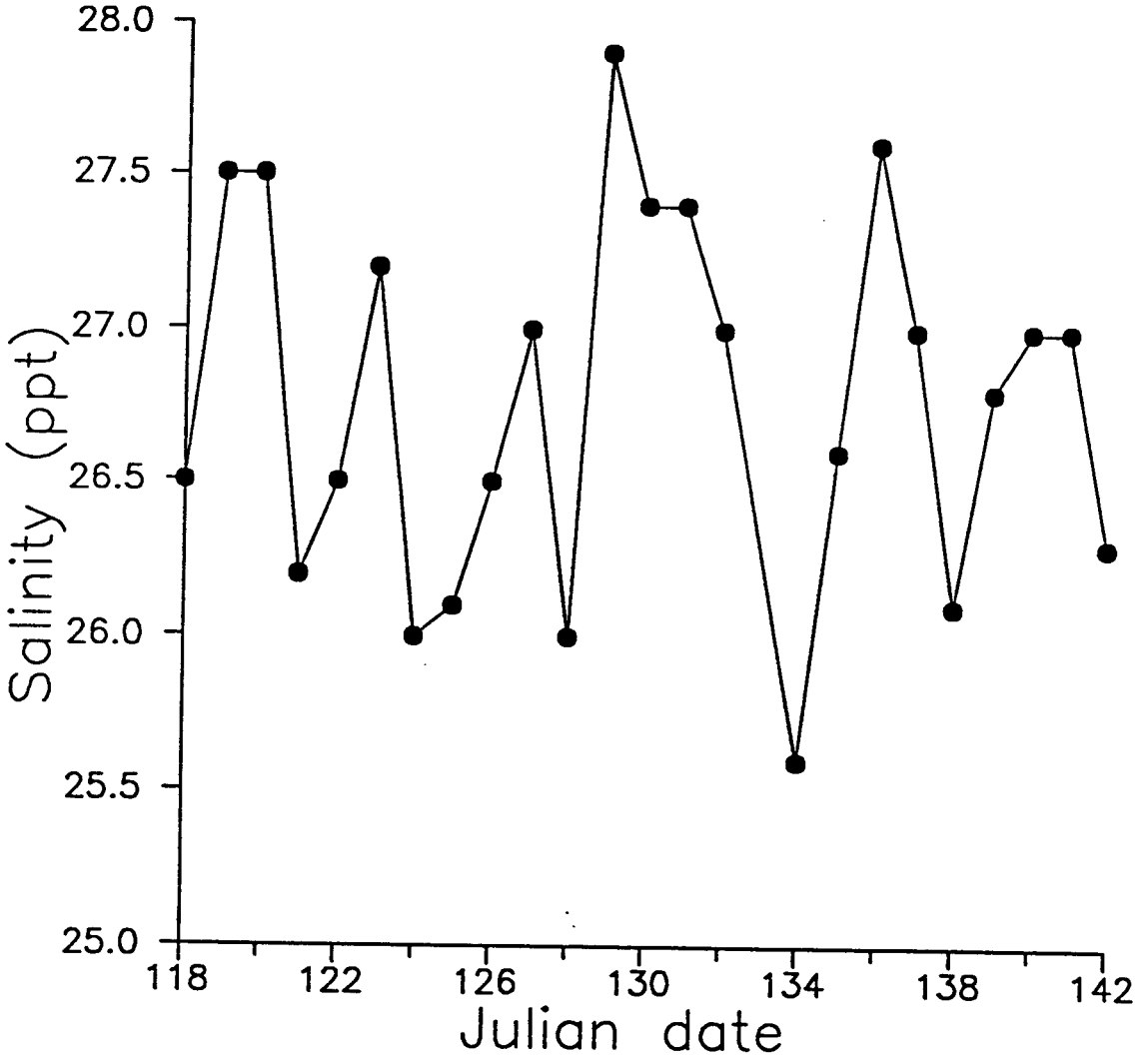

Figure 9. Salinity of Vancouver Public Aquarium seawater system, showing a periodicity of about 1 cycle every four days.

Table 2. Summary statistics of herring egg samples.

Location	ADFG sample number	Depth (ft)	Rep. no.	TRITON sample number	fraction survived to hatch	Age (d) at hatch 50%	Age (d) at hatch 95%	fraction of larvae viable	fraction viable hatch	Fraction of larvae in developmental stages: pre-1a	1a	1b	1c	Fraction of larvae in deformity classes: normal	spine	yolk	jaw	stubby	head	caudal	Yolk sac volume (mm^3) mean	SD	Weight (ug) mean	SD	Length (mm) mean	SD	Condition (ug mm^-3) mean	SD	n
Fairmount	C-01	5	3	53	0.652	22.7	26.1	0.789	0.514	0.070	0.197	0.197	0.535	0.789	0.183	0.028	0.000	0.000	0.000	0.000	0.184	0.130	168	29	8.3	0.6	0.301	0.088	22
Fairmount	C-01	5	1	101	0.577	23.6	27.9	0.867	0.500	0.030	0.056	0.185	0.730	0.867	0.060	0.047	0.026	0.000	0.000	0.000	0.152	0.157	144	58	8.8	0.8	0.227	0.122	47
Fairmount	C-01	5	2	2	0.455	23.7	26.4	0.475	0.216	0.000	0.079	0.086	0.835	0.475	0.072	0.424	0.022	0.007	0.000	0.000	0.182	0.151	164	32	8.3	1.1	0.324	0.178	39
Fairmount	C-01	0	3	172	0.672	21.5	25.2	0.940	0.631	0.004	0.014	0.363	0.619	0.940	0.053	0.000	0.000	0.007	0.000	0.000	0.129	0.122	130	75	9.2	0.9	0.182	0.122	61
Fairmount	C-01	0	1	78	0.740	22.8	25.4	0.941	0.697	0.018	0.086	0.194	0.703	0.941	0.059	0.000	0.000	0.000	0.000	0.000	0.144	0.101	146	58	8.8	0.6	0.213	0.089	25
Fairmount	C-01	0	2	143	0.697	21.9	26.4	0.770	0.537	0.135	0.216	0.000	0.649	0.770	0.122	0.108	0.000	0.000	0.000	0.000	0.164	0.117	167	28	8.3	1.0	0.312	0.125	25
Fairmount	C-01	-5	3	126	0.456	23.3	25.6	0.628	0.286	0.007	0.241	0.641	0.110	0.628	0.366	0.000	0.007	0.000	0.000	0.000	0.230	0.117	147	63	8.5	0.9	0.264	0.141	31
Fairmount	C-01	-5	1	107	0.984	23.7	27.0	0.952	0.936	0.003	0.052	0.339	0.606	0.952	0.035	0.003	0.010	0.000	0.000	0.000	0.219	0.236	185	40	8.9	0.6	0.271	0.088	46
Fairmount	C-01	-5	2	91	0.475	22.7	25.1	0.914	0.434	0.000	0.000	0.691	0.309	0.914	0.049	0.037	0.000	0.000	0.000	0.000	0.204	0.127	169	45	8.3	0.9	0.302	0.132	20
Fairmount	C-02	0	1	58	0.232	24.6	27.0	0.708	0.164	0.000	0.125	0.000	0.875	0.708	0.083	0.167	0.042	0.000	0.000	0.000	0.143	0.136	165	27	9.0	0.9	0.248	0.094	20
Fairmount	C-02	0	3	36	0.709	23.1	25.3	0.921	0.653	0.000	0.281	0.388	0.331	0.921	0.039	0.000	0.039	0.000	0.000	0.000	0.166	0.112	172	29	9.1	0.8	0.238	0.062	26
Fairmount	C-02	0	2	151	0.718	23.4	26.9	0.896	0.643	0.000	0.088	0.088	0.824	0.896	0.096	0.000	0.008	0.000	0.000	0.000	0.096	0.113	163	27	9.3	0.7	0.208	0.045	32
Fairmount	C-02	-5	2	141	0.779	20.9	24.8	0.946	0.737	0.046	0.208	0.285	0.462	0.946	0.008	0.046	0.000	0.000	0.000	0.000	0.160	0.143	170	29	9.0	1.0	0.245	0.083	44
Fairmount	C-02	-5	1	119	0.379	19.6	24.9	0.722	0.274	0.000	0.000	0.583	0.417	0.722	0.056	0.222	0.000	0.000	0.000	0.000	0.194	0.165	170	38	8.8	1.0	0.260	0.086	20
Fairmount	C-02	-5	3	159	0.750	23.6	27.0	0.882	0.662	0.005	0.077	0.436	0.482	0.882	0.046	0.000	0.072	0.000	0.000	0.000	0.180	0.119	162	30	8.9	1.0	0.244	0.107	47
Fairmount	C-02	-15	1	125	0.709	24.1	26.6	0.910	0.645	0.017	0.371	0.461	0.152	0.910	0.062	0.028	0.000	0.000	0.000	0.000	0.221	0.143	163	44	8.8	1.1	0.287	0.149	39
Fairmount	C-02	-15	3	19	0.551	23.3	25.6	0.845	0.465	0.019	0.029	0.369	0.583	0.845	0.068	0.087	0.000	0.000	0.000	0.000	0.221	0.149	185	41	8.7	1.2	0.307	0.143	42
Fairmount	C-02	-15	2	168	0.446	21.4	25.5	0.771	0.344	0.000	0.170	0.277	0.553	0.771	0.104	0.021	0.104	0.000	0.000	0.000	0.121	0.118	86	79	9.3	1.0	0.125	0.126	26
Fairmount	C-03	0	1	23	0.606	24.1	25.9	0.817	0.495	0.021	0.162	0.268	0.549	0.817	0.028	0.155	0.000	0.000	0.000	0.000	0.204	0.172	172	30	8.6	1.1	0.302	0.139	36
Fairmount	C-03	0	2	37	0.596	23.6	25.9	0.893	0.532	0.012	0.054	0.292	0.643	0.893	0.071	0.036	0.000	0.000	0.000	0.000	0.075	0.082	182	30	9.3	0.7	0.227	0.050	27
Fairmount	C-03	0	3	142	0.703	24.6	27.1	0.756	0.532	0.036	0.021	0.036	0.907	0.756	0.197	0.047	0.000	0.000	0.000	0.000	0.056	0.109	176	19	9.5	1.1	0.228	0.126	21
Fairmount	C-03	-5	3	74	0.570	22.9	26.4	0.848	0.483	0.013	0.152	0.641	0.194	0.848	0.135	0.004	0.000	0.013	0.000	0.000	0.162	0.126	167	20	8.7	1.0	0.284	0.142	25
Fairmount	C-03	-5	1	62	0.629	25.2	27.7	0.768	0.483	0.000	0.185	0.026	0.788	0.768	0.113	0.073	0.000	0.046	0.000	0.000	0.146	0.170	174	26	9.0	1.1	0.264	0.118	41
Fairmount	C-03	-5	2	24	0.545	24.3	26.2	0.895	0.488	0.023	0.198	0.163	0.616	0.895	0.058	0.012	0.035	0.000	0.000	0.000	0.189	0.147	165	40	8.1	1.3	0.361	0.193	29
Fairmount	C-03	-15	1	152	0.683	24.9	28.7	0.795	0.543	0.000	0.041	0.008	0.951	0.795	0.082	0.115	0.000	0.008	0.000	0.000	0.105	0.145	172	36	9.1	0.8	0.245	0.139	31
Fairmount	C-03	-15	2	41	0.560	24.1	25.9	0.828	0.464	0.008	0.172	0.033	0.787	0.828	0.066	0.057	0.049	0.000	0.000	0.000	0.120	0.141	161	23	9.0	0.8	0.225	0.057	30
Fairmount	C-03	-15	3	98	0.653	24.3	25.8	0.920	0.601	0.037	0.102	0.364	0.497	0.920	0.048	0.000	0.021	0.000	0.011	0.000	0.174	0.175	180	30	8.9	1.1	0.297	0.230	32
Fairmount	C-04	5	2	25	0.591	21.9	24.6	0.837	0.495	0.012	0.105	0.174	0.709	0.837	0.128	0.035	0.000	0.000	0.000	0.000	0.146	0.140	164	24	9.0	1.0	0.238	0.093	51
Fairmount	C-04	5	1	127	0.440	22.9	25.1	0.900	0.396	0.054	0.146	0.146	0.654	0.900	0.077	0.023	0.000	0.000	0.000	0.000	0.122	0.130	171	28	8.9	1.2	0.270	0.137	38
Fairmount	C-04	5	3	100	0.673	24.4	26.9	0.858	0.577	0.026	0.147	0.053	0.774	0.858	0.042	0.068	0.026	0.000	0.005	0.000	0.190	0.169	161	31	8.5	1.0	0.295	0.163	33
Fairmount	C-04	0	2	35	0.817	22.2	23.9	0.888	0.725	0.009	0.047	0.440	0.504	0.888	0.069	0.034	0.004	0.004	0.000	0.000	0.097	0.099	160	24	8.9	1.0	0.248	0.127	29
Fairmount	C-04	0	1	156	0.512	23.4	25.8	0.646	0.331	0.000	0.037	0.402	0.561	0.646	0.146	0.000	0.061	0.146	0.000	0.000	0.096	0.080	154	29	8.9	0.8	0.224	0.083	22
Fairmount	C-04	0	3	6	0.986	23.3	24.7	0.895	0.882	0.000	0.025	0.331	0.644	0.895	0.047	0.025	0.025	0.000	0.007	0.000	0.157	0.154	168	32	8.7	1.0	0.286	0.150	30
Fairmount	C-04	-5	1	176	0.813	22.7	26.2	0.890	0.723	0.026	0.141	0.247	0.586	0.890	0.084	0.022	0.004	0.000	0.000	0.000	0.166	0.159	173	26	9.0	1.1	0.266	0.141	34
Fairmount	C-04	-5	2	96	0.633	23.4	24.9	0.963	0.610	0.023	0.217	0.097	0.664	0.963	0.028	0.000	0.000	0.000	0.009	0.000	0.221	0.177	177	32	8.4	0.6	0.300	0.053	17
Fairmount	C-04	-5	3	70	0.331	22.6	25.8	0.925	0.306	0.050	0.425	0.075	0.450	0.925	0.025	0.017	0.017	0.008	0.008	0.000	0.172	0.170	172	26	8.5	0.9	0.304	0.156	25
Fairmount	C-05	5	2	95	0.844	22.9	24.9	0.937	0.791	0.000	0.050	0.213	0.736	0.937	0.042	0.000	0.021	0.000	0.000	0.000	0.145	0.144	194	69	9.2	0.8	0.256	0.145	32

Table 2. Summary statistics of herring egg samples. (Continued)

Location	ADFG sample number	Depth (ft)	Rep. no.	TRITON sample number	fraction survived to hatch	Age (d) at hatch 50%	Age (d) at hatch 95%	fraction of larvae viable	fraction viable hatch	Fraction of larvae in developmental stages: pre-1a	1a	1b	1c	Fraction of larvae in deformity classes: normal	spine	yolk	jaw	stubby	head	caudal	Yolk sac volume (mm^3) mean	SD	Weight (ug) mean	SD	Length (mm) mean	SD	Condition (ug mm^-3) mean	SD	n
Fairmount	C-05	5	1	57	0.683	24.5	26.6	0.835	0.570	0.000	0.095	0.063	0.842	0.835	0.046	0.039	0.067	0.014	0.000	0.000	0.118	0.125	171	25	9.1	1.0	0.251	0.117	35
Fairmount	C-05	5	3	3	0.429	22.8	24.9	0.745	0.320	0.006	0.019	0.146	0.828	0.745	0.038	0.210	0.000	0.006	0.000	0.000	0.139	0.166	161	40	8.5	1.5	0.303	0.175	35
Fairmount	C-05	0	3	40	0.625	22.6	24.5	0.925	0.578	0.010	0.219	0.294	0.478	0.925	0.020	0.045	0.005	0.005	0.000	0.000	0.154	0.120	164	31	8.7	0.8	0.263	0.103	17
Fairmount	C-05	0	2	108	0.602	22.5	24.7	0.856	0.516	0.010	0.169	0.610	0.210	0.856	0.144	0.000	0.000	0.000	0.000	0.000	0.191	0.081	173	23	8.6	1.0	0.290	0.109	21
Fairmount	C-05	0	1	69	0.601	23.4	26.4	0.895	0.717	0.000	0.037	0.419	0.544	0.895	0.024	0.078	0.000	0.003	0.000	0.000	0.057	0.076	155	20	9.4	0.6	0.190	0.039	41
Fairmount	C-05	-5	3	167	0.726	24.2	26.0	0.922	0.669	0.024	0.034	0.244	0.698	0.922	0.049	0.020	0.005	0.005	0.000	0.000	0.172	0.125	157	27	8.4	0.8	0.280	0.123	39
Fairmount	C-05	-5	2	92	0.740	24.0	26.0	0.856	0.633	0.054	0.054	0.041	0.851	0.856	0.068	0.050	0.018	0.000	0.009	0.000	0.157	0.127	179	38	8.8	1.0	0.284	0.118	40
Fairmount	C-05	-5	1	7	0.553	23.0	24.4	0.929	0.514	0.109	0.027	0.266	0.598	0.929	0.033	0.027	0.000	0.011	0.000	0.000	0.154	0.145	178	32	8.9	1.2	0.296	0.182	13
Bass Harbour	O-01	0	3	155	0.759	23.8	25.8	0.880	0.668	0.009	0.046	0.046	0.898	0.880	0.046	0.000	0.028	0.046	0.000	0.000	0.107	0.118	159	27	8.8	1.0	0.247	0.094	21
Bass Harbour	O-01	0	1	137	0.504	21.7	24.3	0.817	0.412	0.007	0.922	0.052	0.020	0.817	0.170	0.000	0.013	0.000	0.000	0.000	0.265	0.106	190	35	8.5	0.5	0.309	0.060	19
Bass Harbour	O-01	0	2	68	0.860	23.8	26.7	0.650	0.559	0.007	0.035	0.203	0.755	0.650	0.154	0.084	0.077	0.035	0.000	0.000	0.057	0.068	150	25	8.8	1.0	0.228	0.063	38
Bass Harbour	O-01	-5	1	106	0.651	23.6	25.6	0.894	0.582	0.035	0.278	0.323	0.364	0.894	0.030	0.066	0.005	0.005	0.000	0.000	0.145	0.128	132	65	8.7	1.0	0.224	0.153	42
Bass Harbour	O-01	-5	2	175	0.714	22.3	23.7	0.851	0.607	0.004	0.245	0.585	0.166	0.851	0.116	0.033	0.000	0.000	0.000	0.000	0.238	0.081	176	63	8.4	1.0	0.321	0.161	24
Bass Harbour	O-01	-5	3	90	0.629	24.4	26.0	0.792	0.498	0.038	0.158	0.077	0.727	0.792	0.060	0.038	0.109	0.000	0.000	0.000	0.128	0.115	135	63	9.2	0.7	0.183	0.123	33
Bass Harbour	O-01	-15	2	61	0.653	26.1	28.0	0.712	0.465	0.000	0.174	0.256	0.571	0.712	0.119	0.091	0.078	0.000	0.000	0.000	0.109	0.127	146	53	9.0	0.8	0.211	0.104	25
Bass Harbour	O-01	-15	1	39	0.718	22.9	24.9	0.885	0.635	0.000	0.063	0.445	0.492	0.885	0.063	0.031	0.021	0.000	0.000	0.000	0.105	0.095	156	25	9.1	0.8	0.217	0.071	23
Bass Harbour	O-01	-15	3	124	0.527	23.0	26.0	0.927	0.489	0.006	0.165	0.628	0.201	0.927	0.049	0.018	0.006	0.000	0.000	0.000	0.165	0.097	159	69	8.3	0.8	0.297	0.141	22
Bass Harbour	O-02	0	3	1	0.624	22.2	24.9	0.981	0.613	0.031	0.012	0.360	0.596	0.981	0.019	0.000	0.000	0.000	0.000	0.000	0.126	0.125	171	27	9.2	0.8	0.231	0.074	13
Bass Harbour	O-02	0	1	99	0.707	21.9	24.0	0.946	0.669	0.012	0.096	0.506	0.386	0.946	0.048	0.000	0.000	0.000	0.006	0.000	0.134	0.090	168	35	8.8	1.2	0.269	0.117	37
Bass Harbour	O-02	0	2	18	0.522	22.0	25.0	0.923	0.482	0.010	0.550	0.196	0.244	0.923	0.038	0.038	0.000	0.000	0.000	0.000	0.137	0.128	163	31	8.4	1.1	0.314	0.239	29
Bass Harbour	O-02	-5	3	134	0.606	23.7	26.4	0.901	0.546	0.000	0.227	0.250	0.523	0.901	0.029	0.035	0.029	0.006	0.000	0.000	0.132	0.121	179	37	9.3	0.8	0.233	0.082	29
Bass Harbour	O-02	-5	1	83	0.307	22.7	24.7	0.966	0.297	0.000	0.067	0.404	0.528	0.966	0.000	0.034	0.000	0.000	0.000	0.000	0.128	0.145	167	20	9.1	0.5	0.225	0.047	21
Bass Harbour	O-02	-5	2	34	0.774	22.5	24.8	0.959	0.742	0.000	0.311	0.265	0.425	0.959	0.016	0.016	0.005	0.000	0.000	0.000	0.160	0.125	163	27	8.7	1.0	0.275	0.157	23
Bass Harbour	O-02	-15	3	118	0.416	22.9	24.8	0.912	0.380	0.007	0.161	0.467	0.365	0.912	0.088	0.000	0.000	0.000	0.000	0.000	0.119	0.115	165	28	8.6	0.9	0.275	0.120	31
Bass Harbour	O-02	-15	1	17	0.535	22.5	24.2	0.886	0.474	0.027	0.141	0.611	0.222	0.886	0.070	0.005	0.038	0.000	0.000	0.000	0.141	0.104	177	31	9.0	0.7	0.250	0.049	30
Bass Harbour	O-02	-15	2	4	0.416	22.9	25.0	0.864	0.360	0.000	0.197	0.197	0.606	0.864	0.038	0.083	0.015	0.000	0.000	0.000	0.139	0.086	171	32	9.3	0.8	0.219	0.064	12
Bass Harbour	O-03	5	3	49	0.227	22.9	24.6	0.346	0.078	0.015	0.015	0.830	0.139	0.346	0.077	0.194	0.367	0.015	0.000	0.000	0.175	0.106	157	22	9.4	0.9	0.196	0.063	16
Bass Harbour	O-03	5	1	103	0.757	22.8	26.1	0.898	0.680	0.005	0.063	0.359	0.573	0.898	0.034	0.010	0.058	0.000	0.000	0.000	0.134	0.119	171	22	8.9	1.0	0.265	0.106	47
Bass Harbour	O-03	5	2	5	0.321	22.4	23.9	0.988	0.317	0.000	0.244	0.244	0.512	0.988	0.000	0.012	0.000	0.000	0.000	0.000	0.227	0.026	171	29	8.1	0.2	0.324	0.031	2
Bass Harbour	O-03	0	2	154	0.956	23.7	26.1	0.712	0.681	0.009	0.090	0.069	0.833	0.712	0.103	0.013	0.086	0.086	0.000	0.000	0.103	0.119	159	28	8.9	1.0	0.248	0.149	32
Bass Harbour	O-03	0	1	14	0.708	22.7	24.8	0.904	0.640	0.026	0.262	0.568	0.144	0.904	0.037	0.026	0.033	0.000	0.000	0.000	0.153	0.102	163	25	8.8	1.0	0.259	0.109	24
Bass Harbour	O-03	0	3	104	0.645	22.6	25.4	0.691	0.446	0.000	0.208	0.562	0.230	0.691	0.096	0.084	0.129	0.000	0.000	0.000	0.202	0.130	184	50	8.9	0.9	0.266	0.083	32
Bass Harbour	O-03	-5	2	139	0.189	22.7	24.0	0.861	0.163	0.000	0.889	0.111	0.000	0.861	0.111	0.000	0.028	0.000	0.000	0.000	0.288	0.145	155	35	7.8	0.7	0.332	0.075	12
Bass Harbour	O-03	-5	1	55	0.517	23.6	24.9	0.839	0.434	0.000	0.000	0.339	0.661	0.839	0.107	0.000	0.054	0.000	0.000	0.000	0.132	0.123	163	24	8.6	0.9	0.274	0.101	10
Bass Harbour	O-03	-5	3	120	0.579	23.6	25.9	0.878	0.508	0.011	0.361	0.161	0.467	0.878	0.067	0.050	0.000	0.006	0.000	0.000	0.142	0.119	189	46	8.7	0.9	0.303	0.105	36
Bass Harbour	O-04	0	2	169	0.624	21.3	23.7	0.938	0.585	0.000	0.000	0.375	0.625	0.938	0.009	0.054	0.000	0.000	0.000	0.000	0.216	0.137	164	27	8.6	1.0	0.272	0.069	15
Bass Harbour	O-04	0	3	71	0.516	19.8	23.9	0.863	0.445	0.000	0.130	0.242	0.627	0.863	0.037	0.012	0.062	0.025	0.000	0.000	0.158	0.131	167	31	8.6	0.9	0.276	0.090	37

Table 2. Summary statistics of herring egg samples. (Continued)

Location	ADFG sample number	Depth (ft)	Rep. no.	TRITON sample number	fraction survived to hatch	Age (d) at hatch 50%	Age (d) at hatch 95%	fraction of larvae viable	fraction viable hatch	Fraction of larvae in developmental stages: pre-1a	1a	1b	1c	Fraction of larvae in deformity classes: normal	spine	yolk	jaw	stubby	head	caudal	Yolk sac volume (mm^3) mean	Yolk sac volume (mm^3) SD	Weight (ug) mean	Weight (ug) SD	Length (mm) mean	Length (mm) SD	Condition (ug mm^-3) mean	Condition (ug mm^-3) SD	n
Bass Harbour	O-04	0	1	153	0.536	20.6	21.8	0.969	0.520	0.008	0.492	0.375	0.125	0.969	0.016	0.000	0.008	0.008	0.000	0.000	0.251	0.176	168	25	8.2	0.9	0.342	0.207	12
Bass Harbour	O-04	-5	2	73	0.699	21.2	24.7	0.923	0.645	0.011	0.116	0.394	0.479	0.923	0.046	0.011	0.007	0.014	0.000	0.000	0.155	0.134	166	29	9.2	0.8	0.228	0.081	60
Bass Harbour	O-04	-5	1	32	0.166	21.5	23.7	0.750	0.124	0.083	0.083	0.167	0.667	0.750	0.083	0.083	0.083	0.000	0.000	0.000	0.205	0.139	178	25	9.0	1.7	0.334	0.315	9
Bass Harbour	O-04	-5	3	171	0.993	22.8	24.6	0.763	0.758	0.024	0.185	0.329	0.462	0.763	0.088	0.141	0.008	0.000	0.000	0.000	0.147	0.133	164	27	9.0	0.7	0.238	0.094	45
Bass Harbour	O-04	-15	2	88	0.505	20.6	23.5	0.823	0.416	0.015	0.262	0.492	0.231	0.823	0.108	0.046	0.000	0.023	0.000	0.000	0.216	0.126	179	36	8.4	0.8	0.312	0.095	32
Bass Harbour	O-04	-15	3	121	0.268	20.6	23.5	1.000	0.268	0.035	0.612	0.212	0.141	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.283	0.108	202	36	8.0	0.8	0.417	0.142	12
Bass Harbour	O-04	-15	1	149	0.571	21.5	24.4	0.794	0.453	0.019	0.071	0.781	0.129	0.794	0.129	0.039	0.013	0.026	0.000	0.000	0.177	0.111	164	33	8.7	0.9	0.264	0.094	27
Bass Harbour	O-08	0	2	162	0.562	25.0	28.6	0.532	0.299	0.000	0.029	0.072	0.899	0.532	0.180	0.288	0.000	0.000	0.000	0.000	0.051	0.086	160	30	8.9	0.9	0.244	0.119	30
Bass Harbour	O-08	0	3	147	0.280	23.4	26.1	0.770	0.216	0.016	0.197	0.016	0.770	0.770	0.000	0.230	0.000	0.000	0.000	0.000	0.083	0.083	183	34	9.3	1.2	0.240	0.085	16
Bass Harbour	O-08	0	1	64	0.483	24.5	27.3	0.944	0.456	0.019	0.318	0.159	0.505	0.944	0.000	0.028	0.028	0.000	0.000	0.000	0.128	0.133	167	24	8.4	0.9	0.293	0.100	25
Bass Harbour	O-08	-5	1	178	0.885	23.7	27.1	0.835	0.739	0.000	0.041	0.147	0.812	0.835	0.046	0.083	0.018	0.018	0.000	0.000	0.155	0.123	158	27	8.8	0.8	0.241	0.086	33
Bass Harbour	O-08	-5	2	130	0.328	24.4	26.0	0.872	0.286	0.000	0.032	0.234	0.734	0.872	0.043	0.085	0.000	0.000	0.000	0.000	0.052	0.052	180	27	9.4	0.7	0.216	0.037	12
Bass Harbour	O-08	-5	3	114	0.449	23.6	25.2	0.898	0.403	0.000	0.258	0.570	0.172	0.898	0.031	0.070	0.000	0.000	0.000	0.000	0.107	0.054	155	34	8.6	0.9	0.249	0.052	17
Bass Harbour	O-08	-15	3	13	0.478	24.2	25.9	0.948	0.453	0.000	0.030	0.530	0.440	0.948	0.030	0.000	0.022	0.000	0.000	0.000	0.109	0.072	173	29	9.3	0.6	0.222	0.070	22
Bass Harbour	O-08	-15	1	33	0.621	23.8	25.9	0.961	0.597	0.006	0.112	0.691	0.191	0.961	0.022	0.017	0.000	0.000	0.000	0.000	0.116	0.143	165	22	9.1	0.9	0.231	0.088	20
Bass Harbour	O-08	-15	2	47	0.666	24.7	26.1	0.973	0.648	0.000	0.000	0.331	0.669	0.973	0.007	0.007	0.000	0.014	0.000	0.000	0.143	0.118	151	33	8.8	1.1	0.231	0.071	23
Bass Harbour	O-10	0	1	16	0.817	23.9	25.3	0.908	0.742	0.010	0.117	0.390	0.483	0.908	0.041	0.000	0.051	0.000	0.000	0.000	0.155	0.114	176	21	9.1	0.9	0.252	0.160	27
Bass Harbour	O-10	0	3	115	0.776	24.2	25.9	0.823	0.639	0.036	0.031	0.531	0.401	0.823	0.057	0.000	0.042	0.078	0.000	0.000	0.179	0.145	171	30	8.7	0.8	0.275	0.093	32
Bass Harbour	O-10	0	2	65	0.589	25.4	27.9	0.896	0.528	0.024	0.104	0.152	0.720	0.896	0.030	0.055	0.018	0.000	0.000	0.000	0.084	0.099	152	24	8.7	1.0	0.244	0.158	22
Bass Harbour	O-10	-5	2	45	0.833	23.8	26.0	0.886	0.738	0.004	0.042	0.034	0.920	0.886	0.051	0.059	0.004	0.000	0.000	0.000	0.086	0.073	163	23	9.3	0.8	0.209	0.067	23
Bass Harbour	O-10	-5	1	117	0.467	24.4	27.5	0.841	0.393	0.006	0.006	0.409	0.580	0.841	0.091	0.068	0.000	0.000	0.000	0.000	0.125	0.105	169	35	8.7	0.8	0.262	0.089	21
Bass Harbour	O-10	-5	3	30	0.467	24.1	25.2	0.907	0.424	0.023	0.302	0.395	0.279	0.907	0.047	0.000	0.047	0.000	0.000	0.000	0.197	0.093	166	27	8.3	0.9	0.302	0.102	21
Bass Harbour	O-10	-15	1	80	0.357	24.1	26.2	0.932	0.333	0.000	0.352	0.466	0.182	0.932	0.045	0.023	0.000	0.000	0.000	0.000	0.220	0.159	172	23	8.7	0.9	0.271	0.085	17
Bass Harbour	O-10	-15	3	163	0.560	24.2	27.9	0.789	0.442	0.012	0.090	0.289	0.608	0.789	0.169	0.042	0.000	0.000	0.000	0.000	0.130	0.147	171	33	8.7	0.8	0.277	0.125	24
Bass Harbour	O-10	-15	2	132	0.527	24.0	25.8	0.841	0.443	0.000	0.000	0.000	1.000	0.841	0.057	0.102	0.000	0.000	0.000	0.000	0.181	0.298	171	24	8.5	0.6	0.284	0.091	3
Outside Bay	O-11	5	2	10	0.477	21.7	24.1	0.883	0.421	0.082	0.520	0.123	0.275	0.883	0.029	0.058	0.018	0.000	0.012	0.000	0.213	0.139	173	29	8.8	0.7	0.266	0.091	22
Outside Bay	O-11	5	3	140	0.289	21.9	25.1	0.825	0.238	0.025	0.113	0.113	0.750	0.825	0.075	0.000	0.100	0.000	0.000	0.000	0.117	0.105	147	37	8.9	0.8	0.222	0.094	29
Outside Bay	O-11	5	1	158	0.223	21.9	25.7	0.632	0.141	0.000	0.184	0.303	0.513	0.632	0.132	0.000	0.171	0.066	0.000	0.000	0.139	0.102	168	36	8.6	1.0	0.289	0.153	32
Outside Bay	O-11	0	2	180	0.770	21.1	25.1	0.932	0.718	0.000	0.112	0.671	0.217	0.932	0.007	0.041	0.020	0.000	0.000	0.000	0.188	0.161	156	32	8.8	0.9	0.238	0.082	29
Outside Bay	O-11	0	3	109	0.826	21.7	23.6	0.861	0.711	0.025	0.206	0.155	0.613	0.861	0.034	0.025	0.080	0.000	0.000	0.000	0.107	0.141	163	21	8.7	1.0	0.266	0.108	37
Outside Bay	O-11	0	1	160	0.542	21.8	24.3	0.529	0.287	0.059	0.157	0.461	0.324	0.529	0.235	0.000	0.225	0.010	0.000	0.000	0.160	0.125	161	25	8.8	1.2	0.259	0.108	28
Outside Bay	O-11	-5	1	59	0.587	23.4	26.4	0.899	0.528	0.000	0.011	0.268	0.721	0.899	0.067	0.034	0.000	0.000	0.000	0.000	0.114	0.109	166	36	9.1	0.7	0.231	0.082	34
Outside Bay	O-11	-5	3	46	0.840	22.3	23.6	0.898	0.755	0.000	0.061	0.220	0.719	0.898	0.054	0.020	0.027	0.000	0.000	0.000	0.165	0.133	168	28	8.7	1.1	0.291	0.188	30
Outside Bay	O-11	-5	2	123	0.808	20.7	23.5	0.883	0.714	0.021	0.117	0.473	0.389	0.883	0.117	0.000	0.000	0.000	0.000	0.000	0.158	0.120	188	28	9.3	0.8	0.244	0.079	27
Outside Bay	O-12	5	1	8	0.425	21.5	23.3	0.942	0.400	0.000	0.261	0.609	0.130	0.942	0.058	0.000	0.000	0.000	0.000	0.000	0.157	0.103	155	21	8.3	0.6	0.276	0.055	9
Outside Bay	O-12	5	2	105	0.395	22.0	23.7	0.943	0.372	0.000	0.000	0.023	0.977	0.943	0.023	0.034	0.000	0.000	0.000	0.000	0.027	0.036	159	40	9.8	0.5	0.171	0.042	8
Outside Bay	O-12	5	3	122	0.557	20.8	23.8	0.768	0.428	0.000	0.000	0.121	0.879	0.768	0.071	0.152	0.010	0.000	0.000	0.000	0.021	0.034	158	20	9.3	0.7	0.199	0.040	13

Table 2. Summary statistics of herring egg samples. (Continued)

Location	ADFG sample number	Depth (ft)	Rep. no.	TRITON sample number	fraction survived to hatch	Age (d) at hatch 50%	Age (d) at hatch 95%	fraction of larvae viable	fraction viable hatch	Fraction of larvae in developmental stages: pre-1a	1a	1b	1c	Fraction of larvae in deformity classes: normal	spine	yolk	jaw	stubby	head	caudal	Yolk sac volume (mm^3) mean	Yolk sac volume (mm^3) SD	Weight (ug) mean	Weight (ug) SD	Length (mm) mean	Length (mm) SD	Condition (ug mm^-3) mean	Condition (ug mm^-3) SD	n
Outside Bay	O-12	0	3	22	0.628	21.6	23.7	0.892	0.560	0.005	0.065	0.281	0.649	0.892	0.038	0.054	0.011	0.005	0.000	0.000	0.116	0.089	183	36	9.4	0.7	0.224	0.050	29
Outside Bay	O-12	0	2	170	0.999	22.7	25.0	0.914	0.913	0.000	0.079	0.038	0.883	0.914	0.038	0.041	0.006	0.000	0.000	0.000	0.115	0.133	161	24	9.3	1.0	0.214	0.072	50
Outside Bay	O-12	0	1	54	0.521	21.9	25.2	0.633	0.330	0.023	0.055	0.227	0.695	0.633	0.031	0.180	0.156	0.000	0.000	0.000	0.102	0.118	161	19	9.0	0.9	0.233	0.081	19
Outside Bay	O-12	-5	1	51	0.634	23.7	25.8	0.688	0.436	0.007	0.007	0.220	0.766	0.688	0.135	0.021	0.106	0.050	0.000	0.000	0.100	0.114	165	14	9.4	0.9	0.213	0.074	36
Outside Bay	O-12	-5	2	89	0.469	23.1	25.5	0.826	0.387	0.013	0.052	0.090	0.845	0.826	0.103	0.013	0.058	0.000	0.000	0.000	0.136	0.188	175	34	9.1	0.8	0.240	0.069	22
Outside Bay	O-12	-5	3	77	0.496	21.8	25.4	0.617	0.306	0.023	0.509	0.223	0.246	0.617	0.120	0.000	0.211	0.000	0.000	0.051	0.243	0.193	167	28	8.4	1.1	0.328	0.212	16
Cabin Bay	O-13	0	3	60	0.648	22.6	26.6	0.722	0.468	0.014	0.024	0.189	0.774	0.722	0.038	0.231	0.000	0.009	0.000	0.000	0.123	0.121	164	29	8.9	1.1	0.258	0.136	26
Cabin Bay	O-13	0	1	173	0.544	21.7	25.9	0.888	0.483	0.005	0.005	0.051	0.939	0.888	0.020	0.091	0.000	0.000	0.000	0.000	0.104	0.112	162	25	8.8	1.0	0.261	0.127	22
Cabin Bay	O-13	0	2	82	0.363	22.5	24.6	0.356	0.129	0.000	0.038	0.385	0.577	0.356	0.038	0.000	0.000	0.606	0.000	0.000	0.105	0.085	179	37	8.6	0.5	0.283	0.063	13
Cabin Bay	O-13	-5	2	128	0.606	22.7	24.1	0.963	0.584	0.000	0.042	0.232	0.726	0.963	0.032	0.005	0.000	0.000	0.000	0.000	0.147	0.133	159	27	8.7	0.6	0.248	0.082	18
Cabin Bay	O-13	-5	3	110	0.813	23.2	24.9	0.950	0.772	0.016	0.384	0.443	0.157	0.950	0.019	0.025	0.006	0.000	0.000	0.000	0.107	0.127	177	33	9.0	0.8	0.247	0.073	20
Cabin Bay	O-13	-5	1	9	0.683	22.5	24.2	0.880	0.601	0.008	0.036	0.708	0.248	0.880	0.020	0.024	0.024	0.052	0.000	0.000	0.191	0.127	172	27	9.0	0.7	0.245	0.064	29
Cabin Bay	O-13	-15	3	136	0.534	23.4	26.4	0.915	0.489	0.000	0.169	0.515	0.315	0.915	0.069	0.000	0.000	0.008	0.008	0.000	0.157	0.112	153	20	8.8	0.8	0.235	0.075	23
Cabin Bay	O-13	-15	1	75	0.625	25.3	27.5	0.817	0.511	0.000	0.310	0.155	0.535	0.817	0.117	0.019	0.047	0.000	0.000	0.000	0.106	0.096	162	29	9.0	0.7	0.234	0.074	32
Cabin Bay	O-13	-15	2	94	0.652	23.6	25.0	0.886	0.578	0.000	0.050	0.382	0.568	0.886	0.050	0.000	0.064	0.000	0.000	0.000	0.128	0.167	178	26	9.2	0.8	0.237	0.081	12
Outside Bay	O-14	5	3	20	0.547	21.7	24.1	0.730	0.399	0.054	0.054	0.473	0.419	0.730	0.014	0.243	0.014	0.000	0.000	0.000	0.150	0.128	172	34	9.0	0.7	0.241	0.081	18
Outside Bay	O-14	5	1	76	0.357	22.9	25.9	0.434	0.155	0.053	0.053	0.115	0.779	0.434	0.071	0.389	0.106	0.000	0.000	0.000	0.076	0.129	150	24	9.1	0.7	0.202	0.046	12
Outside Bay	O-14	5	2	93	0.326	21.4	22.9	0.963	0.314	0.037	0.201	0.075	0.687	0.963	0.037	0.000	0.000	0.000	0.000	0.000	0.107	0.117	171	21	9.1	0.8	0.234	0.077	10
Outside Bay	O-14	0	2	11	0.728	21.5	23.0	0.882	0.642	0.007	0.170	0.399	0.424	0.882	0.045	0.066	0.007	0.000	0.000	0.000	0.159	0.097	176	34	8.9	0.8	0.256	0.060	39
Outside Bay	O-14	0	1	38	0.670	20.8	23.5	0.885	0.593	0.024	0.068	0.310	0.599	0.885	0.077	0.018	0.018	0.000	0.003	0.000	0.121	0.117	161	19	8.8	1.0	0.252	0.098	28
Outside Bay	O-14	0	3	21	0.486	21.5	22.9	0.900	0.437	0.071	0.157	0.386	0.386	0.900	0.029	0.000	0.071	0.000	0.000	0.000	0.179	0.150	177	27	8.7	0.9	0.282	0.082	12
Outside Bay	O-14	-5	2	111	0.574	21.7	24.0	0.833	0,478	0.033	0.050	0.117	0.800	0.833	0.000	0.167	0.000	0.000	0.000	0.000	0.121	0.101	167	36	9.1	0.6	0.225	0.076	14
Outside Bay	O-14	-5	3	28	0.708	21.5	22.7	0.610	0.432	0.000	0.098	0.805	0.098	0.610	0.159	0.146	0.000	0.085	0.000	0.000	0.193	0.114	155	27	8.4	0.7	0.262	0.056	20
Outside Bay	O-14	-5	1	145	0.619	20.0	24.4	0.837	0.518	0.000	0.060	0.754	0.187	0.837	0.131	0.012	0.020	0.000	0.000	0.000	0.115	0.100	156	23	8.9	0.5	0.225	0.060	25
Story Island	O-15	0	3	164	0.732	23.9	26.3	0.923	0.676	0.009	0.063	0.180	0.748	0.923	0.068	0.005	0.000	0.000	0.005	0.000	0.074	0.089	161	28	8.7	1.2	0.279	0.195	19
Story Island	O-15	0	2	161	0.573	24.6	25.9	0.772	0.442	0.000	0.047	0.035	0.918	0.772	0.222	0.006	0.000	0.000	0.000	0.000	0.099	0.168	183	34	9.1	0.8	0.248	0.070	14
Story Island	O-15	0	1	79	0.740	24.0	26.9	0.961	0.711	0.000	0.227	0.367	0.406	0.961	0.027	0.000	0.008	0.004	0.000	0.000	0.103	0.087	164	22	9.0	0.8	0.228	0.045	31
Story Island	O-15	-5	2	146	0.377	23.7	26.2	0.869	0.327	0.000	0.000	0.440	0.560	0.869	0.083	0.048	0.000	0.000	0.000	0.000	0.083	0.090	166	25	9.7	0.4	0.183	0.032	21
Story Island	O-15	-5	3	44	0.759	23.5	25.9	0.959	0.728	0.000	0.004	0.609	0.387	0.959	0.030	0.000	0.008	0.004	0.000	0.000	0.121	0.088	167	33	9.0	0.7	0.230	0.062	38
Story Island	O-15	-5	1	177	0.631	22.8	27.5	0.839	0.530	0.000	0.046	0.609	0.345	0.839	0.029	0.115	0.000	0.017	0.000	0.000	0.102	0.087	153	41	9.3	0.8	0.191	0.047	20
Story Island	O-15	-15	3	174	0.733	23.3	26.3	0.859	0.630	0.000	0.110	0.667	0.224	0.859	0.055	0.039	0.031	0.016	0.000	0.000	0.120	0.114	153	26	8.5	1.0	0.277	0.134	32
Story Island	O-15	-15	2	66	0.357	25.5	27.7	0.933	0.333	0.000	0.050	0.317	0.633	0.933	0.050	0.000	0.017	0.000	0.000	0.000	0.103	0.068	167	23	9.1	0.4	0.222	0.041	17
Story Island	O-15	-15	1	157	0.691	25.3	28.9	0.783	0.541	0.005	0.015	0.030	0.949	0.783	0.131	0.086	0.000	0.000	0.000	0.000	0.037	0.048	151	27	9.5	1.1	0.193	0.085	28
Story Island	O-16	0	1	97	0.357	22.7	23.9	1.000	0.357	0.000	0.187	0.421	0.393	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.104	0.068	168	55	8.7	0.8	0.276	0.152	17
Story Island	O-16	0	3	112	0.732	24.1	26.3	0.952	0.696	0.000	0.253	0.211	0.536	0.952	0.030	0.018	0.000	0.000	0.000	0.000	0.189	0.124	156	19	8.9	1.2	0.240	0.064	18
Story Island	O-16	0	2	133	0.462	23.4	24.9	0.941	0.435	0.000	0.206	0.235	0.559	0.941	0.020	0.039	0.000	0.000	0.000	0.000	0.142	0.133	163	25	8.7	1.1	0.270	0.118	30
Story Island	O-16	-5	3	129	0.585	23.2	24.9	0.850	0.497	0.023	0.000	0.429	0.549	0.850	0.090	0.060	0.000	0.000	0.000	0.000	0.144	0.151	172	17	8.7	0.7	0.275	0.100	17

Table 2. Summary statistics of herring egg samples. (Continued)

Location	ADFG sample number	Depth (ft)	Rep. no.	TRITON sample number	fraction survived to hatch	Age (d) at hatch		fraction of larvae viable	fraction viable hatch	Fraction of larvae in developmental stages				Fraction of larvae in deformity classes							Yolk sac volume (mm^3)		Weight (ug)		Length (mm)		Condition (ug mm^-3)		
						50%	95%			pre-1a	1a	1b	1c	normal	spine	yolk	jaw	stubby	head	caudal	mean	SD	mean	SD	mean	SD	mean	SD	n
Story Island	O-16	-5	1	144	0.826	24.7	26.8	0.945	0.781	0.005	0.265	0.055	0.675	0.945	0.005	0.045	0.005	0.000	0.000	0.000	0.096	0.092	154	27	8.7	1.0	0.267	0.165	35
Story Island	O-16	-5	2	43	0.765	22.9	26.0	0.931	0.712	0.025	0.262	0.327	0.386	0.931	0.054	0.010	0.005	0.000	0.000	0.000	0.124	0.095	162	27	8.6	0.8	0.269	0.091	37
Story Island	O-16	-15	3	63	0.293	24.5	26.9	0.902	0.264	0.000	0.171	0.000	0.829	0.902	0.098	0.000	0.000	0.000	0.000	0.000	0.058	0.046	151	19	8.3	0.6	0.269	0.060	8
Story Island	O-16	-15	1	26	0.711	23.5	25.1	0.888	0.631	0.000	0.123	0.037	0.840	0.888	0.059	0.053	0.000	0.000	0.000	0.000	0.111	0.107	157	21	8.2	1.2	0.331	0.210	22
Story Island	O-16	-15	2	12	0.559	23.6	25.5	0.879	0.491	0.000	0.284	0.395	0.321	0.879	0.026	0.000	0.095	0.000	0.000	0.000	0.231	0.167	164	30	8.8	0.9	0.263	0.105	25
Rocky Bay	O-17	5	2	42	0.388	21.7	22.8	0.750	0.291	0.125	0.750	0.125	0.000	0.750	0.250	0.000	0.000	0.000	0.000	0.000	0.319	0.060	164	59	8.2	0.3	0.310	0.138	6
Rocky Bay	O-17	5	3	27	0.071	21.7	23.0	1.000	0.071	0.156	0.375	0.469	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.262	0.085	171	21	8.6	0.9	0.283	0.078	11
Rocky Bay	O-17	5	1	150	0.194	22.2	24.6	0.848	0.164	0.000	0.022	0.217	0.761	0.848	0.043	0.022	0.065	0.000	0.022	0.000	0.083	0.089	149	25	9.4	0.9	0.187	0.051	17
Rocky Bay	O-17	0	1	116	0.612	23.3	26.8	0.865	0.529	0.000	0.032	0.173	0.795	0.865	0.065	0.032	0.038	0.000	0.000	0.000	0.089	0.103	155	21	9.2	0.9	0.217	0.115	29
Rocky Bay	O-17	0	3	84	0.517	21.7	23.1	0.784	0.405	0.000	0.020	0.944	0.036	0.784	0.208	0.000	0.000	0.000	0.008	0.000	0.112	0.085	159	26	8.5	0.6	0.260	0.057	14
Rocky Bay	O-17	0	2	135	0.842	22.4	27.3	0.704	0.592	0.004	0.363	0.288	0.345	0.704	0.058	0.040	0.199	0.000	0.000	0.000	0.217	0.152	159	25	8.8	0.9	0.255	0.128	62
Rocky Bay	O-17	-5	3	102	0.690	24.0	26.9	0.861	0.594	0.008	0.174	0.409	0.409	0.861	0.054	0.066	0.019	0.000	0.000	0.000	0.140	0.148	166	35	9.0	0.9	0.238	0.081	48
Rocky Bay	O-17	-5	2	67	0.838	23.1	26.7	0.828	0.694	0.007	0.232	0.360	0.401	0.828	0.088	0.020	0.064	0.000	0.000	0.000	0.177	0.124	168	31	8.9	0.7	0.242	0.057	35
Rocky Bay	O-17	-5	1	52	0.759	22.5	25.7	0.870	0.660	0.065	0.133	0.451	0.351	0.870	0.091	0.006	0.026	0.006	0.000	0.000	0.163	0.126	169	32	9.0	0.9	0.251	0.157	34
Rocky Bay	O-18	5	1	50	0.194	23.0	25.5	0.766	0.149	0.109	0.453	0.109	0.328	0.766	0.125	0.000	0.109	0.000	0.000	0.000	0.207	0.200	164	20	9.0	1.4	0.285	0.251	10
Rocky Bay	O-18	5	3	166	0.616	22.7	26.8	0.831	0.512	0.000	0.257	0.153	0.590	0.831	0.082	0.000	0.087	0.000	0.000	0.000	0.147	0.152	155	25	9.0	0.8	0.228	0.082	28
Rocky Bay	O-18	5	2	81	0.610	23.5	26.0	0.848	0.517	0.000	0.092	0.641	0.267	0.848	0.106	0.009	0.037	0.000	0.000	0.000	0.172	0.105	174	19	9.4	0.6	0.215	0.038	22
Rocky Bay	O-18	0	1	15	0.609	21.6	23.0	0.918	0.559	0.026	0.544	0.379	0.051	0.918	0.056	0.000	0.026	0.000	0.000	0.000	0.276	0.103	190	29	8.6	0.6	0.300	0.066	18
Rocky Bay	O-18	0	3	131	0.401	22.9	24.9	0.643	0.257	0.004	0.076	0.576	0.344	0.643	0.183	0.058	0.116	0.000	0.000	0.000	0.162	0.131	163	25	8.9	1.0	0.251	0.120	33
Rocky Bay	O-18	0	2	85	0.465	22.4	26.1	0.682	0.318	0.000	0.265	0.394	0.341	0.682	0.176	0.029	0.112	0.000	0.000	0.000	0.196	0.171	170	38	9.0	0.9	0.250	0.120	38
Rocky Bay	O-18	-5	2	48	0.856	23.1	24.4	0.506	0.433	0.016	0.156	0.758	0.070	0.506	0.054	0.328	0.105	0.006	0.000	0.000	0.197	0.146	173	28	9.2	0.7	0.234	0.075	46
Rocky Bay	O-18	-5	1	29	0.577	23.0	25.1	0.794	0.458	0.042	0.079	0.228	0.651	0.794	0.122	0.000	0.037	0.037	0.011	0.000	0.116	0.084	160	22	8.9	0.7	0.238	0.086	22
Rocky Bay	O-18	-5	3	56	0.597	23.2	25.7	0.865	0.516	0.027	0.311	0.284	0.378	0.865	0.086	0.000	0.045	0.005	0.000	0.000	0.250	0.165	166	28	8.9	1.1	0.263	0.118	40
Rocky Bay	O-19	5	1	165	0.509	22.3	26.2	0.799	0.407	0.024	0.541	0.110	0.325	0.799	0.086	0.029	0.086	0.000	0.000	0.000	0.177	0.158	163	27	9.1	1.0	0.242	0.110	55
Rocky Bay	O-19	5	3	148	0.597	21.4	24.8	0.880	0.525	0.032	0.259	0.285	0.424	0.880	0.070	0.000	0.051	0.000	0.000	0.000	0.322	0.194	175	31	8.2	1.3	0.372	0.195	29
Rocky Bay	O-19	5	2	87	0.662	22.5	25.5	0.654	0.433	0.046	0.087	0.430	0.437	0.654	0.186	0.080	0.080	0.000	0.000	0.000	0.140	0.162	173	30	8.9	0.7	0.259	0.104	40
Rocky Bay	O-19	0	1	113	0.541	22.8	24.5	0.766	0.414	0.025	0.456	0.063	0.456	0.766	0.038	0.025	0.171	0.000	0.000	0.000	0.178	0.163	157	28	8.4	1.0	0.301	0.221	20
Rocky Bay	O-19	0	3	179	0.797	22.6	25.3	0.793	0.632	0.000	0.108	0.327	0.566	0.793	0.125	0.000	0.082	0.000	0.000	0.000	0.113	0.108	157	17	9.3	0.8	0.202	0.056	34
Rocky Bay	O-19	0	2	31	0.629	22.2	24.5	0.758	0.477	0.004	0.542	0.263	0.192	0.758	0.096	0.042	0.100	0.004	0.000	0.000	0.139	0.145	160	29	9.3	0.6	0.208	0.067	34
Rocky Bay	O-19	-5	1	72	0.805	23.6	26.3	0.845	0.680	0.006	0.149	0.055	0.790	0.845	0.049	0.003	0.103	0.000	0.000	0.000	0.171	0.161	156	30	8.9	0.9	0.242	0.116	52
Rocky Bay	O-19	-5	3	86	0.635	24.2	26.4	0.789	0.502	0.000	0.038	0.402	0.560	0.789	0.045	0.023	0.143	0.000	0.000	0.000	0.096	0.087	161	24	9.3	0.7	0.205	0.037	33
Rocky Bay	O-19	-5	2	136	0.575	22.9	25.8	0.699	0.402	0.004	0.157	0.686	0.153	0.699	0.081	0.000	0.220	0.000	0.000	0.000	0.176	0.132	169	42	8.9	0.8	0.247	0.084	38

Notes:

1. ADFG = Alaska Department of Fish and Game; TRITON = Triton Environmental Consultants Ltd.
2. C = control station; O = oil station.

Table 3. Parameter values of the modified Weibull models describing survival at age, the fraction of eggs at age that were alive, and the cumulative fraction of hatched larvae at age.

Parameter	coefficient	SE	P	r^2	n
	Survival [s(t)]				
	32.62	2.41	<0.0001	0.10	819
y	0.8991	0.0955	<0.0001		
	Fraction of live eggs [f(t)]				
a	30.49	1.44	<0.0001	0.34	730
y	6.4666	0.3353	<0.0001		
b1	0.0281	0.0072	0.0001		
b2	-0.3098	0.1059	0.0035		
	Cumulative fraction hatched [h(t)]				
a	8.63	0.16	<0.0001	0.70	1265
y	4.8357	0.0903	<0.0001		
b1	0.0487	0.0055	<0.0001		
b2	-0.3191	0.0762	<0.0001		
b3	-0.0362	0.0113	0.0015		

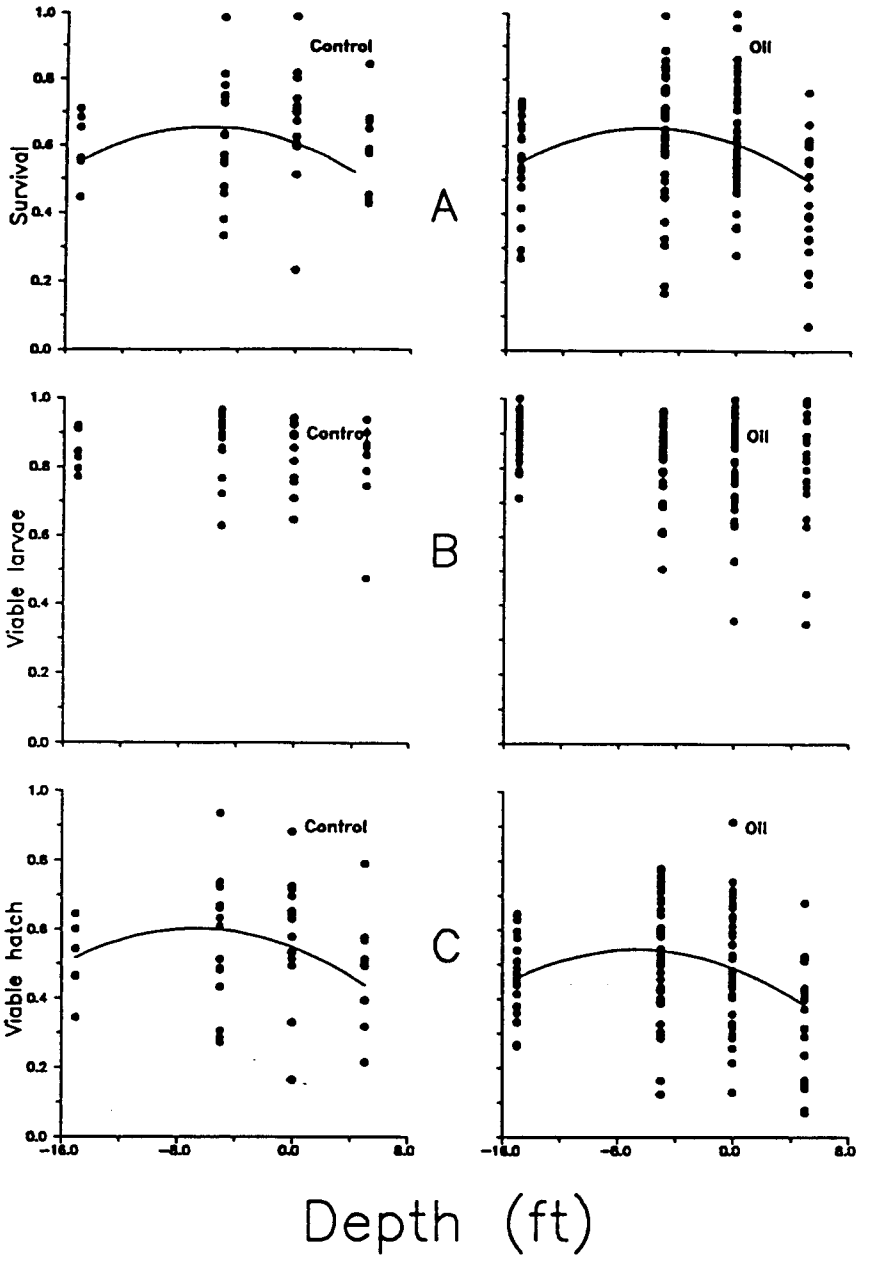

Figure 10. A. Fraction of control and oiled herring eggs at four depth classes that survived to hatch larvae. Solid line is survival predicted from equation (9). B. Fraction of larvae that were viable. C. Fraction of eggs that hatched viable larvae. Solid line is viable hatch predicted from equation (10).

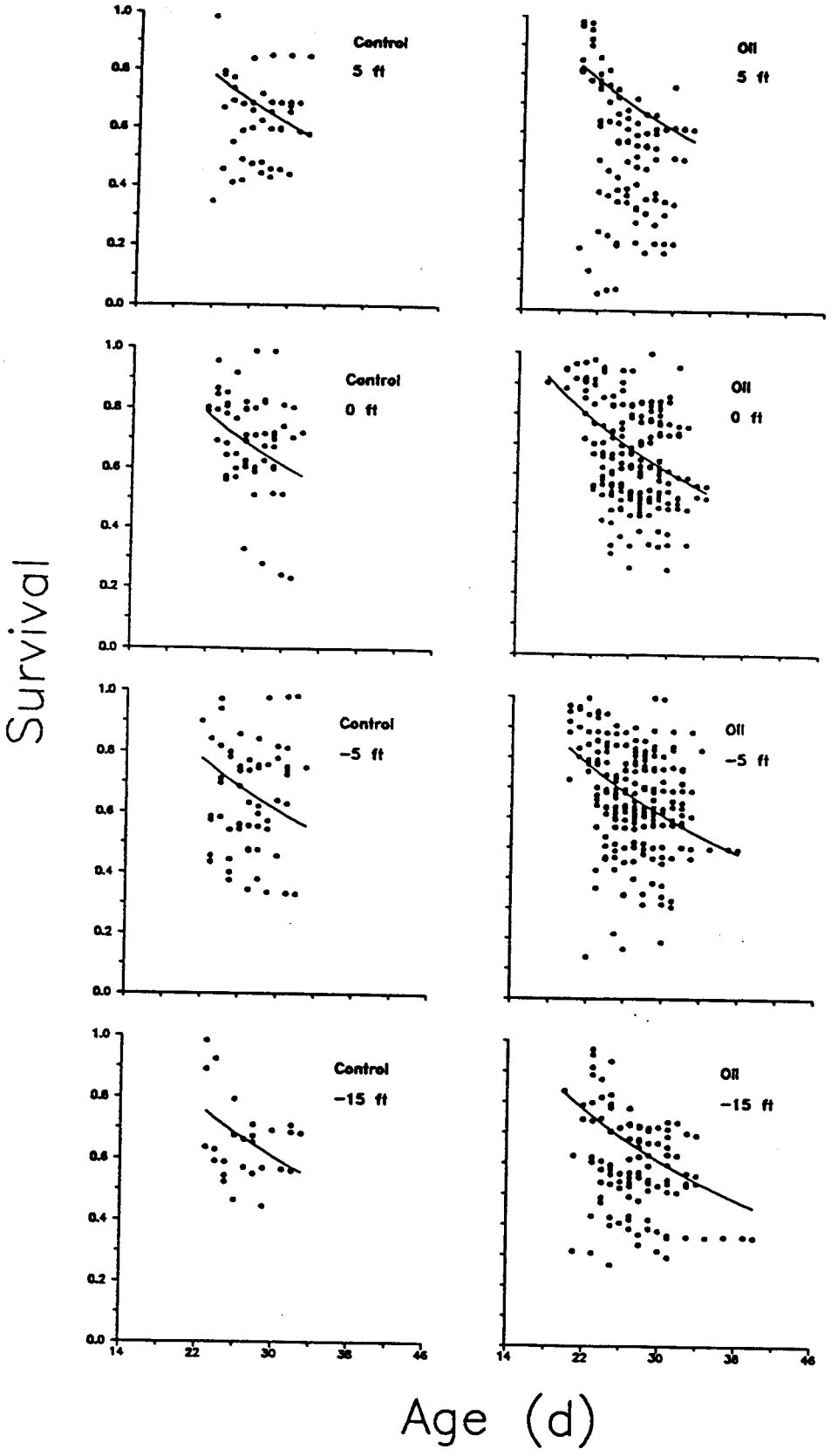

Figure 11. Age trajectory of survival of control and oiled herring eggs from four depths. Solid line is predicted survival from a Weibull model. See Table 3 and text for details.

suggests the presence of a depth effect and perhaps an oil effect, but there is too much variability in s(t) to detect it statistically.

3.3 Fraction of Live Eggs

The fraction of eggs that were live was constant or declined slowly until age 22 and then it decreased rapidly to zero by an age of about 32 d (Fig. 12). The sudden decline after age 22 was due to the onset of hatching; during this period the eggs that remained unhatched were predominantly dead or dying. A modified Weibull model was fit to these data; its parameters are shown in Table 3 and its predicted f(t) is plotted in Fig. 12. The model showed that both depth and oil treatment were significant auxiliary factors; f(t) increased with increasing depth and was higher in the control group than in the oiled group. This is a reflection of the hatching schedule and not egg survival; eggs hatched earlier in shallow water than in deep water and they hatched earlier in oiled eggs than in control eggs. This subject is examined in greater detail in section 3.4 of this report.

Fraction of Live Eggs as an Index of Total Survival

If the fraction of live eggs during the hatching period is an unreliable indicator of survival, then perhaps the fraction of live eggs observed before the beginning of hatching may be an index of total survival. This hypothesis was the rationale for ADF&G's survey of live/dead herring egg ratios in Prince William Sound in 1989. We tested it by regressing survival on f(t) for the 180 replicate samples shown in Table 2. Fig. 13 shows that there was a significant correlation between s(t) and f(t), but that the best-fitting regression only explained 17% of the variance in s(t). In other words, ratios of live to total eggs are not good predictors of survival at any age; they can only estimate the approximate fate of an egg mass, i.e. whether survival will be greater or less than about 0.4.

3.4 Hatching Schedule

The average age of the eggs at collection ranged from 11 to 17 d with a mean of 14 d (SD = 2, n = 21), which meant that the eggs began to hatch several days after they arrived in the laboratory. The mean age at which 50% of the larvae had hatched was 22.9 d (SD = 1.2, n = 180) and the mean age at which 95% of the larvae had

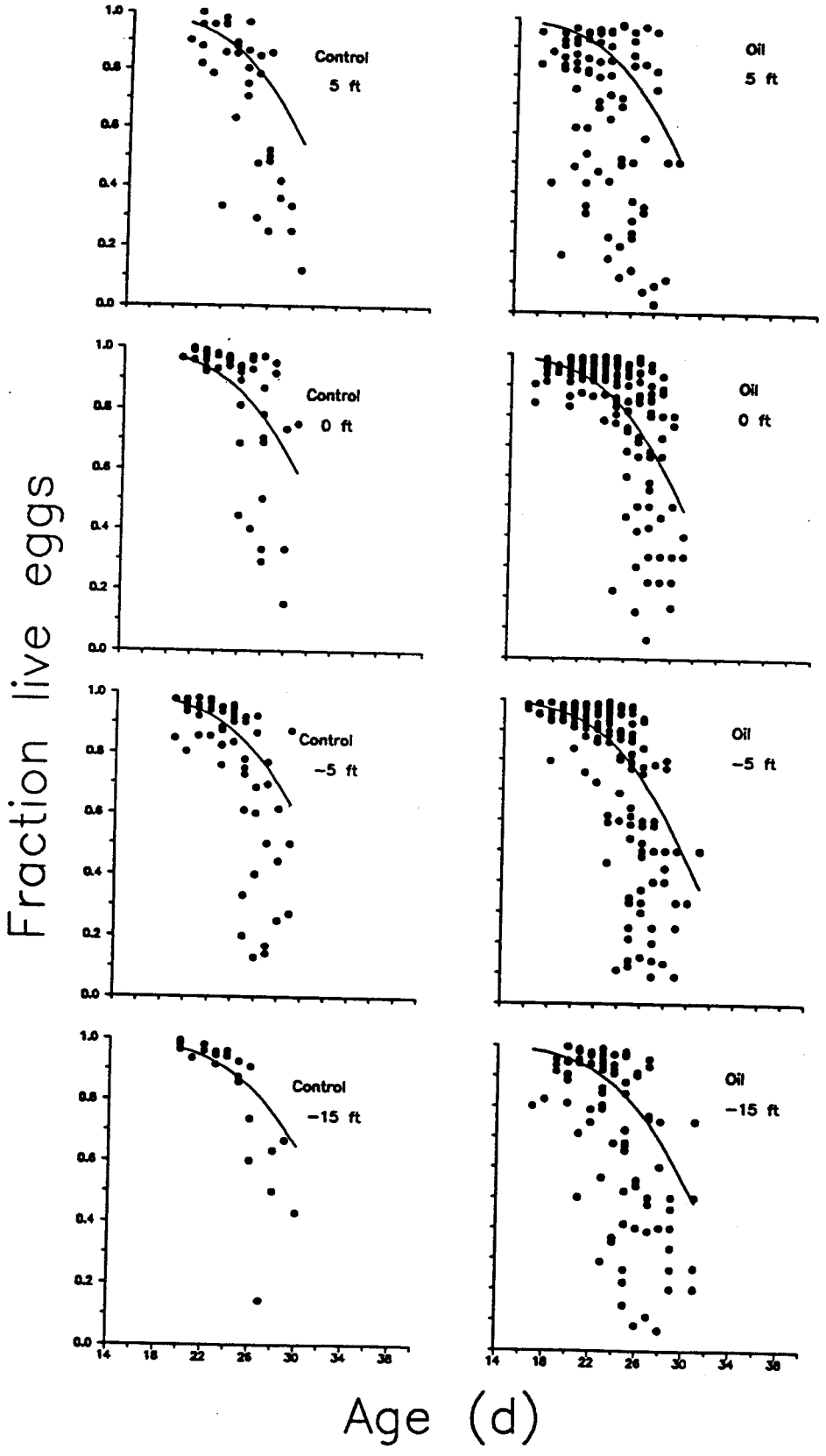

Figure 12. Fraction of herring eggs that were alive at age. Solid line is a modified Weibull model incorporating age, depth and oil treatment. See Table 3 and text for details.

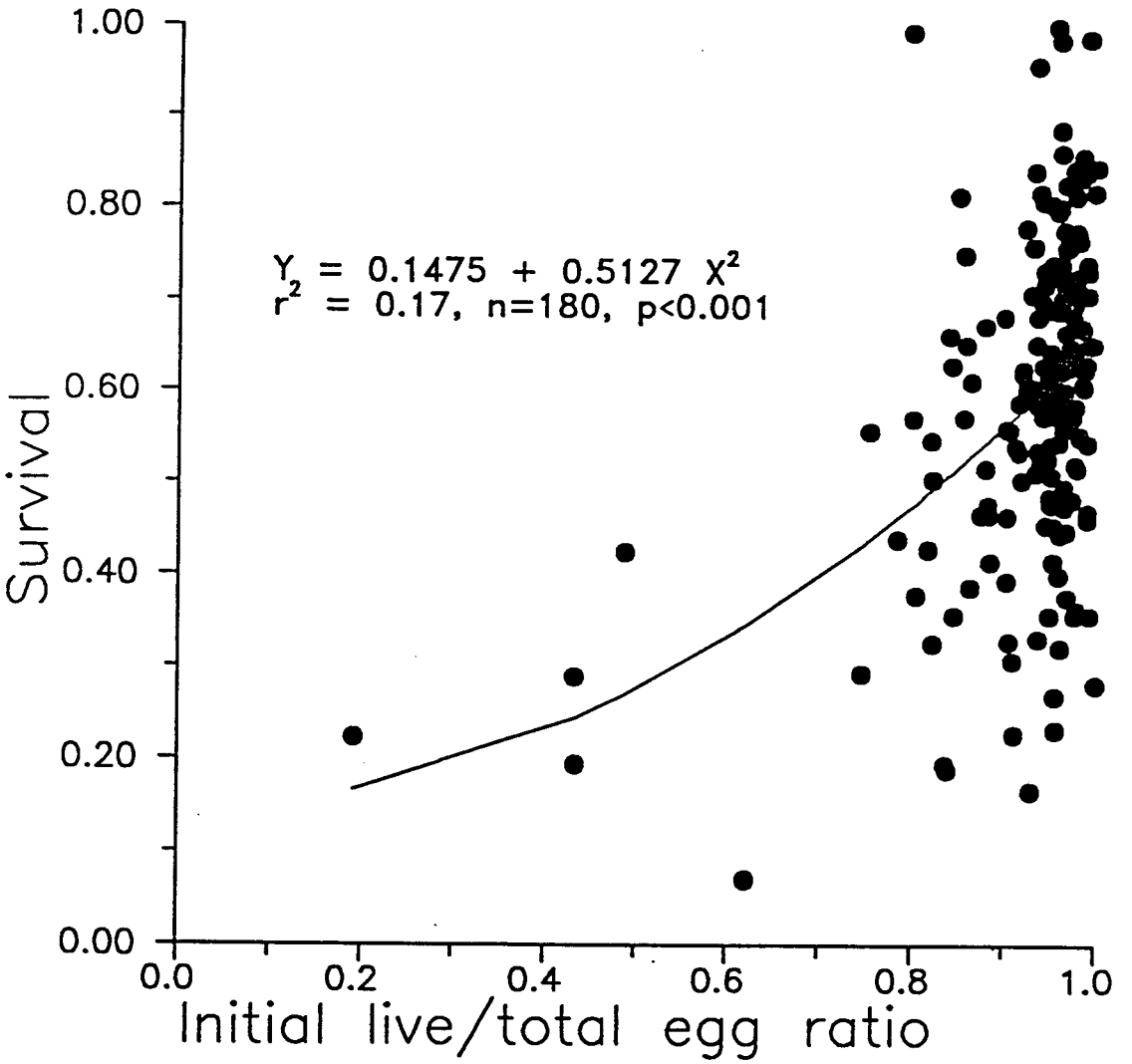

Figure 13. Survival as a function of the fraction of live eggs measured at the age of cut-down before hatching began. The solid line is a quadratic regression of survival on the fraction of live eggs. It shows that the fraction of live eggs is a poor predictor of survival.

hatched was 25.4 d (SD = 1.3, n = 180) (Table 2). Most hatching was completed by age 31 d, although at least one sample continued to produce larvae until age 35 (Fig. 14).

A modified Weibull model showed that the cumulative fraction of hatched larvae, h(t), was significantly affected by depth, oil treatment, and the interaction of depth and oil treatment (Table 3 and Fig. 14). Hatching occurred sooner in the upper depths than the lower depths, and it occurred sooner in oiled eggs than in non-oiled eggs. The interaction of these variables reduced the effect of depth for the control samples, but it increased the difference in hatching schedules for the oiled samples. For example, 50% of the larvae in the oiled/5 ft cell had hatched by age 22.5 d, but only 20% of the larvae in the oiled/-15 ft cell had hatched at the same age.

3.5 Viable Larvae

There were six kinds of gross morphological deformity (Appendix C). Table 2 shows the total fraction of larvae in each of the six deformity classes for all 180 samples. They were, in order of decreasing frequency: kinked or coiled spines (mean = 0.071, SD = 0.055); deformities of the yolk sac including no yolk sac, an anomolously small yolk sac, and a double yolk sac (mean = 0.046, SD = 0.070); missing or deformed jaw (mean = 0.034, SD = 0.053); a short stubby body (mean = 0.009, SD = 0.048); deformations of the head (mean = 0.001, SD = 0.003); and incomplete development of the caudal region of the body (mean = 0.001, SD = 0.004). Fig. 15 shows two examples of coiled spines; many of these fish were still alive and swimming in spirals when they were collected from the bottles, so the deformity was not the result of pre-preservation rigor mortis or of post-preservation shrinkage. Absence of a yolk sac was the most common deformation of the yolk sac; they were clearly distinguishable from larvae whose yolk had been ripped off by rough handling because no remnant of a yolk sac membrane or of its insertion in the ventral surface of the body was visible. Fig. 16 shows two examples of jaw deformity; note that the lower jaw is not long enough to extend to the tip of the snout as it does in normal larvae, e.g. 1c larvae in Fig. 19. Fig. 17 shows two larvae with misshapen heads.

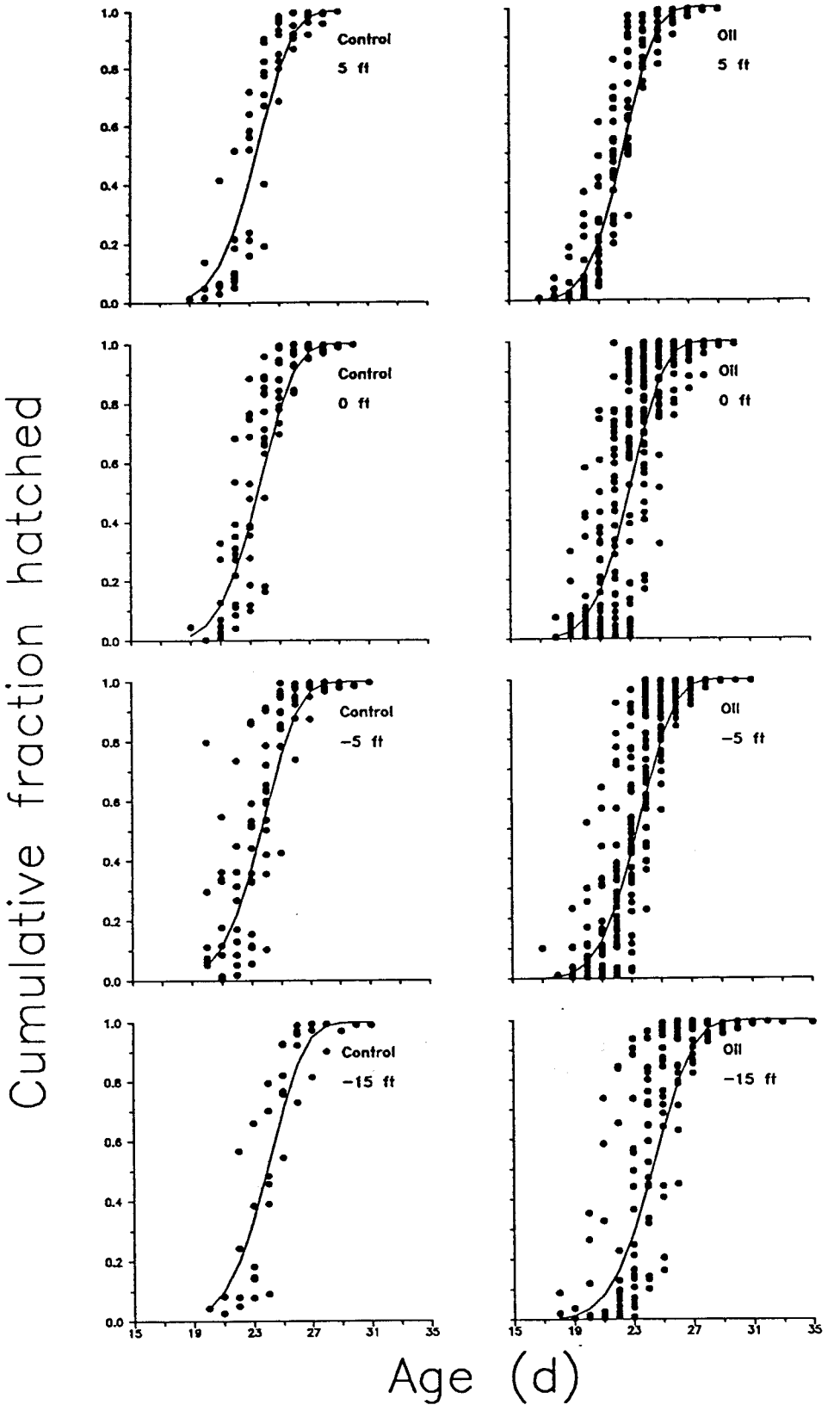

Figure 14. Hatching schedules of herring eggs from control and oiled samples at four depths. Solid line is the predicted cumulative fraction of hatched larvae from a modified Weibull model. See Table 3 and text for details.

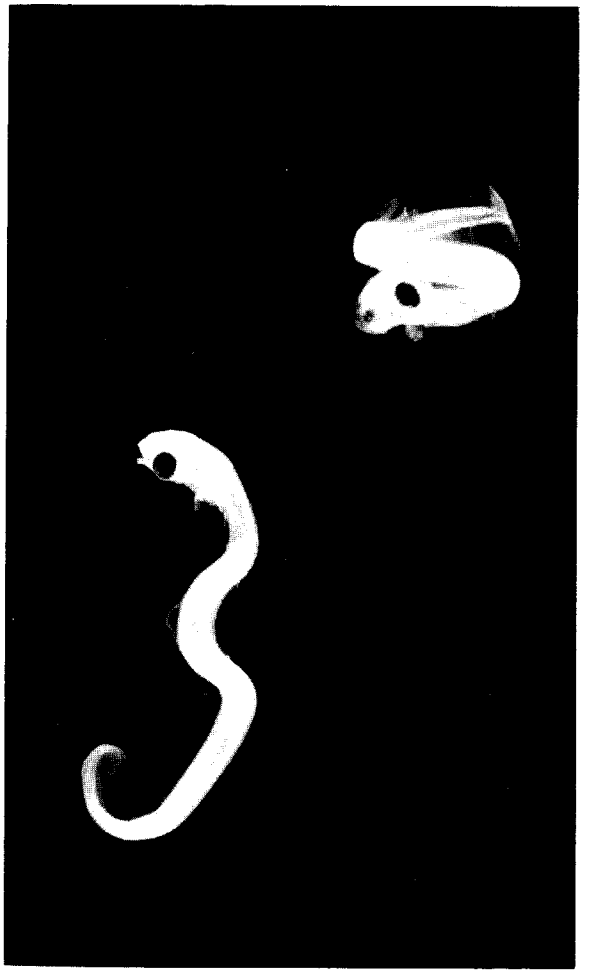

Figure 15. Two larvae with coiled spine deformity.

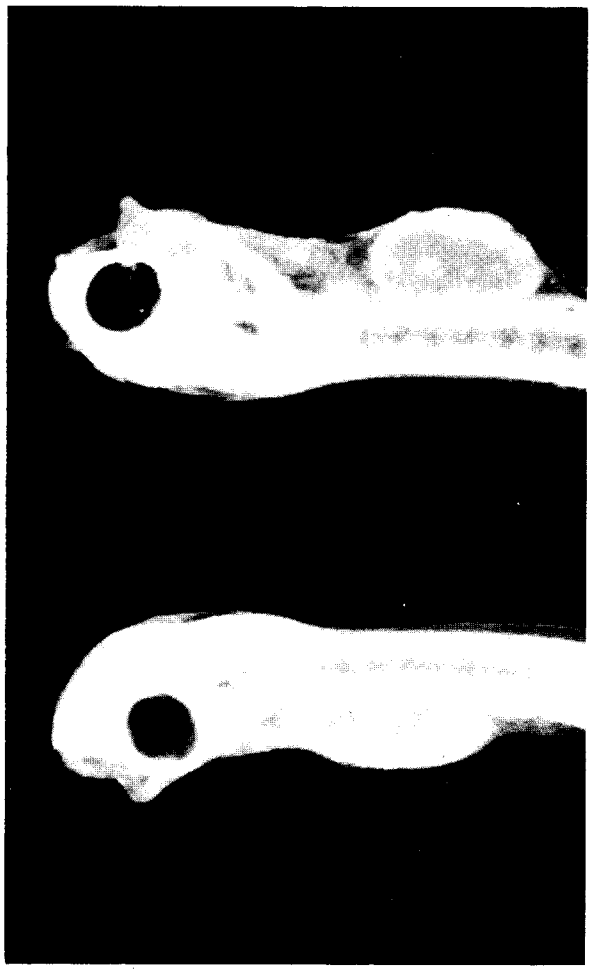

Figure 16. Two larvae with lower jaw deformity. Note that the lower jaw does not extend to the tip of the snout as it does in the normal larvae shown in Fig. 19.

Figure 17. Two larvae with deformed heads.

Fraction of Viable Larvae

Table 2 also shows the fraction of larvae that did not exhibit any of these deformities; it was the fraction of larvae that were viable and it ranged from 0.346 to 1.000 with a mean of 0.838 (SD = 0.117). A two-way ANOVA showed that there were no significant effects of depth, oil treatment, or their interaction on the fraction of viable larvae. This is shown graphically in Fig. 10B.

Fraction of Viable Hatch

The fraction of hatch that was viable is the product of egg survival and the fraction of viable larvae (Table 2). It ranged from 0.071 to 0.882 with a mean of 0.500 (SD = 0.169). A two-way ANOVA showed that the fraction of viable hatch varied significantly ($P < 0.0001$) with depth and with oil treatment ($P = 0.033$), but not with the interaction of these two factors. Multiple regression showed that the most variance in viable hatch ($r^2 = 0.12$, $n = 180$) was explained by a quadratic regression on depth

(10)

variable	coefficient	SE	P
constant	0.4920	0.0158	<0.0001
x	0.0577	0.0275	0.0374
depth	-0.0159	0.0036	<0.0001
$depth^2$	-0.0012	0.0003	<0.0001

where x = a dummy variable with a value of 1 for control eggs and 0 for oiled eggs. The fit of this model is shown in Fig. 10C.

Deformity Classes

A two-way ANOVA showed that only the jaw deformity varied significantly ($0.001 < P < 0.01$) with oil treatment. There was no significant variation with depth or with the interaction of depth and oil treatment. Comparisons of means showed that the means were significantly ($0.01 < P < 0.05$) higher in the 0 and 5 ft depth classes of the control group than in the 0 and 5 ft classes of the treatment groups. There were no differences between the -5 and -15 ft classes.

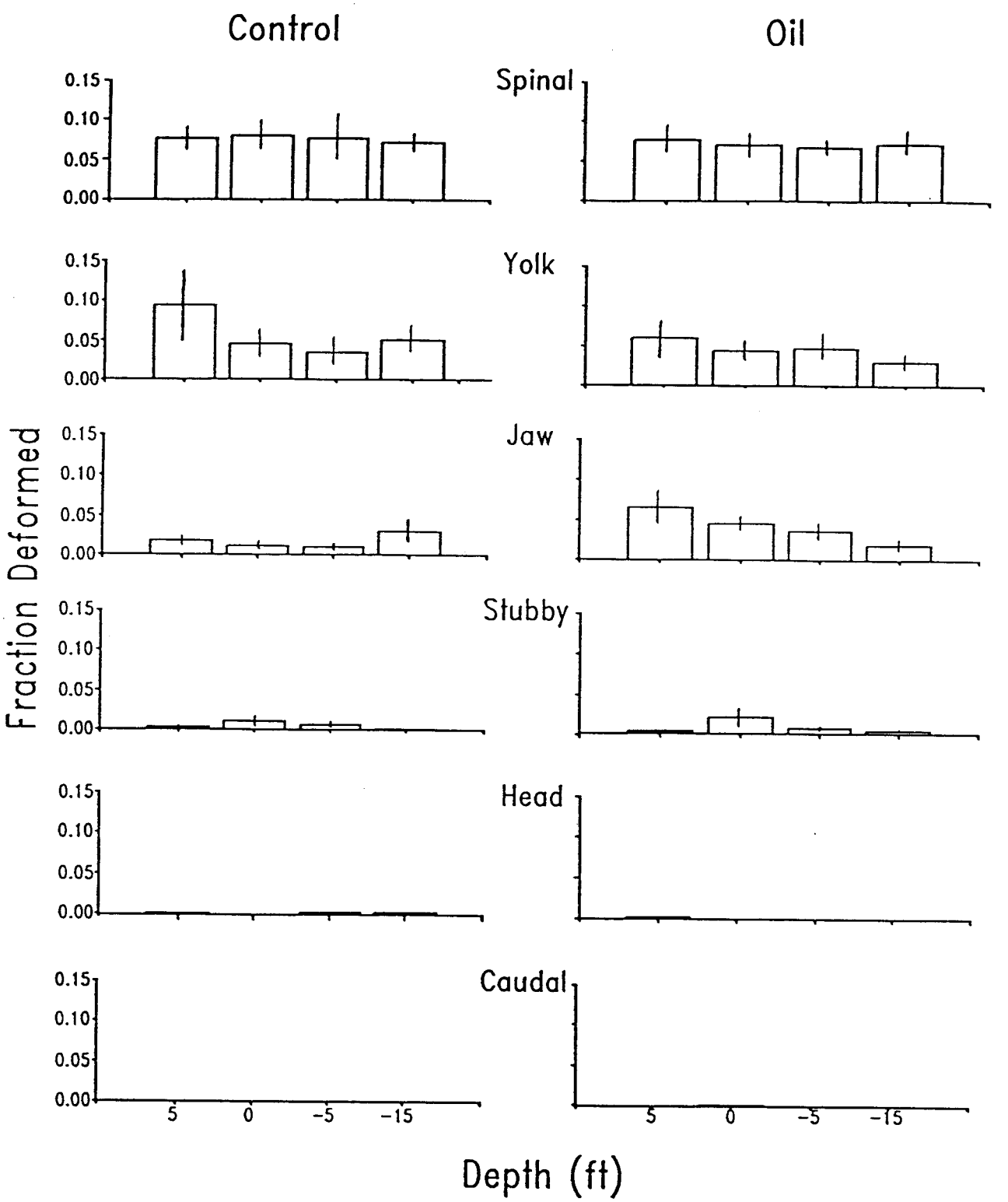

Figure 18. Mean fractions (±1 SE) of larvae in deformity classes for control and oiled groups. Stars indicate the statistical significance of differences between control and treatment means of the same depth class: *0.01<P0.05, **0.001<P<0.01, ***P<0.001.

3.6 Developmental Stage

Fig. 19 shows the four developmental stages of newly-hatched herring larvae based on Doyle's (1977) staging system: pre-1a, 1a, 1b and 1c. Pre-1a was not described by Doyle (1977), but was invented by us in order to account for larvae that were much less developed than the 1a class. None of the pre-1a larvae were found to be alive when the incubation bottles were opened.

Mean fractions of larvae in the four stages of development are shown in Fig. 20. The data was first analysed using two-way ANOVAs; significant results were found only in the two extreme stages: pre-1a and 1c. The mean fraction of larvae classified as pre-1a varied significantly ($P = 0.001$) with depth, but not with oil treatment or with the interaction of depth and oil treatment. Comparison of means showed that this depth effect was due to a significantly higher fraction of pre-1a larvae in the oiled/5 ft class than in the oiled/-15 ft class. The mean fraction of 1c larvae varied significantly ($P = 0.007$) with oil treatment, but not with depth or the interaction of depth and oil treatment. Comparison of means showed that this oil effect was due to the fact that the mean fraction of 1c larvae in the control/5 ft class was significantly higher than all four depth classes in the oiled group.

The data was also analysed by comparing control and treatment means of the same depth classes. Only one of the 16 comparisons was significant - the fraction of 1c larvae in the control/5 ft group was significantly ($0.001 < P < 0.01$) greater than the fraction of 1c larvae in the oiled/5 ft group. This difference is marked in Fig. 20.

3.7 Size and Condition of Larvae

Mean lengths, dry weights, yolk sac volumes and condition factors for each of the 180 samples are shown in Table 2. They are plotted against age for each of the eight combinations of oil treatment and depth in Figs. 21 to 24. Examination of these plots shows that size and condition varied with age. Therefore, comparisons were made between treatment/depth cells using age as a covariate.

Figure 19. Four stages of newly hatched herring larvae ranked right to left in order of increasing size and development: pre-1a, 1a, 1b, and 1c.

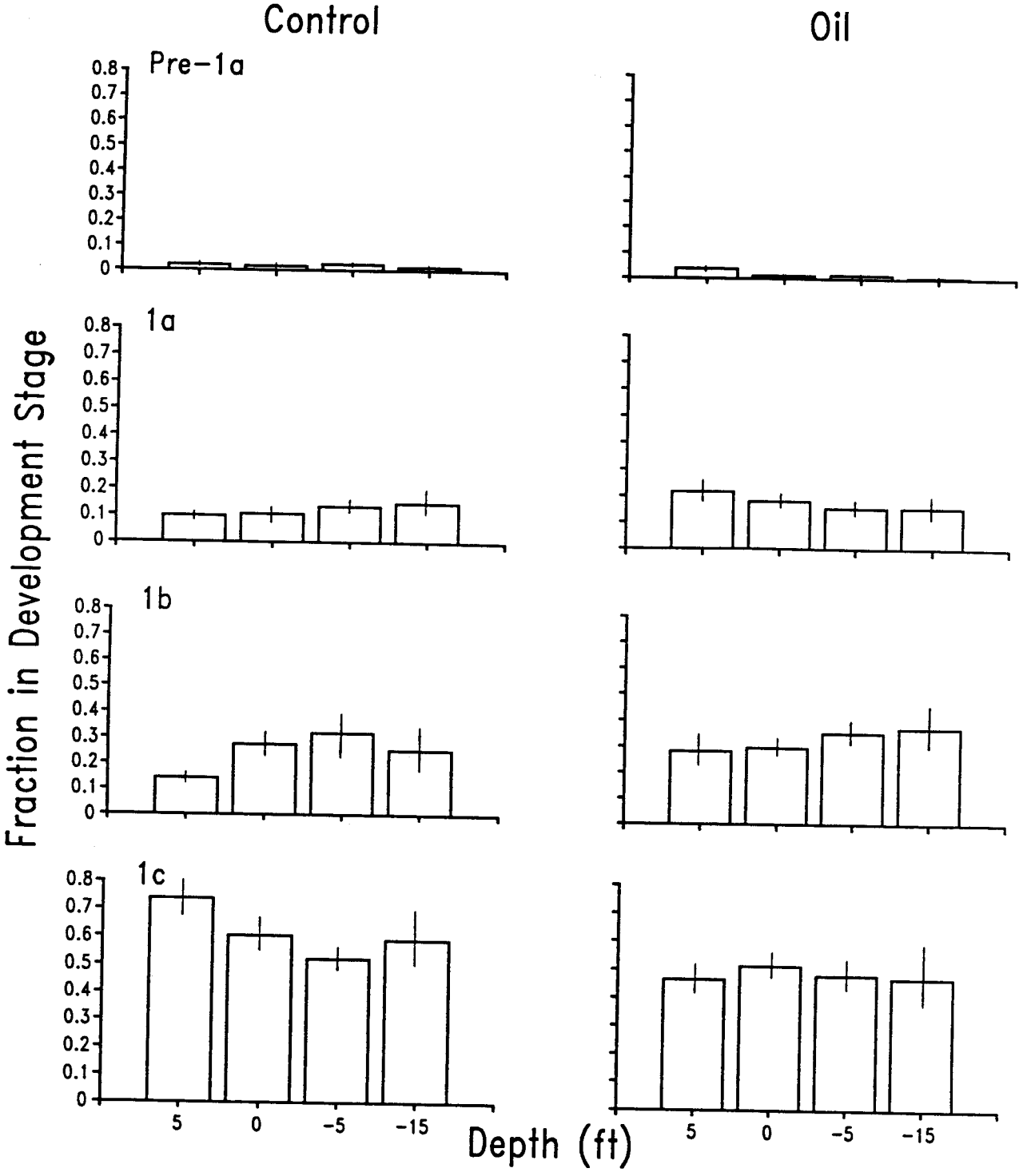

Figure 20. Mean fractions (±1 SE) of larvae in the four stages of development. Stars indicate the statistical significance of differences between control and treatment means of the same depth classes: *$0.01<P<0.05$, **$0.001<P<0.01$, ***$P<0.001$.

3.7.1 Length

Fig. 21 shows that length rose from 6-8 mm at ages of 16-20 d to 9-10 mm at ages of 21-27 d, and then it fell in late-hatching larvae greater than 27 d old. The initial increase in length with age was due to growth in the egg by unhatched larvae. The decrease in length of larvae that hatched at an older age may have been due to the delayed hatching of non-viable larvae.

Preliminary trials showed that the trend of length with age was best described with a polynomial of the third degree. The multiple regression equation that explained the maximum amount of variance in length (r^2 = 0.168, n = 4820) with all-significant parameters was

(11)

variable	coefficient	SE	P
constant	-3.8229	0.6375	<0.0001
age	0.7530	0.0411	<0.0001
age^3	-3.67×10^{-4}	2.5×10^{-5}	<0.0001
x	-0.0990	0.0273	0.0003
depth	0.0122	0.0021	<0.0001

where x = a dummy variable with a value of 1 for control sites and 0 for oiled sites. This equation is plotted in Fig. 21; it shows that length decreased with depth at a rate of 0.01 $mm \cdot ft^{-1}$, that it was approximately 0.1 mm lower in the control sites than in the treatment sites, and that there was no interaction of depth and treatment.

3.7.2 Weight

Fig. 22 shows that dry weight of newly-hatched herring larvae decreased linearly with age due to the expenditure of yolk by metabolism. The multiple regression equation that explained the most variance (r^2 = 0.076, n = 4820) with all-significant coefficients was

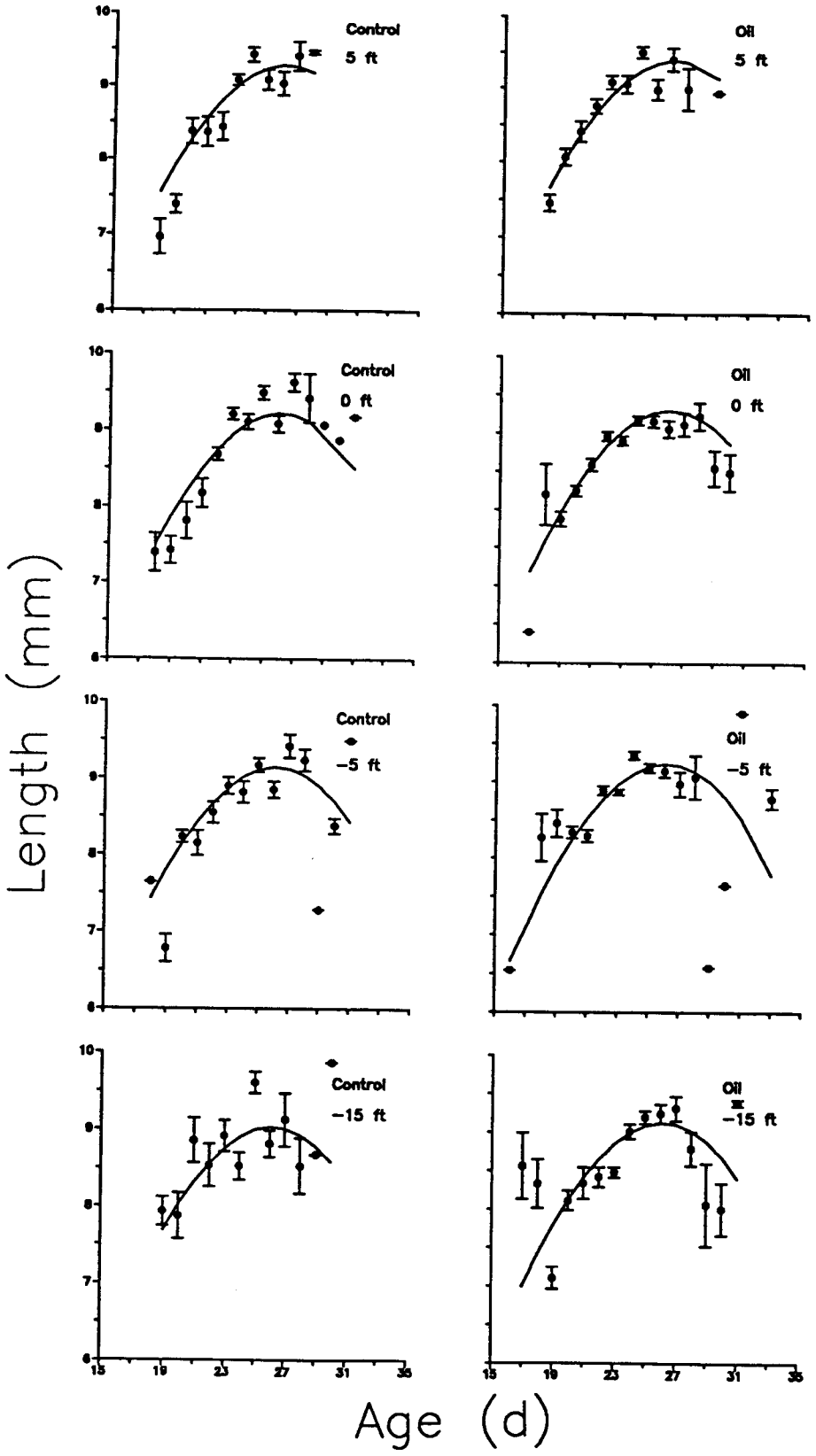

Figure 21. Mean length (±1 SE) of larvae at age of hatching showing larger length in oiled than in control transects and decreasing length with increasing depth. Solid line is length predicted from equation (11).

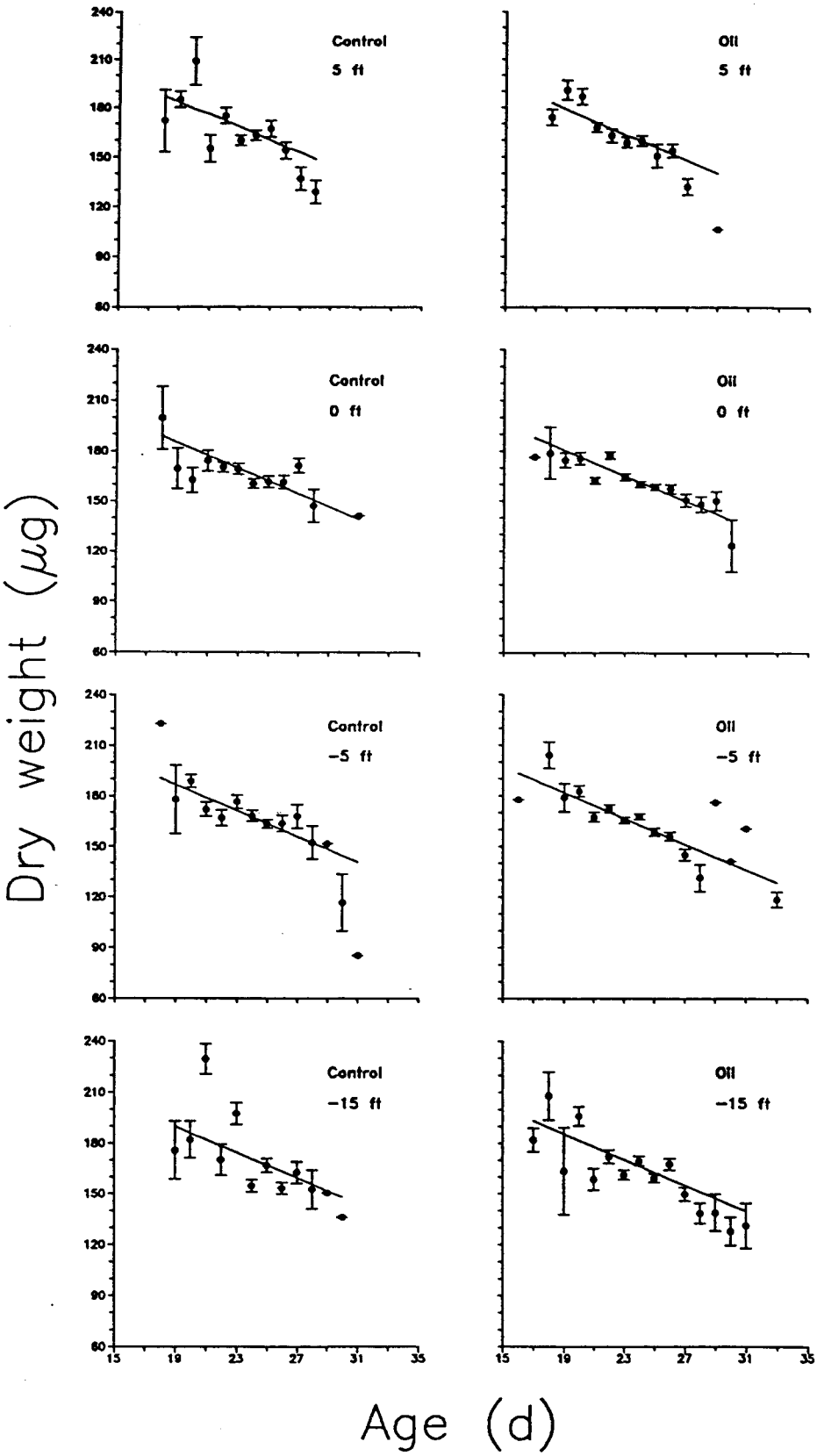

Figure 22. Mean dry weight (±1 SE) of larvae showing linear decrease in weight with age at hatching. Solid line is weight predicted by equation (12).

(12)

variable	coefficient	SE	P
constant	253.1	4.5	<0.0001
age	-3.828	0.196	<0.0001
x	4.510	0.945	<0.0001
depth	-0.3395	0.0727	<0.0001

This equation is plotted in Fig. 22; it shows that weight decreased at a constant rate of 3.8 $\mu g \cdot d^{-1}$, that control larvae were 4 μg heavier at all ages than oil treated larvae, that larvae increased in weight with increasing depth at a rate of 0.3 $\mu g \cdot ft^{-1}$ (= a difference of 6.7 μg between depths of +5 and -15 ft), and that there was no interaction of depth and oil treatment.

3.7.3 Condition Factor

Condition decreased exponentially with age, as was expected from the nonlinear growth of length with age (Fig. 23). Preliminary trials showed that this decrease was best described as a simple exponential decay of condition with age, rather than by a polynomial of age. The multiple regression (r^2 = 0.216, n = 4820) of ln(condition) on age and auxiliary variables was

(13)

variable	coefficient	SE	P
constant	0.3043	0.0489	<0.0001
age	-0.0765	0.0021	<0.0001
x	0.0677	0.0102	<0.0001
depth	-0.0062	0.0008	<0.0001

This equation shows that condition decreased at an average instantaneous rate of 7.7%$\cdot d^{-1}$, that it was 7% higher in control transects than in oiled transects, that it increased with decreasing depth at a rate of 1%$\cdot ft^{-1}$, and that there was no interaction of depth and oil treatment.

3.7.4 Yolk Sac Volume

Yolk sac volume also decreased with age, but the decrease was best described with a polynomial of age (r^2 = 0.451, n = 4820) rather than exponential decay, i.e.

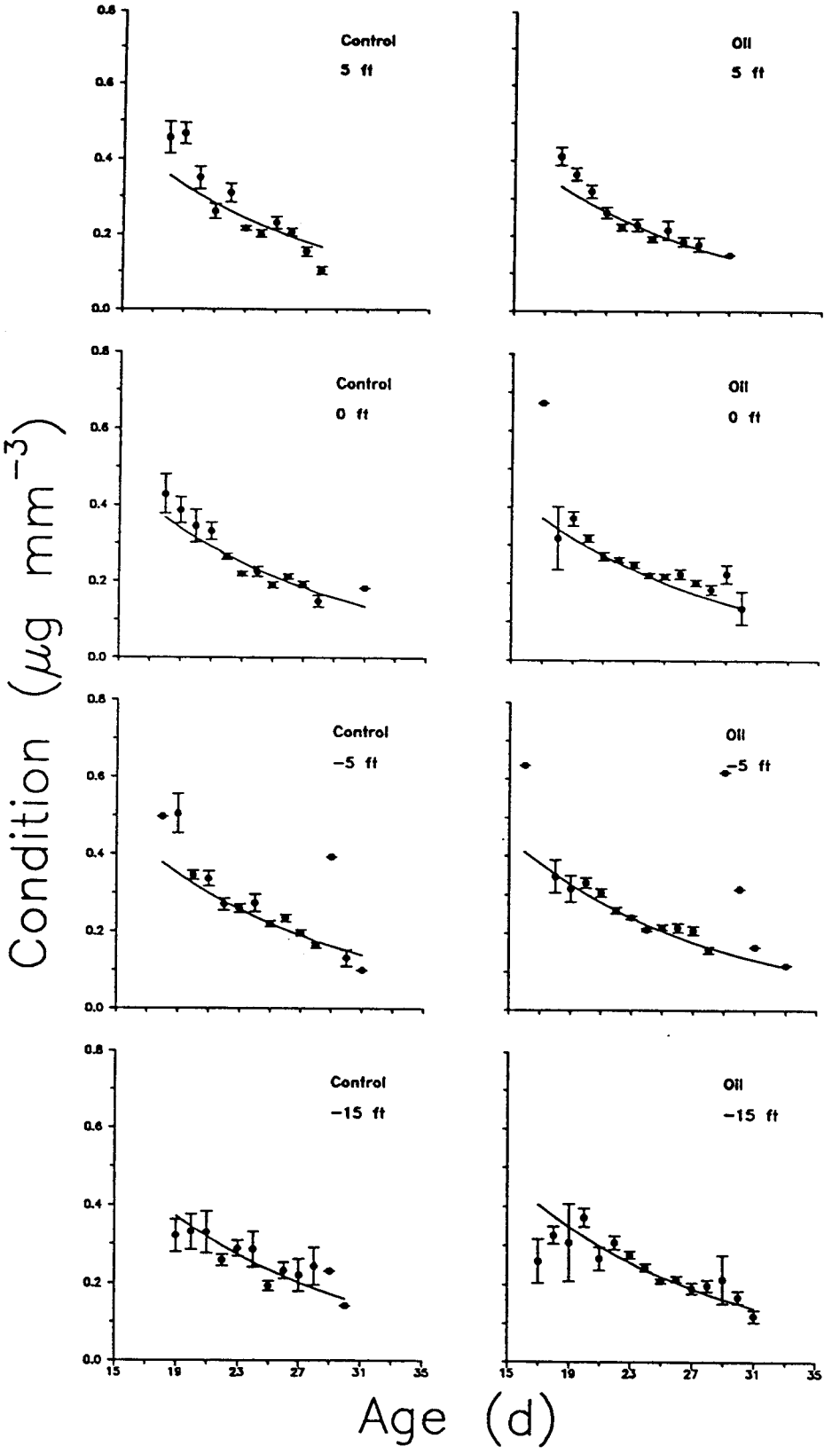

Figure 23. Mean condition (±1 SE) of larvae showing exponential decrease in condition with age at hatching. Solid line is condition predicted by equation (13).

(14)

variable	coefficient	SE	P
constant	2.1430	0.0750	<0.0001
age	-0.1101	0.0048	<0.0001
age^3	$4.27x10^{-5}$	$2.9x10^{-6}$	<0.0001
x	0.0149	0.0035	<0.0001
depth	-0.0021	0.0003	<0.0001
x*depth	-0.0017	0.0005	0.0011

Fig. 24 shows the fit of this equation to the mean yolk sac volumes.

3.8 Multivariate Analyses

In sections 3.1 to 3.7 of this report we examined the data on a variable by variable basis; in this section we examine the data as a single object using multivariate statistics. The reason for this is that the variables are all manifestations of a single phenomenon - the effects on growth and development of herring embryos of concentrations of hydrocarbons. By treating the data as a single matrix, we account for interactions between variables that cannot be accounted for by univariate analyses.

3.8.1 Correlation Matrix

The first step of multivariate analysis was to examine the correlation matrix of the variables derived from the means of the 180 samples shown in Table 2. Examination of large matrices that included such variables as the fraction of larvae in all four developmental stages and the fraction of larvae in all six classes of abnormalities showed that almost all of the statistically significant correlations were retained by a matrix containing only nine variables: survival, age at 50% hatch, fraction of larvae in development stage 1c, fraction of larvae that were viable, yolk sac volume, dry weight, length, oil treatment (1 for control and 0 for oiled), and depth. This reduced variable set was used in all subsequent analysis.

Table 4 shows that the highest correlations occurred between size, the fraction of larvae in stage 1c, and age at 50% hatch. As expected, late hatch was associated with an increased fraction of larvae in stage 1c, longer length, and smaller yolk sac volumes and early hatch was associated with decreased fraction of larvae in stage 1c,

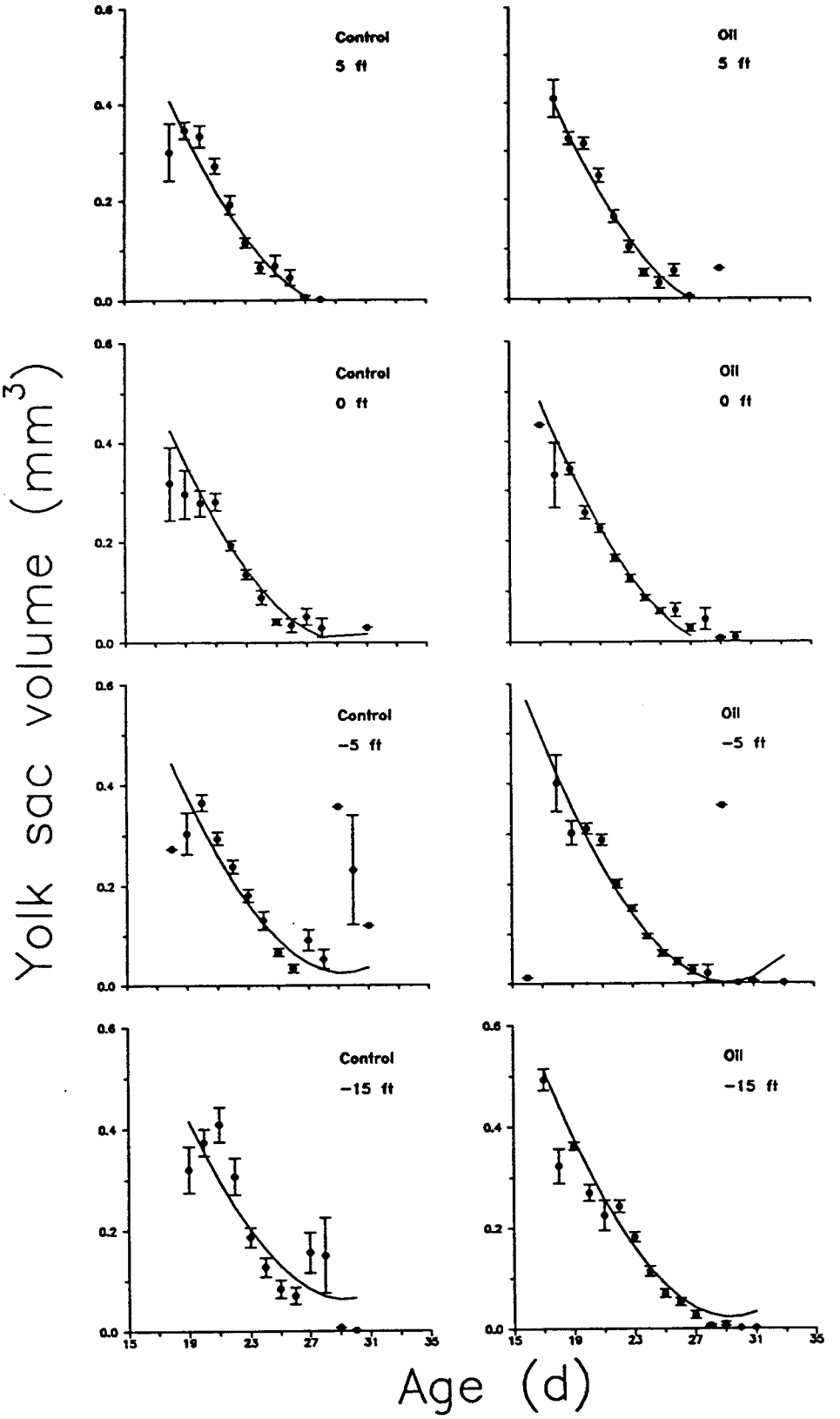

Figure 24. Mean yolk sac volume (±1 SE) of larvae showing decrease in volume with age at hatching. Solid line is yolk sac volume predicted by equation (14).

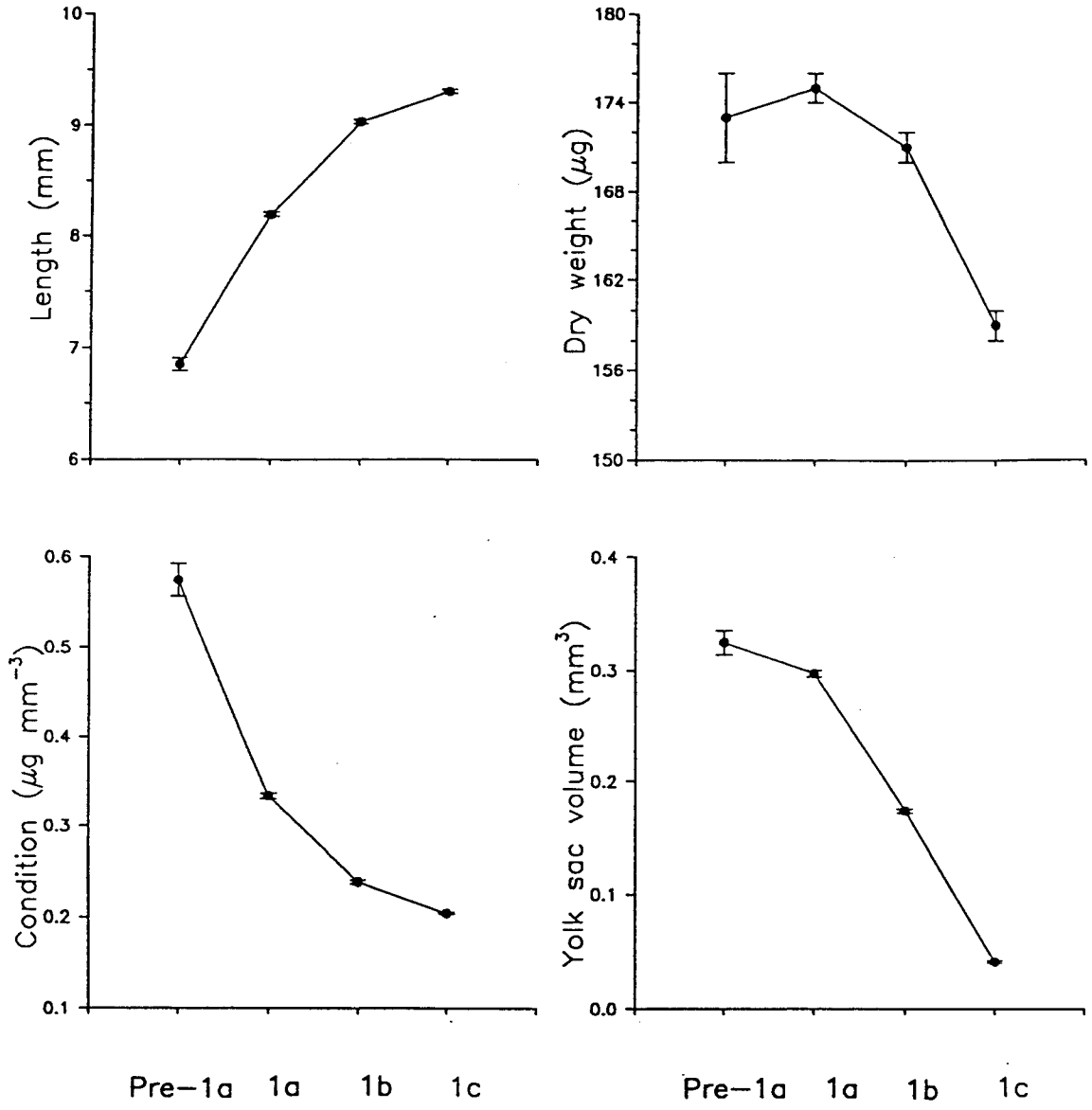

Figure 25. Mean (±1 SE) length, weight, condition and yolk sac volume of herring larvae classified into development stages.

Table 4. Correlation matrix of variables describing herring embryo survival, hatching schedule, development, viability and size with oil treatment and depth.

	survival	age50	1c	normal	ysvol	weight	length	oil	depth
survival	1.00								
age50	0.14	1.00							
1c	0.13	0.36 *	1.00						
normal	0.15 *	-0.01	-0.03	1.00					
ysvol	-0.12	-0.31 *	-0.58 **	0.05	1.00				
weight	-0.02	-0.08	-0.12	0.12	0.28 **	1.00			
length	0.15 *	0.15 *	0.33 **	-0.08	-0.58 **	-0.05	1.00		
oil	0.12	0.13	0.20 *	0.04	0.07	0.00	-0.06	1.00	
depth	-0.06	-0.30 *	0.08	-0.19 *	0.01	0.03	0.04	0.06	1.00

Notes:

1. survival = fraction of eggs surviving to hatch;
   age50 = age (d) at 50% hatch;
   1c = fraction of larvae hatching at development stage 1c;
   normal = fraction of larvae with no morphological abnormalities;
   ysvol = yolk sac volume (mm^3);
   weight = dry weight (ug) of larva;
   length = length of larva (mm);
   oil = 1 for control transect and 0 for oiled transects;
   depth = depth (-15 to 15 ft) at which eggs were spawned.

shorter length and larger yolk sac volumes. Weight was positively correlated with yolk sac volume, but not with length, development stage or age at hatch. There were no correlations between survival and size or survival and development stage, but there was a weak positive correlation with the fraction of viable larvae. The only significant correlation between these variables and oil treatment was a weak positive correlation between the fraction of larvae in development stage 1c and the absence of oil. Both age at 50% hatch and the fraction of viable larvae were negatively correlated with depth, i.e. both decreased as depth increased from -15 ft to 5 ft.

3.8.2 Multivariate ANOVA

The extension of univariate ANOVA to the case of multiple dependent variables is called multivariate ANOVA or MANOVA. In this procedure the single dependent variable specified in an ANOVA is replaced by a vector of dependent variables. The seven biological variables listed in Table 4: fractional survival, age at 50% hatch, fraction in stage 1c, fraction viable larvae, yolk sac volume, larval weight and larval length, were the dependent variables and oil treatment and depth were the factors. The MANOVA reflected the pattern of correlations seen in Table 4 by showing that a highly significant ($n = 180$, $P = 0.004$) variation in the vector was due to depth and a barely significant ($P = 0.026$) variation was due to oil treatment. The oil x depth interaction was not significant ($P = 0.164$).

These results are similar to those from ANOVAs reported earlier in this report: both oil treatment and depth are responsible for significant changes in the suite of variables that characterize herring embryo survival, viability, development, and size, but the effect of depth is often more significant than the effect of oil. This result is due, in part, to our present lack of knowledge concerning the exact degree of exposure to oil within the treated samples of eggs.

3.8.3 Factor Analysis

The correlation matrix showed that there were significant relationships between biological variables, and the MANOVA showed that the vector of biological variables varied significantly with oil treatment and depth. The next step in analysis was to identify and describe the processes that underlie the observed variation in the biological variables. The procedure is called factor analysis; it identifies the major

axes of variation by converting a set of observed variables into a set of artificial variables or factors. Unlike the raw variables, the factors are completely uncorrelated with each other, so the information contained in one factor will not be duplicated in another. This makes the biological interpretation of the data much more clear.

Before extracting the factors the raw variables were standardized by subtracting their mean and dividing by their standard deviation, i.e.

(15) $z_{ij} = (x_{ij} - X_i)/s_i$

where z_{ij} = case j of standardized variable i, x_{ij} = case j of raw variable i, X_i = mean of raw variable i (i.e. the grand mean of the 180 sample means), and s_i = standard deviation of variable i.

Table 5 shows the eigenvalues and the percent of variance explained by each of the factors extracted from these standardized variables. Only the first four factors are examined further because they were the only factors with eigenvalues greater than one and because all other factors each explained only 3-10% of the variance in the sample means. Together, factors 1 to 4 explained 66.1% of the variance in the standardized means.

The loadings of these factors are shown in Table 6, after varimax rotation, which was used to make the loadings more easily interpretable. The loadings are coefficients whose sign and magnitude indicate the contribution of each standardized variable to the factor. Based on these loadings we interpreted factor 1 as an index of the development of the larvae, i.e. as a contrast between small yolk sac volumes and long larval lengths versus large yolk sac volumes and short lengths. We interpreted factor 2 as the effect of depth on age of 50% hatching and larval viability, i.e. high ages of 50% hatch and high viability in deep water compared to low ages of 50% hatch and low viability in shallow water. We interpreted factor 3 as the effect of oil on stage of development, age of 50% hatch, larval length, and egg survival. We interpreted factor 4 as a contrast between depth and survival, viability and weight, i.e. high survival and viability in deep water and low survival and viability in shallow water.

Table 5. Eigenvalues and percent of variance explained by the nine factors extracted from the nine standardized biological variables.

Factor	Eigenvalue	Percent of variance	Cumulative percent of variance
1	2.3306	25.9	25.9
2	1.3979	15.5	41.9
3	1.1607	12.9	54.3
4	1.0563	11.7	66.1
5	0.9142	10.2	76.2
6	0.7976	8.9	85.1
7	0.6148	6.8	91.9
8	0.4549	5.1	97.0
9	0.2731	3.0	100.0

Table 6. Loadings on factors 1 to 4 after varimax rotation. Variable names are explained in Table 4.

	Rotated factor			
Variable	1	2	3	4
oil	-0.077	0.024	0.904	0.067
depth	0.125	0.852	0.187	-0.144
survival	0.287	-0.086	0.238	0.556
age50	0.326	-0.661	0.317	-0.055
1c	0.704	-0.080	0.412	-0.061
normal	-0.083	-0.240	-0.037	0.713
ysvol	-0.876	0.155	0.042	0.135
weight	-0.197	0.280	-0.057	0.578
length	0.807	0.097	-0.179	0.089

In summary, factor analysis reveals three conclusions that were suggested by the correlation matrix of Table 4. First, the greatest contrast in the data set is the inverse relationship between larval size (especially yolk sac volume) and stage of development at hatch. Second, depth has two impacts on the biology of herring embryos: the age of 50% hatch decreases with decreasing depth, and the fraction of surviving eggs and viable larvae decreases with decreasing depth. Third, the effect of oil treatment is also twofold: the most important effect is an acceleration of development, which causes earlier hatch and increases the frequency of early development stages at hatch; the second effect is a decrease in survival of eggs.

This analysis identified factor 3 as a possible index of oil treatment. This is illustrated by Fig. 26, which shows that factor 3 is the only one of the four factors to exhibit differences between control and oiled samples. Factor 3 can now be used to rank the samples according to the degree of "oil impact". Table 7 shows the ranking of the 180 samples according to their values of factor 3. If one assumes that there is a direct relationship between exposure to hydrocarbon concentrations and 'viability' of herring embryos, then this ranking is actually a prediction of the rank order of hydrocarbon concentrations to which the eggs were exposed. This prediction can be tested if data on the hydrocarbon concentration of samples of herring eggs ever becomes available.

4. DISCUSSION

This study shows that there was a weak, but statistically significant, effect of oil from the Exxon Valdez spill on the biology of herring eggs laid on beaches in central and southern Prince William Sound. There are two possible reasons for the weak statistical link: the spawning beaches were not contaminated by high concentrations of hydrocarbons, and we lacked a satisfactory measurement of the amount of hydrocarbons to which each egg sample was exposed and of the duration of its exposure to hydrocarbons. It is almost certain that some of the eggs from the oiled class were exposed to low concentrations of hydrocarbons, as is suggested by the accelerated hatching. However, considering the large volume of oil that was spilled and the large number of beaches that were fouled by oil, we believe that the second reason was also a major cause of the weak relationship.

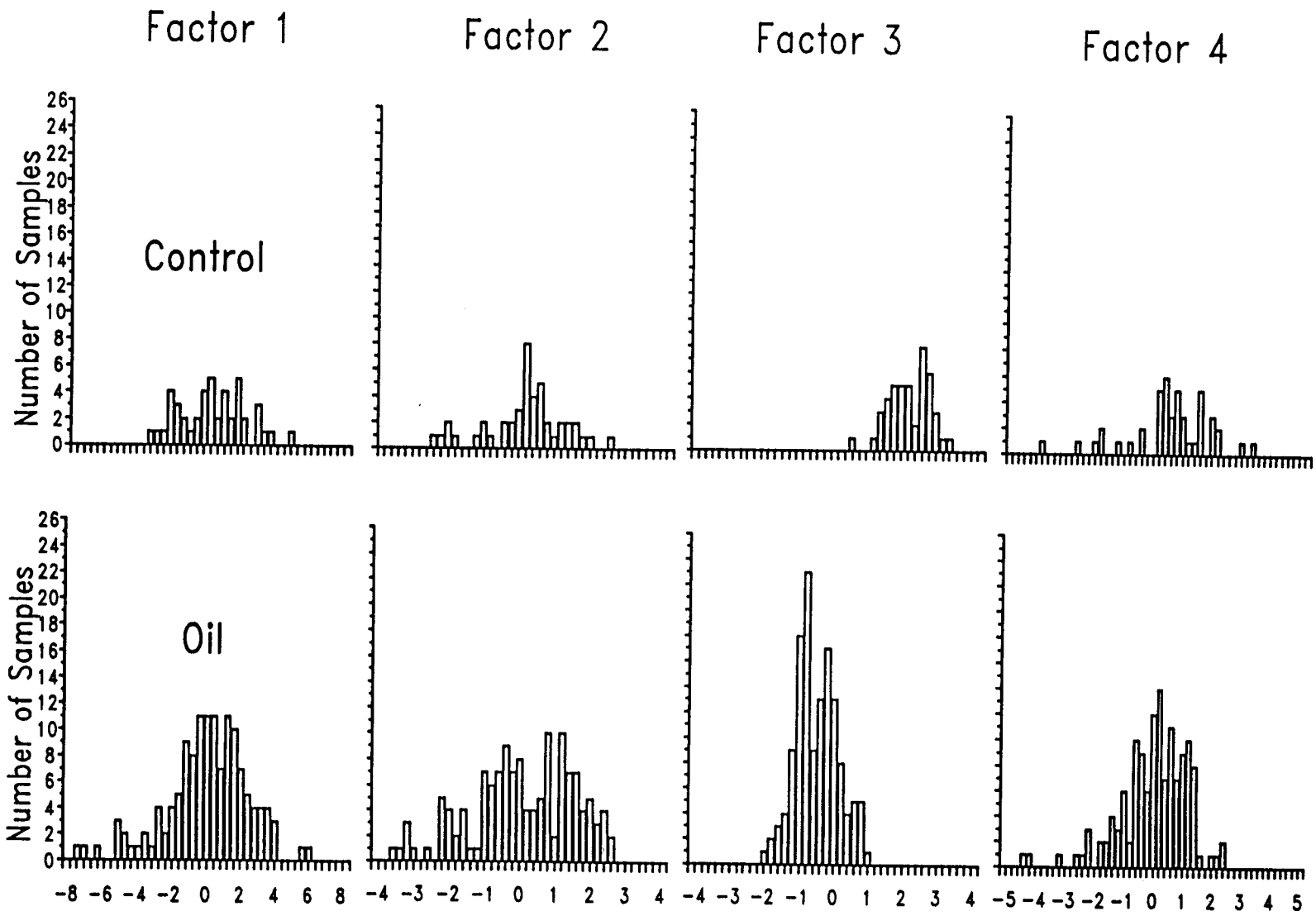

Figure 26. Frequency distributions of control and oiled samples against factors 1 to 4, showing that only factor 3 is an index of oil contamination.

Table 7. Rank of herring egg samples based on factor 3, in order of decreasing factor value.

Location	ADFG no.	Depth (ft)	Rep. no.	Triton no.	Factor 3 value	Factor 3 rank
Fairmount	C-01	5	1	101	2.494	8
Fairmount	C-01	5	2	2	2.885	2
Fairmount	C-01	5	3	53	2.270	15
Fairmount	C-01	0	2	143	2.166	21
Fairmount	C-01	0	3	172	1.525	34
Fairmount	C-01	0	1	78	2.292	14
Fairmount	C-01	-5	1	107	2.359	13
Fairmount	C-01	-5	2	91	1.340	37
Fairmount	C-01	-5	3	126	1.226	40
Fairmount	C-02	0	1	58	2.214	19
Fairmount	C-02	0	2	151	2.218	18
Fairmount	C-02	0	3	36	1.404	36
Fairmount	C-02	-5	3	159	1.905	23
Fairmount	C-02	-5	1	119	0.317	59
Fairmount	C-02	-5	2	141	1.058	43
Fairmount	C-02	-15	1	125	1.306	38
Fairmount	C-02	-15	3	19	1.468	35
Fairmount	C-02	-15	2	168	0.841	44
Fairmount	C-03	0	3	142	2.486	10
Fairmount	C-03	0	2	37	1.695	30
Fairmount	C-03	0	1	23	2.260	16
Fairmount	C-03	-5	2	24	2.488	9
Fairmount	C-03	-5	1	62	2.573	7
Fairmount	C-03	-5	3	74	1.064	42
Fairmount	C-03	-15	3	98	1.563	32
Fairmount	C-03	-15	1	152	2.440	11
Fairmount	C-03	-15	2	41	1.909	22
Fairmount	C-04	5	1	127	1.797	28
Fairmount	C-04	5	3	100	3.040	1
Fairmount	C-04	5	2	25	1.818	25
Fairmount	C-04	0	1	156	1.860	24
Fairmount	C-04	0	2	35	1.751	29
Fairmount	C-04	0	3	6	2.615	5
Fairmount	C-04	-5	2	96	2.224	17
Fairmount	C-04	-5	1	176	1.798	27
Fairmount	C-04	-5	3	70	1.184	41
Fairmount	C-05	5	1	57	2.754	3

Table 7. Rank of herring egg samples based on factor 3, in order of decreasing factor value. (Continued)

Location	ADFG no.	Depth (ft)	Rep. no.	Triton no.	Factor 3 value	Factor 3 rank
Fairmount	C-05	5	2	95	2.182	20
Fairmount	C-05	5	3	3	2.397	12
Fairmount	C-05	0	3	40	1.678	31
Fairmount	C-05	0	2	108	1.249	39
Fairmount	C-05	0	1	69	1.800	26
Bass Harbor	O-01	0	3	155	0.714	47
Bass Harbor	O-01	0	1	137	-1.475	173
Bass Harbor	O-01	0	2	68	0.709	48
Bass Harbor	O-01	-5	1	106	-0.303	88
Bass Harbor	O-01	-5	2	175	-0.838	126
Bass Harbor	O-01	-5	3	90	0.180	62
Bass Harbor	O-01	-15	1	39	-0.873	127
Bass Harbor	O-01	-15	2	61	0.194	61
Bass Harbor	O-01	-15	3	124	-1.080	151
Bass Harbor	O-02	0	1	99	-0.743	119
Bass Harbor	O-02	0	2	18	-0.940	135
Bass Harbor	O-02	0	3	1	-0.706	118
Bass Harbor	O-02	-5	3	134	-0.672	116
Bass Harbor	O-02	-5	1	83	-1.171	161
Bass Harbor	O-02	-5	2	34	-0.479	103
Bass Harbor	O-02	-15	3	118	-1.235	162
Bass Harbor	O-02	-15	2	4	-1.250	164
Bass Harbor	O-02	-15	1	17	-1.677	175
Bass Harbor	O-03	5	1	103	-0.033	71
Bass Harbor	O-03	5	2	5	-0.308	89
Bass Harbor	O-03	5	3	49	-1.480	174
Bass Harbor	O-03	0	1	14	-0.904	131
Bass Harbor	O-03	0	3	104	-0.921	132
Bass Harbor	O-03	0	2	154	0.836	45
Bass Harbor	O-03	-5	3	120	-0.498	107
Bass Harbor	O-03	-5	1	55	-0.067	73
Bass Harbor	O-03	-5	2	139	-1.239	163
Bass Harbor	O-04	0	3	71	-0.988	142
Bass Harbor	O-04	0	1	153	-1.309	166
Bass Harbor	O-04	0	2	169	-0.408	100
Bass Harbor	O-04	-5	1	32	-1.309	167
Bass Harbor	O-04	-5	2	73	-1.142	156

Table 7. Rank of herring egg samples based on factor 3, in order of decreasing factor value. (Continued)

Location	ADFG no.	Depth (ft)	Rep. no.	Triton no.	Factor 3 value	Factor 3 rank
Bass Harbor	O-04	-5	3	171	-0.193	81
Bass Harbor	O-04	-15	2	88	-1.776	177
Bass Harbor	O-04	-15	3	121	-2.125	180
Bass Harbor	O-04	-15	1	149	-1.752	176
Bass Harbor	O-08	0	1	64	0.064	65
Bass Harbor	O-08	0	2	162	0.771	46
Bass Harbor	O-08	0	3	147	-0.639	114
Bass Harbor	O-08	-5	2	130	-0.611	112
Bass Harbor	O-08	-5	3	114	-0.994	143
Bass Harbor	O-08	-5	1	178	0.637	50
Bass Harbor	O-08	-15	3	13	-1.152	158
Bass Harbor	O-08	-15	1	33	-1.313	168
Bass Harbor	O-08	-15	2	47	0.045	66
Bass Harbor	O-10	0	1	16	-0.106	74
Bass Harbor	O-10	0	3	115	0.107	64
Bass Harbor	O-10	0	2	65	0.693	49
Bass Harbor	O-10	-5	2	45	0.379	57
Bass Harbor	O-10	-5	1	117	-0.151	76
Bass Harbor	O-10	-5	3	30	-0.451	102
Bass Harbor	O-10	-15	3	163	-0.332	93
Bass Harbor	O-10	-15	1	80	-1.320	169
Bass Harbor	O-10	-15	2	132	0.369	58
Outside Bay	O-11	5	2	10	-1.102	154
Outside Bay	O-11	5	3	140	-0.495	105
Outside Bay	O-11	5	1	158	-0.830	124
Outside Bay	O-11	0	3	109	-0.181	79
Outside Bay	O-11	0	2	180	-1.048	147
Outside Bay	O-11	0	1	160	-0.926	133
Outside Bay	O-11	-5	1	59	-0.269	85
Outside Bay	O-11	-5	2	123	-1.418	172
Outside Bay	O-11	-5	3	46	0.043	67
Outside Bay	O-12	5	1	8	-1.145	157
Outside Bay	O-12	5	2	105	-0.635	113
Outside Bay	O-12	5	3	122	-0.549	110
Outside Bay	O-12	0	1	54	-0.497	106
Outside Bay	O-12	0	2	170	0.428	55
Outside Bay	O-12	0	3	22	-0.933	134

Table 7. Rank of herring egg samples based on factor 3, in order of decreasing factor value. (Continued)

Location	ADFG no.	Depth (ft)	Rep. no.	Triton no.	Factor 3 value	Factor 3 rank
Outside Bay	O-12	-5	3	77	-1.005	144
Outside Bay	O-12	-5	1	51	-0.184	80
Outside Bay	O-12	-5	2	89	-0.294	86
Cabin Bay	O-13	0	1	173	-0.066	72
Cabin Bay	O-13	0	3	60	0.019	68
Cabin Bay	O-13	0	2	82	-0.500	108
Cabin Bay	O-13	-5	3	110	-0.974	139
Cabin Bay	O-13	-5	1	9	-1.079	150
Cabin Bay	O-13	-5	2	128	-0.156	77
Cabin Bay	O-13	-15	2	94	-0.783	120
Cabin Bay	O-13	-15	1	75	-0.230	82
Cabin Bay	O-13	-15	3	136	-1.062	148
Outside Bay	O-14	5	3	20	-0.880	129
Outside Bay	O-14	5	1	76	-0.136	75
Outside Bay	O-14	5	2	93	-0.969	138
Outside Bay	O-14	0	3	21	-1.081	152
Outside Bay	O-14	0	2	11	-0.810	122
Outside Bay	O-14	0	1	38	-0.684	117
Outside Bay	O-14	-5	1	145	-1.851	178
Outside Bay	O-14	-5	3	28	-1.031	146
Outside Bay	O-14	-5	2	111	-0.591	111
Story Island	O-15	0	3	164	0.472	52
Story Island	O-15	0	1	79	-0.255	84
Story Island	O-15	0	2	161	0.445	53
Story Island	O-15	-5	1	177	-1.063	149
Story Island	O-15	-5	3	44	-0.530	109
Story Island	O-15	-5	2	146	-1.124	155
Story Island	O-15	-15	3	174	-0.803	121
Story Island	O-15	-15	1	157	0.266	60
Story Island	O-15	-15	2	66	-0.489	104
Story Island	O-16	0	3	112	0.168	63
Story Island	O-16	0	1	97	-0.975	140
Story Island	O-16	0	2	133	-0.295	87
Story Island	O-16	-5	2	43	-0.401	99
Story Island	O-16	-5	3	129	-0.379	96
Story Island	O-16	-5	1	144	0.582	51
Story Island	O-16	-15	2	12	-0.948	137

Table 7. Rank of herring egg samples based on factor 3, in order of decreasing factor value. (Continued)

Location	ADFG no.	Depth (ft)	Rep. no.	Triton no.	Factor 3 value	Factor 3 rank
Story Island	O-16	-15	1	26	0.392	56
Story Island	O-16	-15	3	63	-0.005	69
Rocky Bay	O-17	5	3	27	-1.978	179
Rocky Bay	O-17	5	2	42	-1.162	160
Rocky Bay	O-17	5	1	150	-0.874	128
Rocky Bay	O-17	0	2	135	-0.321	91
Rocky Bay	O-17	0	3	84	-1.406	171
Rocky Bay	O-17	0	1	116	-0.019	70
Rocky Bay	O-17	-5	2	67	-0.380	97
Rocky Bay	O-17	-5	3	102	-0.414	101
Rocky Bay	O-17	-5	1	52	-0.812	123
Rocky Bay	O-18	5	2	81	-0.836	125
Rocky Bay	O-18	5	3	166	-0.180	78
Rocky Bay	O-18	5	1	50	-1.082	153
Rocky Bay	O-18	0	1	15	-1.380	170
Rocky Bay	O-18	0	3	131	-0.897	130
Rocky Bay	O-18	0	2	85	-1.023	145
Rocky Bay	O-18	-5	1	29	-0.326	92
Rocky Bay	O-18	-5	3	56	-0.645	115
Rocky Bay	O-18	-5	2	48	-0.977	141
Rocky Bay	O-19	5	2	87	-0.394	98
Rocky Bay	O-19	5	3	148	-0.310	90
Rocky Bay	O-19	5	1	165	-0.944	136
Rocky Bay	O-19	0	1	113	-0.246	83
Rocky Bay	O-19	0	2	31	-1.296	165
Rocky Bay	O-19	0	3	179	-0.357	95
Rocky Bay	O-19	-5	3	86	-0.343	94
Rocky Bay	O-19	-5	2	138	-1.162	159
Rocky Bay	O-19	-5	1	72	0.432	54
-	-	-	-	-	-	-

It is highly probable that the concentration of oil and the duration of oil exposure varied widely within small geographic areas due to differences in the topography of the shoreline, in the strength of local wind and wave events, and in the tide levels at the time that the front of the oil slick first encountered shore. The variability of exposure within the so-called "oiled" group is shown by the ranking of samples by factor 3. Table 7 shows that within Bass Harbor the rankings ranged from 45 to 180 and within Rocky Bay they ranged from 54 to 179, but the control sites in Fairmount Bay had a much narrower range of ranking: 2 to 59. (Other "oiled" sites had a similarly wide range of rankings.) This indicates that exposure to oil varied substantially within the oiled areas. A correct assessment of the actual impact of the Exxon Valdez spill requires a much more precise index of oil contamination than the simple presence/absence index used in this study.

One consequence of using a simple presence/absence index of oil treatment was that it was difficult to disentangle the effects of oil from the effects of independent environmental factors (e.g. temperature or exposure) that were related with depth. This difficulty was compounded by the fact that these factors varied non-linearly with depth; they were greatest for shallow and deep water and least for the mid-range of depths.

Survival

The survivals reported in this study (range = 7.1 to 99.9%, mean = 59.2%, SD = 17.7) are very similar to those that have been reported by other authors for medium and low densities of natural herring spawn incubated in environments free of predators and chemical contamination. Hourston et al. (1984) incubated natural spawn of Pacific herring collected in the Strait of Georgia, British Columbia, in laboratory tanks. They reported that percent hatching was highly variable, ranging from 16 to 100%, and that it tended to decrease with increasing egg density, probably due to asphyxiation of eggs inside clumps. Mean hatch was 30% for cases of heavy intensity, defined as >78 eggs$\cdot$cm^{-2}, 71% for cases of light to medium intensity, i.e. <78 eggs$\cdot$cm^{-2}, and 54% for all cases combined. Similar results were reported by Johannessen (1986) for natural Atlantic herring, Clupea harengus harengus, spawn collected from western Norway: percent hatching ranged from 17.2

to 84.4 and decreased from 50.5 for light egg densities (<25 eggs·cm^{-2}) to 27.7 for heavy egg densities (50-100 eggs·cm^{-2}) for a grand mean of 42.8%.

We did not find any evidence of a significant effect of oil on survival or hatching success, but survival is usually less sensitive to pollutants than percent viability, according to von Westernhagen's (1988) review of the sublethal effects of pollutants on fish eggs and larvae. The only other study that compared survival of natural herring spawn from oil-contaminated and pristine areas found significant reductions in survival in the contaminated area eight months after the oil spill. Aneer and Nellbring (1982) compared hatching success of Baltic herring, Clupea harengus membras, eggs collected from sites in the northern Baltic sea. They collected spawn of low to medium density in June-July, 1978, from pristine areas and from a neighbouring area contaminated by the 'Tsesis' oil spill of October, 1977, and incubated them in laboratory containers. Percent hatch ranged from 0.0 to 94, and was significantly ($P<0.01$) higher in the uncontaminated area (mean = 58.5%, SD = 39.0, n = 43) than in the contaminated area (mean = 34.8%, SD = 23.7, n = 51). We suspect that a similar significant relationship between survival of herring eggs and degree of oil contamination may exist in the data reported in this study, but that the relationship may be obscured by the wide range of actual oil contaminations within the oil treatment group.

Another factor that obscured the putative oil-survival relationship is the dome-shaped relationship between percent survival and depth. This phenomenon has not been previously reported in the scientific literature, apparently because this is the first study that examined percent hatch and percent viable hatch of herring spawn over the majority of its depth range. Previous studies examined portions of the range. However, its existence is supported by at least two studies on survival of Pacific herring eggs. Jones (1972) incubated artificially spawned herring eggs in incubators that simulated tidal exposure and showed that "prehatching mortality" increased linearly with number of hours of exposure to air; from 13% in unexposed eggs to 31% in eggs that were exposed to air for 8 hours twice daily. Taylor (1971) incubated artificially spawned herring eggs on ropes at various depths and showed that percent survival decreased linearly with depth regardless of egg density. Combining these two results indicates that percent survival should be low in the upper intertidal zone and low near the lowest depths at which spawn is laid and maximal at some intermediate depth. Our study supports these predictions by

showing that survival and the fraction of viable hatch was low at both depth extremes and maximal at a depth of about -5 ft from the lower low water mark.

Live/Dead Egg Ratios

Our finding that herring eggs died at a rate of about $3\%\cdot d^{-1}$ is in good agreement with most studies that have examined the mortality of natural herring spawn. It is generally accepted that mortality of herring eggs due to causes other than predation is low, i.e. less than $10\%\cdot d^{-1}$. Baxter (1971) and Hempel and Hempel (1971) reported that an average of 95.8% and 96.1 to 94.3% of North Sea and Clyde Sea herring eggs, respectively, were alive. Haegele et al. (1981) reported that they rarely ever saw natural Pacific herring spawn with less than 90% live eggs. The very high mortality rates that have been reported for herring spawn (up to 90% - see review by Pallson 1984) are due almost entirely to predation by birds, fishes and invertebrates.

One of the consequences of the low rate of non-predation mortality is that the ratio of live eggs to total eggs measured at only one age is not an accurate index of the viability of herring embryos. In this study the ratios of most samples fell within a narrow range of 0.80-0.99, and only a few exhibited extraordinarily low live/total egg ratios. Herring eggs apparently do not exhibit morbidity or non-viability until relatively late in their development, at an age when larvae have begun to hatch. During the hatching period the live/total egg ratio is dominated by the schedule of hatching. If the number of hatched larvae is not known, then the survival dynamics of the egg mass are not known. Thus, knowledge of the live/dead egg ratio is not enough in itself to reliably and accurately predict total egg survival.

This conclusion may be subject to change if a more accurate index of oil contamination becomes available in the future. If it does, then the analysis should be repeated in order to test the usefulness of the live/dead egg ratio.

Hatching Schedule

The significant decrease in age at 50% hatching that was observed in the oiled treatment is in agreement with results reported by studies that examined the effect of low concentrations of the water soluble fraction (WSF) of petroleum

hydrocarbons on developing eggs of fish. It is in contradiction to studies that used high concentrations of WSF hydrocarbons. von Westernhagen's (1988) review of this subject indicates that most authors report delayed hatch of larvae after treatment with petroleum hydrocarbons, primarily because they used high concentrations of WSF. For example, Linden (1978) reported delayed hatch of Baltic herring larvae exposed to 54 $mg \cdot L^{-1}$ of the WSF of light fuel oil. Struhsaker et al. (1974) reported similar results for Pacific herring exposed to pulses of benzene at concentrations of 40-45 $mg \cdot L^{-1}$. Other authors cited by von Westernhagen (1988) report similar results for other species of fish. The most likely reason for delayed hatch is that the embryos are narcoticized by high concentrations of WSF hydrocarbons. However, at least two authors have reported premature hatching of fish embryos after treatment with low concentrations of WSF hydrocarbons (Ernst et al. 1977: Fundulus grandis; Leung and Bulkley 1979: Oryzias latipes). The mechanism is considered to be stimulation of the hatching mechanism by oil components.

It is not unusual for a pollutant to shorten or lengthen incubation depending on its concentration. In fact, von Westernhagen (1988) reports that most pollutants, especially metals, appear to stimulate early hatch. The results of this study suggest that most of the oiled egg samples from Prince William Sound were exposed to low concentrations of hydrocarbons. This prediction should be tested by reanalysing the data on cumulative fraction of hatching with a more precise index of hydrocarbon concentration.

The significant increase in age at 50% hatch with increasing depth was almost certainly a response to a decrease in water temperature with depth. It must be remembered that the eggs had already incubated on their spawning grounds for approximately 14 d before they were collected. This was sufficient time for significant differences in stage of development to have been established between eggs from different depths.

What are the consequences of early hatching to survival of herring larvae? This question is difficult to answer with certainty because most fisheries scientists believe that survival of fish larvae in the sea is determined mainly by the presence or absence of predators (Bailey and Houde 1989), so there is a strong and unpredictable environmental component to this problem. For the sake of argument, we will assume that predation pressure on herring larvae was the same at all sites

regardless of their level of oil contamination. It is well known that mortality rates of natural populations of marine fish larvae decrease exponentially with size, e.g. Bailey and Houde (1989: Fig. 1), so it is possible that small difference in larval size may have led to larger differences in total survival over the larval stage. In order to test the null hypothesis of identical larval survival between oiled and non-oiled sites we refer to the mortality rates measured from wild herring larvae collected in Prince William Sound in May-June, 1989. McGurk et al. (1990) reported that the mortality rates for the single largest cohort found at each of four sites, Tatitlek Narrows, Fairmount Island, Bass Harbor and Rocky Bay, were all a constant 0.25 d^{-1}, and there were no significant ($P>0.05$) differences associated with site. Therefore, the null hypothesis is supported; we conclude that the relative frequency of early and late stage larvae did not lead to detectable differences in population survival.

Viability of Larvae

The average viability of herring larvae measured in this study, 84%, is very close to that found by other authors. For example, Hourston et al. (1984) reported that the viability of Pacific herring larvae was usually high (over 80% in 89% of their samples) and not related to the type of spawning substrate, the intensity of spawning, or whether the eggs were naturally spawned or artificially spawned.

The rank order of morphological deformities reported in this study is also similar to that reported in the scientific literature for other sub-species of herring and other species of fish. The most conspicuous deformity is usually associated with curvature of the spine, followed by abnormal development of the head, jaw and eye and irregular development of the yolk (von Westernhagen 1988). These deformities are not a specific response to pollutants, but are common in all eggs of all fishes. They are the equivalent of spontaneous abortions in mammals and may be caused by natural stressors as well as unnatural stressors. It is commonly assumed that all deformed larvae die soon after hatch either because they cannot feed or because they cannot evade predators. This assumption is supported by the fact that not a single deformed larvae was ever observed in the survey of wild herring of Prince William Sound in May-June, 1989 (McGurk et al. 1990).

Although bent spines are the most common abnormality observed in herring embryos exposed to hydrocarbons (Linden 1878, Smith and Cameron 1979,

Struhsaker et al. 1984), we did not find any significant differences between our control and treatment classes in the fraction of spinal deformities. This may be due to the non-specificity of spinal deformities - other stressors could have produced enough variability in its frequency to obscure a relationship with the presence/absence of oil. Only a more accurate index of oil contamination will allow a test of the hypothesis of a positive relationship between the frequency of spinal deformity and oil treatment.

Unlike spinal deformities, there was a highly significant increase in jaw deformities in larvae from oiled eggs. A response of jaw development to hydrocarbons has also been reported by previous controlled experiments. For example, Struhsaker et al. (1984) reported jaw anomalies in Pacific herring larvae exposed as eggs to 4.8-45 mg benzene$\cdot L^{-1}$, and Smith and Cameron (1979) reported a high incidence of jaw deformities in Pacific herring larvae that had been exposed at an age of 6 d to concentrations of 1 mg$\cdot L^{-1}$ of the WSF of Prudhoe Bay crude oil for only 48 h. Linden (1978) reported similar deformities in Baltic herring embryos exposed to 59 mg hydrocarbons$\cdot L^{-1}$.

This study does not deal with sublethal effects of exposure to hydrocarbons that are not expressed as morphological deformities. Other investigators were contracted for this purpose.

Viable Hatch

The fact that the product of survival and viability is 6% lower in oiled eggs than in control eggs [see equation (10) and Fig. 10C] supports the idea that there are both a survival-oil relationship and a viability-oil relationship hidden in the data set.

Size and Condition of Larvae

In general, pollutant stressors such as petroleum hydrocarbons tend to produce fish larvae with reduced length (von Westernhagen 1988). These premature larvae are heavier than untreated larvae because they carry a larger yolk sac, and so they also have a higher condition. The results of this study are the exact opposite: on average after correction for age and depth, larvae from oiled samples were 0.1 mm longer, 4 μg lighter, had 7% lower condition and had a 1% larger yolk sac than larvae from

control samples. Although these differences were statistically significant, they were probably too minor, e.g. a 1.2% increase in mean length and a 2.4% decrease in mean weight, to have had any effect on subsequent larval survival. These results suggest that oil may have had the effect of stimulating the hatch of larger larvae, but it is difficult to reconcile that conclusion with a significantly reduced age at 50% hatch.

We suggest that one reason for the apparently anamolous results was a confounding of the oil effect with a temperature effect. Oil from the Exxon Valdez spill contaminated beaches in the central and southern parts of Prince William Sound, but not beaches in the north of the Sound. This pattern coincides with a geographic trend of low water temperatures in central and southern Prince William Sound and higher temperatures in the north. Table 1 shows that surface water temperatures at the control transects in and near Fairmount Bay were 1.1 to 2.2°C higher in late April than those at oiled transects of Naked Island and Montague Island. A similar pattern of higher May-June temperatures in the north of the Sound was reported by McGurk et al. (1990). The cause of the temperature differences is the inflow of cold oceanic water into the Sound through Hinchinbrook Entrance; sites close to the Entrance are always colder than sites far from the Entrance.

At present, there is no way of incorporating the effect of temperature into the general linear models of size and condition [equations (11) to (14)] because we do not possess any records of temperature for the incubation period before April 21, 1989, and because the temperature records for the period April 21 - May 2, 1989, do not contain any information on temperature at depth. It may be possible to remove the temperature effect by examining size and condition of larvae within smaller geographic areas, such as the Naked Island archipelago, where temperature would be expected to vary much less than within larger geographic units. However, this analysis requires an index of oil contamination that varies within the oil-treatment group.

Ranking of Samples with Factor 3

We encourage future investigators to test our prediction of the rank order of oil contamination of herring eggs.

5. RECOMMENDATIONS

Reanalyse Data using Hydrocarbon Concentrations

As stated several times in this report, the major drawback of this study was our reliance on a simple presence/absence index of oil exposure. This was unavoidable because we had no other information at the time of writing this report. We are aware that samples of herring eggs were taken by ADF&G from the transects used in this study and frozen, and that these samples have been or will be analysed for hydrocarbon concentration. Therefore, we recommend that the data set presented in this report and in the accompanying appendices be reanalysed with the hydrocarbon concentrations whenever their measurement is completed. At the very least, the hydrocarbon concentrations should be compared with the values of factor 3 in order to test our predictions of the rank order of oil impact between samples and transects.

Replicate Egg Incubation Experiment in 1990

Some residual oil is still contained within the gravel of spawning beaches in Prince William Sound. It may affect the survival and viability of herring embryos spawned in the spring of 1990. Therefore, we recommend that the herring egg incubation experiment be replicated in 1990. We suggest that biochemical indices of growth and condition should be employed, as well as morphological indices, because biochemical indices have a clearly defined methodology, they are more precise in measurement, and they may lead to a more biologically meaningful assessment of the capacities of the larvae. Specifically, we recommend the use of RNA-DNA ratios of newly-hatched herring larvae as an index of their instantaneous growth rates. We strongly recommend the use of Clemmessen's (1988) method of measuring RNA and DNA concentrations because it is more accurate and more precise than all other methods previously reported in the scientific literature. McGurk et al. (1990) describe a comparison of methods for measuring nucleic acid concentrations that identifies Clemmessen's (1988) method as superior to all others. We also recommend the use of mixed-function oxygenase (MFO) enzymes as an index of exposure to hydrocarbons (Payne et al. 1987).

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EARLY LIFE HISTORY OF PACIFIC HERRING: 1989 PRINCE WILLIAM SOUND HERRING LARVAE SURVEY

by

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ABSTRACT

This study measured growth, mortality and dispersal of wild Pacific herring, Clupea harengus pallasi, larvae from two oiled sites and two non-oiled sites in Prince William Sound in order to determine the impact of the Exxon Valdez oil spill on larval population dynamics. Water temperatures and degree of stratification were highest in the two shallow control sites in the north of the Sound and lowest in the two oiled sites nearest Hinchinbrook Entrance. Concentration of prey of herring larvae increased over the May-June period and was not significantly different between sites. One major cohort and several minor cohorts of herring larvae were found at each of the four sites. No evidence was found to support the hypothesis that oil reduced growth rates or increased mortality rates of the larvae. Population growth rates measured from length frequency analysis ranged from 0.1 $mm \cdot d^{-1}$ in early May to 0.4 $mm \cdot d^{-1}$ in mid-June, and were highest in the two control sites and lowest in the two treatment sites. This was due to higher temperatures at the northern control sites, and not to any independent site effect. Recent growth rates measured by otolith ring widths rose from an average of 5.7%$\cdot d^{-1}$ in 10 d old larvae to 7.0%$\cdot d^{-1}$ in 30 d old larvae and then decreased to 5.6%$\cdot d^{-1}$ in 50 d old larvae; no differences were found between the four sites. Morphometric condition increased with age at a significantly slower rate at the Fairmount Island site than at the other three sites, but since it was a control site the cause was not related to oil. Mean RNA-DNA ratios of the larvae ranged from 4.65 at Rocky Bay to 6.39 at Tatitlek Narrows and did not vary significantly with site, date of capture or larval size and age. Mortality was highest at the Fairmount Bay control site, and lowest at the Rocky Bay treatment site. Transport of larvae away from the hatch site was greatest in the two southern treatment sites and least in the two northern control sites. This was most likely due to north-south transport of surface water in the Sound, and not to any oil-related factor. Comparison of densities of non-herring fish larvae between the four sites did not indicate any differences due to oil.

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*Appendices C–J are not included in this volume. Readers desiring these appendices may obtain them from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

1. INTRODUCTION

On March 24, 1989, the oil tanker Exxon Valdez struck Bligh Reef spilling 250,000 bbl of Prudhoe Bay oil into Prince William Sound, Alaska. Several weeks later, Triton Environmental Consultants Ltd. was hired by the U.S. National Oceanic and Atmospheric Administration (NOAA) to assess the impact of this spill on the growth and survival of Pacific herring, Clupea harengus pallasi, larvae hatching into the Sound. This is the final report of our investigations. It describes the population dynamics (growth, mortality and transport) of four cohorts of herring larvae that hatched into the Sound, and compares the dynamics between oil-contaminated and non-oil-contaminated sites. Appendices to this report are contained in a separate volume.

This study was planned in cooperation with the Alaska Department of Fish and Game (ADF&G) as one part of a seven part study of the impact of the oil spill on all life stages of herring in Prince William Sound. Commercial Fisheries Division of ADF&G is responsible for the first five components: (1) long term impacts on adult herring abundance; (2) impacts on adult herring growth and fecundity; (3) hydrocarbon content of adult herring tissues; (4) documentation of short-term adult herring mortality; and (5) field studies of herring egg survival. Triton is responsible for the last two tasks: (6) laboratory studies of herring egg and larval survival; and (7) field studies of herring larval growth, fitness and survival. Both studies (6) and (7) were administered under one contract. The results of the herring egg incubation experiment are described in a separate report (McGurk et. al. 1990).

2. STUDY SITES

The study was designed as a comparison between two oil-contaminated sites and two non-contaminated sites. Before proceeding further it is appropriate to define the labels we attach to the four sampling sites. At the time of writing we have no information on the concentrations of hydrocarbons that existed in the water column at the four plankton sampling stations in May-June 1989. Thus, we are forced to use a simple presence/absence index. This is complicated by the fact that most of the free-floating oil had left the Sound by April 4, almost one month before the start of hatching of herring eggs (Fig. 2). It is conceivable that few, if any, herring larvae were directly exposed to hydrocarbon concentrations above background levels.

However, to replace "oiled" with the more vague label "treatment" is equally misleading because it implies a uniform and known level of contamination. In this report we use the words "oiled" and "control" only because there are no better labels.

Selection of sites was based on a map of the 1989 herring spawn survey conducted by ADF&G, and on a map of the drift of oil produced by the Alaska Department of Environmental Conservation (ADEC). The spawn map showed that there were four major concentrations of spawning: the Northwest area centered on Tatitlek Narrows; the North area centered on Fairmount Bay; the Naked Island archipelago; and the northern tip of Montague Island. One minor concentration of spawn was observed in Sheep Bay. Fig. 1 shows the locations of spawn inside these five areas, the total length of spawn, and the range of spawning dates. Stars mark the locations of the plankton sampling stations.

The oil map, reproduced here as Fig. 2, showed that oil from Exxon Valdez drifted in a southeasterly direction from Bligh Reef through the Naked Island archipelago, down the west and east shores of Knight Island and out of the Sound through Montague Strait. Some oil drifted around the northern tip of Montague Island.

Therefore, the Northwest and North areas were chosen as control areas, and the Naked Island archipelago and the northern tip of Montague Island were treatment areas. The choice of sites within these areas was based on their proximity to beach transects from which herring eggs were removed for the herring egg incubation experiment, and on the depth of water. The sites had to be within 1 km of the beach transects in order to link the dynamics of the egg stage and the early yolk sac stage, as measured by the incubation experiment, with the dynamics of free-swimming herring larvae, as measured by the larval surveys. The water also had to be at least 30 m deep for the safe deployment of the bongo nets. Therefore, a site off the western shore of Fairmount Island ($60^{o}52.30$'N, $147^{o}28.80$'W) was chosen because it was relatively deep and close to the transects inside Fairmount Bay (Fig. 1). Similar reasons guided the choice of a site inside Bass Harbor at Naked Island ($60^{o}37.40$'N, $147^{o}24.50$'W) and a site inside Rocky Bay on Montague Island ($60^{o}21.25$'N, $147^{o}04.00$'W). No beach transects were placed in Tatitlek Narrows, so the choice of a site in the northern entrance, off Black Point ($60^{o}54.40$'N, $146^{o}45.00$'W), was based solely on depth concerns.

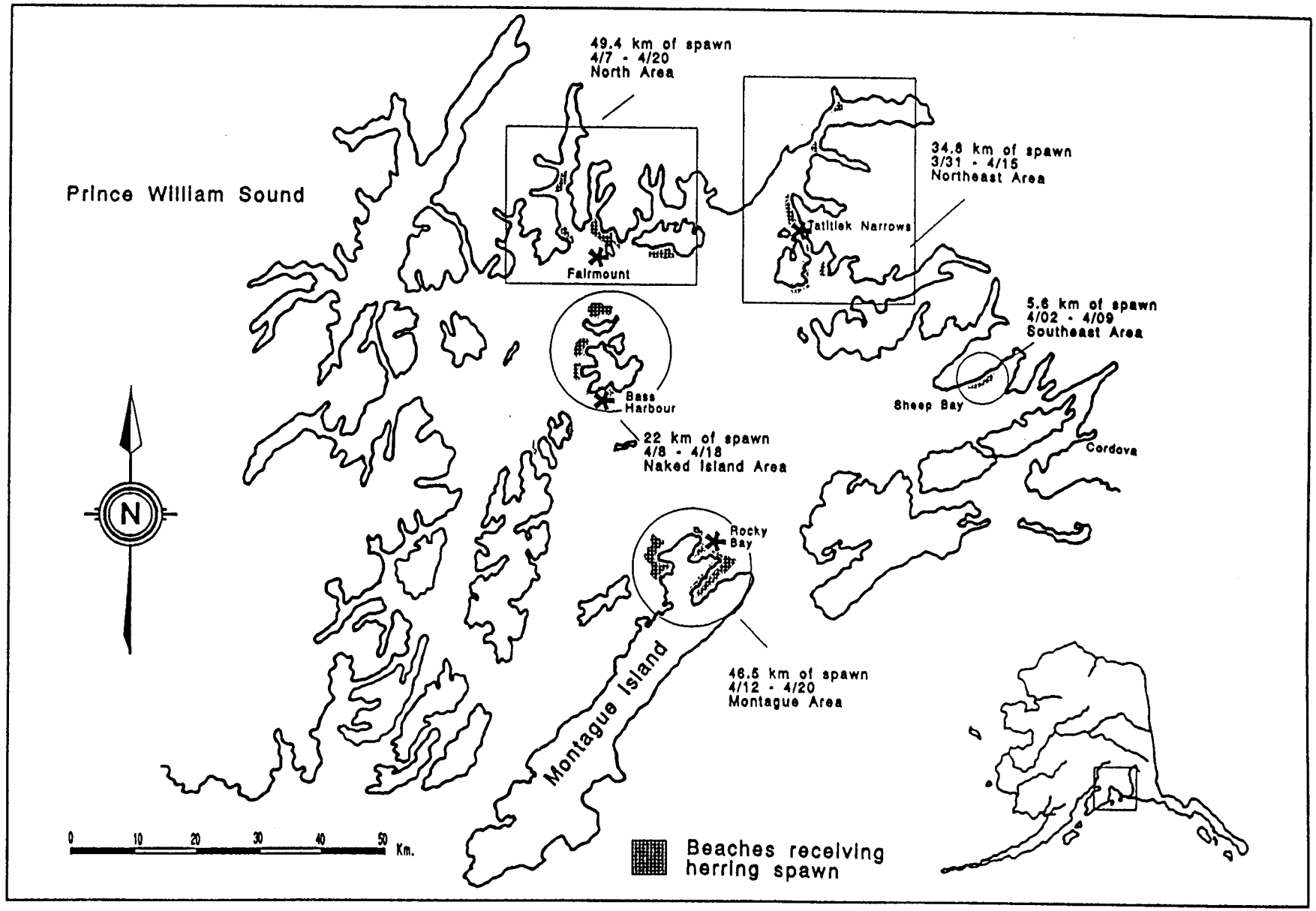

Figure 1. Map of Prince William Sound showing the locations of herring spawning in 1989, the total length of spawn and the range of spawning dates. Stars mark the locations of the four plankton sampling sites.

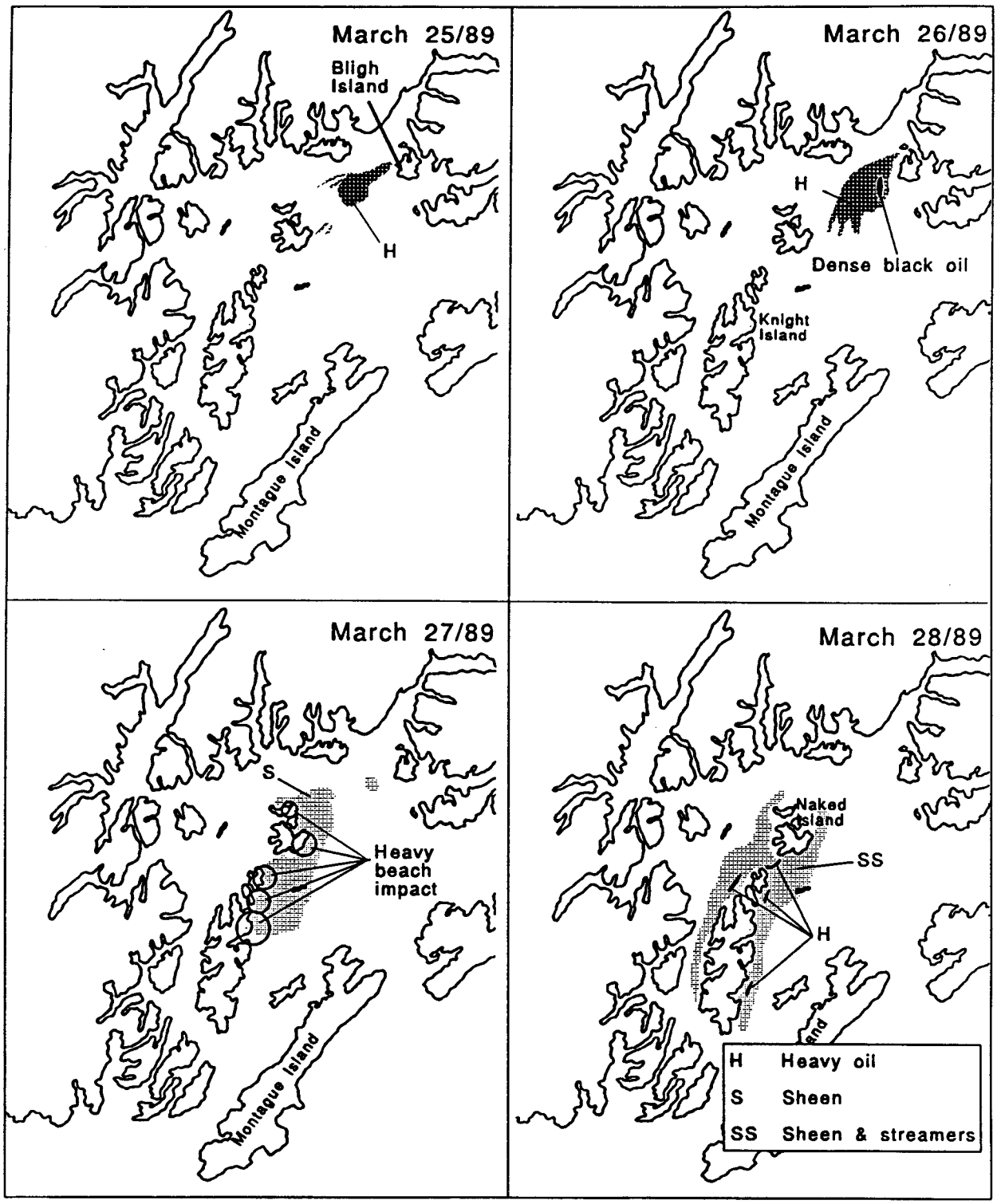

Figure 2. Seven maps of Prince William Sound showing the trajectory of oil spilled from the Exxon Valdez from March 25 to April 4, 1989.

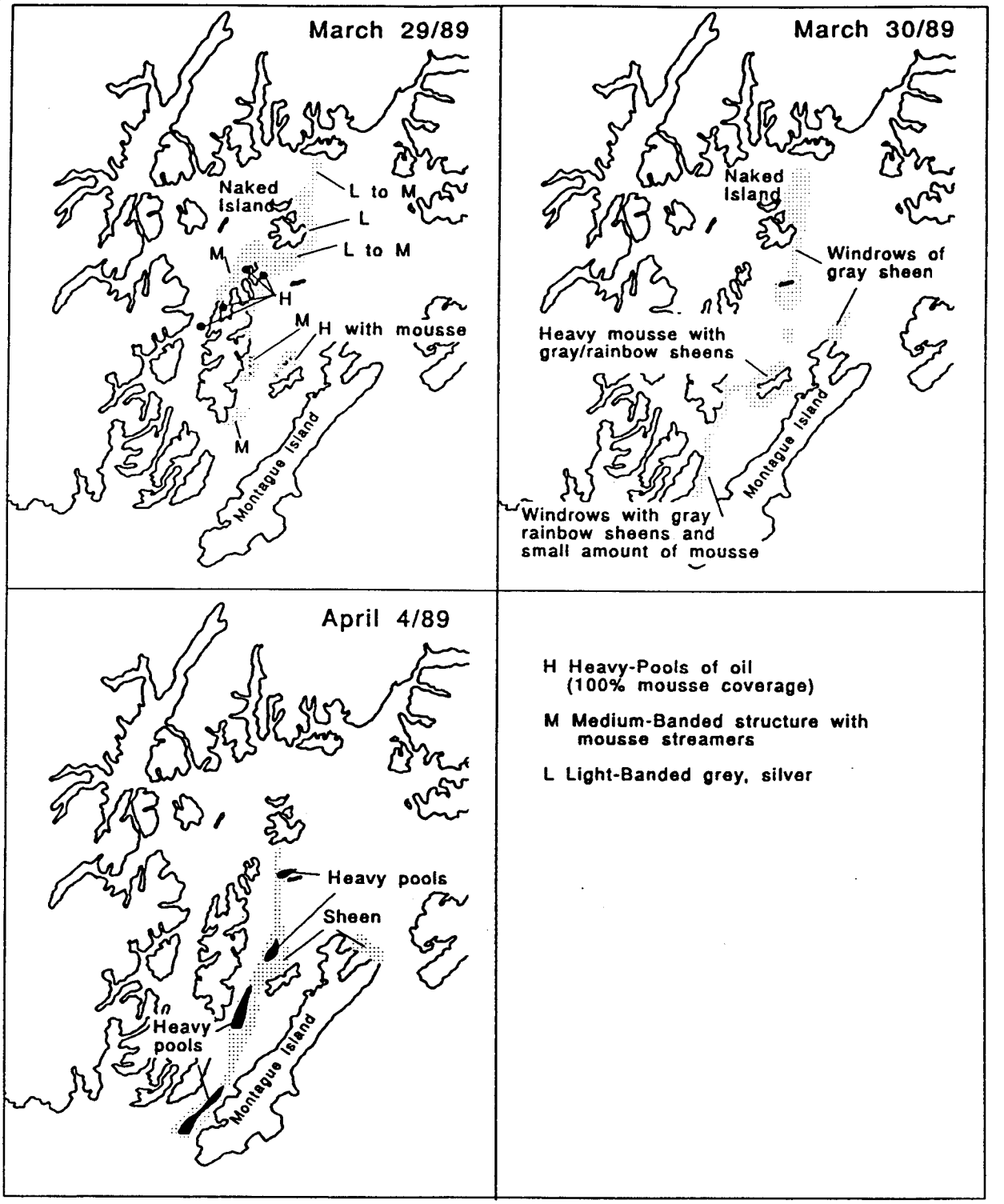

Figure 2. Seven maps of Prince William Sound showing the trajectory of oil spilled from the Exxon Valdez from March 25 to April 4, 1989.

3. MATERIALS AND METHODS

We conducted seven cruises of the Sound, one each week from May 1 to June 22, 1989. At each of the four sites, we collected samples of herring larvae for measurement of growth and condition and measured the density of herring larvae for estimation of mortality and transport. Auxillary information was also collected on the depth distribution of salinity and temperature, and on the densities of the zooplankton prey of herring larvae.

3.1 Plankton Sampling

The same sampling protocol was followed at each site. Temperature and salinity were measured at 2 m intervals from the surface to a depth of 30 m with a conductivity-temperature meter. These data are shown in Appendix D. Density of microzooplankton prey was measured by making four casts of a 30 L open-closing water bottle to 5, 10, 20 and 30 m, filtering the contents of the bottle through a 25 μm mesh bag and preserving the filtrates in 5% seawater formalin. The density of macrozooplankton was measured by towing a bongo net with a mouth diameter of 20 cm, a length of 1.5 m and a mesh size of 165 μm in a double oblique pattern from the surface to 30 m and back. The catch was preserved in 5% formalin. The volume of water filtered by all bongo nets was measured with a flowmeter placed off center in one of the two mouths.

Herring larvae were captured with double oblique tows to 30 m of a bongo net with a 60 cm mouth diameter, a length of 3 m and a mesh size of 333 or 505 μm. The 333 μm mesh was used to capture newly-hatched larvae and the 505 μm mesh was used to capture older, mid-size larvae. The contents of the first 60 cm tow were preserved in 5% formalin for enumeration and morphometry. The contents of the second tow were preserved in isopropyl alcohol (37% by volume diluted with freshwater) for subsequent extraction of the sagittal otoliths. Finally, up to three more tows of the 60 cm net were done in order to capture live herring for RNA-DNA analysis. The live larvae were picked from the fresh zooplankton within minutes of capture and placed in small plastic vials which were immediately sandwiched between large blocks of dry ice (frozen CO_2: melting point of -56^{o}C) in an insulated chest. After the end of each cruise, the frozen larvae were flown or driven to Anchorage where they were stored at -70^{o}C in the freezers of the U.S. Fish and Wildlife Service. After

the end of the field season the frozen larvae were flown in blocks of dry ice to Microtek Research and Development Ltd. (Sidney, B.C.) where they were stored at -70°C until analysed for RNA and DNA concentration.

3.2 Temperature and Salinity Contouring

In this report temperature and salinity are displayed in the form of depth-date contour plots in order to better show the timing of stratification and mixing events. The raw data used to produce these plots are contained in Appendix D. They were converted to contour plots using the computer program Surfer - version 4.0 produced by Golden Software, Inc., P. O. Box 281, Golden, Colorado. This program creates a regularly spaced grid using the inverse distance interpolation method:

$$(1)\quad Y = [\sum_{n} Y_i/(d_i)^2]/[\sum_{n} 1/(d_i)^2]$$

where Y = temperature or salinity at any intersection in the grid, Y_i = neighboring point, d_i = distance of the neighboring point, and n = the number of neighboring points. This equation weights data points such that their influence declines with the square of their distance.

3.3 Prey Concentration

All micro- and macrozooplankton samples were identified and enumerated by Moira Galbraith of Sy-Tech Research Ltd. (Sidney, B.C.). Samples were first washed through a 40 μm seive in order to remove formalin. Very few organisms other than diatoms passed through this seive. The sample was scanned for exotic taxa which, if present, were removed for closer study. Then, the sample was split to a size of approximately 250 individuals and all were identified and enumerated to genus, species, sex and developmental stage. Copepod nauplii and copepodites were separated into four length categories: <0.2 mm, 0.2-0.4 mm, 0.4-0.6 mm and >0.6 mm, before enumeration. Minimum and maximum lengths and widths were measured for each taxon. Densities were calculated by dividing numbers by the volume of water filtered by each cast or tow. These densities are tabulated in Appendix E.

Animals smaller than about 0.4 mm in minimum length were extruded through the meshes of the 165 μm net (M. Galbraith, Sy-Tech Research Ltd., pers. comm.). Therefore, the densities of all organisms smaller than 0.4 mm were taken from the microzooplankton samples collected by the water bottle, and the densities of all zooplankters larger than 0.4 mm were taken from the macrozooplankton samples collected by the 165 μm mesh net.

The list of organisms from both types of gear was first reduced by removing all organisms that are rarely eaten by herring larvae because they are too large to fit inside the mouth. Checkley's (1982) laboratory feeding experiments with Atlantic herring, Clupea harengus harengus, larvae showed that the maximum width of prey was 0.51 mm. McGurk's (1989b) review of the diet of Pacific herring larvae captured in the Strait of Georgia, showed that the maximum prey length was 1.4 mm. Other items were excluded on the basis that they have rarely ever been observed in the guts of wild herring larvae. This left a prey field consisting of microzooplankton: copepod nauplii, copepodites, bivalve veligers, gastropod veligers, trochophore larvae and small unidentified eggs; and macrozooplankton: 16 species of adult copepods, the cladoceran Evadne, and euphausiid nauplii.

A prey field was created from these remaining organisms using rules taken from McGurk (1989b):

maximum prey length = 0.050L - 0.095; and

minimum prey width = 0.019L - 0.060.

where L = length (mm) of herring larvae. Prey concentrations were calculated from prey densities using weight-length relationships taken from the scientific literature:

Copepods, cladocerans and euphausiid nauplii

Pearre (1980) reviewed weight-width relations of marine copepods to obtain

(2) $Y = 1.5598X^{2.9776}$

where Y = wet weight (mg) fixed in formalin and X = fixed width (mm). An 80% water content was assumed in order to convert wet fixed weight to dry fixed weight. In order to convert fixed dry weight to live dry weight, the percentage loss in dry weight was assumed to decrease with the length of an organism according to an equation proposd by Giguere et al. (1989)

(3) $Y = 63.37\exp(-0.576X^{0.333})$

where Y = percent dry weight loss and X = fixed length (mm).

Bivalve and gastropod veligers

From Holland and Spencer (1973) the weight-length relationship for oyster, Ostrea edulis, larvae is

(4) $Y = 0.59X^{3.6966}$

where Y = live dry weight (mg) and X = mean live length (mm). It was assumed that length of veligers was not substantially changed by fixation.

Eggs and trochophore larvae

Volume was obtained by the equation for an ellipsoid

(5) $$Y = \frac{4}{3}\pi\left(\frac{L}{2}\right)^2\left(\frac{W}{2}\right)$$

where Y = volume (mm^3), L = length (mm) of the longest axis, and W = width (mm) of the shortest axis. Wet weight was obtained by multiplying volume by a specific gravity of 1 $mg \cdot mm^{-3}$. Dry weight was obtained by assuming that 80% of the wet weight was water. These prey concentrations are shown in Appendix F.

3.4 Cohort Analysis

All fish larvae were picked from the 333 or 505 μm mesh plankton samples, except for several samples that contained so many larvae (>10,000) that they had to be

split before sorting, and several alcohol-preserved samples that were too poorly preserved to sort. All fish larvae were identified and counted and density was calculated as the number$\cdot m^{-3}$ of water filtered by a tow. It was corrected for net evasion using a procedure described in Appendix B. Densities of non-herring larvae fish larvae are tabulated in Appendix C.

One hundred herring larvae were randomly chosen from each formalin-preserved sample, the presence or absence of a yolk sac was recorded, and standard length (tip of snout to tip of notochord) was measured to the nearest 0.1 mm with an ocular micrometer. Length was corrected for pre-preservation shrinkage due to net capture using an equation described in McGurk (1985b). These data are shown in Appendix G.

Length frequency plots for each sample were used to identify the number of cohorts at each site and the mean length of each cohort at each site and date, and to assign each measured larva to a cohort. The length ranges of the cohorts did not usually overlap, but some judgement was necessary in ambiguous cases.

Five morphometric characters were measured from ten herring larvae from each formalin-preserved sample: length (L), anal body depth (ABD), pectoral body depth (PBD), head width (HW), and eye diameter (ED). Then each larvae was rinsed in freshwater, dried at $60^{o}C$ for 24 h, and weighed to the nearest 1 μg on an electrobalance. A condition factor

$$(6) \quad CF = 14.191 - 4.389\ln L + 2.184\ln ABD + 2.197\ln PBD - 12.331\ln W + 3.770\ln ED + 0.419\ln W$$

described by McGurk (1985a) was calculated from these measurements after they were corrected for shrinkage or expansion due to net capture with equations taken from McGurk (1985b). This factor classifies a herring larvae as feeding ($CF<0$) or starving ($CF>0$). It is only applicable to non-yolk sac larvae less than 20 mm long. This data is shown in Appendix H.

3.5 Otolith Radius and Ring Number

Approximately ten herring larvae were randomly chosen from each alcohol-preserved sample and the two sagittal otoliths were removed from each larva with fine probes. They were prepared for examination with techniques described by Neilson and Geen (1980) and McGurk (1984a). Otoliths were examined under 400-1000X using a video camera and monitor attached to a compound microscope. Otolith radius was always measured along the longest axis because herring otoliths become increasingly ovoid as they grow larger. The number of rings was counted and the width of each of the outer five rings was measured. This data is shown in Appendix I.

3.6 RNA-DNA Analysis

RNA and DNA concentrations are shown in Appendix J. Details of the techniques used to measure RNA and DNA concentrations of herring larvae are contained in Appendix A. The method described by Clemmessen (1988) was found to be more accurate and precise than the methods of Karsten and Wollenberger (1972, 1977) and Bentle et al. (1981). All concentrations of nucleic acids measured by other methods were corrected to those expected from Clemmessen's (1988) method for non yolk sac larvae.

4. RESULTS

4.1 Temperature and Salinity

The isopleths of temperature and salinity shown in Fig. 3 show that temperature was consistently higher in the two control sites than in the two oil treatment sites, that salinity followed the opposite pattern, and that stratification of the water column began earlier in the two control sites.

These trends demonstrate the strong influences of average water depth, and of the distance between the sites and the entrance to the Gulf of Alaska. Both control sites were shallower than the two treatment sites and so they warmed up faster. They were also closer to the northern shore of the Sound and farther from Hinchinbrook Entrance. The northern shore is covered with glaciers that pump freshwater into the

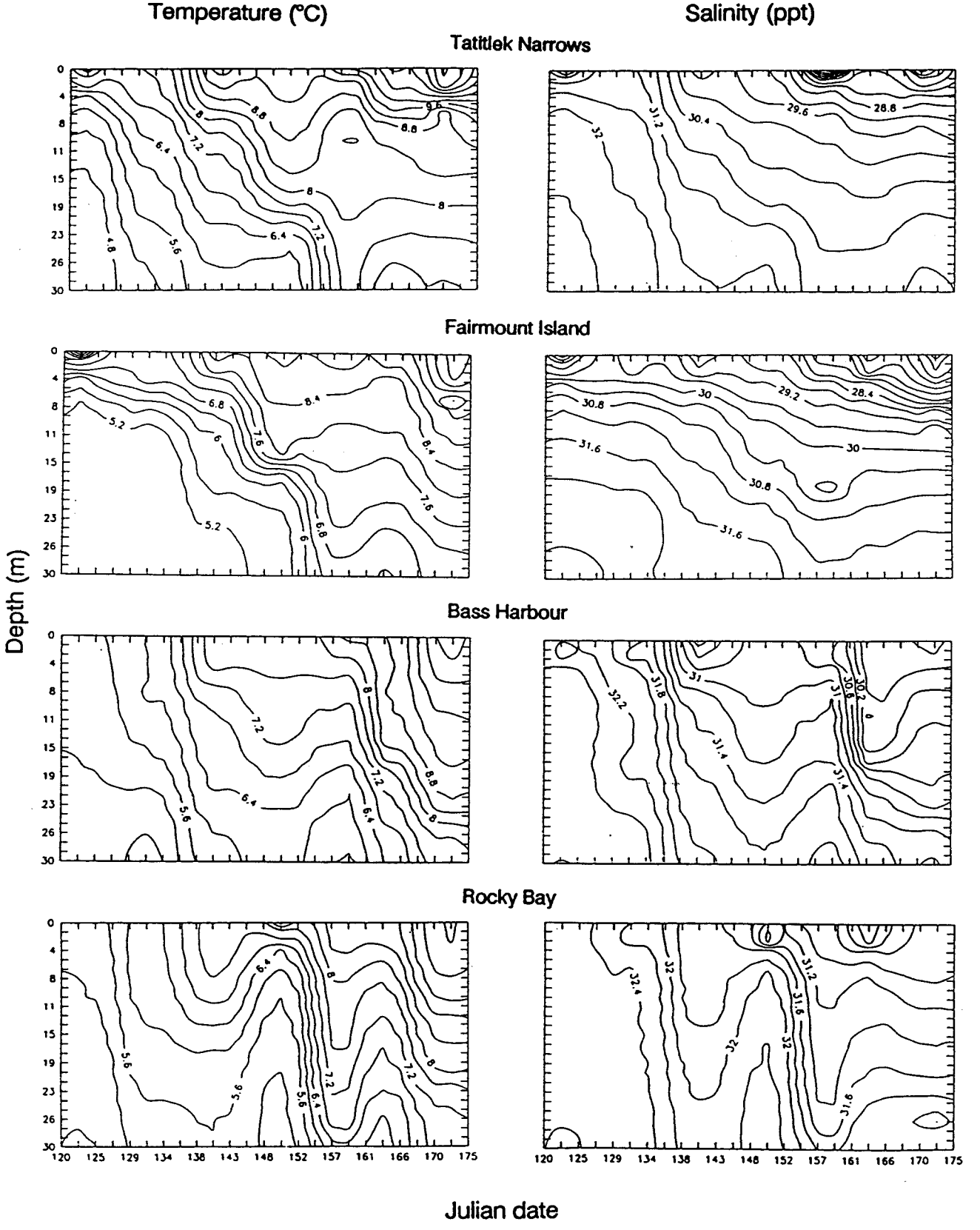

Figure 3. Contour plots of temperature and salinity at four sites in the sound. See text for details of their construction. Depth profiles of temperature and salinity are shown in Appendix D.

nearshore zone, but Hinchinbrook Entrance is the major site of entry for cold, high-salinity oceanic water from the Gulf of Alaska. Thus, the surface waters of the treatment sites are colder and more saline than those of the control sites.

Meunch and Schmidt (1975) and more recently Royer et al. (1990) have shown that the major inflow into Prince William Sound is through Hinchinbrook Entrance. At this channel the Alaska Coastal Current splits; a portion enters the Sound and the remainder proceeds westward along the southeastern shore of Montague Island. Within the Sound there is a cyclonic (counter-clockwise) circulation cell that is maintained by precipitation and runoff from the fjords along the rim of the Sound. In the northern Sound the flow is weak (< 10 cm·s^{-1}) and westward, ultimately flowing southwestward down either Knight Island passage or Montague Strait.

4.2 Prey Concentration

Relationships between prey concentration, date of capture, and site of capture were analysed by, first, creating eight weight classes with equal size on a logarithmic scale:

weight class (μg)	Contents
0.10 - 0.39	small bivalve and gastropod veligers
0.40 - 3.19	small copepod nauplii
3.20 - 6.39	trochophore larvae, mid-size copepod nauplii, juvenile copepods
6.40 - 12.79	large bivalve veligers and mid-size gastropod veligers
12.80 - 25.59	large copepod nauplii, small and mid-size copepodites, juvenile and adult copepods
25.60 - 51.19	large gastropod veligers, large copepoditeds, juvenile and adult copepods
51.20 - 102.39	cladocerans

Plankton biomass data is commonly ranked on a logarithmic scale for reasons of convenience in analysing the data, e.g. Sprules and Munawar (1986). Preliminary examination of the data showed that the distribution of mean concentration with weight had at least two modes and so it was not amenable to multiple regression

analysis, which requires smooth unidirectional changes in the response variable (Fig. 4). Therefore, a separate multiple regression was fit to each weight class. There were no significant ($P>0.05$) differences between sites in prey concentration in any weight class, but there were significant ($P = <0.0001\text{-}0.015$) positive increases in concentration with date in all weight classes except the two largest (Table 1). The fastest rates of increase were observed in the two smallest weight classes.

4.3 Number of Cohorts

The length frequency distributions of Fig. 5A-D show that one major and two minor cohorts of larvae hatched out at each of the four sites. Cohorts were numbered from 1 to 3 at each site depending on their estimated hatch dates; the earliest cohort was labelled number 1 and the latest cohort was labelled number 3. Some cohorts contained only one or two larvae. For example, cohort 1 of Fairmount Island (Fig. 5B) consisted of only one larvae captured on June 13, but this fish was much too large to be included in cohort 2, it was 9 mm longer than the next largest fish. Therefore, we assumed that it represented a very small cohort that hatched in mid- to late-April but was so small in number that it was sampled only once in seven cruises. The same reasoning applies to the two largest herring larvae captured at Rocky Bay on May 3 and May 12 (Fig. 5C); they were too large to belong to cohort 2 from this site so they were placed in their own cohort. Similarly, the two smallest larvae captured at Tatitlek Narrows on June 7 and June 12 were too small to belong to cohort 2 and so they were clasified as the sole representatives of a third cohort (Fig. 5D).

We assume that each of these 12 cohorts were separate entities and not mixtures of cohorts from other sites. We recognize that it is not possible to exclude mixing of cohorts because it is difficult to identify larvae from different areas by their mean length when these fish have hatched within one week of each other (Table 5). However, we believe it is a reasonable assumption because the catch curves shown in Fig. 15 do not exhibit the multiple modes that would be expected if cohorts mixed. Instead, the curves display a single mode (i.e. the dome of the catch curve) and the right-hand limbs of the curves display the steady decreases in density that are expected for single cohorts experiencing losses due to natural mortality and diffusion away from the centroid of distribution. This implies that the average rate of transport of larvae away from their hatch site and towards another sampling

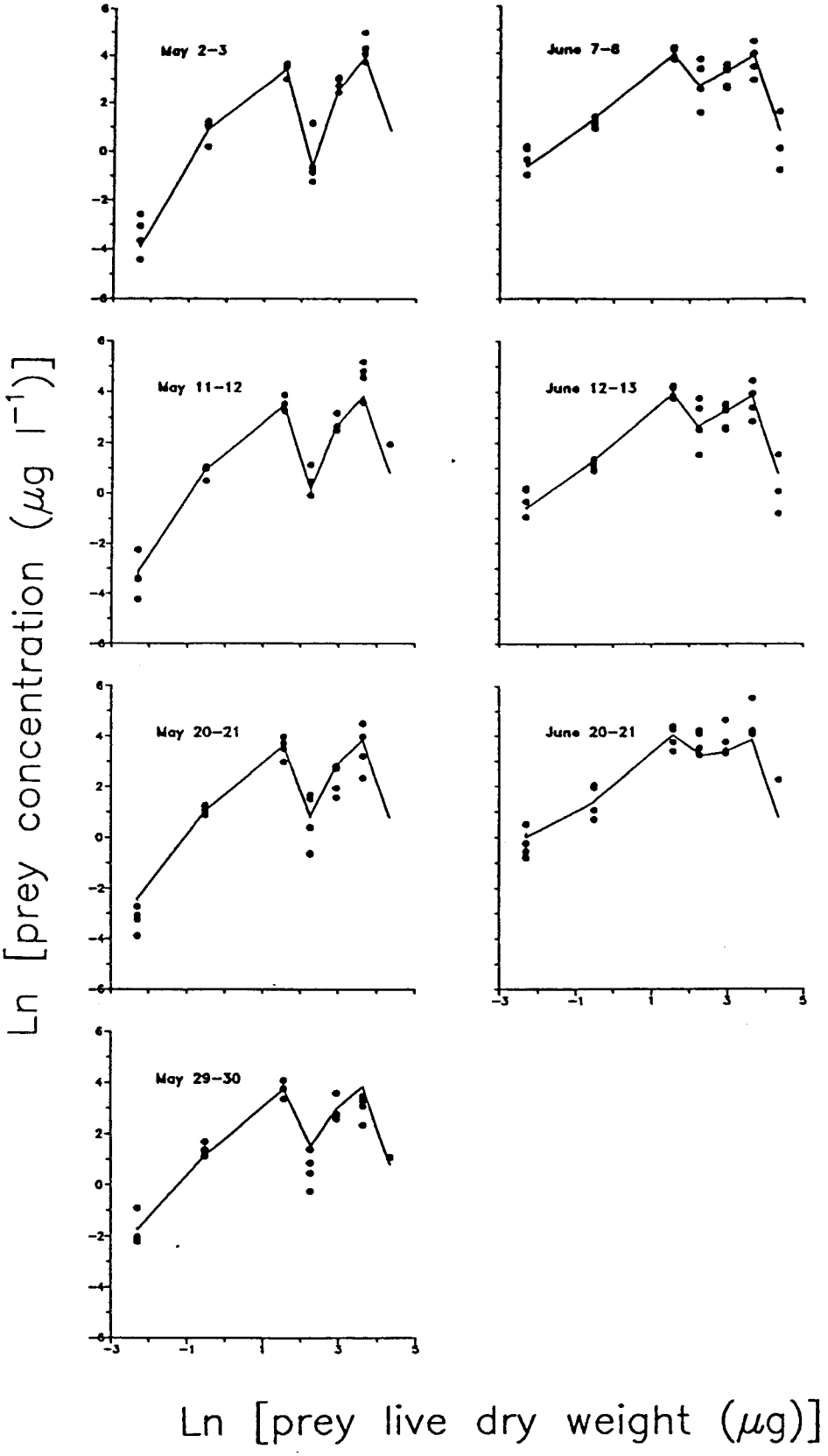

Figure 4. Observed (closed circles) and predicted (lines) concentrations of prey for herring larvae plotted against weight class and date of capture. See Table 1 for regression equations. There were no significant differences between sites in prey concentration.

Table 1.

Regressions of ln[prey concentration ($\mu g \cdot L^{-1}$)] on Julian date for five weight classes of prey of herring larvae. Regressions for the two largest weight classes, 38.4 and 76.8 μg, were not significant.

Midpoint of weight class (μg)	intercept	SE	slope	SE	r^2	P
0.1	-13.6858	1.3027	0.0801	0.0087	0.76	<0.0001
0.6	-0.4881	0.6314	0.0110	0.0042	0.18	<0.01
4.8	1.7079	0.5637	0.0136	0.038	0.31	<0.001
9.6	-10.2971	1.5376	0.0791	0.0103	0.68	<0.0001
19.2	0.2849	0.9011	0.0180	0.0060	0.22	<0.001

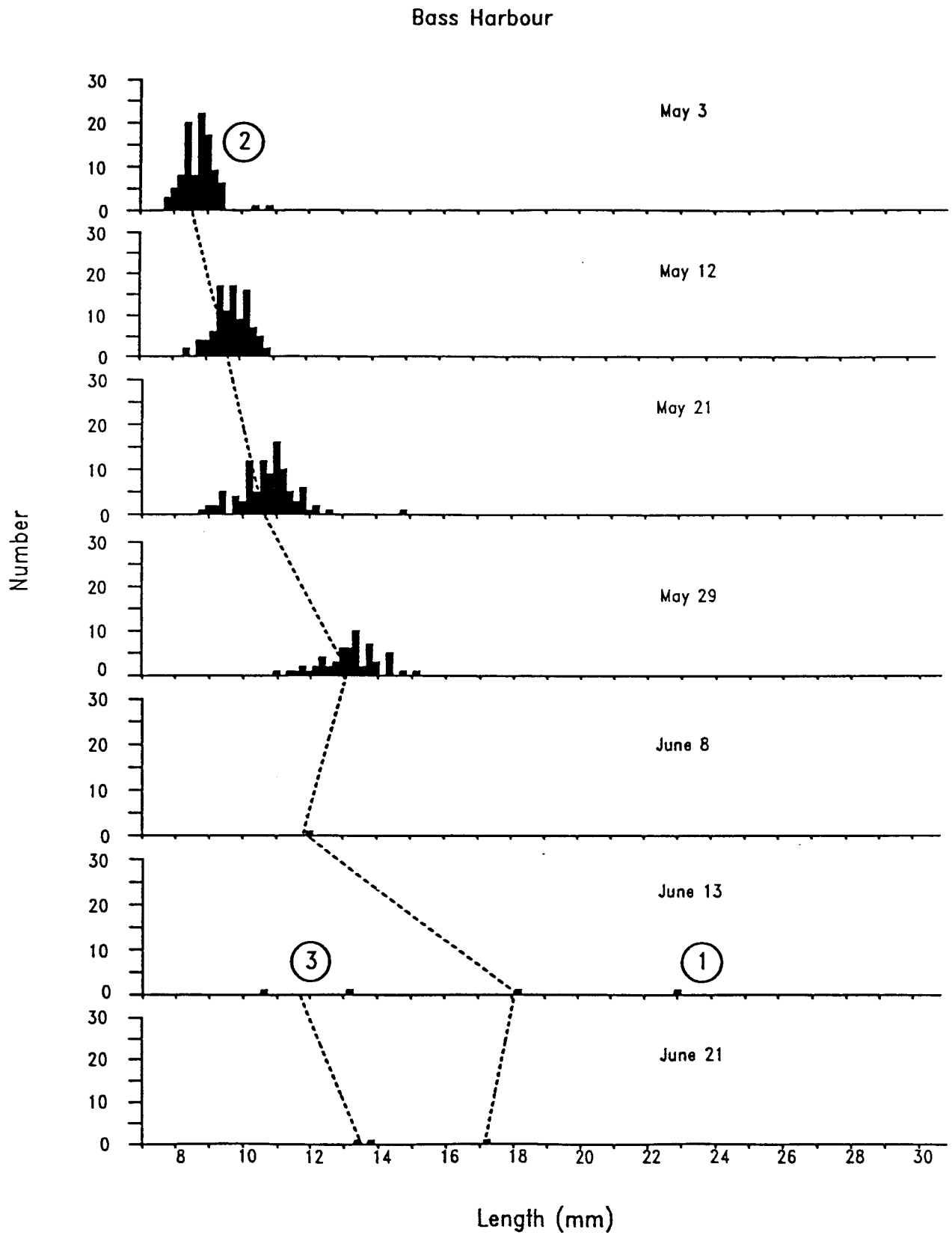

Figure 5A. Length frequency distributions at date for the 3 cohorts of herring larvae found at Bass Harbor. Each cohort is identified by a circled number and by a broken line connecting mean lengths at date.

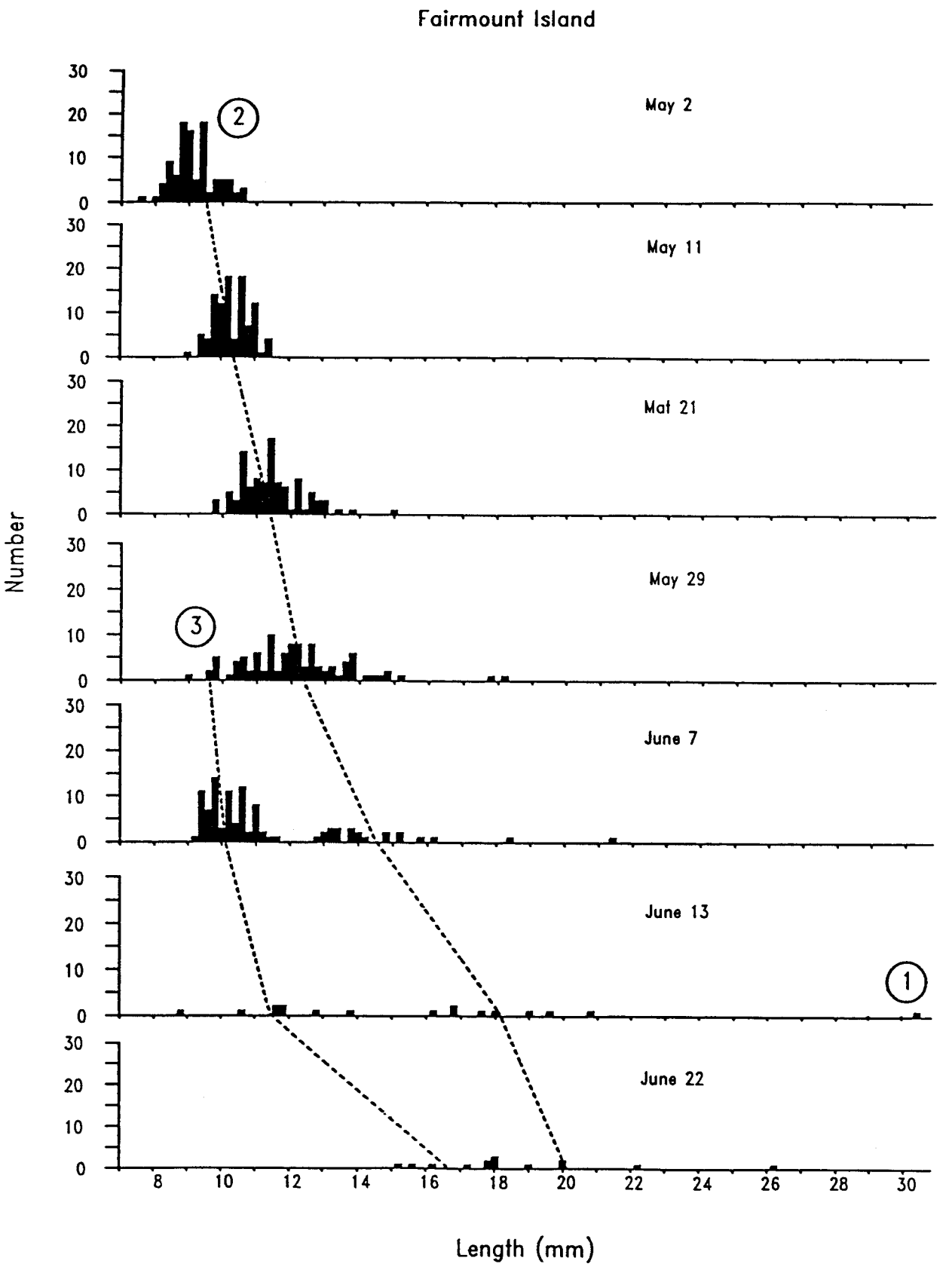

Figure 5B. Length frequency distributions at date for the 3 cohorts of herring larvae found at Fairmount Island. Each cohort is identified by a circled number and by a broken line connecting mean lengths at date.

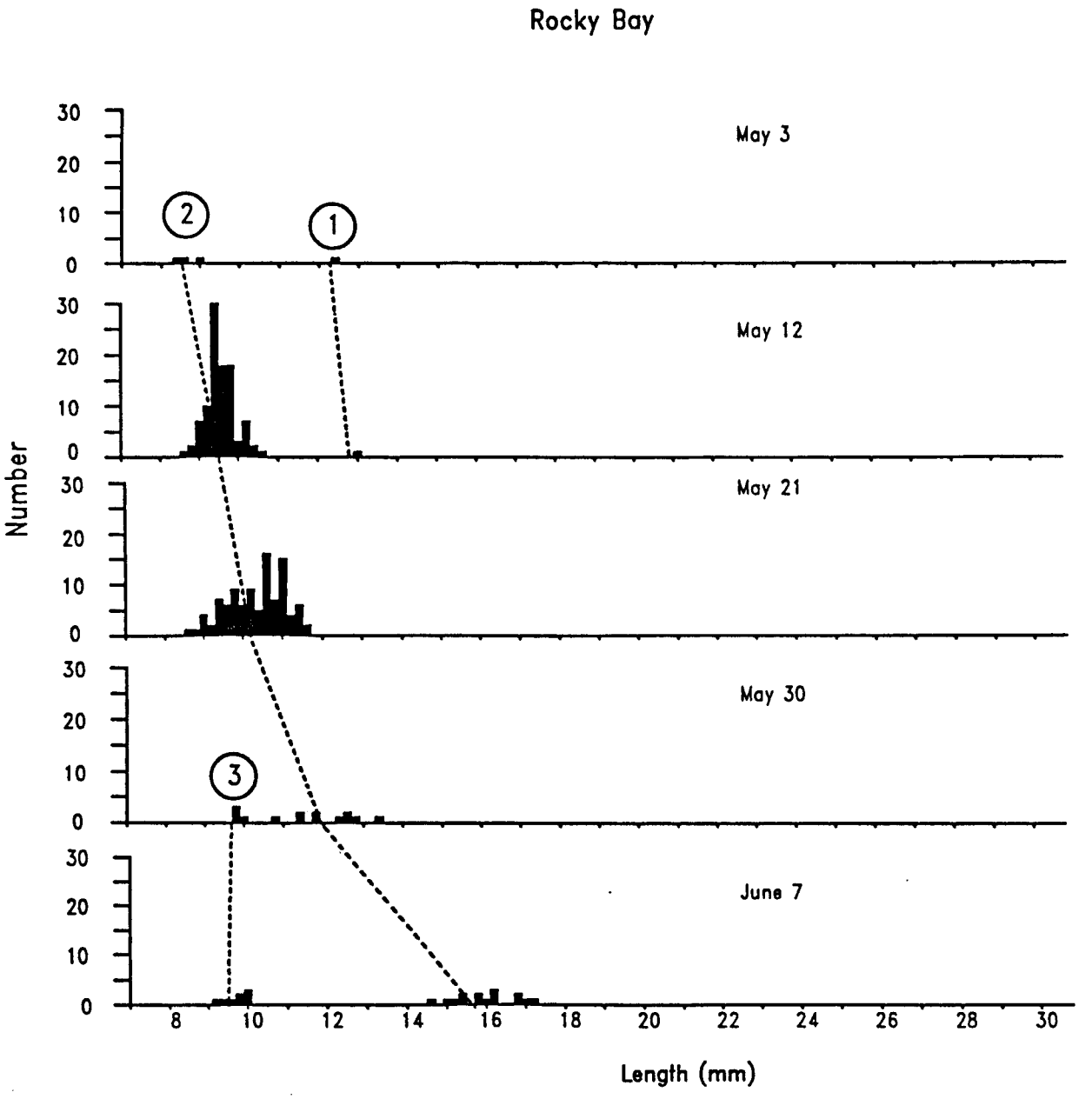

Figure 5C. Length frequency distributions at date for the 3 cohorts of herring larvae found at Rocky Bay. Each cohort is identified by a circled number and by a broken line connecting mean lengths at date.

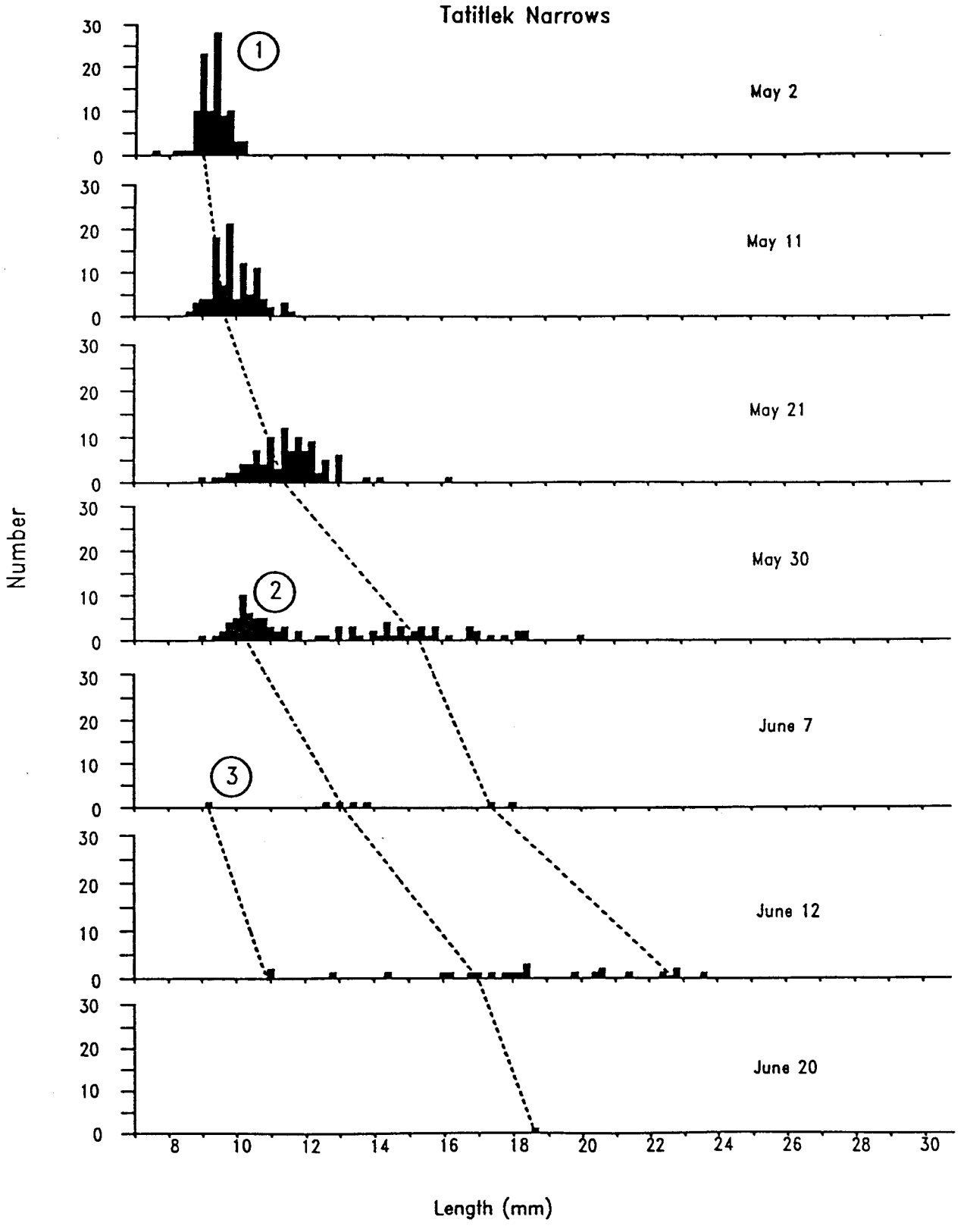

Figure 5D. Length frequency distributions at date for the 3 cohorts of herring larvae found at Tatitlek Narrows. Each cohort is identified by a circled number and by a broken line connecting mean lengths at date.

station must have been less than 30 km/50 d or 0.6 $km \cdot d^{-1}$ because the shortest straight-line distance between any two of the four stations was at least 30 km and they were sampled over a 50 d period. We have no direct estimates of transport rate (see section 4.8 for a discussion of this topic), but Fig. 15 shows that waves of newly-hatched larvae passed through the sampling stations 1-5 d after hatch. Since the stations were 1-5 km from the egg beds, the rate of transport was within the range 0.2-1.0 $km \cdot d^{-1}$, which supports our assumption that the cohorts did not substantially mix during the May-June period.

4.4 Age and Growth

Gompertz Growth Curves

Three independent methods were used to estimate the mean dates of hatching of these cohorts and so estimate the age of each larva. The first method was to back-calculate the date of hatching from a modified Gompertz growth curve fit to the lengths at date:

$$(7)\quad L_D = L_0 \exp\left[\frac{A_0}{a}\{1 - \exp[-a(D - D_0)]\}\right]$$

where L_D = length (mm) at Julian date D, L_0 = length (mm) at hatch, A0 = rate of growth ($mm \cdot d^{-1}$) at hatch, a = rate of change ($mm \cdot d^{-1}$) of A_0, and D_0 = Julian date of hatch. This growth model differs from the conventional Gompertz curve in the inclusion of D_0 and the fixing of L_0 at 8.8 mm. This was necessary because the age of larvae was known with less certainty than their length at hatching.

An estimate of L_0 was obtained by regressing mean length against the fraction of yolk sac larvae for all samples that contained yolk sac larvae. Fig. 6 shows that this regression was significant ($P<0.01$) and that it predicted a mean length of 8.8 mm at 100% yolk sac.

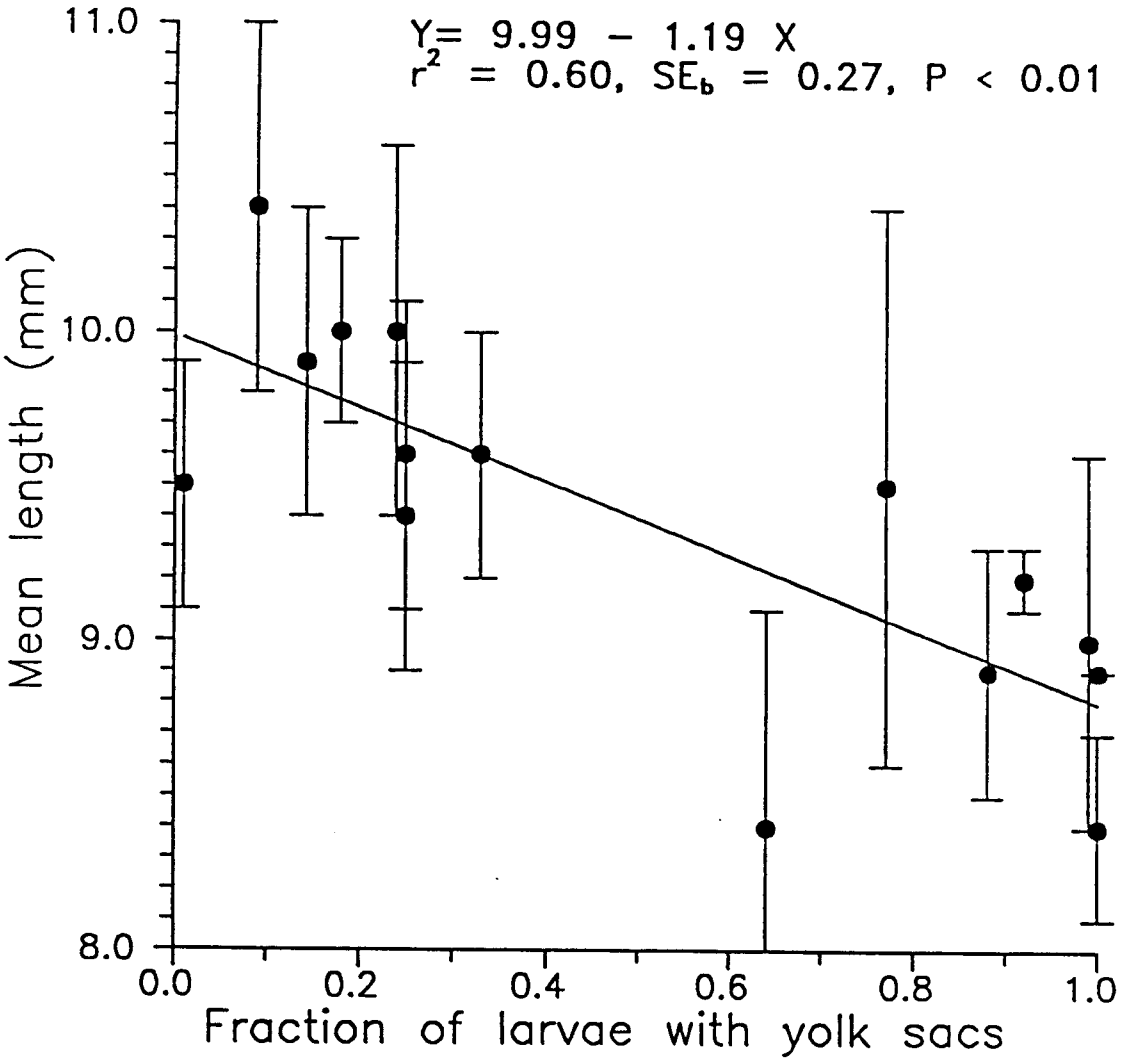

Figure 6. Regression of mean length of herring larvae on the fraction of larvae with yolk sacs. Vertical bars indicate 1 SD. The predicted length at 100% yolk sac, 8.8 mm, is the mean length at hatch.

The Gompertz models were fit by non-linear regression; parameters are reported in Table 2 only for those cohorts with sufficient sample size for a significant ($P<0.05$) regression.

Duration of Yolk Sac Stage

The second method of estimating hatch dates was based on the fact that the number of days from hatching to exhaustion of yolk in Pacific herring larvae decreases with temperature. Alderdice and Velsen (1971) reported times to yolk exhaustion for 12 combinations of salinity and temperature. Response surface analysis showed that the times were not significantly related to salinity, and that the best relationship with temperature was

$$(8) \quad Y = 40.9T^{-0.84}$$

where Y = time from hatching to yolk exhaustion (d) and T = temperature (^{o}C) (McGurk 1989c). Therefore, the average age of a sample containing at least one yolk sac larvae is

$$(9) \quad t = 40.9T^{-0.84}(1-f)$$

where t = age (d) of sample, T = mean temperature of the upper 30 m measured on the same date as the sample was collected, and f = fraction of yolk sac larvae in the sample. The average hatch date of a cohort is the mean of the Julian dates back-calculated from the mean ages weighted by the density of herring larvae measured on that date, i.e.

$$(10) \quad D_0 = [\sum_{i} N_i(D_i - t_i)]/(\sum_{i} N_i)$$

where N_i = density (m^{-3}) of herring larvae of sample i collected on Julian date D_i. The dates of hatching calculated by this method are shown in Table 3.

Table 2.

Parameters of Gompertz growth models for cohorts of herring larvae. D_0 is the Julian date of hatch. Brackets enclose one standard error of the parameters.

Site	Cohort	A_0 ($mm \cdot d^{-1}$)	a ($mm \cdot d^{-1}$)	D_0	r^2	n
Bass Harbor	2	0.01341 (0.00078)	-0.01491 (0.00321	127.1 (0.5)	0.80	362
Fairmount Island	2	0.00815 (0.00092)	-0.02234 (0.00273)	120.0 (1.4)	0.78	429
Fairmount Island	3	0.00233 (0.00515)	-0.10090 (0.02680)	140.0 (16.8)	0.84	101
Rocky Bay	2	0.00299 (0.00147)	-0.07560 (0.00752)	121.7 (4.2)	0.88	227
Tatitlek Narrows	1	0.01129 (0.00103)	-0.03096 (0.00309)	122.5 (0.9)	0.87	353
Tatitlek Narrows	2	0.05794 (0.01171)	0.04990 (0.02588)	147.5 (0.6)	0.88	68

Table 3.

Julian dates of hatch estimated from the fraction of yolk sac larvae and the mean water temperature.

Site	Cohort	Julian date of capture	Mean T (^{o}C)	fraction yolk sac	Age (d)	Julian date at hatch	Mean N_i (m^{-3})
Bass Harbor	2	123	5.2	0.64	3.7	119	1.307
		132	5.5	0.77	2.2	130	252.844
		141	6.7	0.09	7.5	133	1.878
					mean	130	
Fairmount Island	2	122	5.4	0.88	1.2	121	11.961
		132	5.5	0.24	7.4	125	737.344
					mean	125	
Fairmount Island	3	149	7.0	0.01	7.9	141	0.364
		158	7.7	0.14	6.3	152	2.017
					mean	150	
Rocky Bay	2	123	5.0	1.00	0.0	123	0.015
		132	5.9	0.92	0.7	131	275.270
		141	6.4	0.18	7.1	134	2.861
					mean	131	
Rocky Bay	3	150	5.7	0.25	7.1	143	0.013
		158	7.9	0.25	5.4	153	0.125
					mean	152	
Tatitlek Narrows	1	122	5.1	0.99	0.1	122	152.788
		131	6.1	0.33	6.0	125	237.799
					mean	124	
Tatitlek Narrows	3	158	8.2	1.00	0.0	158	

Date of Zero Otolith Rings

The third method of back-calculating hatch dates was based on the number of rings in the sagittal otoliths. The first step was to calculate for each cohort the Julian date on which the mean number of rings was zero. These dates were calculated from equation (12) of section 4.5. Since the first visible otolith ring is deposited after the exhaustion of the yolk (McGurk 1984a, Campana et al. 1987), the second step was to calculate the duration of the yolk sac stage from equation (9) and then subtract it from the date of zero ring number. These calculations are summarized in Table 4.

Examination of the hatch dates calculated from the three methods showed that the growth curve method tended to give low estimates, the yolk sac method gave consistently high estimates, and the estimates provided by the otolith method fell in between (Table 5). Since the three methods are independent of each other, their mean was chosen as the best estimate of hatch date. Based on these mean dates, the interval of time between cohorts ranged from 11 to 22 d, and decreased with Julian date and increasing water temperature. The mean interval was 18 (SD = 5, n = 4) d.

Growth from Mean Lengths at Age

Growth in length of cohorts were calculated from mean lengths at age, i.e.

$$(11) \quad G = (L_2 - L_1)/(t_2 - t_1)$$

where G = growth rate ($mm \cdot d^{-1}$) and L_1 and L_2 are mean lengths at two successive ages t_1 and t_2, respectively. Growth rates rose from approximately 0.1 $mm \cdot d^{-1}$ in early and mid-May to 0.4 $mm \cdot d^{-1}$ in June (Table 6). The increase was caused by an increase in mean water temperature over the May-June period. Fig. 7 plots the growth rates from Table 6 against the mean water temperature between dates. All negative values of G and one value greater than 1.0 $mm\ d^{-1}$ were excluded from this plot. A regression of lnG on ln(temperature) was highly significant and explained 1% more variance than a regression of lnG on temperature. Covariance analysis indicated that there were no significant ($P > 0.05$) differences between sites in the growth-temperature relationship.

Table 4.

Julian dates of hatch calculated from the dates of zero rings in the sagittal otoliths and the duration of the yolk sac stage.

Site	Cohort	Julian date of zero ring no.	Mean T (^{o}C)	Duration of yolk sac stage (d)	Julian date of hatch
Bass Harbor	2	132.0	5.5	9.8	122.2
Fairmount Island	2	134.8	5.5	9.7	125.1
	3	152.6	7.7	7.3	145.3
Rocky Bay	2	138.2	6.1	8.9	129.3
	3	152.6	6.8	8.1	144.5
Tatitlek Narrows	1	131.2	6.7	8.2	123.0
	2	141.5	7.6	7.4	134.1
	3	152.6	8.0	7.1	145.5

Table 5.

Mean Julian dates of hatch estimated from three different methods.

Cohort	Ageing method	Bass Harbor	Fairmount Island	Rocky Bay	Tatitlek Narrows
1	growth curve	-	-	-	122
	fraction yolk sac	-	-	-	124
	otolith ring no.	-	-	-	123
	mean	-	-	-	123
2	growth curve	127	120	122	147
	fraction yolk sac	130	125	131	-
	otolith ring no.	122	125	129	134
	mean	126	123	127	140
3	growth curve	-	140	-	-
	fraction yolk sac	-	150	152	158
	otolith ring no.	-	145	144	145
	mean	-	145	148	151
	cohort interval (d)		22	21	11-17

Notes:

1. Dashes indicate no data available.

Table 6. Population growth in length.

Date	Site	Mean temp (oC)	Cohort 1 age (d)	Cohort 1 length (mm) mean	Cohort 1 length (mm) SD	Cohort 1 length (mm) n	Cohort 1 growth rate (mmd^-1)	Cohort 2 age (d)	Cohort 2 length (mm) mean	Cohort 2 length (mm) SD	Cohort 2 length (mm) n	Cohort 2 growth rate (mmd^-1)	Cohort 3 age (d)	Cohort 3 length (mm) mean	Cohort 3 length (mm) SD	Cohort 3 length (mm) n	Cohort 3 growth rate (mmd^-1)
3-May-89	Bass Harbour	5.2	-	-	-	-	-	-3	8.4	0.5	100	-		-	-	-	-
12-May-89	Bass Harbour	5.5	-	-	-	-	-	6	9.5	0.5	100	0.12		-	-	-	-
21-May-89	Bass Harbour	6.7	-	-	-	-	-	15	10.4	0.9	100	0.10		-	-	-	-
29-May-89	Bass Harbour	7.0	-	-	-	-	-	23	12.9	0.8	58	0.31	-2	-	-	-	-
8-Jun-89	Bass Harbour	6.7	-	-	-	-	-	33	11.7	-	1	-0.12	8	-	-	-	-
13-Jun-89	Bass Harbour	7.9	-	-	-	-	-	38	20.3	3.4	2	1.72	13	11.6	1.8	2	-
21-Jun-89	Bass Harbour	9.2	-	-	-	-	-	46	16.9	-	1	-0.43	21	13.3	0.2	2	0.21
2-May-89	Fairmount Island	5.4		-	-	-	-	-1	8.9	0.6	100	-	-	-	-	-	-
12-May-89	Fairmount Island	5.5		-	-	-	-	9	10.0	0.5	100	0.11	-	-	-	-	-
21-May-89	Fairmount Island	6.1		-	-	-	-	18	11.1	0.9	100	0.12	-4	-	-	-	-
29-May-89	Fairmount Island	7.0		-	-	-	-	26	12.0	1.4	90	0.11	4	9.5	0.4	10	-
7-Jun-89	Fairmount Island	7.7		-	-	-	-	35	14.2	2.0	23	0.24	13	9.9	0.6	77	0.04
13-Jun-89	Fairmount Island	7.5		30.0	-	1	-	41	17.8	1.6	8	0.60	19	11.3	1.5	8	0.23
22-Jun-89	Fairmount Island	8.6		-	-	-	-	50	19.8	2.8	8	0.22	28	16.4	1.1	6	0.57
3-May-89	Rocky Bay	5.0		12.1	-	1	-	-4	8.4	0.3	3	-	-	-	-	-	-
12-May-89	Rocky Bay	5.9		12.6	-	1	0.06	5	9.2	0.4	99	0.09	-	-	-	-	-
21-May-89	Rocky Bay	6.4		-	-	-	-	14	10.0	0.7	100	0.09	-9	-	-	-	-
30-May-89	Rocky Bay	5.7		-	-	-	-	23	11.8	0.8	10	0.20	2	9.6	0.1	4	-
7-Jun-89	Rocky Bay	7.9		-	-	-	-	31	15.7	0.8	15	0.49	10	9.4	0.3	8	-0.02
2-May-89	Tatitlek Narrows	5.1	-1	9.0	0.4	100	-	-	-	-	-	-	-	-	-	-	-

Table 6. Population growth in length. (Continued)

			Cohort 1					Cohort 2					Cohort 3				
				length (mm)					length (mm)					length (mm)			
Date	Site	Mean temp (oC)	age (d)	mean	SD	n	growth rate (mmd^-1)	age (d)	mean	SD	n	growth rate (mmd^-1)	age (d)	mean	SD	n	growth rate (mmd^-1)
11-May-89	Tatitlek Narrows	6.1	8	9.6	0.6	100	0.07	-	-	-	-	-	-	-	-	-	-
20-May-89	Tatitlek Narrows	7.3	17	11.2	1.0	100	0.18	0	-	-	-	-	-	-	-	-	-
30-May-89	Tatitlek Narrows	7.8	27	15.1	1.8	43	0.39	10	10.1	0.6	49	-	-1	-	-	-	-
7-Jun-89	Tatitlek Narrows	8.2	35	17.4	0.4	2	0.29	18	12.9	0.6	4	0.35	7	8.9	-	1	-
12-Jun-89	Tatitlek Narrows	8.5	40	21.6	1.2	8	0.84	23	16.8	1.8	14	0.78	12	10.7	0.0	2	0.36
20-Jun-89	Tatitlek Narrows	8.7	48	-	-	-	-	31	18.3	-	1	0.19	20	-	-	-	-

Notes:

1. growth rate = (L2 - L1)/(t2 - t1).

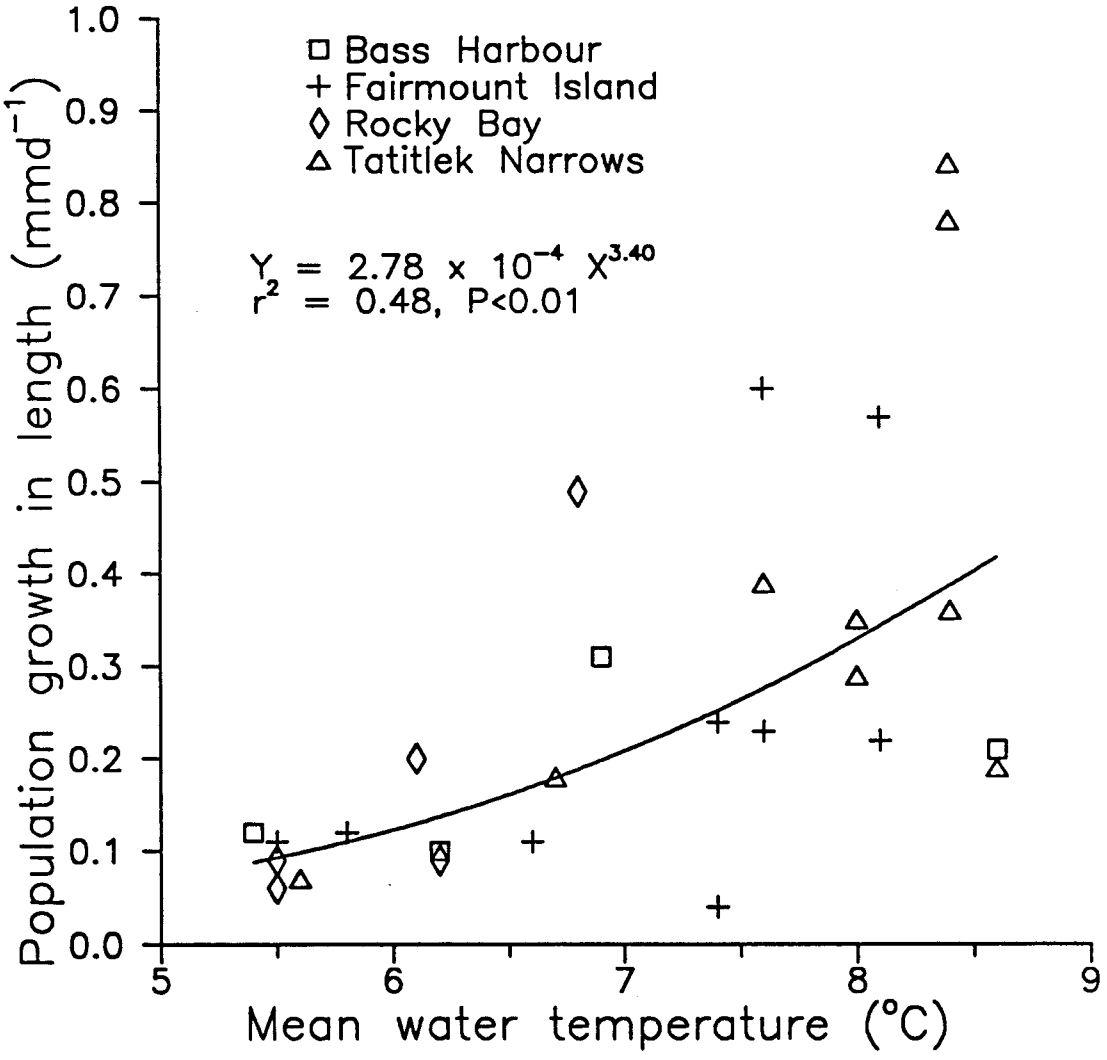

Figure 7. Regression of population growth rates on mean water temperature for the four sites. No differences in growth rate were found between sites.

4.5 Otolith Analysis

Fish Length-Otolith Radius Relationship

Recent growth rates of individual larvae were calculated from the average width of the outer five rings of the sagittal otolith. The first step in converting ring width to growth rate was to calculate a regression between fish length and otolith radius. Radius was first linearized by ln-transformation. Then multiple regression with dummy variables was used to determine if either the intercept or slope of the relationship was significantly different between cohorts or sites. Analysis on a cohort basis was first attempted, but failed because there were not enough larvae to give the degrees of freedom necessary to allow the inclusion of one dummy variable for each of the eight cohorts plus an interaction of the dummy variable and ln(radius). Therefore, the analysis was restricted to a site basis with one dummy variable and one interaction term for each of the four sites. The final regression model was:

$$(12)\quad L = -4.9621 + 6.2217\ln R + 0.9337 g_4$$
$$(SE)\quad (0.9526)\qquad (0.3115)\qquad (0.3354)$$
$$r^2 = 0.84,\ n = 84,\ P < 0.001$$

where L = fish length (mm), R = radius (μm) of otolith, and g_4 = dummy variable with a value of 1 for Tatitlek Narrows fish and 0 for the other three sites.

The model shows that the rate of increase of otolith radius with fish length was the same in all larvae, but that herring larvae from Tatitlek Narrows had significantly smaller otoliths at any length than larvae from the other three sites (Fig. 8). This finding indicates that herring larvae from Tatitlek Narrows had higher average growth rates than fish from the other three sites. Reznick et al. (1989) and Secor and Dean (1989) recently reported that fast growing guppies, Poecilia reticulata, and striped bass, Morone saxitilis, respectively, have smaller otoliths than slower growing fish of the same size.

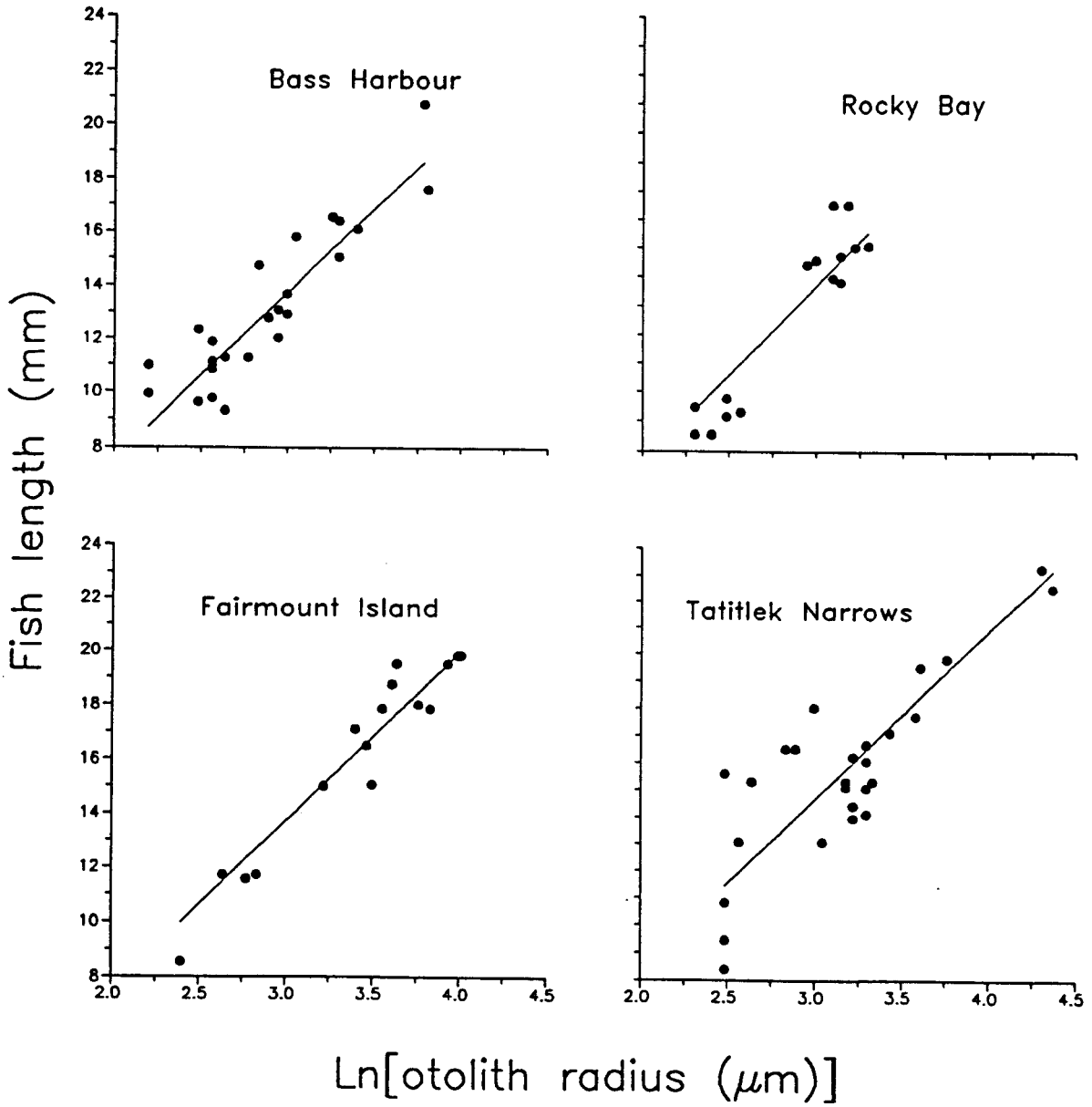

Figure 8. Regression of fish length on ln(otolith radius) for herring larvae from four sites. See text and equation (12) for detail. Larvae from Tatitlek Narrows had significantly smaller otoliths at any length than larvae from other sites.

Equation (12) was used to convert an increment in otolith radius, in this case the average width of one otolith ring, to an increment in fish length, i.e.

(13) $L_2 - L_1 = 6.2217\ln(R_2/R_1)$

where L_1 = length (mm) before deposition of a ring, L_2 = length (mm) after deposition of that ring, R_1 = otolith radius (μm) before deposition, and R_2 = otolith radius (μm) after deposition. This increment in length was converted to an increment in dry weight using a weight-length regression described in section 4.6.

Otolith Ring Deposition Rate

The second step in converting ring width to growth rate was to estimate the average time required to deposit one ring. This was done with a covariance analysis of the ring number-Julian date relationship. One dummy variable and its corresponding interaction term was inserted for each of the eight cohorts that had otolith ring number data. Each dummy variable had a value of 1 for its cohort and 0 for all other cohorts. The dummy variables were

Site	Cohort	Variable
Bass Harbor	2	x_1
Fairmount Island	2	x_2
Fairmount Island	3	x_3
Rocky Bay	2	x_4
Rocky Bay	3	x_5
Tatitlek Narrows	1	x_6
Tatitlek Narrows	2	x_7
Tatitlek Narrows	3	x_8

The multiple regression model that explained the most variance ($r^2 = 0.81$, n = 84) in the ring data with all significant ($P<0.0001$) coefficients was

(14)

variable	coefficient	SE
intercept	-142.7	12.2
Julian date	0.9347	0.0756
x_1	19.25	2.00
x_2	16.67	2.11
x_4	13.46	2.08
x_6 x Julian date	0.1530	0.0124
x_7 x Julian date	0.0736	0.0170

The fit of the model to the data is shown in Fig. 9.

The model shows that the rate of ring deposition was a constant 0.93 rings·d^{-1} for all fish except cohorts 1 and 2 from Tatitlek Narrows; they had significantly higher deposition rates: 1.09 and 1.01 rings·d^{-1}, respectively. This result supports the conclusions derived from the analysis of the fish length-otolith radius relationship; growth of herring larvae was faster in fish from Tatitlek Narrows than in fish from the other three sites.

Recent Growth Rates

The third step was to calculate recent growth rates as

(15) $G_w = (1/t_i)\ln(W_2/W_1)$

where G_w = recent growth rate (%·d^{-1}), t_i = the time (d) required to deposit one ring in cohort i, W_2 = dry weight (μg) of larvae after deposition of one ring and W_1 = dry weight (μg) before deposition. Multiple regression analysis was used to test the hypothesis that G_w was significantly different between sites due to a non-environmental, i.e. oil-related, cause. G_w was regressed on age of fish larvae, mean water temperature of the upper 30 m, prey concentration, four dummy variables corresponding to the four sites, and the interactions of these variables. The model that explained the most variance with all significant ($P<0.001$) coefficients was

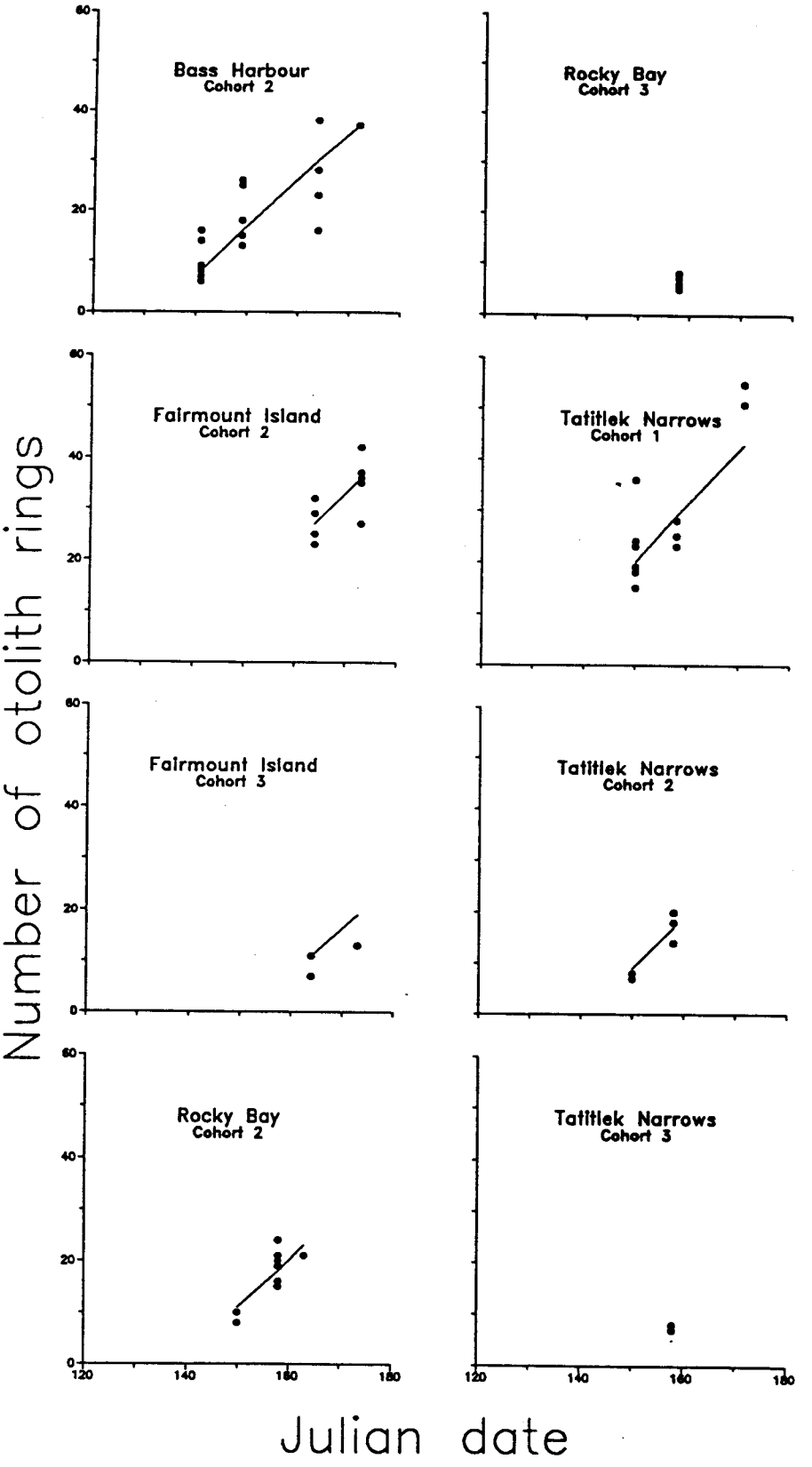

Figure 9. Observed (closed circles) and predicted (lines) number of otolith rings against Julian date for eight cohorts of herring larvae. The rates of ring deposition for cohorts 1 and 2 from Tatitlek Narrows were both significantly higher than the rates for the other six cohorts.

(16) $G_W = 4.6108 + 0.1281t - 4.4x10^{-5}t^3$

(SE) (0.5802) (0.0320) ($1.1x10^{-5}$)

$r^2 = 0.16, n = 82$

where t = age (d) of larvae (Fig. 10). This result is not unexpected; dome-shaped relationships between G_W and age of herring larve have previously been reported by Oiestad (1983) and McGurk (1989b). The model shows that there were no significant effects of environmental factors or of site (i.e. oil) on recent growth rate.

4.6 Morphometry

Weight-Length Relationship

A logistic model best described the relationship between dry weight and length of all herring larvae (Fig. 11). The model was fit to the ln-transformed weight and length with non-linear regression.

Morphometric Condition

The mean CFs for the four sites ranged from 0.357 to 0.995 and none were significantly ($P>0.05$) different from each other or from zero. The mean CF for the pooled data was 0.717 (SD=1.300, n=200), which was also not significantly ($P>0.05$) different from zero.

The distribution of larvae with morphometric condition shows that the slope of the right-hand limb of the catch curve was much steeper than the slope of the left-hand limb, indicating a rapid loss of poorly-conditioned fish from the populations (Fig. 12). Presumably, larvae with condition greater than about 4.25 were not available to the towed plankton nets because they were either dead from starvation or predation or because they had lost osmotic control and had fallen out of the water column. The single larva with a CF value of 5.25 may have been an artifact. This feature of Fig. 12 means that the equivalent number of days of starvation can be estimated from the morphometric condition factor by assuming direct proportionality, i.e.

(17) $n_S = (n_{S,max}/CF_{max})CF, CF \geq 0$

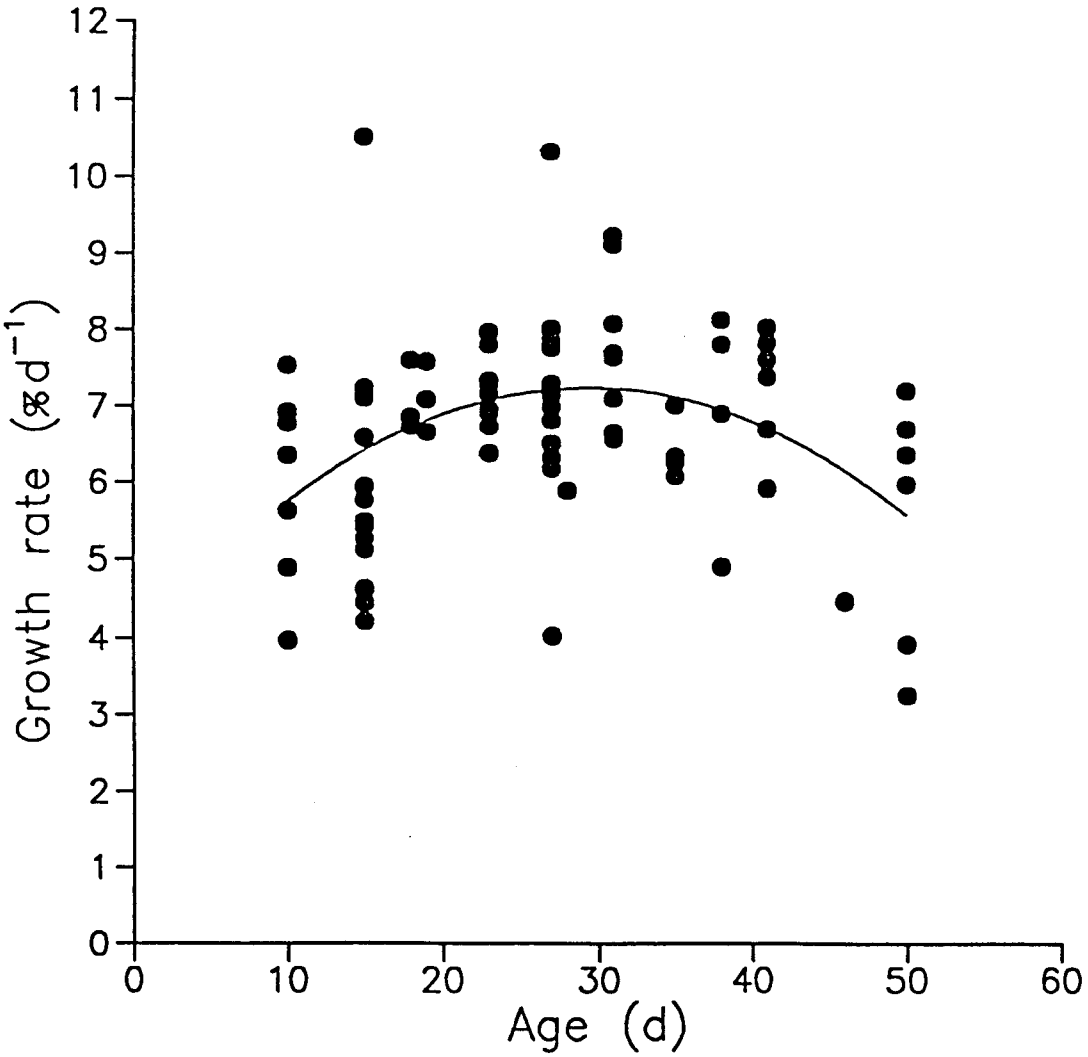

Figure 10. Regression of recent growth rate on age for all herring larvae. See text and equation (16).

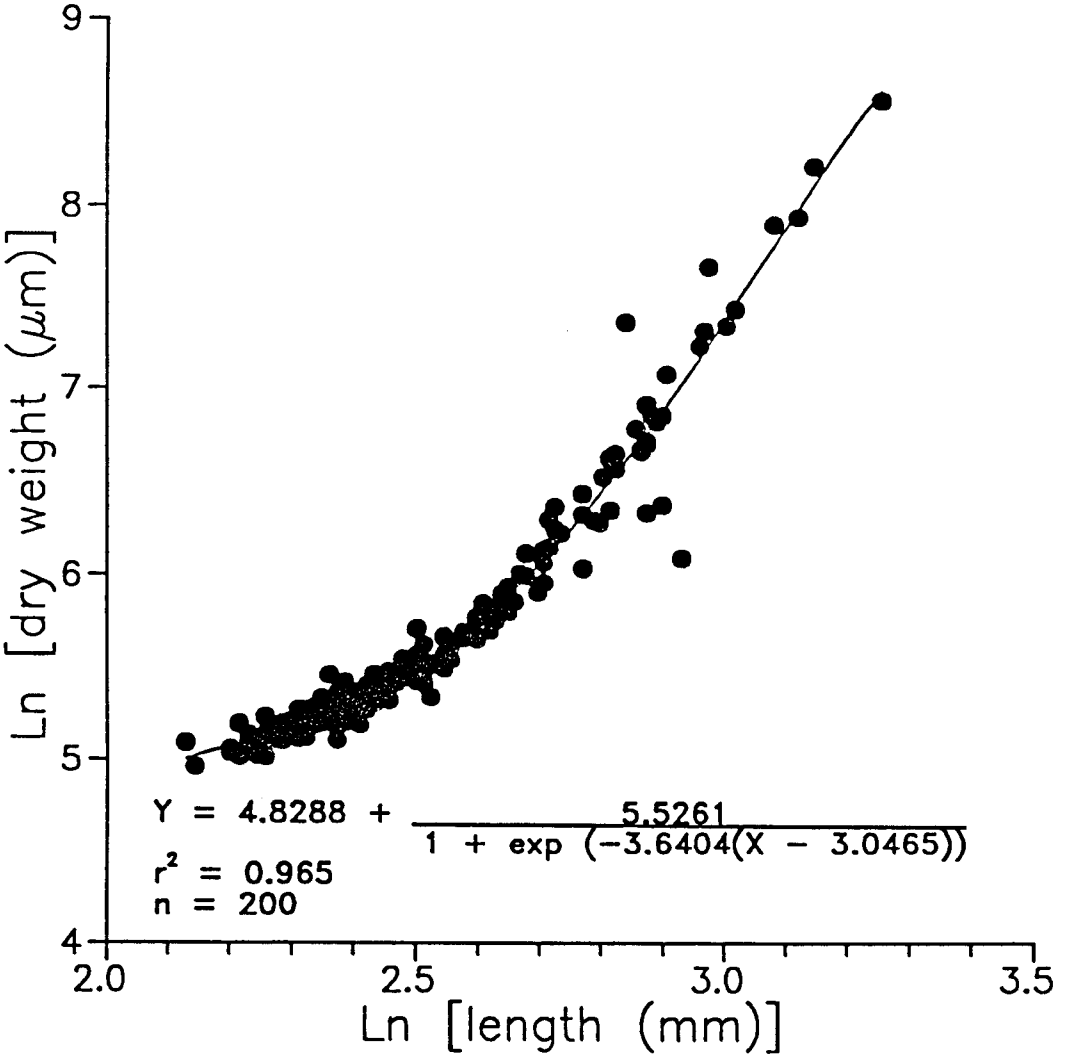

Figure 11. Logistic regression of ln(dry weight) on ln(length) for all herring larvae.

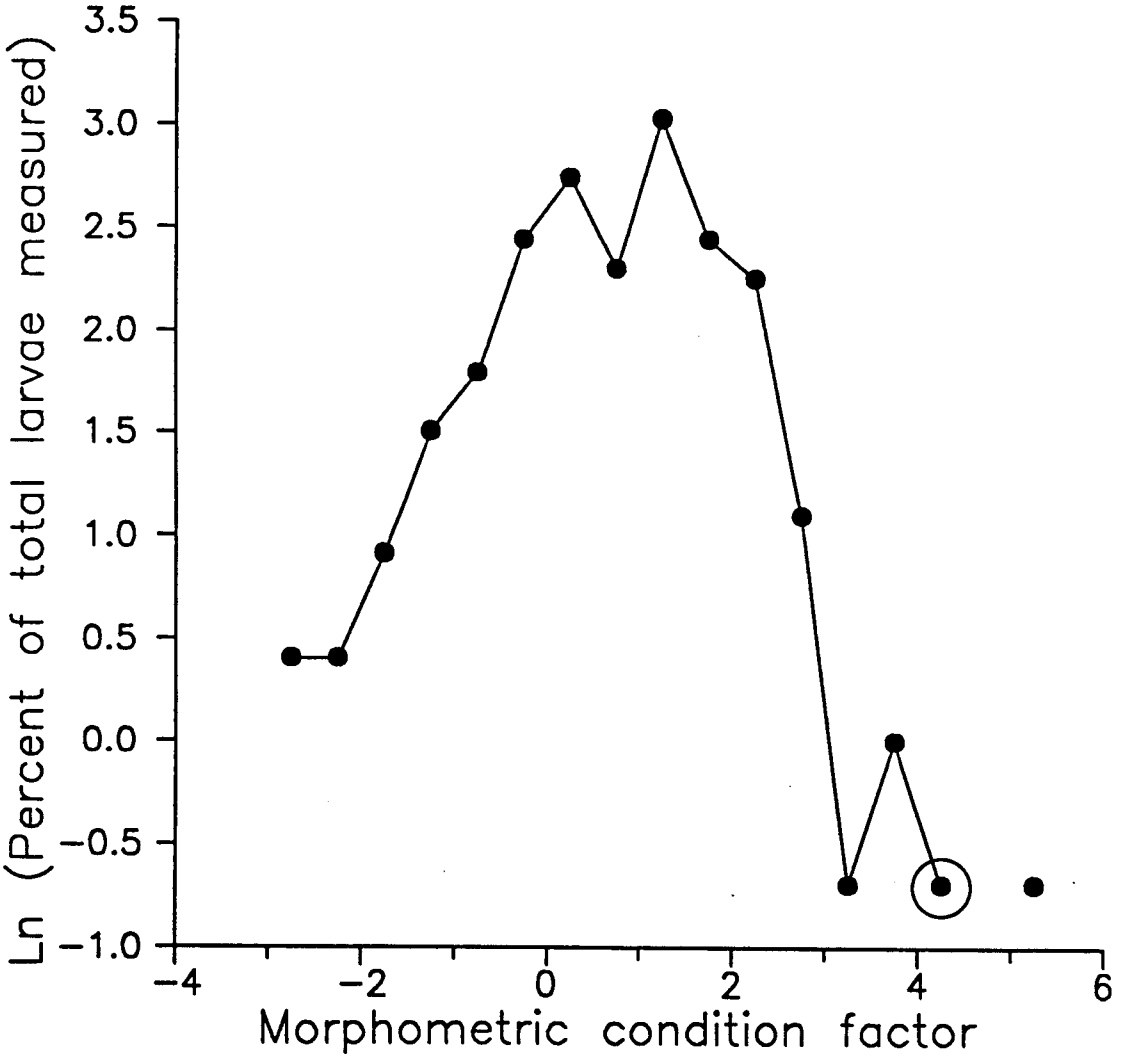

Figure 12. Frequency distribution of morphometric condition of herring larvae. The mean CF was 0.717 and the poorest conditioned larvae (circled) had a CF of 4.25.

where n_S = duration (d) of period of starvation, $n_{S,max}$ = the maximum number of days that a Pacific herring larva can starve before falling out of the water column and so becoming unavailable to plankton nets, and CF_{max} = the largest positive value of CF found in the catches. McGurk (1984b) reported that larvae reared in water temperatures of 6-8^{o}C and starved from hatch begin falling out of the water column at an age of 11.5 d and complete fallout at an age of 15 d. Therefore, the median age of fallout at these temperatures was 13 d. Since larvae reared at these temperatures are capable of feeding at an age of 3 d, $n_{S,max}$ was 10 d. Therefore, the ratio of $n_{S,max}$ to CF_{max} is 2.35 days per unit of positive condition, which means that the mean CF of 0.717 corresponded to 1.7 d of food deprivation, a negligible period of time.

Even though there were no differences between sites in the mean condition of herring larvae, differences may have existed in the age trajectory of condition. Multiple regression of morphometric condition on age, dummy variables for cohorts, and the interactions of age and cohort showed that the maximum amount of variance in condition, CF, was explained by the following model

(18)	CF =	2.0648 -	0.0784t +	$0.0264x_2t$ +	$0.0584x_3t$
	(SE)	(0.1510)	(0.0070)	(0.0067)	(0.0161)
	(P)	(<0.0001)	(<0.0001)	(0.0001)	(0.0004)

r^2 = 0.38, n = 199

where x_2 = 1 for cohort 2 of Fairmount Island and 0 for all other cohorts, and x_3 = 1 for cohort 3 of Fairmount Island and 0 for all other cohorts. This model indicates that condition increased with age at a significantly slower rate in herring larvae from Fairmount Island than in fish from the other three sites (Fig. 13). Since Fairmount was a control site this effect was not related to oil.

4.7 RNA-DNA Ratios

No significant correlations were found between the RNA-DNA ratios of herring larvae and their age and size (length and dry weight), or with environmental variables (site, mean water temperature and mean prey concentration) (Fig. 14). The mean RNA-DNA ratios of Table 7 show that the two control sites have the highest mean ratios, which suggests a subtle effect of oil on instantaneous growth

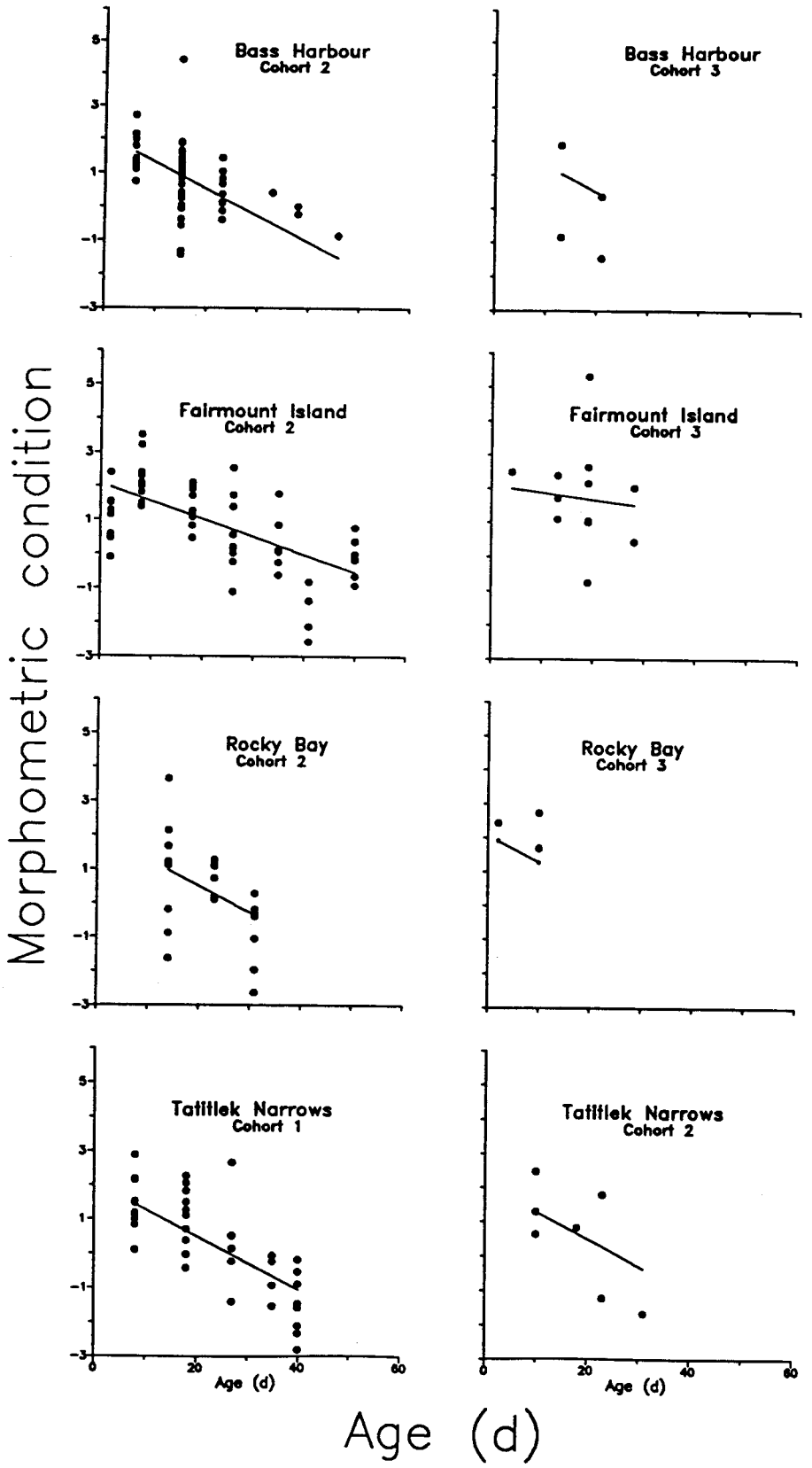

Figure 13. Regression of morphometric condition factor on age for herring larvae from eight cohorts at four sites. See text for equation (18).

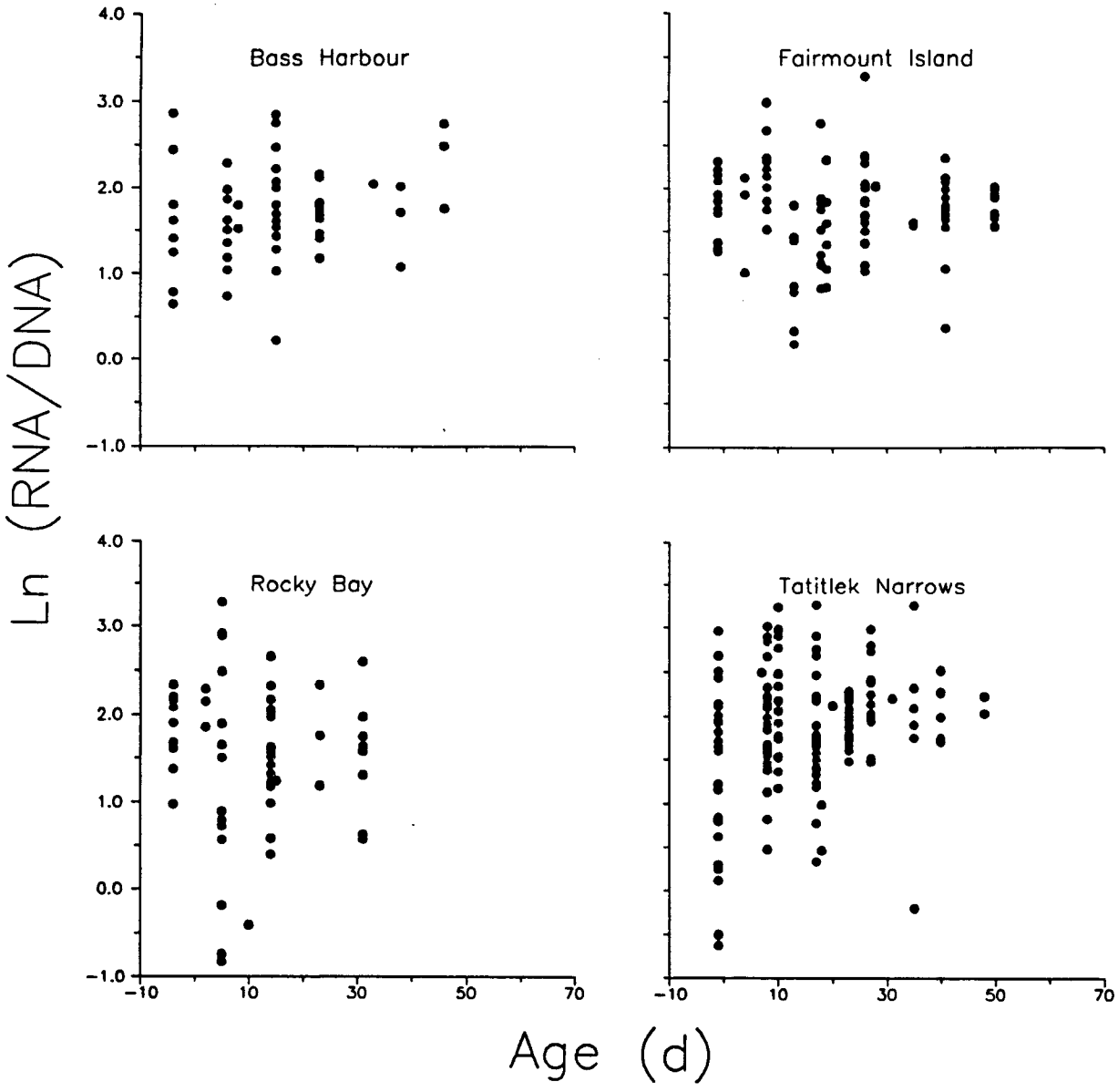

Figure 14. Plots of RNA-DNA ratio of herring larvae against age, showing no change with age and no differences between sites.

Table 7.

Mean ln(RNA-DNA) and the equivalent geometric mean ratios for the four sites.

Site	mean ln(RNA/DNA)	SD	n	geometric mean RNA/DNA
Bass Harbor	1.6849	0.5757	53	5.392
Fairmount Island	1.7287	0.5192	96	5.633
Rocky Bay	1.5362	0.8258	62	4.647
Tatitlek Narrows	1.8545	0.6735	159	6.388
Grand mean	1.7442	0.6604	370	5.721

rates. However, the variance of the ratios is too large to demonstrate this effect. The main reason for the large variance is that all of the larvae from Bass Harbor, Fairmount Island and Rocky Bay and 100 of the 159 larvae from Tatitlek Narrows were analysed with Karsten and Wollenberger's (1972, 1977) method, which is less accurate and less precise than the best method that is now available, that of Clemmessen (1988). This conclusion is a finding of this study and is described in Appendix A. All of the RNA-DNA ratios shown in Fig. 14 were either measured with Clemmessen's (1988) method or were calculated from RNA and DNA concentrations that were corrected for differences in accuracy between the two methods. However, the latter ratios were not corrected for differences in precision because there is no satisfactory method of correcting for precision that would not bias subsequent analysis of the corrected data. It is important to stress that the RNA-DNA ratios shown in Fig. 14 must not be used as absolute RNA-DNA ratios, but only as relative ratios, i.e. their mean is reliable but their range is not biologically reasonable.

The mean RNA-DNA ratios for each of the four sites are smaller than those reported by Fukuda et al. (1986) and Clemmessen (1987), but similar to those reported by Robinson and Ware (1988). We are reluctant to calculate protein growth rates from our RNA-DNA ratios using Buckley's (1984) equation because we are uncertain whether RNA-DNA ratios measured with Clemmessen's (1988) method are comparable to Buckley's (1984) data, which was made using the Schmidt-Thannhauser (1945) method. For the same reason we are also reluctant to use Clemmessen's (1987) equation to calculate the number of degree-days of starvation from RNA-DNA ratios.

4.8 Mortality and Transport

Mortality and transport of herring larvae were estimated with two population models incorporating different assumptions about the time trajectories of diffusion and mortality. It was necessary to combine the two processes of mortality and transport in order to correct for the fact that larvae are recruited to and "lost" from a sampling station due to both processes rather than mortality alone (McGurk 1989a), and because it is the best explanation for the ascending limbs of the catch curves shown in Fig. 15.

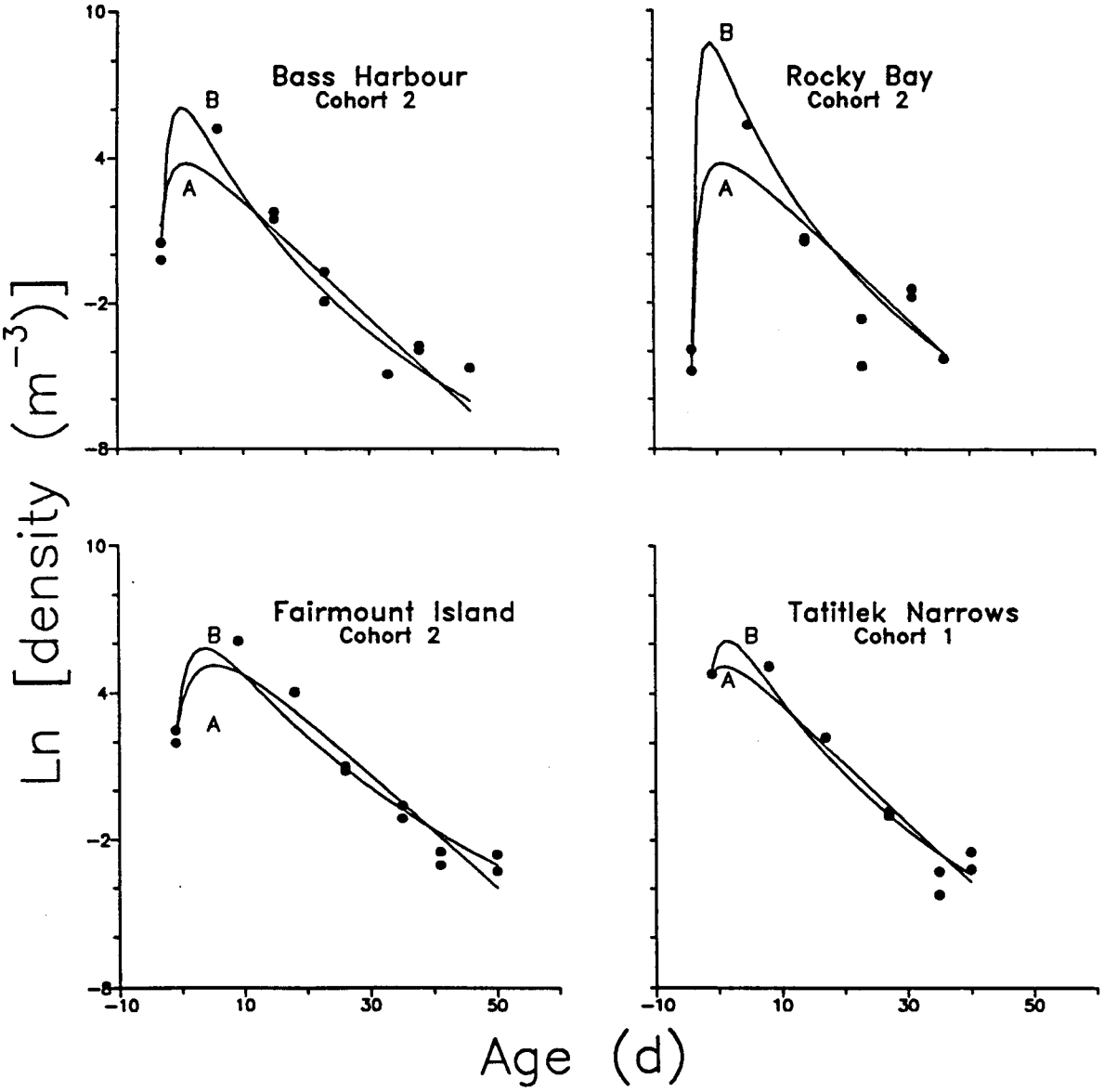

Figure 15. Densities of herring larvae at age and site. Solid lines are densities predicted from diffusion-mortality models. Model A [equation (22)] incorporates Fickian diffusion and constant mortality, and model B [equation (23)] incorporates time-dependent diffusion and mortality.

The simplest model assumes Fickian diffusion and a constant mortality with age

$$(19)\quad N = \frac{C}{4\pi HKt} \exp\left[\frac{-x^2}{4Kt} - Zt\right]$$

where N = density (m^{-3}) of herring larvae at age t (d), C = number of herring larvae hatched at t = 0, H = maximum depth (m) of distribution of herring larvae, x = distance (m) between the hatch site and the plankton station, K = coefficient of Fickian diffusion ($m^2 \cdot d^{-1}$), and Z = coefficient of mortality (d^{-1}) (Okubo 1980). This model was fit to the herring larval densities of this study because it was used previously for Pacific herring larvae by McGurk (1989a), and because its parameters are relatively easy to interprete. However, as will be shown below, it does not provide the best fit to the data, probably because its assumptions are unrealistic. For example, Fickian diffusion assumes that horizontal variance is constant with time from release, but Okubo (1971) showed that horizontal variance of dye particles in the sea is actually proportional to time to a power between 2 and 3. Mortality of fish is known to decrease with time over the egg to juvenile stages (e.g. Bailey and Houde 1989) but has usually been expressed as a constant mortality over single stages for reasons of computational convenience. Recent studies have reported that larval mortality declines exponentially with age for at least one species, jack mackerel, Trachurus symmetricus (Hewitt et al. 1985), according to the form $N = N_0 t^{-\beta}$, where N_0 = density (m^{-3}) at hatch (t = 0) and β = coefficient of mortality, i.e. $Z = \beta / t$.

The second model was based on two other solutions to the basic equations of tubulent diffusion that assume horizontal variance increases exponentially with time:

Joseph-Sendner:

$$(20a)\quad N = \frac{C}{2\pi HP^2t^2} \exp\left(\frac{-x}{Pt}\right)$$

Ozmidov:

$$(20b)\quad N = \frac{C}{6\pi Hy^3t^3}\exp\left(\frac{-x^{2/3}}{yt}\right)$$

where P = diffusion velocity ($m \cdot d^{-1}$) and y = energy dissipation parameter ($m^{2/3} \cdot d^{-1}$) (Okubo 1980). Adding a term for a non-constant mortality rate gives

$$(21a)\quad N = \frac{Ct^{(2+\beta)}}{2\pi HP^2}\exp\left(\frac{-x}{Pt}\right)$$

$$(21b)\quad N = \frac{Ct^{(3+\beta)}}{6\pi Hy^3}\exp\left(\frac{-x^{2/3}}{yt}\right)$$

Equation (19) was fit to the avoidance-corrected herring densities with non-linear multiple regression after ln-transformation and rearrangement, i.e.

$$(22)\quad \ln(N) = b_0 - \ln(t) - b_1t^{-1} - Zt$$

where $b_0 = \ln(C/4\pi HK)$ and $b_1 = x^2/4K$. Distance, x, was treated as part of a coefficient rather than a variable because it was not possible to identify a single accurate value of x for each site; the larvae of each of the four major cohorts hatched from beaches which extended for kilometers along the nearby shores. However, the average value of x was probably within the range of 1-5 km for all four sites. Equation (21) was fit using linear multiple regression, i.e.

$$(23)\quad \ln(N) = b_0 - b_1\ln(t) - b_2t^{-1}$$

where $b0 = C/2\pi HP^2$ or $C/6\pi Hy^3$, $b_1 = 2+\beta$ or $3+\beta$, and $b_2 = x/P$ or $x^{2/3}/y$. The uncertainty about whether equation (21a) is more or less correct than equation (21b) is the reason why the second type of population model is less easy to interprete than equation (19).

Only non-zero densities were used because zero counts could not be assigned an age, and because they do not represent true zero densities but only indicate that the density of the larvae was lower than the limit of detection of the gear.

In order to identify statistically significant differences in mortality and transport coefficients between sites, the non-zero densities of each of the four major cohorts were pooled into a single data set and fit with modified versions of equations (22) and (23). The modifications consisted of inserting dummy variables for cohorts and the interactions of dummy variables with t^{-1}, t or ln(t). The same dummy variables that were used for otolith and morphometric analyses were used in these analyses. Preliminary analysis showed that it was not possible to produce a unique result when all nine cohorts were included in the pooled data set because nine dummy variables and their interactions produced a too-sparse data matrix; one that consisted primarily of 0s and 1s. Therefore, only the four major cohorts were included.

The version of the simple model [equation (22)] that explained the most variance in density (r^2 = 0.83, n = 42) with all-significant parameters was

(24)

variable	coefficient	SE	P
b0	9.209	0.6507	<0.0001
x_3	3.840	0.6104	<0.0001
x_7	1.334	0.5087	0.0127
$(t+5)^{-1}$	-13.7446	1.151	<0.0001
$x_3(t+5)^{-1}$	-19.87	5.072	0.0004
t+5	-0.2252	0.0184	<0.0001

where x_3 = 1 for cohort 2 of Fairmount Island and 0 for the other four major cohorts, x_7 = 1 for cohort 1 of Tatitlek Narrows and 0 for the other four cohorts, and age was transformed by the addition of 5 d in order to avoid negative ages due to the capture of larvae before the mean hatch dates. The fit of this model to the data is shown as curve A in Fig. 15. It clearly underestimates the density of 5-15 d old larvae and overestimates the density of 25-35 d old larvae.

The most important result of this simple model was the finding that a constant mortality of 0.23 d^{-1} occurred in all four major cohorts and that there were no site effects that could be related to the presence or absence of oil. Equation (24) indicates that the highest initial density was measured for cohort 2 of Fairmount Island, that the initial density of cohort 1 of Tatitlek Narrows was significantly lower, and that both initial densities were higher than those of cohort 2 of Bass Harbor and cohort 2 of Rocky Bay. The latter two initial densities were not significantly

($P > 0.05$) different from each other. Equation (24) also indicates that diffusive transport was significantly lower at the Fairmount Island site than at the other three sites.

One interesting result of this model is that it shows that the waves of newly-hatched larvae passed through the sampling stations 1 and 5 d after hatch. This supports the assumption that the ascending limb of the catch curve is caused by the time required for the larvae to be transported from the hatch sites to the plankton station 1-5 km offshore.

The second model explained 5% more variance ($r^2 = 0.88$, $n = 42$) than the first, and it provided a superior fit to the densities of young larvae (Fig. 15: Curve B)

(25)

variable	coefficient	SE	P
b_0	29.284	2.141	<0.0001
x_3	4.191	0.566	<0.0001
x_7	1.920	0.601	0.0030
$\ln(t+5)$	-8.766	0.608	<0.0001
$(t+5)^{-1}$	-33.78	2.32	<0.0001
$x_1(t+5)^{-1}$	-11.93	2.20	<0.0001
$x_3(t+5)^{-1}$	-41.81	5.76	<0.0001
$x_7(t+5)^{-1}$	-22.43	6.79	0.0022

where $x_1 = 1$ for cohort 2 of Bass Harbor and 0 for all other cohorts. These results support the conclusion that mortality is not significantly different between sites. If we assume that horizontal variance due to diffusion increases with age to a power between 2 and 3, as Okubo (1971) reported in his review of dye experiments in the sea, then the mortality coefficient, β, ranges from 5.77 to 6.77, which means that Z fell from 5.77-6.77 d^{-1} at age 1 to 0.23-0.27 d^{-1} at age 25 d and to 0.10-0.0.12 d^{-1} at age 55 d. The second model also supports the conclusion that the Fairmount Island site supported the highest initial larval density, followed by Tatitlek Narrows and the two treatment sites.

The second model differs from the first in that it indicates that all four sites had significantly different rates of diffusion. In order of increasing diffusive transport they are: Fairmount Island, Tatitlek Narrows, Bass Harbor and Rocky Bay. These

differences are almost certainly related to the general counter-clockwise pattern of surface water circulation in the Sound, and not to oil contamination. Herring larvae that hatch near Hinchinbrook Entrance will tend to be transported northward at a faster rate than larvae that hatch near the northern shore of the Sound.

5. DISCUSSION

This study shows that growth and mortality of herring larvae in Prince William Sound in 1989 was not affected by the Exxon Valdez oil spill. There is no evidence that oil decreased the number of cohorts of larvae or their initial density in the treatment sites. Three cohorts were hatched at each of the four sites, which is the usual number observed at a spawning site, e.g. Lambert (1984), McGurk (1989a,b). Initial densities of larvae were much higher in the two northern control sites than the two treatment sites, but this is probably a consequence of a greater number of eggs laid in the two control sites, rather than a reflection of differences in egg mortality. McGurk et al. (1990) reported that herring eggs from the Fairmount area, the Naked Island archipelago and Rocky Bay that were incubated in the laboratory died at a rate of only $3\%\cdot d^{-1}$ for all sites. Since natural mortality of herring eggs, which includes predation, is usually much higher than this rate, e.g. as much as 90% over the incubation period [see review by Palsson (1984)], a difference in non-predation survival of a few percentage points due to oil would not have had a measurable effect on initial densities of herring larvae. We encourage other investigators to test this argument by comparing the density of herring eggs and the areal extent of herring spawn between treatment and control areas.

Population growth rates of all four sites were within the range observed for Atlantic and Pacific herring larvae, i.e. between 0.1 $mm\cdot d^{-1}$ and 0.5 $mm\cdot d^{-1}$ (Jones 1978, McGurk 1984b). All differences in growth between sites and cohorts were due to differences in water temperature; there was no evidence for an independent site effect. Similarly, there were no significant differences between sites in recent growth rates calculated from otolith ring widths. Age was the only factor that explained a significant amount of variance in recent growth rates. Neither morphometric condition or RNA-DNA ratios support the hypothesis that growth and condition was less in the oiled sites than in the control sites.

Mortality rates were not significantly different between sites, regardless of which model was used: constant or age-dependent. The average constant rate of 0.23 d^{-1} falls within the range reported for both Atlantic and Pacific herring larvae (McGurk 1984b, 1989a, b).

The finding of no obvious oil effect on growth and development of herring larvae is supported by the lack of differences in prey concentration and in the densities of non-herring fish larvae between sites. It indicates that the average concentration of hydrocarbons in the pelagic zone at the time the larvae hatched were probably too low to affect subsequent larval growth and mortality. Rice et al. (1987) reported a list of lethal doses for Pacific herring larvae exposed to the water-soluble fraction (WSF) of Cook Inlet crude oil: yolk sac larvae exposed from 16 h to 6 d had LC_{50}s of 2.8 to 2.3 ppm; feeding larvae exposed for 7 and 21 d had LC_{50}s of 1.8 and 0.36 ppm, respectively; and larval growth was significantly reduced after 7 d of exposure to 0.3 ppm. Therefore, it follows that hydrocarbon concentrations in the upper 30 m of the Prince William Sound were probably less than 0.3 ppm. We encourage other investigators to test this statement by reporting the concentrations of hydrocarbons measured from the pelagic zone of the Sound.

This argument is based on the assumption that the Tatitlek Narrows and Fairmount Island sites were completely free of any non-natural concentrations of hydrocarbons. It is a reasonable assumption given the fact that the oil slick never travelled near those sites. However, the assumption was never tested by chemical means. We understand that it may never be possible to know the hydrocarbon concentrations in the Fairmount Island site because few, if any, water samples were ever collected there in 1989 (Jeffrey Short, NOAA, Auke Bay Laboratory, Auke Bay, AK, pers. comm.). However, it may be possible to test its status as a control site by measuring the activity of mixed-function oxygenase (MFO) enzymes of fishes captured there, specifically some of the frozen herring larvae that remain in cold storage.

6. RECOMMENDATIONS

Herring Larvae Surveys

Since there is no evidence for an effect of oil on the population dynamics of herring larvae in the Sound, we do not recommend that a survey of larval herring in Prince

William Sound be repeated as part of the Exxon Valdez oil impact assessment program. Any future research on the early life history of herring in the Sound should be designed and conducted in order to answer questions related to fisheries ecology and management. These could include, but not be limited to, questions concerning the number of spawning stocks in the Sound and their degree of mixture; back-calculation of spawning stock biomass from larval densities; and the environmental factors controlling recruitment.

Of special relevance to this last point is the relationship between transport of herring larvae and the surface current patterns in the Sound. This report shows that larvae from the southern spawning grounds disperse at a faster rate than larvae from northern spawning grounds. Is this a response to current patterns? and if so, does this indicate that habitat for juvenile herring is concentrated in the northern half of the Sound?

Hydrocarbon Concentrations

We do not recommend reanalysing the data of this study in order to include hydrocarbon concentrations measured from the water or from pelagic organisms because there are no differences in growth and mortality of herring larvae between sites that require an explanation based on oil contamination. Although such a comparison would be scientifically interesting, it is not directly relevant to the task of assessing the impact of the Exxon Valdez oil spill on herring resources of Prince William Sound.

However, we do recommend that hydrocarbon concentrations measured in the Sound should be compared to mixed function oxygenase (MFO) enzyme activity of the remaining frozen herring larvae that are stored by Microtek Ltd. Payne et al. (1987) has shown that MFO enzyme activity is a very sensitive indicator of exposure to hydrocarbons. The purpose of this proposed work would be to determine if the detoxification system of the larvae was stimulated by the hydrocarbons present in the pelagic zone of the Sound in May-June, 1989, or whether the concentration of hydrocarbons was too low to provoke a biochemical response. If the former is the case, then we may conclude that the detoxification system protected herring larvae and this was part of the explanation for the absence of an effect of oil on growth and

mortality. If the latter is true, then we may conclude that the larvae were never exposed to sufficient levels of hydrocarbons to threaten their growth or survival.

Cytogenetic Analyses of Herring Larvae

We recommend that some of the formalin-preserved larvae should be examined for the presence of cytogenetic abnormalities such as disruptions of the mitotic bundles. The purpose of this work would be to confirm that there were no sublethal effects of oil that were not expressed as growth or mortality.

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Appendix A. Comparison of Methods of RNA-DNA Analysis

A1. INTRODUCTION

The oldest method used to measure the concentrations of RNA and DNA in marine fish larvae is the Schmidt-Thannhauser (1945) technique modified by Munro and Fleck (1966) (Buckley 1979, 1984, Wright and Martin 1985, Fukuda et al. 1986, Buckley and Lough 1987, and Clemmessen 1987). It is based on the absorbance of UV light in the 260 nm band by purified nucleic acids. It has the disadvantage of requiring a minimum of 800 μg dry weight·sample^{-1}, which means that the nucleic acid concentrations of individual Prince William Sound herring larvae < 17 mm long could not be measured with this method. A technique for measuring amounts as small as 0.05 μg·mL^{-1} of DNA and 0.1 μg·mL^{-1} of RNA was introduced by LePecq and Paoletti (1966) and modified by Karsten and Wollenberger (1972, 1977). Prasad et al. (1972) showed that it produced results comparable to those of the Schmidt-Thannhauser method, at least for mammalian tissues. It was used most recently by Robinson (1988) and Robinson and Ware (1988) to measure RNA-DNA ratios of Pacific herring larvae of Georgia Strait, British Columbia. We used Karsten and Wollenberger's (1972, 1977) method as modified by Robinson (1988) on 270 herring larvae from four sites in Prince William Sound, but found that it produced a large number of very low RNA-DNA ratios, which suggested that the method was not giving accurate measurements of one or both kinds of nucleic acids. This appendix reports the experiments we carried out in order to determine which factor(s) were responsible for these unexpected results, and the method by which we corrected these data.

There were three possible sources of error. The RNA standard may have been contaminated with DNA, thereby inflating the slope of the standard curve and leading to underestimates of RNA concentration and underestimates of the RNA-DNA ratio. Contamination by small concentrations of DNA can lead to large errors in the RNA standard curve because DNA has a fivefold greater flourescence yield than RNA. Both Bentle et al. (1981) and Robinson (1988) reported that their RNA standards had to be corrected for contamination with DNA. This possibility was investigated by testing the purity of the RNA standard.

The second possibility was inhibition of RNAse leading to underestimation of RNA concentration and of the RNA-DNA ratio. This was investigated by using Bentle et al.'s (1981) method, which is a modification of Karsten and Wollenberger (1972, 1977) method that measures nucleic acid concentration through the loss of flourescence occurring after the sequential addition of DNAse and RNAse to the same reaction mixture. The flourescence remaining after addition of both enzymes represents background flourescence due to undigested RNA plus compounds other than nucleic acids.

The third possibility was that unknown compounds in herring larvae were flourescing thereby inflating the estimate of DNA concentration. Clemmessen (1988) recently described a method for measuring small quantities of nucleic acids that excludes this possibility by purifying nucleic acids of all cellular debris that could affect flourescence.

Our experimental design was based on comparing the RNA-DNA ratios of herring larvae collected from one control site, Tatitlek Narrows, in order to avoid confounding the results with a site effect or an oil effect. A total of 159 larvae were analysed: 71 with Karsten and Wollenberger's (1972, 1977) method, 58 with Clemmesen's (1981) method and 30 with Bentle et al.'s (1981) method. A wide range of dates and larval lengths were chosen for each group in order to account for date- and size-related effects.

A2. METHODS

Karsten and Wollenberger's (1972, 1977) method

In the first phase of this analysis whole-body concentrations of RNA and DNA were measured for 270 herring larvae that were chosen randomly from each of the 28 combinations of four sites and seven dates. This data is shown in Appendix J. Karsten and Wollenberger's (1972, 1977) method as modified by Robinson (1988) was used for the analysis. The technique is based on the enhanced flourescence of nucleic acids after introduction of the dye ethidium bromide. For this study, each individual larva was thawed and measured for standard length to the nearest 0.5 mm. The larva was then placed in 3 mL of ice-cold phosphate-buffered saline (PBS) and homogenized at 25,000 rpm for two 15 s treatments. Two replicates of 0.5 mL

aliquots were taken and processed for determination of DNA. This involved adding 0.5 mL of heparin plus 0.5 mL of RNAse in order to digest all of the RNA leaving only DNA. Two replicates were processed for total nucleic acids, which meant adding ethidium bromide and heparin and measuring total flourescence. One replicate was used to measure the flourescence background; no ethidium bromide was added to that aliquot. One blank aliquot (PBS but no herring larvae) was run each day in order to calibrate the flourometer. The difference between the mean concentration of total nucleic acids and the mean concentration of DNA was the concentration of RNA. Robinson (1988) modified this method by increasing the time that the DNA aliquots were incubated with RNAse from 20 to 30 min, and by increasing the concentration of RNAse from 50 to 100 $\mu g \cdot mL^{-1}$. These modifications were added in order to increase confidence that all RNA would be digested by the RNAse. The flourometric response to known concentrations of nucleic acids (i.e. standard curves) was measured in triplicate at eight concentrations of DNA (0.05, 0.1, 0.25, 0.5, 1, 2, 3, and 4 $\mu g \cdot mL^{-1}$) and six concentrations of RNA (0.25, 1, 3, 5, 10, and 15 $\mu g \cdot mL^{-1}$). The DNA standard was Sigma number D6898 and the RNA standard was Sigma number R7250.

Purity of RNA Standard

In the second phase of analysis we tested the purity of the RNA standard in five ways:

(1) digesting it with RNAse/PBS and measuring flourescence. A pure sample would exhibit no residual flourescence;

(2) digesting it with DNAse/PBS and measuring flourescence. A pure sample would exhibit no change in flourescence;

(3) digesting it with RNAse/buffer C and measuring flourescence. A pure sample would exhibit no change in flourescence;

(4) measuring the concentration of DNA in the RNA standard using a dye specific for DNA - bisbenzimidazole. A pure sample would not flouresce; and

(5) adding 10 μg of DNA to the RNA standard and measuring the concentration of DNA using bisbenzimidazole. A pure sample would flouresce by an amount equivalent to 10 μg of DNA.

We used DNAse rather than alakali hydrolysis to digest any DNA that was present in the RNA standard because DNAse is more specific to DNA than alkali hydrolysis.

Bentle et al.'s (1981) Method

In the third phase of analysis we measured nucleic acid concentrations of a subset of 30 larvae from the Tatitlek Narrows site using Bentle et al.'s (1981) method. This method also depends on the enhanced flourescence of ethidium bromide-nucleic acid complexes, but a different ionic medium is used in order to optimize the activity of DNAse when it is used in combination with RNAse. Each larva was thawed, measured for standard length to the nearest 0.1 mm and homogenized in 3 mL of ice-cold buffer C, instead of PBS. Buffer C consisted of 20 mM Tris-HCl at a pH of 7.5, 1 mM MgCl, 0.8 nM CaCl and 50 mM NaCl. Ethidium bromide was added to two aliquots and the mean concentration of total nucleic acids was measured flourometrically. Then, RNAse to a final concentration of 25 $\mu g \cdot mL^{-1}$ was added to two other aliquots in order to digest all RNA and give a concentration of DNA. Finally, RNAse plus DNAse I to a final concentration of 5 $\mu g \cdot mL^{-1}$ was added to another two aliquots in order to digest all nucleic acids and give a background flourescence. Volumes of aliquots and incubation times were the same as in the first stage of analysis. A separate set of standard curves were run for this method.

Clemmessen's (1988) Method

In the fourth phase of analysis 58 herring larvae were analysed with Clemmesen's (1988) method. This method differs from the previous two methods in two ways: nucleic acids of fish larvae were purified of all compounds that may alter flourescence by repeatedly washing the homogenized fish with organic solvents; and a DNA-specific dye, bisbenzimidazole, was used instead of ethidium bromide to measure DNA concentration. Each larva was thawed and standard length was measured to the nearest 0.1 mm. The larva was homogenized in an ice-cold buffer

containing 0.3 mL of 0.05 M Tris-HCl, 0.1 M NaCl, 0.01 M EDTA at a pH of 9.0, and 0.2 $mg \cdot mL^{-1}$ of proteinase K. The homogenate was centrifuged at 6,000 rpm for 15 min and then the supernatant was decanted into a new vial into which 0.3 mL of 80% phenol and 0.3 mL of chloroform/isoamylalcohol (24:1) were added. The solution was mixed for 10 min and then centrifuged at 6,000 rpm for 10 min. The phenol-chloroform/isoamylalcohol phase was discarded and the aqueous phase containing the nucleic acids was washed a second time. The aqueous phase from that washing was extracted, combined with 0.3 mL of the chloroform/isoamyalcohol mixture, mixed for 1 min and then centrifuged for 5 min. This procedure was repeated a second time in order to completely wash the aqueous phase and prepare it for measurement of nucleic acid concentration. Finally, 0.2 mL of buffer was added to the aqueous phase and it was separated into several aliqots. Ethidium bromide was added to one aliquot and total nucleic acid concentration was measured from its flourescence. Bisbenzimidazole was added to another aliquot and DNA concentration was measured flourometrically. RNA concentration was calculated as the difference between total nucleic acid and DNA concentration. There was sufficient material to allow two measurements of total nucleic acid concentration and DNA concentration for each fish. A standard curve for DNA was used, and the fluorometer was blanked every day.

Methods of Comparison

Nucleic acid concentrations were compared between methods using general linear models with dry weight as a covariate. Weight was a more acccurate measure of size than length because yolk sac larvae were the shortest larvae but were actually heavier than small non yolk sac larvae. Dry weight was calculated from larval length using the logistic weight-length equation shown in Fig. 11. An additional 22 μg of dry weight was added to yolk sac larvae. This was the mean dry weight (SD = 11) of 20 larvae whose yolk sac dimensions had been measured. Julian date of larval collection and average water temperature in the upper 30 m were included as auxiliary variables. Prey concentration was not included as an auxillary variable because it was highly correlated with larval size having been derived from larval length. Weight, DNA, RNA, and the RNA-DNA ratio were ln-transformed in order to normalize their distributions.

Yolk Sac vs Non Yolk Sac Larvae

Before comparing nucleic acid concentrations between groups of larvae it was necessary to determine whether yolk sac larvae could be pooled with non yolk sac larvae. Were there significant differences in concentration of nucleic acids per μg dry weight between yolk and non-yolk tissue? The concentrations of RNA and DNA in the yolk and non-yolk tissues of ten larvae were measured with Clemmessen's (1988) method. The length and height of each yolk sac was measured in order to calculate yolk sac volume using the equation for an ellipsoid [equation (5)] and then the sac, including its epithelium was removed with a dissecting pin. Dry weight of the yolk sac was calculated from yolk sac volume by assuming a specific gravity of 1 $g \cdot cm^{-3}$ and an 80% water content or 200 $\mu g \cdot mm^{-3}$. RNA and DNA concentrations (μg per yolk sac or per larva) were divided by dry weight of the yolk sac or of the larva in order to remove the effect of size. These new concentrations, μg nucleic acid per μg dry weight of larval or yolk tissue, were ln-transformed in order to normalize their distributions and then compared between body compartments with one-way analysis of variance (ANOVA).

A3. RESULTS AND DISCUSSION

A3.1 Contamination of Standards

The weight of evidence supports the conclusion that the RNA standard was pure and that no correction for DNA contamination was necessary. Four of the five tests shown in Table A1 support this conclusion including Clemmessen's (1988) method, which is the most accurate and precise of the three methods examined in this study. The incubation of RNA with RNAse/PBS caused complete digestion of RNA in three replicate samples. The absence of residual flourescence indicated that no other nucleic acids were present. Similar results were obtained when buffer C was used instead of PBS. These results were supported by using Clemmesen's (1988) method to analyse the RNA standard: it did not produce any flourescence of the DNA-specific dye, bisbenzimidazole. In order to see if Clemmessen's (1988) method was able to detect small quantities of DNA, we added 10 μg DNA to the RNA standard and repeated the test. Flouresence equivalent to 10 μg of DNA was measured, confirming the high sensitivity of the method. In contrast to these results, the incubation of the RNA standard with DNAse/PBS caused a partial loss of

TABLE A1

Tests for contamination of RNA standard (Sigma #R7250) by DNA. Predicted response assumes pure RNA.

Treatment		Predicted	Measured
1.	Incubation of RNA standard with RNAse-PBS.	complete loss of fluorescence	complete loss of fluorescence
2.	Incubation of RNA standard with DNAse-PBS.	no change in fluorescence	50% loss of fluorescence
3.	Incubation of RNA standard with RNAse-buffer C.	complete loss of fluorescence	complete loss of fluorescence
4.	Measurement of DNA concentration in RNA standard with DNA - specific dye (Clemmessen 1988).	no fluorescence	no fluorescence
5.	Measurement of 10 μg DNA added to RNA standard with DNA - specific dye (Clemmessen 1988).	fluorescence equivalent to 10 μg DNA	fluorescence equivalent to 10 μg DNA

flourescence, which appeared to indicate the presence of DNA. Fig. A1 shows the standard curves for RNA with and without the addition of DNAse/PBS; the latter slope is 2.39 times higher than the former slope.

We have no explanation for the anomolous results of the DNAse/PBS treatment. It can be hypothesized that they were due to contamination of DNAse with RNAse. We used high concentrations of DNAse, 20 $\mu g \cdot mL^{-1}$, in order to digest any DNA that may have been present in the RNA standard. If the DNAse was contaminated with RNAse, then there may have been sufficient RNAse to cause the observed loss in flourescence. This would not have affected the results of RNA-DNA measurements made with Karsten and Wollenberger's (1972, 1977) and Clemmessen's (1988) method because DNAse is not used in either method. However, it would have affected the results made with Bentle et al.'s (1981) method because DNAse is added to the reaction mixture before RNAse. It would cause an overestimation of DNA concentration, an underestimation of RNA concentration and an underestimation of the RNA-DNA ratio because the RNAase-contaminated DNAse would cause a greater loss of flourescence than was justified by the amount of DNA present.

We have no explanation why Bentle et al. (1981) and Robinson (1988) observed partial loss of flouresence of their RNA standard after alkali hydrolysis.

A3.2 Comparison of Methods

Comparison of Yolked and Non-Yolked Larvae

Table A2 shows the ranges and arithmetic mean ($\pm$ 1 SD) sizes and RNA and DNA concentrations of the ten larvae whose nucleic acid concentrations were measured for the yolk sac and the body separately with Clemmessen's (1988) method. The geometric mean DNA concentration of yolk, 0.006 $\mu g \cdot (\mu g \text{ dry weight})^{-1}$, was significantly ($0.001 < P < 0.01$) higher than the geometric mean DNA concentration of the body, 0.003 $\mu g \cdot (\mu g \text{ dry weight})^{-1}$. The geometric mean RNA concentration of the yolk, 0.029 $\mu g \cdot (\mu g \text{ dry weight})^{-1}$, was also significantly ($0.02 < P < 0.05$) higher than the geometric mean RNA concentration of the body, 0.016 $\mu g \cdot (\mu g \text{ dry weight})^{-1}$. Although these differences did not translate into significant ($P > 0.05$) differences

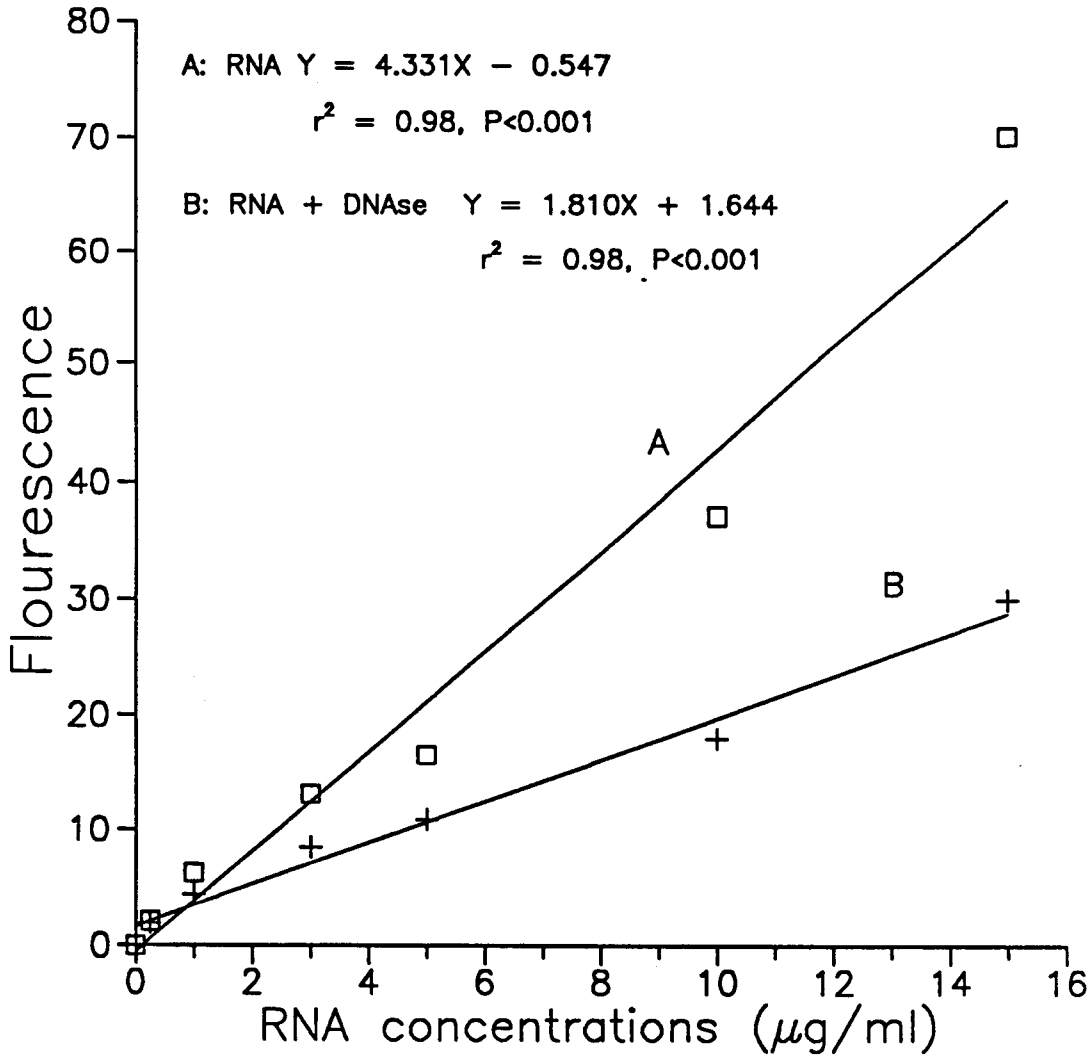

Figure A1. Standard curves for RNA and for RNA plus DNAse I.

TABLE A2

Size and nucleic acid concentrations of the yolk and non-yolk compartments of 10 larvae measured with Clemmessen's (1988) method. Star indicates a significant (0.02<P<0.05) difference between mean geometric DNA and RNA concentrations of yolk sac and body.

	Larval length	Dry weight (μg)			DNA (μg fish^{-1})			RNA (μg fish^{-1})			RNA/DNA			DNA (μg/μgW)		RNA (μg/μgW)	
	(mm)	larvae	yolk	total	larvae	yolk	total	larvae	yolk	total	larvae	yolk	total	larvae	yolk	larvae	yolk
minimum	6.5	135	13	156	0.215	0.080	.0305	1.460	0.135	2.130	2.496	0.370	2.278	0.001	0.002	0.010	0.009
maximum	8.2	145	42	186	0.605	0.365	0.965	3.360	1.545	4.340	14.000	15.737	11.469	0.004	0.024	0.024	0.058
mean	7.4	141	25	166	0.393	0.236	0.544	2.273	0.865	3.138	6.690	7.983	6.664	0.003	0.007*	0.016	0.040*
SD	0.5	4	11	11	0.149	0.266	0.202	0.566	0.512	0.842	3.271	6.000	3.169	0.001	0.006	0.004	0.032

in RNA-DNA ratios, yolk sac and non yolk sac larvae were treated as separate populations in subsequent analyses.

Comparison of Methods

Two-way ANOVA showed that dry weight of larvae varied significantly ($P<0.001$) with date, but not with method or the interaction of date and method. This meant that weight could be used as an independent covariate for comparing nucleic acid concentrations obtained from the three methods. Weight was preferred over date because the samples from Tatitlek Narrows were mixtures of three separate cohorts (i.e. size-classes) of larvae.

The general linear model that explained the most variance ($r^2 = 0.91$, $n = 159$) in ln(DNA) with all-significant parameters was:

(A1)

variable	coefficient	SE	P
constant	-2.1572	0.5759	0.0003
ln(weight)	0.6730	0.0608	<0.0001
g_1	1.5819	0.0639	<0.0001
g_3*yolk	-0.3554	0.1230	0.0044
date	-0.0385	0.0110	0.0006
temperature	0.5988	0.1284	<0.0001

where g_1 is a dummy variable with a value of 1 for Karsten and Wollenberger's (1972, 1977) method and a value of 0 for all other methods, g_2 has a value of 1 for Bentle et al.'s (1981) method and 0 for all other methods, g_3 has a value of 1 for Clemmessen's (1981) method and 0 for all other methods, and the dummy variable 'yolk' has a value of 1 for yolk sac larvae and 0 for non-yolk sac larvae. Fig. A2 shows the fit of the model to the data. The non-linear shape of the predicted DNA concentration is due to differences in water temperature between dates.

The model indicates that DNA concentration was greater for Karsten and Wollenberger's (1972, 1977) method that for the other two methods. It also shows that DNA concentration was lower in yolk sac larvae than in non yolk sac larvae.

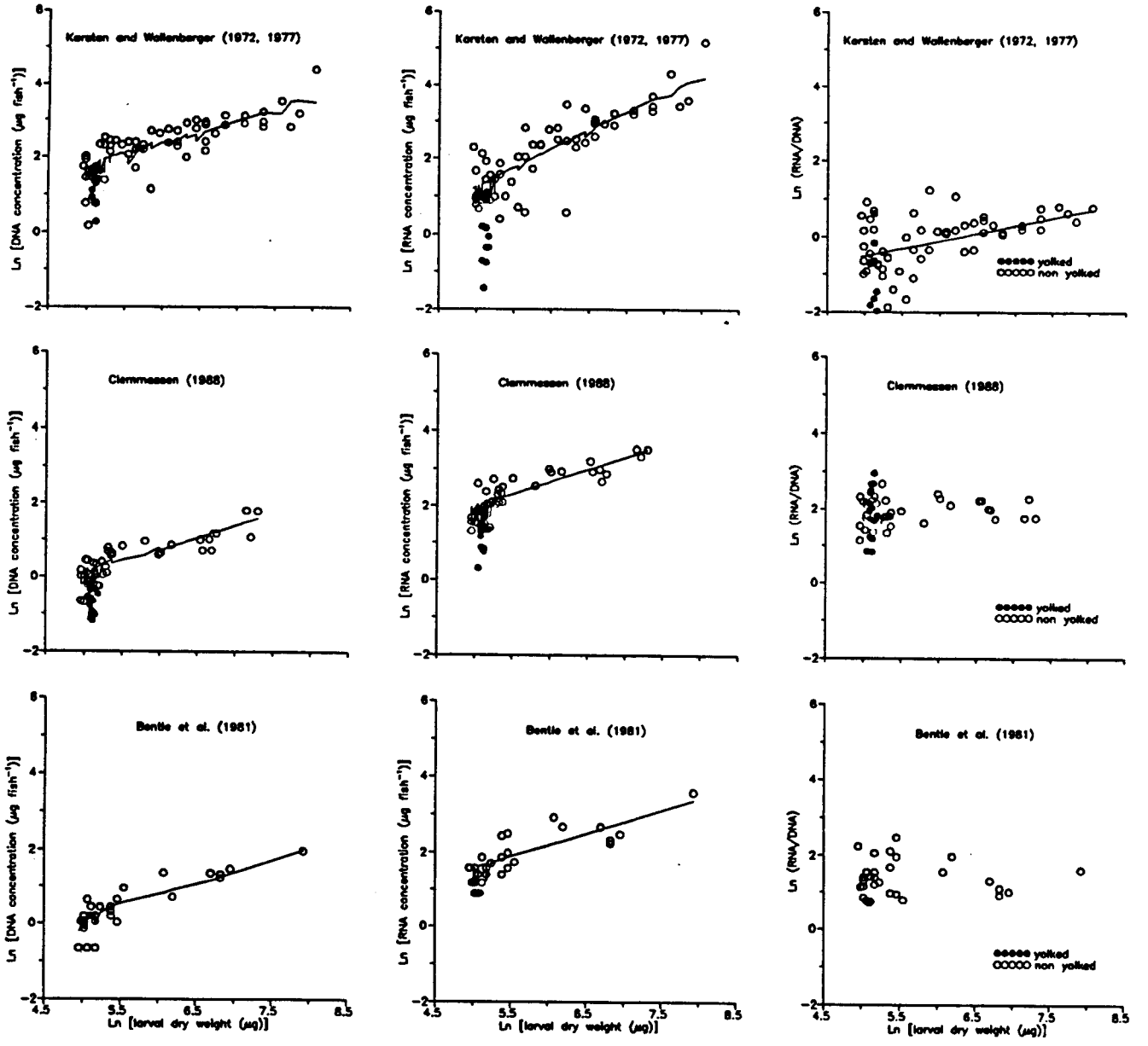

Figure A2. Plots of DNA concentration, RNA concentration, and the ratio of RNA to DNA of herring larvae against weight of larvae for each of three different methods of RNA-DNA analysis. Solid lines are from equations (A1), (A2) and (A3) respectively.

The general linear model that explained the most variance in ln(RNA) (r^2 = 0.80, n = 159) was:

(A2)	variable	coefficient	SE	P
	constant	-3.7237	0.8489	<0.0001
	ln(weight)	1.0060	0.0907	<0.0001
	g_2	2.3135	0.8021	0.0045
	g_3	2.4971	0.7534	0.0012
	g_2*ln(weight)	-0.3981	0.1397	0.0050
	g_3*ln(weight)	-0.3512	0.1311	0.0082
	g_1*yolk	-0.8708	0.1914	<0.0001
	date	-0.0330	0.0142	0.0214
	temperature	0.6276	0.1624	0.0002

This model shows that RNA concentrations were significantly higher with Clemmessen's (1988) method than with the other two methods.

The general linear model that explained the most variance in ln(RNA/DNA) (r^2 = 0.78, n = 159) was:

(A3)	variable	coefficient	SE	P
	constant	-2.5182	0.5543	<0.0001
	g_2	3.8883	0.5650	<0.0001
	g_3	4.4200	0.5599	<0.0001
	g_1*ln(weight)	0.4023	0.0921	<0.0001
	g_1*yolk	-0.9538	0.2002	<0.0001

This model shows that the RNA-DNA ratio measured with Clemmessen's (1988) method was about 1.5 times higher than the ratios measured with Bentle et al.'s (1981) method, and 5-17 times higher than the ratios measured with Karsten and Wollenberger's (1972, 1977) method (Fig. A2). The RNA-DNA ratios measured with Clemmessen's (1988) and Bentle et al.'s (1981) methods did not vary with length. These results are independent of temperature or date of collection.

These results indicate that the phenomenon of "quenching" of flourescence that was briefly discussed by Clemmessen (1988) was affecting nucleic acid concentrations

measured with Karsten and Wollenberger's (1972, 1977) and Bentle et al.'s (1981) methods. It inflated the measurement of DNA concentration in Karsten and Wollenberger's (1972, 1977) method by a factor of 4 to 5 and deflated RNA concentration by a factor of 1 to 3. This produced RNA-DNA ratios for this method that were at least 4 to 15 times lower than the other two methods.

There are several possible mechanisms of quenching including inhibition of RNAse, flourescence of compounds other than nucleic acids, and contamination of DNAse with RNAse. In Clemmessen's (1988) method these factors were removed by purifying the homogenized larva, by using bisbenzimidazole to measure DNA flourescence, and by not using either DNAse or RNAse. Although purification was not part of Bentle et al.'s (1981) method, inhibition of RNAse or residual flourescence would not have affected measurement of DNA concentration because it was measured by adding DNAse to the homogenate. However, it would have affected measurement of RNA concentration. Regardless of the mechanism of quenching, the result would be the same - the production of a block of unexplained flourescence that must be added or subtracted from RNA or DNA. The amount of flourescence remaining after the addition of both DNAse and RNAse was measured in the 30 larvae processed with Bentle et al.'s (1981) method. Expressed as a percentage of total flourescence for nucleic acids for each fish, it ranged from 40 to 72.4% with a mean of 60.8% (SD = 8.4). It was not significantly correlated with larval length, RNA and DNA concentrations or the ratio of RNA to DNA concentration. It was not possible to compare background flourescence between yolked and non-yolked larvae because only one of the 30 larvae was yolked. However, equations (A1) to (A3) clearly show that yolk was an important source of background flourescence.

Accuracy of Methods

Clemmessen's (1988) method was the most accurate method and Karsten and Wollenberger's (1972, 1977) method was the least accurate method. Over 50% of the RNA-DNA ratios estimated with Karsten and Wollenberger's (1972, 1977) method were below 1.0. These ratios are too low to be acceptable because they indicate massive starvation, a phenomenon that is not compatible with the results of the other two methods of nucleic acid analysis, or with other evidence on growth and condition collected in this study, or with the fact that some of the 'starving' fish

were over 15 mm long. Such large larvae were unlikely to be starving given the relatively high prey concentrations measured in Prince William Sound, and given the fact that the larvae were large enough to have successfully ascended the learning curve for foraging. The primary cause of the low ratios measured by Karsten and Wollenberger's (1972, 1977) method was an overestimation of DNA concentration by a factor of 4 to 5 times. The secondary cause was an underestimation of RNA concentration by a factor of 1 to 3 times.

The difference in accuracy is calculated from equation (A3): for an 8.0 mm long larvae with no yolk sac the mean ln(RNA-DNA ratio) was 0.549 for Karsten and Wollenberger's (1972, 1977) method, 4.041 for Bentle et al.'s (1981) method and 6.576 for Clemmessen's (1988) method. Thus Clemmessen's (1988) method is 12.0 times more accurate than Karsten and Wollenberger's (1972, 1977) method and 1.63 times more accurate than Bentle et al.'s (1981) method.

Precision of Methods

Clemmessen's (1988) method is more precise than Bentle et al.'s (1981) method, and both are much more precise than Karsten and Wollenberger's (1972, 1977) method. This rank order was based on the standard error (SE) of the intercept of a separate linear regression of ln(RNA-DNA ratio) on ln(weight) for each method. The SE was 0.4417, 0.4887 and 0.7939 for Clemmessen's (1988), Bentle et al.'s (1981) and Karsten and Wollenberger's (1972, 1977) method, respectively. This is shown graphically in Fig. A2; the scatter of ln(RNA-DNA ratio) about the regression model was least for Clemmessen's (1988) method and most for Karsten and Wollenberger's (1972, 1977) method.

Correction of RNA-DNA Ratios

The relatively high r^2 of equations (A1) and (A2) makes it possible to correct the RNA and DNA concentrations measured with Karsten and Wollenberger's (1972, 1977) method and Bentle et al.'s (1981) method to values approximating those that would have been measured if Clemmessen's (1988) method had been used on all larvae. Correction factors for DNA and RNA concentrations were calculated from the coefficients of equations (A1) and (A2) and are shown in Table A3. The corrected RNA-DNA ratios were then calculated from the corrected concentrations.

RNA-DNA ratios of yolk sac larvae were corrected using the same factors used for non yolk sac larvae.

TABLE A3

Factors for correcting RNA and DNA concentrations measured with Karsten and Wollenberger's (1972, 1977) and Bentle et al.'s (1981) methods. The factor is multiplied by the original measurement to obtain the corrected measurement.

Method	DNA	RNA
Karsten and Wollenberger (1972, 1977)	0.2056	$12.1472W^{-0.3512}$
Bentle et al. (1981)	0.7009	$1.2015W^{0.0469}$

Note: W = larval dry weight.

Appendix B. Corrections of Herring Density for Net Avoidance

It is well known that fish larvae evade towed plankton nets and that evasion increases with increasing size of larvae (Smith and Richardson 1977). Therefore, although newly-hatched herring larvae are probably completely vulnerable to capture with the 60 cm diameter bongo nets used in this study, the densities of larger larvae must be corrected for evasion.

Night/day catch ratios are not available for this study because no night catches were taken in Prince William Sound. McGurk (1989a) reported night/day catch ratios for Pacific herring larvae from Bamfield Inlet, B.C., but it is uncertain whether they are applicable to this study because they were based on catches taken with a different kind of gear: a 40 cm diameter bongo net with 471 μm mesh. There is also some question whether night/day catch ratios are sufficient to account for all evasion because avoidance of nets by large Pacific herring larvae occurs at night as well as during the day (McGurk 1989a).

In this report, I adopted the method used by Ware and Lambert (1985) to correct the densities of Atlantic mackerel, Scomber scombrus, larvae for net evasion. This method is based on a model of the probability of capture, p, proposed by Clutter and Anraku (1968)

$$(B1)\quad p = 1 - \frac{1}{\pi}\left[\frac{a}{R^2}(R^2 - a^2/4)^{1/2} + 2R^2\sin^{-1}(a/2R))\right]$$

where R = radius of net (mm) and a = distance (mm) a larva moves between the time it reacts to a net and the time the net reaches its plane. This distance is the product of the escape speed of a larva, U_{max} ($mm.s^{-1}$), and the time it has to avoid the net, t_r (s), once it has detected it, i.e.

$$(B2)\quad a = t_r U_{max}.$$

Escape Speed of Herring Larvae

U_{max} of Atlantic herring larvae increases with larval size and water temperature, and it follows a dome-shaped relationship with number of days of starvation, increasing over the first four days of starvation and then decreasing afterward (Bailey 1984, Bailey and Batty 1984, Yin and Blaxter 1987). Preliminary multiple regression analysis showed significant differences between these three sets of data which were correlated with temperature. However, the escape speeds predicted by this analysis for temperatures below 9°C were too low to be realistic, indicating that the speed-temperature relationship developed from the narrow temperature range of 9-11°C could not be extrapolated to the relatively low temperatures of 5-7°C measured in Prince Wiliam Sound. Therefore, we adopted the method used by Ware and Lambert (1985): the length-and starvation-dependence of escape speed was estimated from one set of data collected at one temperature, and then an assumed Q_{10} rate was used to extrapolate a temperature effect.

Yin and Blaxter (1987) reported the most complete set of escape speeds of Atlantic herring larvae (Table B1). Multiple regression showed that 71% of the variance in U_{max} ($mm \cdot s^{-1}$) could be explained by

(B3a)	$\ln(U_{max}) =$	1.4694 +	1.1499ln(L) -	$2.36 \times 10^{-3} N_s^2$
	(SE)	(0.2469)	(0.1000)	(0.548×10^{-3})
	(P)	(<0.0001)	(<0.0001)	(0.0001)

or

(B3b) $U_{max} = 4.35\exp(-2.36 \times 10^{-3} n_s^2) L^{1.15}$

where L = length (mm) of larvae and n_s = duration (d) of period of starvation.

Table B1.

Mean effective escape speeds of Atlantic herring larvae reported by Yin and Blaxter (1987). Water temperature was 8-9°C. Stimulus for escape was either the touch of a wire probe or an attempt to suck them into a glass pipette.

	Stimulus = probe		Stimulus = pipette	
Length (mm)	Escape speed ($mm.s^{-1}$)	Number of days starved	Escape speed ($mm.s^{-1}$)	Number of days starved
8.0	54	0	57	0
8.3	55	2	59	2
8.6	59	4	65	4
8.7	54	8	57	8
8.7	40	10	48	10
8.7			45	12
8.8	55	6	58	6
9.1	29	0		
9.4	44	0	57	0
9.7	53	0	65	0
10.0	58	2	67	2
10.2	66	4	72	4
10.3	50	6	55	6
10.3			37	14
10.4	51	8	61	8
10.4	43	10	51	10
10.4	19	12	48	12
13.4	52	0	67	0
14.5	76	2	91	2
14.5	82	4	100	4
14.5	81	6	95	6
14.5	72	8	91	8
14.5	55	10	80	10
14.5	50	12	76	12
19.0	106	2	138	2
19.0	126	4	144	4
19.0	121	6	141	6
19.0	117	8	134	8
19.0	111	11	118	11
19.0	90	13	109	13

If a Q_{10} of 2 is assumed, then the intercept is doubled from 4.35 to 8.69. A two-point regression describes this increase as

(B4) intercept = $2.37\exp(0.066T)$

where T = temperature (^{o}C). Substituting equation (B4) into equation (B3b) gives

(B5) $U_{max} = 2.37\exp(0.066T - 2.36\times10^{-3}n_s^2)L^{1.15}$.

Time to React

Ware and Lambert (1985) argued that fish larvae probably react to pressure waves extending up to 1.5 m in front of a towed net. Therefore, t_r should be independent of the size of fish. If a net is towed at a speed of 1-3 $m{\cdot}s^{-1}$, then t_r should be approximately 1-2 s. A more accurate way of calculating t_r is to note that p goes to zero as a approaches the diameter of the net (= 2R) (Ware and Lambert 1985). Thus,

(B6a) $2R = t_rU(L_{max})$

where $U(L_{max})$ = escape speed for L_{max}, the length (mm) of the largest larvae captured in the study, and

(B6b) $t_r = 2R/U(L_{max})$.

Examination of the catch curve for the pooled samples of this study shows that L_{max} was about 24 mm (Fig. B1). The average water temperature during the study was $6.9^{o}C$, and all large larvae are assumed to be successfully feeding, i.e. $n_s=0$. Therefore, U_{max} predicted from equation (B5) is 145 $mm{\cdot}s^{-1}$, and t_r is predicted from equation (B6b) to be 4 s. This value of t_r was used in all corrections of larval densities. Table B2 shows that the correction factors (=1/p) calculated from equation (B1) ranged from 1.2 in newly-hatched larvae to 1.5 in large larvae.

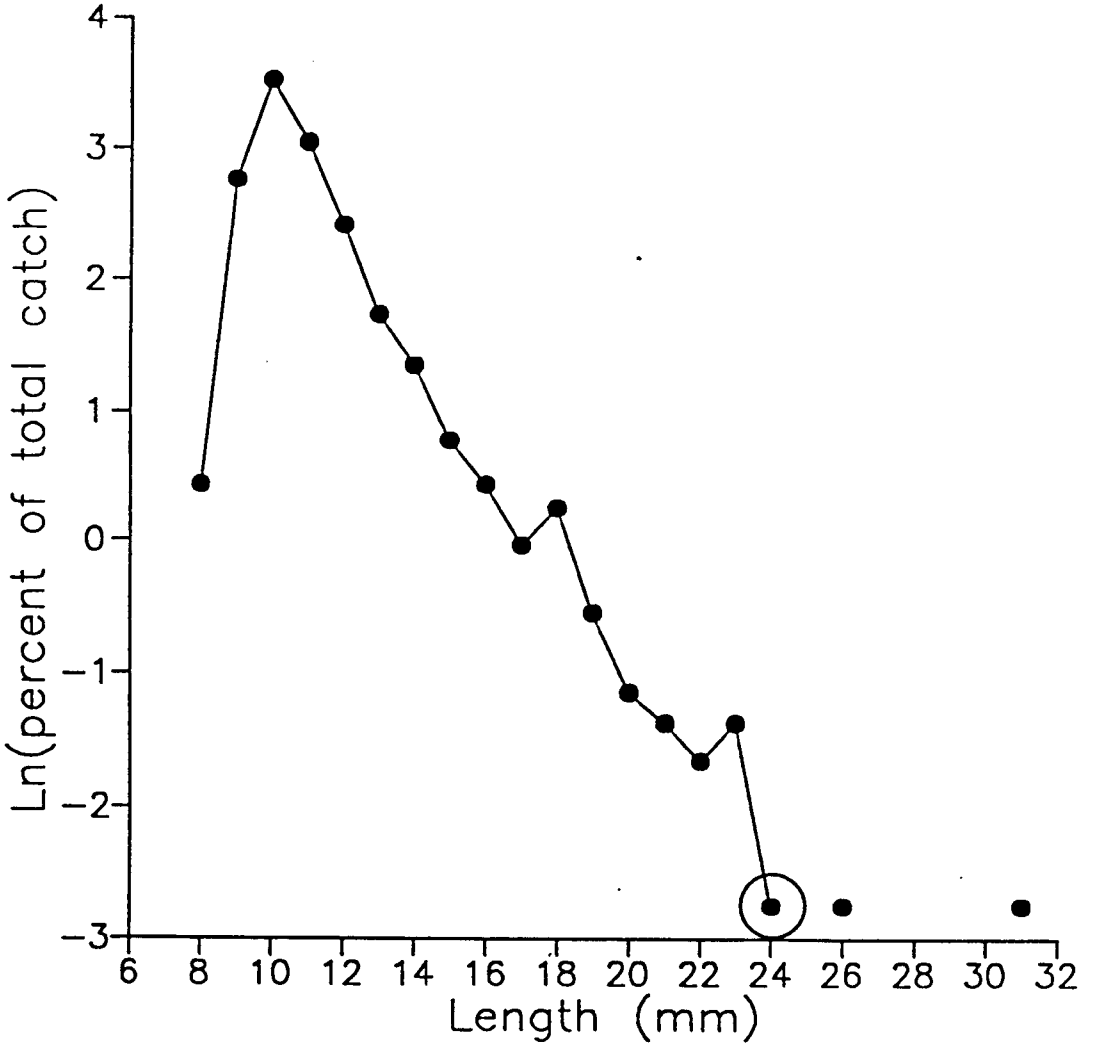

Figure B1. Catch curve of herring larvae, combining all samples. The circled point is L_{max}, the largest larvae that could be captured. Larvae longer than L_{max} were incidental catches.

Table B2. Number and density of herring larvae in Prince William Sound in 1989.

Date	Cohort 1				Cohort 2				Cohort 3				Total	
	no. larvae	density (m^-3)	evasion factor	adjusted density (m^-3)	no. larvae	density (m^-3)	evasion factor	adjusted density (m^-3)	no. larvae	density (m^-3)	evasion factor	adjusted density (m^-3)	no. larvae	density (m^-3)
Bass Harbor														
3-May-89	0	0.000	-	0.000	209	1.335	1.1925	1.592	0	0.000	-	0.000	209	1.335
3-May-89	0	0.000	-	0.000	142	0.663	1.1925	0.791	0	0.000	-	0.000	142	0.663
12-May-89	0	0.000	-	0.000	16976	143.532	1.2299	176.523	0	0.000	-	0.000	16976	143.532
21-May-89	0	0.000	-	0.000	654	3.340	1.2795	4.273	0	0.000	-	0.000	654	3.340
21-May-89	0	0.000	-	0.000	1018	4.522	1.2795	5.786	0	0.000	-	0.000	1018	4.522
29-May-89	0	0.000	-	0.000	58	0.350	1.3721	0.480	0	0.000	-	0.000	58	0.350
29-May-89	0	0.000	-	0.000	11	0.104	1.3721	0.143	0	0.000	-	0.000	11	0.104
8-Jun-89	0	0.000	-	0.000	0	0.000	1.3251	0.000	0	0.000	-	0.000	0	0.000
8-Jun-89	0	0.000	-	0.000	1	0.005	1.3251	0.007	0	0.000	-	0.000	1	0.005
13-Jun-89	0	0.000	-	0.000	3	0.016	1.4172	0.023	2	0.013	1.34895	0.017	5	0.032
13-Jun-89	0	0.000	-	0.000	2	0.013	1.4172	0.019	2	0.013	1.34895	0.018	4	0.027
21-Jun-89	0	0.000	-	0.000	0	0.000	1.4431	0.000	1	0.008	1.43746	0.011	1	0.008
21-Jun-89	0	0.000	-	0.000	1	0.006	1.4431	0.009	2	0.013	1.43746	0.018	3	0.019
Fairmount Island														
2-May-89	0	0.000	-	0.000	1534	9.964	1.2103	12.059	0	0.000	-	0.000	1534	9.964
2-May-89	0	0.000	-	0.000	1221	6.005	1.2103	7.267	0	0.000	-	0.000	1221	6.005
12-May-89	0	0.000	-	0.000	46288	365.709	1.23595	451.998	0	0.000	-	0.000	46288	365.709
21-May-89	0	0.000	-	0.000	6112	44.359	1.28415	56.964	0	0.000	-	0.000	6112	44.359
29-May-89	0	0.000	-	0.000	262	1.700	1.34131	2.280	29	0.189	1.23522	0.233	291	1.889

Table B2. Number and density of herring larvae in Prince William Sound in 1989. (Continued)

Date	Cohort 1				Cohort 2				Cohort 3				Total	
	no. larvae	density (m^-3)	evasion factor	adjusted density (m^-3)	no. larvae	density (m^-3)	evasion factor	adjusted density (m^-3)	no. larvae	density (m^-3)	evasion factor	adjusted density (m^-3)	no. larvae	density (m^-3)
29-May-89	0	0.000	-	0.000	313	2.026	1.34131	2.717	35	0.225	1.23522	0.278	348	2.251
7-Jun-89	0	0.000	-	0.000	40	0.230	1.42896	0.329	136	0.771	1.27741	0.985	176	1.002
7-Jun-89	0	0.000	-	0.000	58	0.384	1.42896	0.548	196	1.285	1.27741	1.641	254	1.669
13-Jun-89	0	0.000	-	0.000	5	0.032	1.48399	0.048	5	0.032	1.31419	0.042	10	0.068
13-Jun-89	1	0.007	-	0.007	8	0.056	1.48399	0.083	8	0.056	1.31419	0.074	17	0.119
22-Jun-89	0	0.000	-	0.000	4	0.027	1.4001	0.037	3	0.020	1.48177	0.030	7	0.047
22-Jun-89	0	0.000	-	0.000	8	0.053	1.4001	0.075	6	0.040	1.48177	0.059	14	0.093
						Rocky Bay								
3-May-89	0	0.000	1.2813	0.000	2	0.007	1.18974	0.008	0	0.000	-	0.000	2	0.009
3-May-89	1	0.006	1.2813	0.007	3	0.017	1.18974	0.020	0	0.000	-	0.000	4	0.022
12-May-89	271	1.712	1.3318	2.279	26865	169.446	1.22761	208.014	0	0.000	-	0.000	27136	171.158
21-May-89	0	0.000	-	0.000	209	1.308	1.2608	1.649	0	0.000	-	0.000	209	1.308
21-May-89	0	0.000	-	0.000	341	1.530	1.2608	1.930	0	0.000	-	0.000	341	1.530
30-May-89	0	0.000	-	0.000	11	0.052	1.30454	0.068	3	0.015	1.22563	0.018	14	0.068
30-May-89	0	0.000	-	0.000	2	0.007	1.30454	0.010	0	0.000	1.22563	0.000	2	0.010
7-Jun-89	0	0.000	-	0.000	11	0.113	1.46819	0.166	6	0.061	1.26011	0.077	17	0.173
7-Jun-89	0	0.000	-	0.000	15	0.159	1.46819	0.233	8	0.085	1.26011	0.107	23	0.243
12-Jun-89	0	0.000	-	0.000	1	0.009	1.47087	0.013	0	0.000	-	0.000	1	0.009
12-Jun-89	0	0.000	-	0.000	0	0.000	-	0.000	0	0.000	-	0.000	0	0.000
21-Jun-89	0	0.000	-	0.000	0	0.000	-	0.000	0	0.000	-	0.000	0	0.000
21-Jun-89	0	0.000	-	0.000	0	0.000	-	0.000	0	0.000	-	0.000	0	0.000

Table B2. Number and density of herring larvae in Prince William Sound in 1989. (Continued)

Date	Cohort 1				Cohort 2				Cohort 3				Total	
	no. larvae	density (m^-3)	evasion factor	adjusted density (m^-3)	no. larvae	density (m^-3)	evasion factor	adjusted density (m^-3)	no. larvae	density (m^-3)	evasion factor	adjusted density (m^-3)	no. larvae	density (m^-3)
Tatitlek Narrows														
2-May-89	16176	99.269	1.2087	119.990	0	0.000	-	0.000	0	0.000	-	0.000	16176	99.269
11-May-89	20752	131.395	1.2406	163.007	0	0.000	-	0.000	0	0.000	-	0.000	20752	131.395
20-May-89	1667	7.076	1.3173	9.322	0	0.000	-	0.000	0	0.000	-	0.000	1667	7.076
30-May-89	43	0.308	1.4540	0.448	49	0.351	1.28523	0.451	0	0.000	-	0.000	92	0.659
30-May-89	31	0.259	1.4540	0.376	35	0.295	1.28523	0.379	0	0.000	-	0.000	66	0.554
7-Jun-89	2	0.010	1.4833	0.015	4	0.020	1.39868	0.027	1	0.005	1.25809	0.006	7	0.034
7-Jun-89	5	0.025	1.4833	0.038	10	0.051	1.39868	0.071	2	0.013	1.25809	0.016	17	0.089
12-Jun-89	17	0.068	1.2491	0.085	29	0.119	1.48399	0.176	4	0.017	1.3314	0.023	50	0.204
12-Jun-89	8	0.033	1.2491	0.041	14	0.058	1.48399	0.086	2	0.008	1.3314	0.011	24	0.099
20-Jun-89	0	0.000	-	0.000	2	0.017	1.46128	0.025	0	0.000	-	0.000	2	0.017
20-Jun-89	0	0.000	-	0.000	1	0.007	1.46128	0.010	0	0.000	-	0.000	1	0.007

Notes:

1. Dashes indicate data not available.

Appendix C. Non-herring Fish Larvae from Prince William Sound

C1. INTRODUCTION

Little is known of the composition of ichthyoplankton in the waters of Prince William Sound because few studies have included more than one or two stations inside the Sound and all previous plankton surveys in the Gulf of Alaska, except for Kendall and Dunn (1985), have treated ichthyoplankton as a secondary objective. This appendix reports the abundance and taxonomic composition of larval fishes that were captured at four sites in Prince William Sound as part of the herring larval survey. It uses this data to test for possible effects of oil on the abundance of non-herring fish larvae. The working hypothesis is that the two oiled sites (Bass Harbor and Rocky Bay) had lower numbers and diversity than the two control sites (Fairmount Island and Tatitlek Narrows).

C2. METHODS

Fish larvae were sorted from the formalin-preserved samples taken with the 333 and 505 μm mesh bongo nets. Fish eggs were not separated from the plankton or identified. Larvae were identified to the species/family level with the use of a laboratory guide (Matarese et al. 1986) and by consultation with J. Marliave (Vancouver Public Aquarium, Vancouver, B.C., Canada) and A. Kendall (Northwest and Alaska Fisheries Center, NMFS, NOAA, Seattle, WA).

C3. RESULTS AND DISCUSSION

C3.1 Total Numbers

The plankton samples contained 5,482 non-herring fish larvae distributed among 28 species and 12 families (Table C1). Walleye pollock, Theragra chalcogramma, made up 76.5% of the total number of non-herring fish larvae followed by capelin, Mallotus villosus (8.6%), flathead sole, Hippoglossoides elassodon (4.8%), northern smoothtongue, Leuroglossus schmidtii (3.2%), and starry flounder, Platichthys stellatus (2.0%) (Fig. C1). The remaining 23 species each made up less than 1% of the total number. Except for the ubiquity of walleye pollock, this rank ordering does not resemble any of the recurrent groups found on the continental shelf of Kodiak

Table C1. Non-herring larvae.

Date	Site	Microstomas pacificus		Hippoglossoides elassodon		Isopsetta isolepis		Lepidopsetta bilineata		Parophrys vetulus		Platichthys stellatus	
		no.	density (m^-3)	no.	density (m^3)	no.	density (m^-3)	no.	density (m^-3)	no.	density (m^-3)	no.	density (m^-3)
3-May-89	Bass Harbour	-	-	1	0.006	-	-	-	-	-	-	-	-
12-May-89	Bass Harbour	-	-	-	-	-	-	-	-	-	-	-	-
21-May-89	Bass Harbour	1	0.005	8	0.041	-	-	-	-	-	-	9	0.046
29-May-89	Bass Harbour	-	-	1	0.006	-	-	-	-	-	-	-	-
8-Jun-89	Bass Harbour	-	-	1	0.005	-	-	-	-	-	-	-	-
13-Jun-89	Bass Harbour	-	-	-	-	-	-	-	-	-	-	-	-
21-Jun-89	Bass Harbour	-	-	-	-	-	-	-	-	-	-	-	-
	SUM	1	0.005	11	0.059	0	0.000	0	0.000	0	0.000	9	0.046
2-May-89	Fairmount Island	-	-	1	0.005	-	-	2	0.010	-	-	1	0.005
12-May-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	-	-
21-May-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	-	-
29-May-89	Fairmount Island	-	-	1	0.006	-	-	-	-	-	-	-	-
7-Jun-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	-	-
13-Jun-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	-	-
22-Jun-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	-	-
	SUM	0	0.000	2	0.011	0	0.000	2	0.010	0	0.000	1	0.005
3-May-89	Rocky Bay	-	-	5	0.028	-	-	4	0.022	-	-	-	-
12-May-89	Rocky Bay	-	-	48	0.303	16	0.101	-	-	-	-	-	-
21-May-89	Rocky Bay	-	-	9	0.040	-	-	-	-	-	-	-	-
30-May-89	Rocky Bay	-	-	4	0.019	-	-	-	-	-	-	-	-
7-Jun-89	Rocky Bay	-	-	2	0.021	-	-	-	-	-	-	-	-
12-Jun-89	Rocky Bay	-	-	-	-	-	-	-	-	-	-	-	-
21-Jun-89	Rocky Bay	-	-	-	-	-	-	-	-	-	-	-	-
	SUM	0	0.000	68	0.411	16	0.101	4	0.022	0	0.000	0	0.000
2-May-89	Tatitlek Narrows	-	-	96	0.589	-	-	-	-	-	-	96	0.589
11-May-89	Tatitlek Narrows	-	-	64	0.405	-	-	16	0.101	-	-	-	-
20-May-89	Tatitlek Narrows	-	-	21	0.089	-	-	6	0.025	-	-	1	0.004
30-May-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	3	0.022
7-Jun-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-
12-Jun-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-
20-Jun-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	1	0.007	-	-
	SUM	0	0.000	181	1.084	0	0.000	22	0.127	1	0.007	100	0.615
	GRAND SUM	1		262		16		28		1		110	

Table C1. Non-herring larvae.

Date	Site	Stenobrachius leucopsarus		Anoplarchus purpurescens		Lumpenus sagitta		Stichaeus punctatus		Xiphister atropurpureus		Sebastes spp. 1	
		no.	density (m^-3)	no.	density (m^-3)	no.	density (m^-3)	no.	density (m^-3)	no.	density (m^-3)	no.	density (m^-3)
3-May-89	Bass Harbour	-	-	-	-	-	-	-	-	-	-	-	-
12-May-89	Bass Harbour	-	-	-	-	-	-	-	-	-	-	-	-
21-May-89	Bass Harbour	1	0.005	-	-	-	-	-	-	1	0.005	-	-
29-May-89	Bass Harbour	-	-	-	-	-	-	-	-	-	-	1	0.006
8-Jun-89	Bass Harbour	-	-	-	-	-	-	-	-	-	-	4	0.021
13-Jun-89	Bass Harbour	-	-	-	-	-	-	-	-	-	-	28	0.186
21-Jun-89	Bass Harbour	-	-	-	-	-	-	-	-	-	-	5	0.032
	SUM	1	0.005	0	0.000	0	0.000	0	0.000	1	0.005	38	0.244
2-May-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	-	-
12-May-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	-	-
21-May-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	-	-
29-May-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	-	-
7-Jun-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	-	-
13-Jun-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	1	0.007
22-Jun-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	-	-
	SUM	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	1	0.007
3-May-89	Rocky Bay	-	-	-	-	-	-	-	-	-	-	-	-
12-May-89	Rocky Bay	-	-	-	-	-	-	-	-	-	-	-	-
21-May-89	Rocky Bay	-	-	1	0.004	2	0.009	2	0.009	-	-	-	-
30-May-89	Rocky Bay	-	-	-	-	-	-	-	-	-	-	-	-
7-Jun-89	Rocky Bay	1	0.011	-	-	-	-	-	-	-	-	-	-
12-Jun-89	Rocky Bay	-	-	-	-	-	-	-	-	-	-	-	-
21-Jun-89	Rocky Bay	-	-	-	-	-	-	-	-	-	-	1	0.009
	SUM	1	0.011	1	0.004	2	0.009	2	0.009	0	0.000	1	0.009
2-May-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-
11-May-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-
20-May-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-
30-May-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-
7-Jun-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-
12-Jun-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-
20-Jun-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	5	0.033
	SUM	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	5	0.033
	GRAND SUM	2		1		2		2		1		45	

Table C1. Non-herring larvae.

Date	Site	Sebastes spp. 2		Sebastes spp. 3		Artedius fenestralis		Artedius harringtoni		Artedius meanyi		Clinocottus acuticeps		Malacocottus zonurus	
		no.	density (m^-3)	no.	density (m^-3)	no.	density (m^-3)	no.	density (m^-3)	no.	density (m^-3)	no.	density (m^-3)	no.	density (m^-3)
3-May-89	Bass Harbour	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-May-89	Bass Harbour	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-89	Bass Harbour	1	0.005	-	-	-	-	-	-	-	-	-	-	-	-
29-May-89	Bass Harbour	-	-	-	-	-	-	-	-	1	0.006	-	-	-	-
8-Jun-89	Bass Harbour	-	-	-	-	-	-	-	-	7	0.037	-	-	-	-
13-Jun-89	Bass Harbour	-	-	-	-	4	0.027	2	0.013	7	0.046	-	-	-	-
21-Jun-89	Bass Harbour	1	0.006	1	0.006	-	-	-	-	4	0.025	-	-	-	-
	SUM	2	0.011	1	0.006	4	0.027	2	0.013	19	0.115	0	0.000	0	0.000
2-May-89	Fairmount Island	-	-	-	-	-	-	-	-	1	0.005	-	-	1	0.005
12-May-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-89	Fairmount Island	3	0.022	-	-	-	-	-	-	2	0.015	-	-	-	-
29-May-89	Fairmount Island	11	0.071	-	-	2	0.013	1	0.006	-	-	-	-	2	0.013
7-Jun-89	Fairmount Island	6	0.039	1	0.007	-	-	2	0.013	-	-	-	-	-	-
13-Jun-89	Fairmount Island	3	0.021	-	-	-	-	-	-	-	-	-	-	-	-
22-Jun-89	Fairmount Island	6	0.040	-	-	-	-	-	-	-	-	-	-	-	-
	SUM	29	0.193	1	0.007	2	0.013	3	0.020	3	0.019	0	0.000	3	0.018
3-May-89	Rocky Bay	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12-May-89	Rocky Bay	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21-May-89	Rocky Bay	1	0.004	-	-	1	0.004	1	0.004	2	0.009	-	-	-	-
30-May-89	Rocky Bay	-	-	-	-	-	-	-	-	2	0.010	-	-	-	-
7-Jun-89	Rocky Bay	6	0.063	-	-	-	-	-	-	3	0.032	1	0.011	-	-
12-Jun-89	Rocky Bay	-	-	-	-	-	-	-	-	2	0.018	-	-	-	-
21-Jun-89	Rocky Bay	-	-	-	-	-	-	1	0.009	3	0.028	-	-	-	-
	SUM	7	0.068	0	0.000	1	0.004	2	0.014	12	0.096	1	0.011	0	0.000
2-May-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11-May-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	16	0.101	-	-	-	-
20-May-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30-May-89	Tatitlek Narrows	3	0.022	-	-	-	-	-	-	-	-	-	-	-	-
7-Jun-89	Tatitlek Narrows	-	-	-	-	2	0.010	1	0.005	3	0.015	1	0.005	-	-
12-Jun-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20-Jun-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SUM	3	0.022	0	0.000	2	0.010	1	0.005	19	0.116	1	0.005	0	0.000
	GRAND SUM	41		2		9		8		53		2		3	

Table C1. Non-herring larvae.

Date	Site	Nautichthys oculofasciatus no.	Nautichthys oculofasciatus density (m^-3)	Radulinus spp. no.	Radulinus spp. density (m^-3)	Agonid spp. no.	Agonid spp. density (m^-3)	Ammodytes hexapterus no.	Ammodytes hexapterus density (m^-3)	Leuroglossus schmidti no.	Leuroglossus schmidti density (m^-3)	Bathymaster spp. no.	Bathymaster spp. density (m^-3)
3-May-89	Bass Harbour	-	-	1	0.006	-	-	2	0.013	-	-	-	-
12-May-89	Bass Harbour	-	-	-	-	-	-	-	-	-	-	-	-
21-May-89	Bass Harbour	-	-	1	0.005	1	0.005	-	-	2	0.010	2	0.010
29-May-89	Bass Harbour	-	-	-	-	-	-	-	-	4	0.024	1	0.006
8-Jun-89	Bass Harbour	-	-	-	-	-	-	-	-	3	0.016	2	0.011
13-Jun-89	Bass Harbour	-	-	1	0.007	-	-	-	-	3	0.020	-	-
21-Jun-89	Bass Harbour	-	-	2	0.013	-	-	-	-	1	0.006	-	-
	SUM	0	0.000	5	0.031	1	0.005	2	0.013	13	0.076	5	0.027
2-May-89	Fairmount Island	-	-	-	-	1	0.005	-	-	92	0.452	-	-
12-May-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	-	-
21-May-89	Fairmount Island	-	-	2	0.015	-	-	-	-	28	0.203	-	-
29-May-89	Fairmount Island	-	-	-	-	-	-	-	-	14	0.091	-	-
7-Jun-89	Fairmount Island	-	-	-	-	-	-	-	-	13	0.085	4	0.026
13-Jun-89	Fairmount Island	-	-	-	-	-	-	-	-	-	-	1	0.007
22-Jun-89	Fairmount Island	-	-	-	-	-	-	-	-	3	0.020	10	0.067
	SUM	0	0.000	2	0.015	1	0.005	0	0.000	150	0.852	15	0.100
3-May-89	Rocky Bay	-	-	1	0.006	-	-	-	-	2	0.011	-	-
12-May-89	Rocky Bay	-	-	-	-	-	-	-	-	-	-	-	-
21-May-89	Rocky Bay	-	-	1	0.004	-	-	-	-	-	-	-	-
30-May-89	Rocky Bay	1	0.005	-	-	-	-	-	-	-	-	-	-
7-Jun-89	Rocky Bay	-	-	1	0.011	-	-	-	-	-	-	-	-
12-Jun-89	Rocky Bay	-	-	-	-	-	-	-	-	-	-	-	-
21-Jun-89	Rocky Bay	-	-	-	-	1	0.009	-	-	-	-	1	0.009
	SUM	1	0.005	3	0.021	1	0.009	0	0.000	2	0.011	1	0.009
2-May-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-
11-May-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-
20-May-89	Tatitlek Narrows	-	-	2	0.008	1	0.004	3	0.013	6	0.025	-	-
30-May-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	1	0.007	-	-
7-Jun-89	Tatitlek Narrows	-	-	-	-	1	0.005	-	-	1	0.005	-	-
12-Jun-89	Tatitlek Narrows	-	-	-	-	-	-	-	-	-	-	-	-
20-Jun-89	Tatitlek Narrows	-	-	-	-	1	0.007	-	-	-	-	1	0.007
	SUM	0	0.000	2	0.008	3	0.016	3	0.013	8	0.038	1	0.007
	GRAND SUM	1		12		6		5		173		22	

Table C1. Non-herring larvae.

Date	Site	Theragra chalcogramma no.	Theragra chalcogramma density (m^-3)	Liparis spp. no.	Liparis spp. density (m^-3)	Mallotus spp. no.	Mallotus spp. density (m^-3)
3-May-89	Bass Harbour	204	1.303	-	-	-	-
12-May-89	Bass Harbour	16	0.135	-	-	-	-
21-May-89	Bass Harbour	17	0.087	-	-	-	-
29-May-89	Bass Harbour	5	0.030	-	-	-	-
8-Jun-89	Bass Harbour	-	-	-	-	1	0.005
13-Jun-89	Bass Harbour	-	-	1	0.007	7	0.046
21-Jun-89	Bass Harbour	-	-	-	-	108	0.685
	SUM	242	1.555	1	0.007	116	0.736
2-May-89	Fairmount Island	661	3.251	-	-	-	-
12-May-89	Fairmount Island	80	0.632	-	-	-	-
21-May-89	Fairmount Island	9	0.065	1	0.007	-	-
29-May-89	Fairmount Island	-	-	-	-	-	-
7-Jun-89	Fairmount Island	-	-	-	-	-	-
13-Jun-89	Fairmount Island	12	0.084	1	0.007	4	0.028
22-Jun-89	Fairmount Island	-	-	-	-	14	0.093
	SUM	762	4.032	2	0.014	18	0.121
3-May-89	Rocky Bay	167	0.920	-	-	-	-
12-May-89	Rocky Bay	304	1.917	-	-	-	-
21-May-89	Rocky Bay	26	0.117	-	-	-	-
30-May-89	Rocky Bay	5	0.024	-	-	-	-
7-Jun-89	Rocky Bay	2	0.021	-	-	-	-
12-Jun-89	Rocky Bay	-	-	1	0.009	1	0.009
21-Jun-89	Rocky Bay	-	-	-	-	328	3.097
	SUM	504	3.000	1	0.009	329	3.105
2-May-89	Tatitlek Narrows	1728	10.604	-	-	-	-
11-May-89	Tatitlek Narrows	304	1.925	-	-	-	-
20-May-89	Tatitlek Narrows	538	2.284	-	-	-	-
30-May-89	Tatitlek Narrows	96	0.688	-	-	-	-
7-Jun-89	Tatitlek Narrows	20	0.098	-	-	-	-
12-Jun-89	Tatitlek Narrows	2	0.008	-	-	1	0.004
20-Jun-89	Tatitlek Narrows	-	-	-	-	10	0.066
	SUM	2688	15.607	0	0.000	11	0.070
	GRAND SUM	4196		4		474	

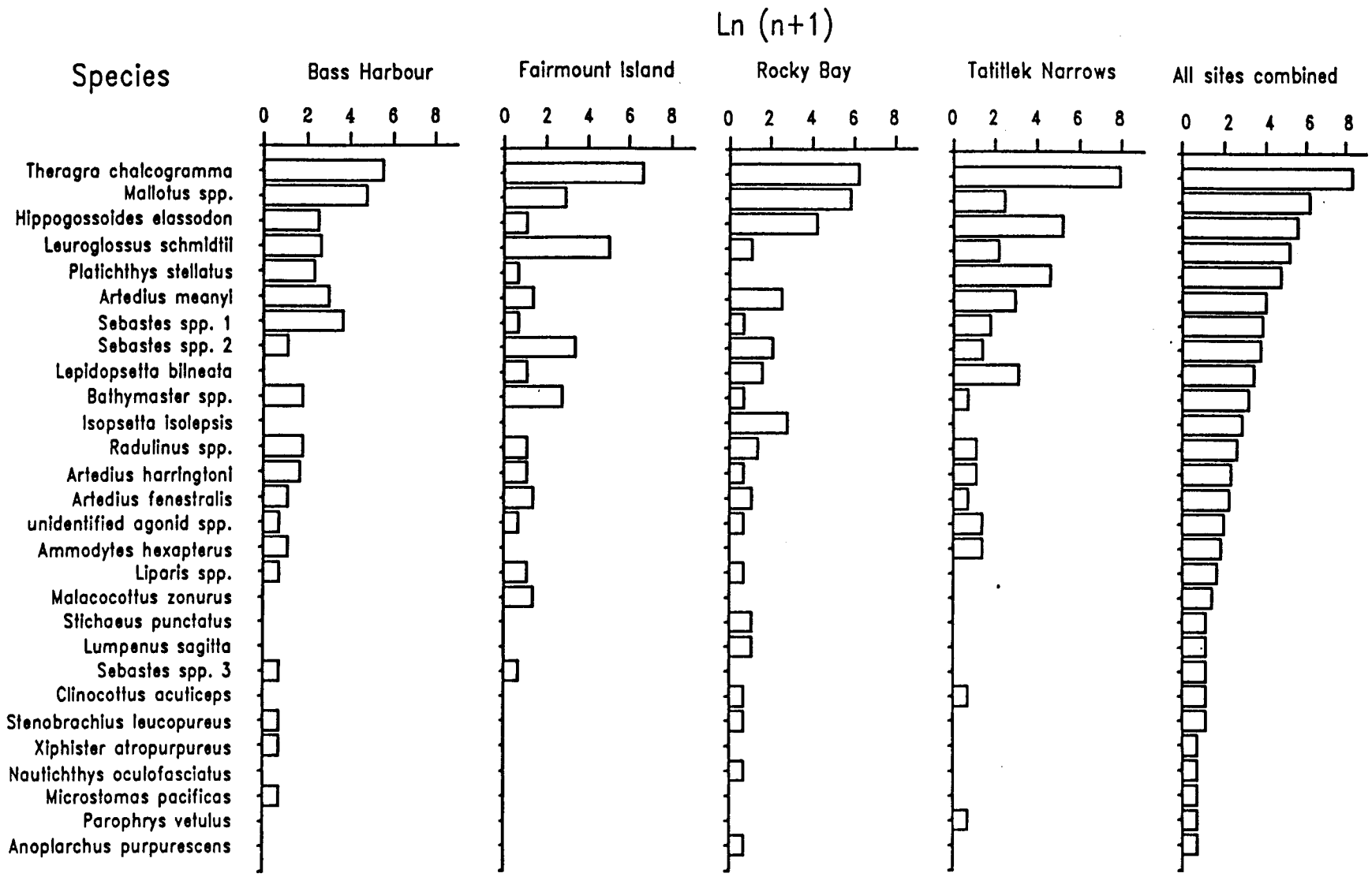

Figure C1. Total number of non-herring fish larvae ranked in decreasing order by site and species.

Island by Kendall and Dunn (1985). The reasons may be related to biophysical factors of Prince William Sound or to the relatively short duration of the sampling period.

Comparisons of total larval abundance between the four sites show that there is little evidence for an oil-related effect on larval abundance or diversity (Fig. C1). Over half (3,051 or 55.7%) of all non-herring fish larvae were captured at Tatitlek Narrows; Fairmount Island and Rocky Bay had similar numbers: 997 (18.2%) and 960 (17.5%), respectively; and Bass Harbor had only 474 (8.6%). However, this rank ordering is due entirely to the fact that pollock made up 88% of all non-herring fish larvae at Tatitlek Narrows. When pollock larvae are removed the rank ordering is: Rocky Bay (456), Tatitlek Narrows (363), Fairmount Island (235) and Bass Harbor (232).

C3.2 Seasonal Change in Number and Density

Comparisons of changes in total larval numbers with date do not support the hypothesis of an oil effect. Regression analysis showed that the total number of non-herring fish larvae decreased at a daily instantaneous rate of 0.05 d^{-1} ($n = 28$, $r^2 = 0.32$, $P<0.001$) from May 1 to June 22, but that this trend was due entirely to the loss of pollock larvae from Tatitlek Narrows. If pollock were excluded, there was no significant ($P>0.05$) correlation between total numbers of larvae and Julian date.

Two species of fish larvae, walleye pollock and northern smoothtongue, were sufficiently abundant to allow a comparison of their seasonal dynamics at each of the four sites. Covariance analysis was used to test for differences between sites in the intercept and slope of linear regressions of ln(density) on Julian date. Zero densities were excluded because they were not true zeros, but probably represented densities too low to be measured by the bongo nets.

The regression model that explained the most variance (r^2 = 0.77, n = 19) in walleye pollock densities with all significant (0.0001<P<0.01) parameters was

(C1) ln(N) =	15.5567 +	$1.6402g_4$ -	0.1236D
(SE)	(2.4527)	(0.5135)	(0.0175)

where N = density (m^{-3}), g4 = dummy variable with a value of 1 for Tatitlek Narrows and 0 for the other three sites, and D = Julian date. This model shows that pollock larvae were five times more dense at Tatitlek Narrows than at any of the three other sites, but that the daily rate of loss of larvae was the same, 0.12 d^{-1}, at all four sites (Fig. C2).

Fig. C3 shows that only the densities of northern smoothtongue larvae from Fairmount Island exhibited a linear trend with date. The best-fitting regression for that site was:

(C2) $\ln(N) = 6.6206 - 0.0596D$

$r^2 = 0.96$, $0.01<P<0.05$

In summary, there is no evidence from the catch curves of walleye pollock or northern smoothtongue to support the hypothesis of an oil effect. The differences between sites in larval numbers and densities were most likely due to the presence or absence of recent hatching events, to the loss of larvae due to natural mortality, and to transport of larvae by water currents.

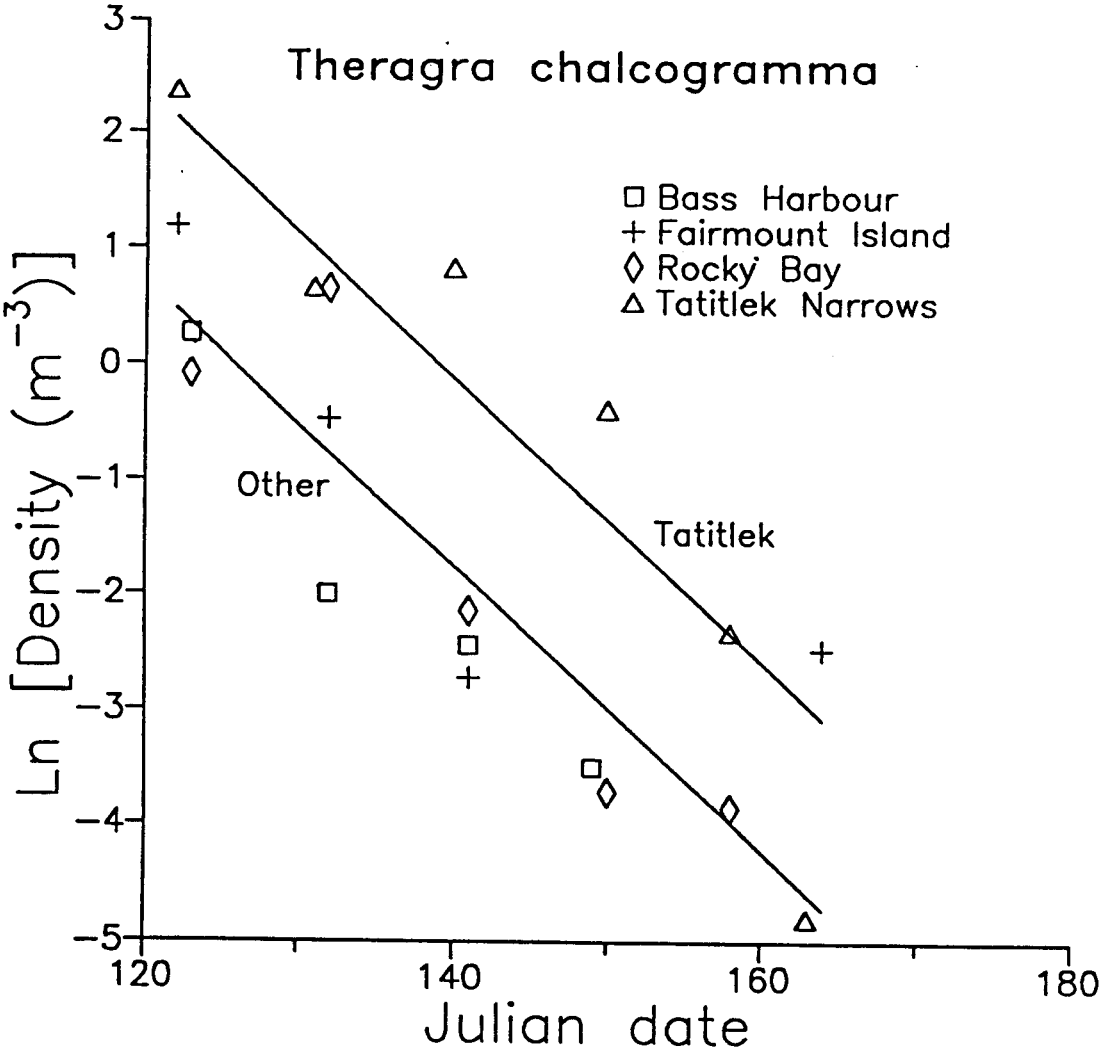

Figure C2. Catch curves of walleye pollock larvae. Highest densities were measured at Tatitlek Narrows, but the rate of loss of density was constant at 0.12 d^{-1} for all four sites. See text and equation (C1) for detail.

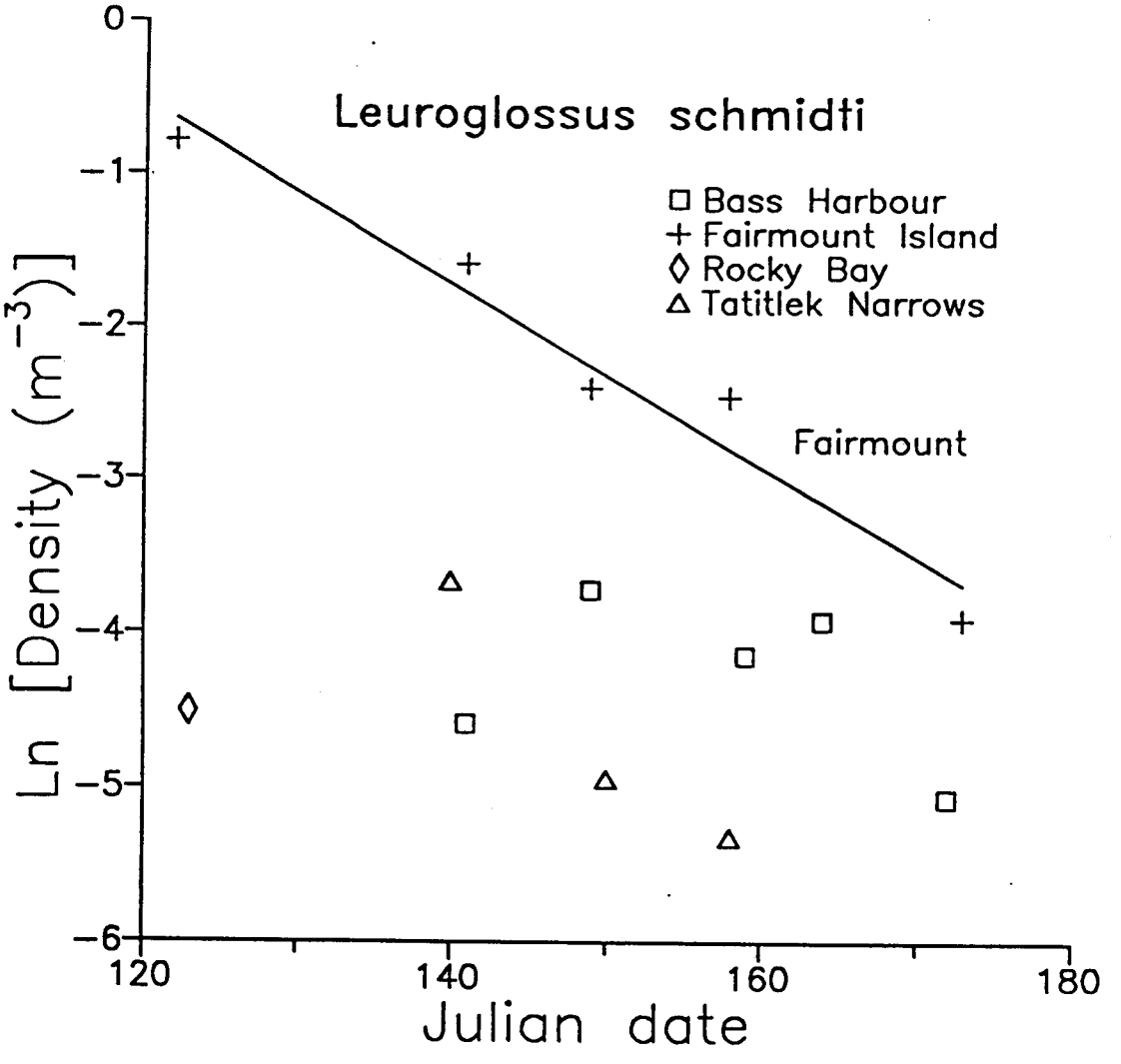

Figure C3. Catch curve of smoothtongue sole larvae. Highest densities were measured at Fairmount Island, and only Fairmount exhibited a significant loss in density with date.

ARCTIC FISH HABITAT USE INVESTIGATIONS: NEARSHORE STUDIES IN THE ALASKAN BEAUFORT SEA, SUMMER 1988

by

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ABSTRACT

During summer 1988, the Ocean Assessments Division Alaska Office conducted a nearshore fish survey in the Beaufort Sea. The primary objective of the study was to collect arctic char for genetic stock identification research being conducted for OCSEAP by the U.S. Fish and Wildlife Service (RU 682). Purse seining provided an offshore dimension to the inshore fyke-net collections by the FWS. The secondary objective of the study was to investigate habitat use by fish in the nearshore zone. A 150-m-long purse seine was the primary sampling gear used; it was supplemented with gillnet sampling when conditions did not allow seining. Hydrographic profiles obtained in conjunction with seine sets allowed investigation of fish habitat use in coastal, transitional, and marine water masses.

Over 3,500 fish were captured in combined purse seine and gillnet catches. Capelin and arctic cod were numerically dominant, occurring with greater frequency in catches from transitional waters. Anadromous species were captured in coastal waters and, of these, only arctic char and arctic cisco were collected far offshore. It appears that coastal water overlaying transitional water provides a physical habitat structure enabling char and arctic ciscoes to use the latter cooler, more saline habitat to forage on small marine fish (cods and capelin). Length frequency distributions, weight–length relationships, and condition factors (Kn) of captured fishes are presented. Stock identification analyses of arctic char collected in early August from Stefansson Sound indicated Sagavanirktok and Canning River fish to be proportionately most abundant. Arctic char from the eastern Beaufort Sea and Canada were also represented in the coastal sampling.

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INTRODUCTION

Background

In 1986 the Outer Continental Shelf Environmental Assessment Program (OCSEAP) initiated an investigation of the coastal migratory behavior of arctic char (Research Unit 682). In 1986 and 1987 the research focused on the genetic characterization of arctic char populations in North Slope drainages of Alaska and western Canada. This work was freshwater oriented and designed to determine if genetic differences between major stocks exist. Arctic char were sampled in rivers between Icy Cape (Chukchi Sea) and the Mackenzie River (Canada). Populations were abundant only in the drainages east of and including the Colville River.

Analysis for genetic similarity in the baseline samples demonstrated enough variation in certain protein structures for stock identification to river-of-origin (Everett and Wilmot 1987; Everett et al. 1988). This result led to a widespread study of coastal char migrations in 1988. The coastal study involved cooperative research between the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Fish and Wildlife Service (FWS). Tissues from the captured char would be sent to the FWS for genetic stock identification (GSI) analysis. Stock identification would be used to examine the migrations and intermixing of North Slope arctic chars during the summer months. This report describes the results of the NOAA arctic fish study; the FWS is preparing separate reports to OCSEAP on GSI objectives of the research.

Arctic char were selected for stock identification research by OCSEAP and the Minerals Management Service (MMS) because: (1) the total population size is relatively small; (2) the species may be limited in coastal range by the availability of relatively warm brackish waters; (3) the species is of subsistence and recreational value; and (4) the species had been identified as one meriting "special concern" through the Outer Continental Shelf (OCS) leasing process. The distinct character of North Slope populations suggests little straying of spawners and concomitant low interchange of genetic material among stocks. It also implies that the time required by a stock to recover from a population-level impact would be lengthened by lack of immigrant spawners from other streams. Additionally, and more germane to this report, if the river-of-origin of arctic char can be determined with a reasonable degree of confidence, stock-specific risk assessments associated with coastal developments may be possible and more cost-effective than traditional mark–recapture studies with similar objectives.

Current State of Knowledge

The development of oil fields in the Alaskan Beaufort Sea has occurred exclusively within the coastal zone. Seismic exploration for commercial offshore reserves, while possible, is limited by open water accessibility and summer sea ice conditions. Most exploration wells have been drilled in water depths less than 22 m (Padron 1988). Today,

oil production in the Endicott area of Prudhoe Bay represents the seaward extent of "offshore" activities. If oil fields are to be developed in deeper waters, their exploitation will require an improved technological capability to operate safely and economically in this ice-impacted environment (Norton and Weller 1984; Padron 1989).

Historically, most arctic fisheries research has been designed to address environmental concerns associated with leasing of state and federal lands for oil and gas exploration and development. A lack of OCS development activities in the Beaufort Sea in concert with logistical difficulties of operating in ice have delayed fishery investigations in deepwater (>50 m) habitats. Several comprehensive reviews and synthesis documents are available that describe the coastal fish community of the Beaufort Sea (Craig and McCart 1976; Barnes et al. 1984; Becker 1987; Winters et al. 1988; Meyer and Johnson 1989; Norton 1989). The literature reveals that most research has been conducted in shallow brackish waters found during summer months along the mainland coast. In areas where extensive nearshore surveys have been conducted, seasonal trends in relative abundance of dominant fish are evident. However, robust population estimates are unavailable; this lack reflects, in part, the fact that most research has been for environmental assessment rather than resource management purposes. Reliable population information will not be forthcoming without long-term commitment for research to this end.

The major environmental issues associated with exploration and development of arctic oil reserves have focused on the protection of subsistence resources and lifestyles. With the discovery of oil in Prudhoe Bay in 1968, anadromous fish species in coastal waters of the central Beaufort Sea have received much attention. Elsewhere along the coast, oil and gas exploration activities have prompted fishery investigations in the Canadian Beaufort Sea (e.g., Kendel et al. 1975; Bond 1989; Hopke 1989), and in lagoons and embayments adjacent to the Arctic National Wildlife Refuge (e.g., see Truett 1983; Fruge et al. 1989). Thus far, little research has been conducted west of Harrison Bay. In 1988, the North Slope Borough conducted a nearshore fish survey in Dease Inlet in preparation of a fishery management plan for Barrow.

The existing arctic fish database is essentially one-dimensional in space, reflecting the inshore concentration of research. Consequently, many onshore–offshore features of fish migration, habitat use, and general ecology are unknown. Only a few American studies have possessed an offshore sampling component (Craig et al. 1982; Frost and Lowry 1983; Moulton and Tarbox 1987; Houghton and Whitmus 1988; and Fruge et al. 1989) although various reports describe the results of incidental offshore fishing (e.g., Craig and Haldorson 1981). Most of these data have been incorporated into existing synthesis documents.

Most fishery sampling in the Alaskan Beaufort Sea has been done using passive gears (e.g., fyke nets and gillnets) with relatively long (12–24 hr) set periods. The resultant "time-integrated" catch data are not amenable to correlation with physical phenomena of brief temporal and small spatial scales, such as the passage of fronts, eddies, and wind-driven upwelling events, which are prevalent in North Slope coastal

waters. Such short-lived phenomena are important because they influence the local distributions, movements, and other daily activities of fish and their prey. Reliable information about the environmental history of the fish is necessary for realism in habitat preference models. If predictive models (e.g., to study population response to habitat modifications) are to be developed, a more detailed record of fish movements along known environmental gradients (e.g., thermal and salinity histories) will be required.

The Coastal Fish Community

The arctic fish community is noted for its low species diversity with many species occurring at the northern limits of their ranges. At present 62 species have been identified from the Alaskan Beaufort Sea (Craig 1984). By comparison, more than 100 species have been collected in the Canadian Arctic. More species will likely be described in Alaska when marine habitats are more thoroughly studied.

The coastal fish community can be grouped into freshwater (restricted to river estuaries), anadromous, and marine categories. In this report, we are concerned primarily with the latter two groups. Common names of fishes used herein are as reported by Bailey et al. (1970). The taxonomic status of several arctic species (and groups) remains unresolved (Craig 1989a). Of particular interest to this study, the western Arctic–Bering Sea char is thought by some to be *Salvelinus alpinus,* and others to be the northern form of Dolly Varden, *S. malma.* A recent meristic analysis of Alaskan chars by Morrow (1980) supports the latter contention.

Craig (1984) provides a list of fishes collected in the Alaskan Beaufort Sea. Arctic cod (*Boreogadus saida*), arctic flounder (*Liopsetta glacialis*), fourhorn sculpin (*Myoxocephalus quadricornis*), and Pacific herring (*Clupea harengus*) are widely distributed and abundant marine species. Sixteen species of anadromous fish are listed but only nine are described as principal species of the southern Beaufort Sea. These include: arctic char (*S. alpinus*), arctic and least ciscoes (*Coregonus autumnalis* and *C. sardinella*), broad and humpback whitefish (*C. nasus* and *C. pidschian*), inconnu (*Stenodus leucichthys*), rainbow smelt (*Osmerus mordax*), and pink and chum salmon (*Oncorhynchus gorbuscha* and *O. kisutch*).

Temporal and areal differences in the composition of coastal fish communities (i.e., species present, frequency of occurrence, size and age of species) have been commonly reported (e.g., Winters et al. 1988). These differences probably reflect local variations in species' ranges and habitats. However, it is noteworthy that several species seem to be well represented in all catches. Arctic cisco, least cisco, arctic char, fourhorn sculpin, and arctic cod composed 91–98% of the species caught at five locations along the coast between Simpson Lagoon and the Yukon Territory (Carey et al. 1987). In a fisheries study of the Canadian coast between Herschel Island and the Blow River, least cisco, arctic cisco, arctic char, fourhorn sculpin, rainbow smelt (= boreal smelt), and humpback whitefish (= lake whitefish) comprised 95% of the total catch (Kendel et al. 1975).

The results of intensive sampling conducted in the 1986 Endicott Environmental Monitoring Program identify the dominant fish of Prudhoe Bay (Glass et al. 1987). The following list shows the rank order of abundance of species in marine, anadromous, and freshwater categories and in the total catch (the arctic grayling, a freshwater species, was ranked #12 overall):

Marine		
Arctic cod	(*Boreogadus saida*)	1
Fourhorn sculpin	(*Myoxocephalus quadricornis*)	3
Saffron cod	(*Eleginus gracilis*)	4
Arctic flounder	(*Liopsetta glacialis*)	7
Snailfish	(*Liparis* spp.)	9
Capelin	(*Mallotus villosus*)	13
Anadromous		
Arctic cisco	(*Coregonus autumnalis*)	2
Least cisco	(*C. sardinella*)	5
Broad whitefish	(*C. nasus*)	6
Ninespine stickleback	(*Pungitius pungitius*)	8
Boreal/rainbow smelt	(*Osmerus mordax*)	10
Round whitefish	(*Prosopium cylindraceum*)	11
Humpback whitefish	(*C. pidschian*)	14

Irvine and Meyer (1989; Table III-7) demonstrate temporal changes in dominance of species at a given fyke net location. In Simpson Lagoon during 1977, fourhorn sculpin were heavily dominant, followed by arctic cisco and arctic cod. During 1978, arctic cod were numerical dominants and fourhorn sculpin comprised the majority of the remaining catch.

Moulton and Tarbox (1987) derived estimates of fish densities from hydroacoustic sampling at fixed locations and transects in Prudhoe Bay. In July, calculated densities were 0.7–10.5 fish/10^4 m^3. In August, mean transect densities were 55.6 fish/10^4 m^3, while fixed location densities were 15.8 fish/10^4 m^3. The range of calculated fish densities during the August survey period was 0–328.6 fish/10^4 m^3. Some indication of the variability of fish density over a few days at a given location can be derived from data presented in Moulton and Tarbox (1987; Table 2). During the period 28 August–1 September, the mean density and the standard deviation about the mean were 55.6 fish and 86.8 fish/10^4 m^3, respectively, on transect 2 ($n = 15$; total volume sampled = 49×10^4 m^3).

Marine Fishes

Some 40 species of marine fish have been collected in the Alaskan Beaufort Sea (Craig 1984). The marine fishes of the coastal waters include pelagic and benthic groups; the former are dominated by arctic cod and the latter by fourhorn sculpin and arctic flounder. Catch data suggest that the pelagic fishes are patchily distributed and often in

large schools, while the benthic fishes seem to be more uniformly dispersed. Fourhorn sculpin and arctic flounder are euryhaline and occur inshore throughout the open-water period.

Historically, fourhorn sculpin made up a large percentage of nearshore fish catches reported from Prudhoe Bay and elsewhere in the Beaufort Sea. Arctic flounder dominated catches at Beaufort Lagoon in 1982 (Griffiths 1983) and 1985 (Wiswar 1986). Gallaway and Britch (1983) noted that peak catches of arctic cod near the Sagavanirktok River delta were related to late season increases in salinity. The annual abundance of capelin and saffron cod is variable but both species are frequently captured along the coast.

Frost and Lowry (1983) captured 19 species, or species groups, of fishes in 35 otter trawls made at several offshore stations across the Beaufort Sea. Only one station was in water depths exceeding 200 m. Arctic cod (Lowry and Frost 1981), Canadian eelpout (*Lycodes polaris*), and twohorn sculpin (*Icelus bicornis*) made up 65% of all fish captured. The results of under-ice gill netting indicated some arctic cod remain in shallow waters of Simpson Lagoon during winter but were more abundant in deeper water catches some 80 km north of Stefansson Sound (Craig et al. 1982). Houghton and Whitmus (1988) found arctic cod and post-larval capelin to be in greatest abundance in offshore sampling conducted in Prudhoe Bay during August 1988.

Anadromous Fishes

Anadromous fishes---mainly coregonids and arctic char---are regionally important because they comprise the bulk of North Slope subsistence, commercial, and sport harvests. The annual subsistence harvest of these fish by North Slope villagers is roughly 190,000 pounds (Craig 1989b), while the annual commercial harvest of arctic and least ciscoes from the Colville River has ranged from about 10,000 to 70,000 fish (Gallaway et al. 1989). Sport angling effort on arctic char is increasing in rivers east of Prudhoe Bay (e.g., the Hulahula River) due to the growth of recreational tourism in northern Alaska. Arctic cisco, least cisco, broad whitefish, and arctic char are dominant target species of commercial, subsistence, or developing sport fisheries.

The size of the Alaskan North Slope arctic char population is uncertain. Historical data from aerial surveys (FWS 1977) would suggest a population exceeding 35,000 fish. The summer 1985 fyke net catch of over 20,000 char in the Prudhoe Bay area (Cannon et al. 1986) is indicative of a considerably larger population. The limited amount of information regarding the availability of instream overwintering habitat suggests a sustainable population more on the order of a few hundred thousand fish.

Anadromous arctic char spend most of their lives in freshwater habitats. Arctic char are common residents of at least ten rivers east of and including the Colville River. These rivers possess perennial freshwater springs and headwaters in the Brooks Range thought to be requisites for overwintering. In addition, the springs provide relatively warm, oxygenated waters that are used for rearing, reproduction, and incubation. Not all

arctic char are anadromous. Certain populations or small segments of populations remain freshwater residents throughout their lives (Armstrong and Morrow 1980).

Anadromous char migrate to sea at the time of, or shortly after, spring breakup. Anadromous char range in length (FL) from 10 to 70 cm and have an average lifespan of about 10 years (Craig 1989a). At breakup, larger fish precede smaller fish in timing of coastal migrations. This probably reflects the larger fishes' greater ability to cope with strong currents and to move quickly offshore to areas where foods are most abundant in June. Although small numbers of fish smolt at age 1+, most are 3 to 4 years old before first entering seawater (Cannon et al. 1986; Craig 1989a).

The coastal migration is metabolically driven over a 1.5- to 2-month period. Norwegian researchers (Berg and Berg 1989) have related sea temperature to growth and timing of migration in anadromous arctic char. They report that the highest average daily growth rates occur in late June and early July despite warmer sea temperatures later in summer. The most favorable environmental conditions for arctic char in the Beaufort Sea may, therefore, be early in the open-water sea with older fish fulfilling energy requirements for growth and spawning at an earlier date than younger fish.

By mid-August ripening spawners begin returning to river habitats, several weeks in advance of non-reproducing members of the population. According to Craig (1989b), approximately 50% of the arctic char population spawns for the first time at age 7, after which spawning occurs in alternate years. Spawning occurs in October and November in areas that may, or may not, coincide with overwintering habitats.

Several authors (e.g., Craig and McCart 1976; Craig et al. 1985) have indicated that sea-going North Slope arctic char have a limited ocean range. The most distant offshore capture of arctic char in the Alaskan Beaufort Sea we are aware of is 18 km offshore (Bendock 1977; Craig 1989a). However, Armstrong and Morrow (1980) reported northern Dolly Varden char captures as far as 420 km off the coast of Kamchatka. Among the dominant anadromous forms, the arctic char is believed to be the most tolerant of increased salinities and colder water temperatures (Ross 1988).

Tag recapture data show that arctic char are capable of traveling as much as 250–300 km during summer excursions and that transboundary migrations occur (Craig 1984). Craig and Griffiths (1981) estimated coastal migration rates of 3–5 km/d during summer periods of active feeding. Feeding movements are thought to reflect responses to local environmental conditions and prey densities. Later in the open-water season, much higher speeds (approximately 75 km/d) are possible as fish return to overwintering sites (Craig and Haldorson 1981). By comparison, Pearcy and Fisher (1988) have reported migration rates of 80 km/d for 140-mm-FL juvenile coho salmon off Oregon and Washington coastlines in warmer water environments.

Arctic cisco disperse during summer throughout the nearshore waters of the Beaufort Sea coast. These fish are thought to be of a single stock or multiple stocks

originating in the Mackenzie River (Gallaway et al. 1983; Bickham 1989; Troy 1989). There are five known spawning "areas" in the Mackenzie River, and others may exist. The coastal range of arctic cisco overlaps that of the closely related Bering cisco (*Coregonus laurettae*) in the Harrison Bay area of the Beaufort Sea. Anadromy in arctic ciscoes differs from other arctic anadromous fishes in that soon after hatching, most juveniles migrate to sea. The mechanisms involved with their subsequent coastal migrations are poorly known, but thought to include passive transport. The small size of ciscoes (30 mm FL) leaves them at least somewhat dependent on prevailing currents (Fechhelm and Fissel 1988). It has been hypothesized that as much as 20–30 percent of the arctic cisco from the Mackenzie River population may be transported into Alaskan waters (Gallaway et al. 1983).

The total number of Mackenzie River fish recruited into Alaskan waters fluctuates widely from year to year. Apparently, recruitment success is related to summer wind conditions, with relatively strong recruitment observed in years when easterly winds predominate (Moulton 1989). Other factors, including aspects of the various years' spawning success and differential mortality in early life stages, must influence the abundance of small fish moving into Alaskan waters. In Alaska, overwintering sites have been located in deep pools of the Sagavanirktok and Colville deltas (Craig 1989a; Schmidt et al. 1989).

It is clear that Alaskan waters provide important summer and winter habitats for immature arctic ciscoes. Fish mature at ages 7–9 (Craig 1989a) and spawning occurs in the fall. The limited tag returns indicate that ripening fish return to the Mackenzie River during the summer of the year preceding first spawning (Moulton 1989). While many features of the life history of the arctic cisco are becoming known (cf. Bickham 1989), the biological contribution of Alaskan-reared fish to the spawning population and fisheries of the Mackenzie River remains unknown.

Least cisco are widely distributed in Alaskan coastal waters and are common along the Beaufort Sea coast (except in the vicinity of Barter Island) in summer months (Craig 1989a). Major centers of coastal dispersal are the Mackenzie and Colville rivers. Least cisco are uncommon or absent in Alaskan rivers east of the Sagavanirktok River and it has been suggested that the species' habitat requirements for overwintering are not met in mountain-fed streams in the eastern Alaskan Beaufort Sea (Craig 1989a). Both anadromous and lake spawning populations are present west of the Colville River. Schmidt et al. (1983) reported least ciscoes to be the most abundant anadromous species west of Prudhoe Bay.

The age of first migration to sea varies in the least cisco and is thought to be similar to that of the broad whitefish. Age-at-size data indicate first migrations in Age 1-, 2-, and 3-year fish (Craig 1989a). Least ciscoes enter coastal waters during spring breakup and return to fresh water by mid-September. Spawning occurs in fall and 50% of the population spawns for the first time at 10–11 years (Craig 1989a). Known overwintering areas are located in deltas and deep river areas of the Colville, Mackenzie,

and other rivers (Schmidt et al. 1989). An analysis of age distributions at the deltaic wintering sites demonstrates the presence of older fish (i.e., 5–13 years; Schmidt et al. 1989). Younger fish also may have been present but none were captured by the size-selective gear used.

The coastal range of broad whitefish extends from Kuskokwim Bay in the southeastern Bering Sea north- and eastward to the Perry River, Northwest Territories. In the Alaskan Beaufort Sea, Flaxman Island approximates the eastern limit of the coastal range of broad whitefish originating in western North Slope streams. The lack of broad whitefish in mountain-fed rivers of the North Slope again suggests that these environments are in some way inhospitable to the species (Craig 1989a).

Broad whitefish display variable periods of freshwater residency prior to migrating to sea for the first time. The species is intolerant of any but very low salinity conditions and summer dispersals are restricted by the availability of very low salinity water adjacent to the coast (Griffiths and Gallaway 1982). One result of this restriction is that their diet is the most disparate of the dominant anadromous forms; freshwater invertebrates (drift and benthic aquatic organisms) are of great nutritional importance in this species' diet. Broad whitefish were among the most commonly captured fishes at Sagavanirktok River wintering sites in 1985–86 and they were present in both fresh and brackish water locations (Schmidt et al. 1989).

Over the past 20 years many researchers have studied the nearshore fish communities along mainland and inner barrier island coasts. Less information is available describing fish occurrence in water depths exceeding 2 m. It is therefore difficult to evaluate the importance of the outer portion of the brackish warm-water zone, or the adjacent purely marine habitats, to arctic fish (see Craig 1989a). Available data from offshore sampling suggests open water expanses (e.g., mid-lagoonal waters) may be a more valued habitat (by virtue of the total area involved) to fish than commonly thought (Craig and Griffiths 1981; Wiswar and West 1986).

Anadromy involves the alternate occupation of freshwater and sea habitats by fish. This usage is linked in time and space by their seasonal migrations. Arctic conditions, especially availability of foods, argue for evolution of a simple diadromous life history (noncompetitive selection) to maximize population fitness in response to environmental conditions originating outside the gene pool (Gross 1987). Craig (1989a) concludes that in the arctic, anadromous fish display several unambiguous K-selected traits (adaptations to predictable seasonal conditions) including long life spans, slow growth, delayed maturity, iteroparity, and low recruitment success. In large part these adaptations are related to the reduced temporal opportunity for feeding (energy acquisition) and this is further reflected in the strategy of seasonal migrations to the coastal sea where food is more plentiful.

Several species of amphipods (*Onisimus glacialis, Pontoporeia affinis, Ampherusa glacialis,* and *Gammarus setosus*) and mysids (*Mysis relicta* and *M. litoralis*) comprise the bulk of coastal prey for arctic char and ciscoes (Craig and Haldorson 1981; Craig 1984). Apparent preferences for a particular prey species have been used, in part, to depict the partitioning of estuarine habitat by arctic char, ciscoes, and broad whitefish (Figure 1). In summer arctic char feed on a wider prey spectrum than the other species. Evidently, larger arctic char cross an ecological threshold leading to piscivory (Craig 1989a) and feed on small fish, such as arctic cod and liparid snailfish, as well as amphipods, copepods, and the mysid *M. relicta.* The arctic and least ciscoes appear less tolerant of cooler temperatures and intermediate salinities, feeding primarily on amphipods and *M. relicta.* Broad whitefish occur in shallow delta waters and feed primarily on amphipods, and terrestrial- and riverine-derived sources of invertebrate foods.

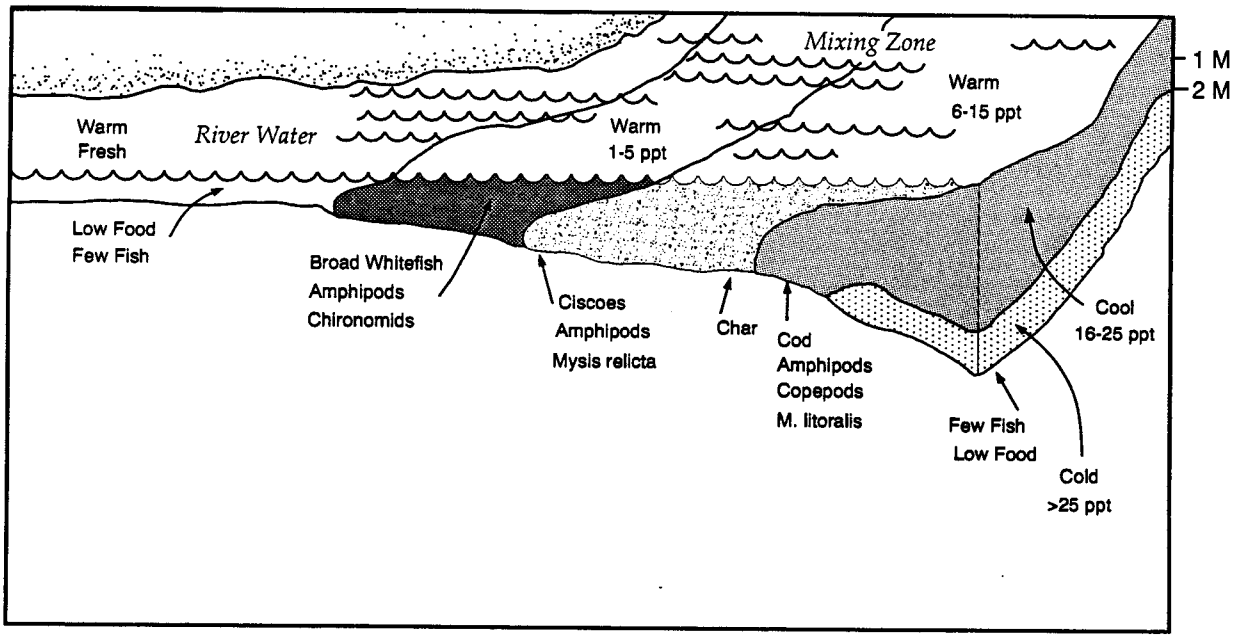


Figure 1.--General fish use of habitat in the nearshore central Beaufort Sea (redrawn from U.S. Environmental Protection Agency 1988).

Environmental Setting

The following paragraphs present an overview of the physical and biological attributes of the coastal Alaskan Beaufort Sea. We have emphasized topics pertaining to our study, thus the discussion is restricted to selected aspects of the dominant fish species, the coastal environment, and the open-water period. Readers desiring additional information are referred to Barnes et al. (1984), Becker (1987), Winters et al. (1988), Meyer and Johnson (1989), and Norton (1989).

Physical Environment

In summer the shorefast ice melts and pack ice recedes northward, resulting in an area of open water fringing the coast. The extent of the open water varies from year to year; in some years it may be expansive, in others, so little as to effectively impede coastal navigation. Large-scale climatic factors play a role in the annual variability.

The open-water season usually begins about mid- to late June, being triggered by warming temperatures, prolonged insolation, and runoff from streams. The pattern of breakup is to some degree predictable, occurring first at the mouths of large rivers and in lagoons, then proceeding elsewhere. River runoff typically peaks in late May and early June. River discharge patterns vary in the region; tundra streams display a brief, "impulse-like" discharge cycle (in response to rainfall and melting snow), while mountain-fed rivers tend to have less peaked, more prolonged discharges (Robertson 1987). About 80% of the annual flow of the Kuparuk River occurs in June, as compared to 35% of the Sagavanirktok River's (Figure 2; see U.S. Geological Survey, various years). The fresh water flows far offshore over the shorefast ice from all rivers and streams and hastens nearshore ice melt.

The spate of runoff in the early part of the open-water season forms a coastal band of freshened water in the shallow coastal waters that is essentially unbroken for some 750 km from Point Barrow eastward into Canada. The band may extend 20–25 km offshore near large rivers (Craig 1984) and 2–10 km along other shorelines (Craig 1989a). This dynamic and ephemeral habitat is typically continuous in early summer and discontinuous later. The relatively warm water of the coastal band is thought to confer benefits to fish in the form of abundant prey and accelerated metabolic processing of ingested food. Both are requisites for building the energy reserves needed for overwintering, and, in the case of mature fish, spawning that year.

A strong front is established between brackish and adjacent marine waters in the early part of summer. The front is constantly eroding, weakening, and re-establishing itself in response to wind mixing and upwelling processes along the coast. As summer advances, declining runoff and turbulent mixing processes contribute to the progressive erosion of the brackish water mass. The first major marine intrusion usually occurs about the third week in July (B. Gallaway, LGL, pers. commun.). The coastal band becomes discontinuous and much reduced in areal extent in late summer.

Moulton and Tarbox (1987) have described two distinctive water masses occurring in the Prudhoe Bay region during summer: *coastal water* (temperature 2–9°C, salinity 6–27 ppt); and *marine water* (temperature below –1°C, salinity 28–32 ppt). These water masses are frequently separated by a pycnocline of variable (1–6 m) thickness containing a mixture of the two primary water masses. Marine waters presumably are derived from the surface waters of the offshore Beaufort Sea, which have temperatures and salinities of –1.4°C to –1.7°C and 28–32 ppt, respectively (Ostenso 1966).

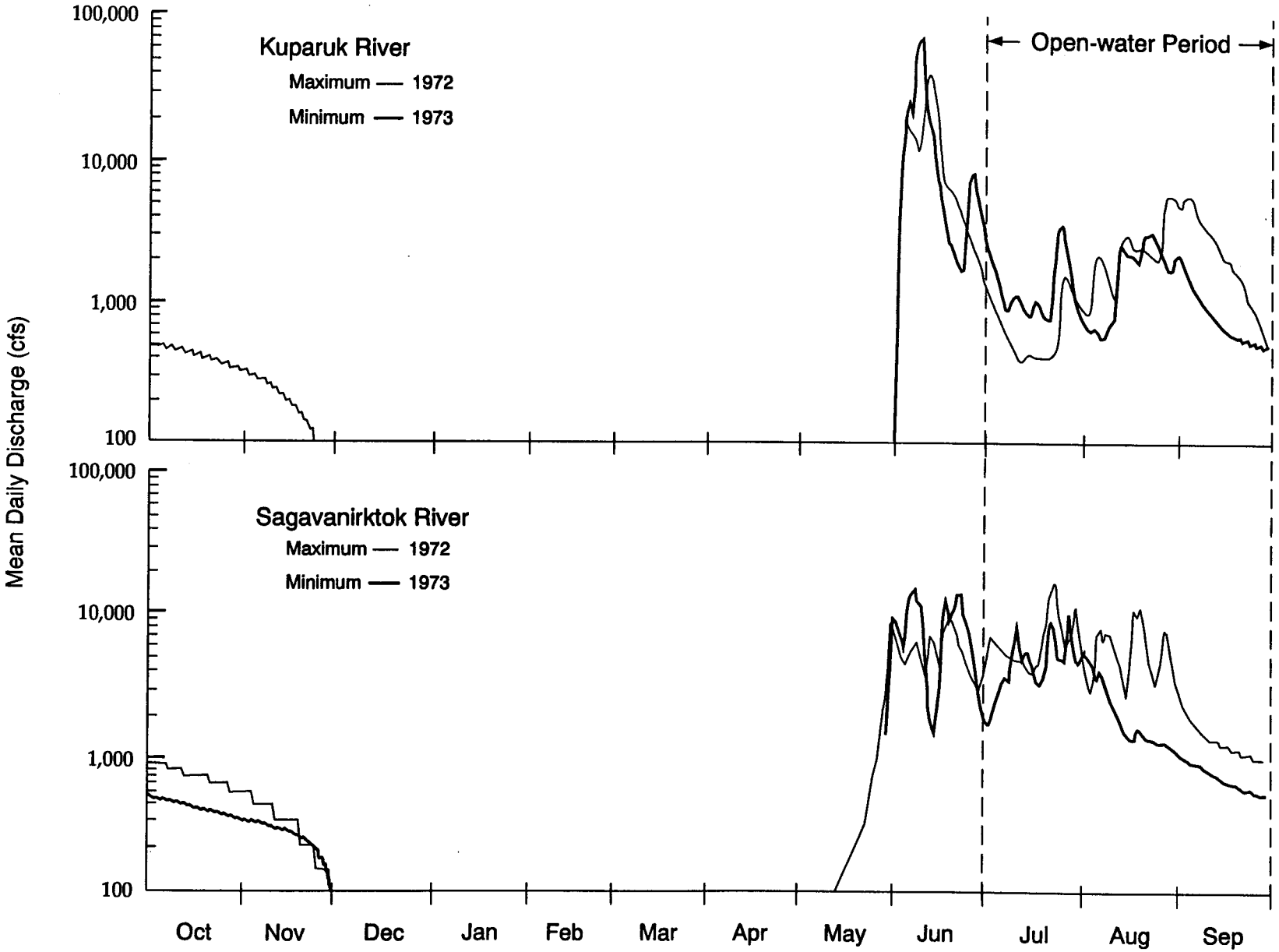


Figure 2.---Kuparuk River and Sagavanirktok River hydrographs (modified from Carlson et al. 1977).

Meteorological observations from Barter Island and Oliktok Pt. (Figure 3) illustrate the dominance of easterly winds in the coastal zone during the open-water season. The more bimodal distribution of winds at Barter Island reflects the steering effect of the Brooks Range, which is near the coast in the eastern portion of the region. Scalar mean wind speeds are about 5 m/sec during summer, but peak speeds often exceed 15 m/sec during storm events. The strongest winds are usually westerlies.

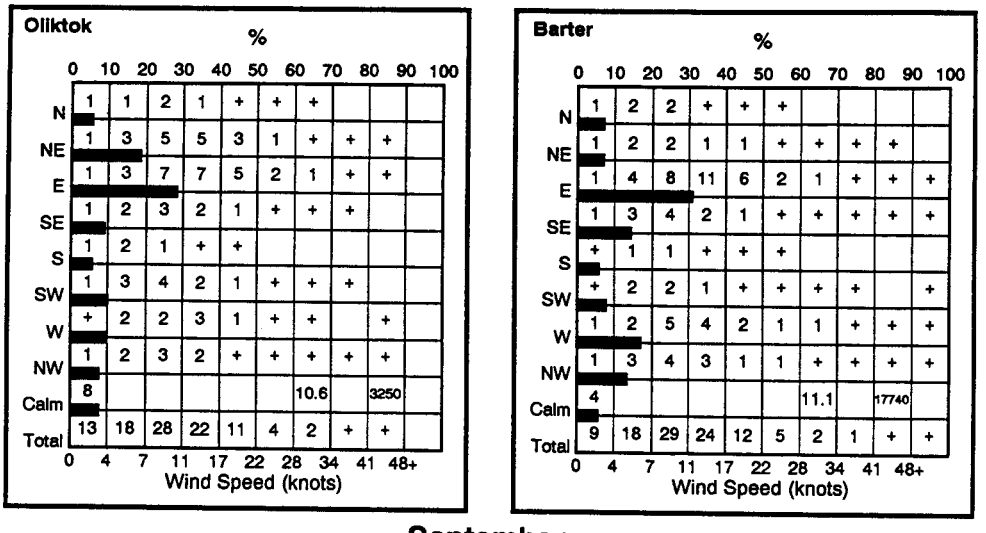
Colonell and Niedoroda (1989) note that wind stress, horizontal pressure gradients, and tides are the driving forces of circulation in coastal waters. Astronomical tides are mixed semidiurnal, range from 10 to 30 cm in amplitude, and due to the small amplitudes have a negligible influence on currents and turbulent mixing in coastal waters. Tidal effects are more pronounced in shallower and confined lagoons (Hale 1989). Winds, especially those associated with storm conditions, are the dominant phenomena driving currents and altering water property distributions over shallow parts of the continental shelf of the Beaufort Sea. Storm surge runups to 3.4 m have been recorded (Wise and Leslie 1988). Coastal currents usually flow westward, reflecting the dominant wind patterns. However, reversals often occur when the winds shift to westerlies. Wind-driven surface current speeds are typically 15–20 cm/sec (Hachmeister 1987).

Currents and thermohaline structure in the coastal waters may change rapidly in response to fluctuating winds and other phenomena. In addition, the responses of coastal waters to winds are affected by the character of their thermohaline structures. Where pronounced stratification occurs in the water column, as is common early in the open-water season, the response is greater than when water column stratification is weak or absent. In the former case, the surface waters are in essence frictionally uncoupled from the deeper waters and momentum transferred from the wind is effectively confined there. If stratification is weak or absent, momentum is distributed through the water column and bottom friction opposes the water's response to wind forcing. Thus, for a given wind speed, surface current speeds will be higher under stratified conditions than under unstratified conditions.

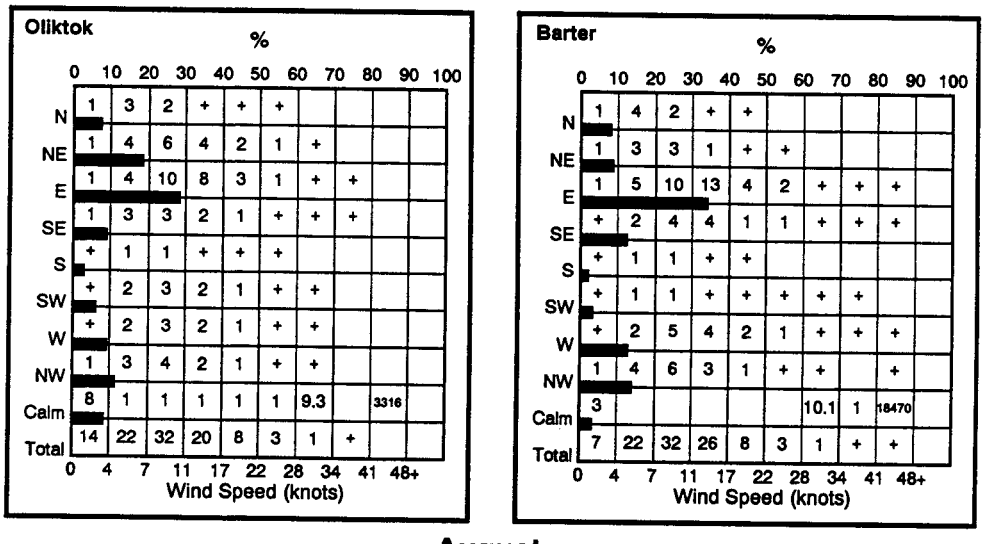
Fish Habitat Utilization

The nature of habitat use by fish in the coastal waters of the central Beaufort Sea has been intensively studied in recent years. Patterns of habitat use by the more common species and life stages are becoming evident and an understanding of the underlying biological and physical factors is emerging.

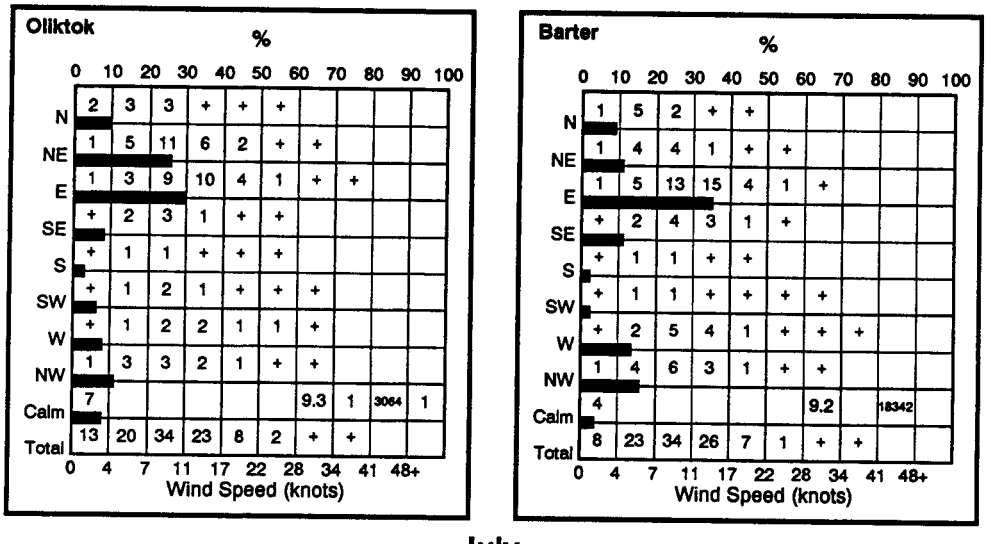
Food availability.--The heavy utilization of the brackish water band by the coastal fish community is partly related to the ready availability of crustacean prey that seasonally colonize shallow waters (Broad et al. 1979). Craig (1989a) estimated that during the open-water season, mysids and amphipods are roughly two orders of magnitude more abundant in coastal waters than are aquatic invertebrates in adjacent freshwater habitats. The spatial dimensions of the two habitats studied by Craig (1989a) are similar,



September



August



July

Figure 3.--Wind speed and direction. Bars represent frequency of winds observed from each direction. Printed figures represent frequency of wind speeds observed from each direction (redrawn from Brower et al. 1988).

about 1,500 km^2 each. The large difference in food abundance thus argues well for the anadromous strategy that has evolved in many North Slope coregonid and char life cycle patterns.

Physiological needs.--Another factor promoting fish utilization of brackish water habitats is their relative warmth in comparison to marine waters. Moulton and Tarbox (1987) suggested that poikilotherm fish seek warm waters to accelerate metabolic processes and thereby allow them to maximize the accumulation of energy reserves during the short summer feeding period. This hypothesis is given weight by Craig's (1989a) observation that while North Slope anadromous fish grow 1–2 cm per year, most of this growth occurs in summer.

Salinity also affects fish use of coastal habitats. Certain marine species, such as arctic cod, appear to become more prevalent inshore as the brackish water habitat becomes more saline in late summer. Conversely, freshwater fish such as grayling are intolerant of saline water and are rarely found far from estuaries. There is some evidence of least cisco overwintering in the Canadian Beaufort near Tuktoyaktuk Harbor and off the Mackenzie River delta; however, no marine overwintering has been observed in Alaskan waters (Schmidt et al. 1989). A continuous supply of fresh water from the Mackenzie River may be the key to the ciscoes wintering in the estuary.

Houghton et al. (1989) recently completed an arctic fish habitat use analysis based on a 4-year database composed of some 180,000 records from Prudhoe Bay and vicinity. Fyke net catch per unit of effort (CPUE, standardized to 24-hr set periods) was examined in relation to temperature and salinity data collected at the time the nets were cleared of their catches. Several cohorts of four fish species--arctic char, arctic cisco, least cisco, and broad whitefish--were evaluated. The general trend evident from the work is that all four species preferred waters having salinities of 0–20 ppt and temperatures of 4–12°C during the early July to mid-August time interval.

Fechhelm et al. (1989) examined short-term movement patterns of least cisco and arctic cisco in the vicinity of the West Dock causeway during 1981–84; they found an apparent dependence of movement around the causeway on prevailing wind direction and water properties. Eastward dispersals of small least and arctic ciscoes from the Colville River were blocked by adverse hydrographic conditions resulting from prolonged easterly winds.

Reproductive state.--Habitat use may be affected by the reproductive state of the fish. Gallaway and Britch (1983) noted that movements of spawning and non-spawning individuals of the same species may differ during the same season. The movements of non-spawners may represent feeding forays that are altered by responses to the environmental variables, while those of the spawners are characterized by very directed movements with little apparent influence of environmental attributes other than those necessary to locate home streams.

Size relationships.—There appears to be a relationship between fish size and habitat association in certain of the species present in North Slope coastal waters. Work by Moulton et al. (1985) and Houghton et al. (1989) suggests that the larger arctic char and arctic cisco occur more frequently in colder, more saline waters than do smaller fish. Again, these differences in habitat use may stem from size-dependent physiological requirements, timing of entry into seawater, size-related rates of movement, and different food preferences. The bimodal distributions observed in the length frequencies of some species in coastal collections (e.g., broad whitefish) may relate to density-dependent mortality at overwintering sites.

Spatial patterns.—The species richness of the coastal fish community is greatest in the vicinity of the large river estuaries (Craig and McCart 1976). Distinctive patterns of fish use of coastal habitats were evident during studies carried out at Simpson Lagoon in the late 1970s. There, the largest gillnet catches consistently occurred within 100 m of the mainland shoreline, with progressively smaller catches along island inner shorelines, in mid-lagoon, adjacent to island outer shorelines, and offshore (Craig and Haldorson 1981). A similar pattern of anadromous fish distribution showing decreasing abundance with increasing distance from shore has been reported in Camden Bay (Fruge et al. 1989). Craig (1984) noted that, among the anadromous fish, least ciscoes and broad and humpback whitefishes were uncommon anywhere but near the mainland shore. In contrast, arctic ciscoes and arctic char were more broadly distributed in the brackish waters, the char being the most abundant anadromous species seaward of barrier islands. Arctic cod are strongly ice-associated (Sekerak 1982). This was the only species captured at a winter station 175 km offshore in the Beaufort Sea (Craig et al. 1982).

Some benthic marine fishes appear to be associated with particular kinds of bottom substrates, while others have no apparent preferences. Snailfish and the fish doctor (*Gymnelis viridis*) apparently prefer rocky bottom–kelp habitats; they were observed by divers at the Boulder Patch in Stefansson Sound (Dunton et al. 1982). The ubiquity of fourhorn sculpin in a variety of habitats (Craig and Haldorson 1981) suggests the species has no strong substrate associations.

The migratory patterns of anadromous species are genetically-cued in time and space to the spawning requirements of the populations. Ripening arctic char that have dispersed while feeding to the western Beaufort Sea return to the mountain streams of the eastern North Slope, while the coregonids return to the tundra streams of the western North Slope and the Mackenzie River system (Craig 1989a). The absence of least cisco and whitefishes in the eastern Beaufort was attributed more to the lack of spawning populations in nearby rivers than to the absence of suitable habitat in coastal waters (Griffiths 1983).

Temporal aspects.—The timing of use of coastal marine habitats varies among species and, for a species, among life stages, years and locales, being controlled by the interplay of numerous extrinsic and intrinsic factors—several of which are mentioned above. The timing of annual migratory movements of anadromous fishes between

freshwater and marine habitats is predictable; however, relatively little is known about their migration patterns in the marine environment. It is theorized that coastal foraging entails random wandering (3–6 km/d) as fish seek environmental optima.

Quantitative data on fish movement patterns in the Alaskan Beaufort Sea have been accumulating rather slowly, in part because of the low marine recapture rates typically occurring in mark–recapture studies. Fechhelm et al. (1989) observed eastward-moving waves of least cisco shortly after breakup in the vicinity of Prudhoe Bay. These fish presumably were coming from the Colville River. During three years least cisco tagged in the Arctic National Wildlife Refuge (ANWR) were recaptured in the fall in the East Channel of the Colville River, suggesting either that Colville stocks disperse eastward to the former area during summer or that some adult fish from the Mackenzie River stocks move westward and overwinter in the Colville (Moulton and Field 1989). Recaptures of marked small arctic cisco in front of the Sagavanirktok delta showed significant directed movements of those fish to the west during the July–September period, with very strong movements in the latter month (Gallaway and Britch 1983).

Some information on fish movement rates along the coast has resulted from the tagging. Craig and Haldorson (1981) estimated that net movements of migrating anadromous fishes are some 3–6 km/day. Fechhelm et al. (1989) noted that a large arctic cisco recovered at Kaktovik had traveled at least 170 km in 7 days, which equates to a swimming speed of at least 1 km/hr. Higher rates have been estimated for anadromous fish during late season return migrations (Craig and Haldorson 1981) and 3 km/hr may indicate the upper limit of sustained migratory speeds.

Onshore–offshore migrations of demersal fishes, such as fourhorn sculpin, from shallow to deeper waters occur in fall; they are driven by the formation of shorefast ice. At the time of maximum ice thickness in late winter, essentially all habitat less than about 2 m deep is inaccessible to them. Many deeper, isolated depressions containing unfrozen water in coastal lagoons and river deltas become unsuitable for fish in late winter due to anoxia and/or hypersalinity resulting from brine rejection during ice formation.

The Issues

The geographic coincidence of valued fish, "critical" habitat, and perturbing anthropogenic activities has prompted a large number of biological and ecological studies by industry and government alike. Of these, an extraordinary amount of scientific attention has focused on the coastal oceanography and fisheries ecology of the central Beaufort Sea. At issue is how causeways affect coastal habitats and their use by anadromous fish (e.g., migration, summer feeding). The emphasis of monitoring research has been on habitats and their use by fish in the Endicott and Prudhoe Bay areas. The resolution of the problem of relating potential modifications in coastal habitat to population health, while often discussed, is not possible within the context of existing information.

There are numerous mechanisms by which populations and fishermen may be adversely affected by North Slope industrialization. Burns and Bennet (1987) identified five categories of possible effects:

1) direct mortality (e.g., from oil spills);

2) habitat destruction (e.g., due to gravel removal from streams);

3) displacement and dislocation by barriers (e.g., from solid fill causeways);

4) changes in access to resources (e.g., adverse habitat alterations); and

5) regulatory barriers affecting harvesting activities (e.g., decreased catch limits due to increasing human use of resources).

All of the above pertain to oil and gas development activities in the Prudhoe Bay area and those contemplated off the ANWR. The 4.4-km West Dock and 7.7-km Endicott causeways at Prudhoe Bay have demonstrably altered local currents, sediment transport, and thermohaline structure within the brackish water zone (Envirosphere 1987; Stringer 1988; Hale and Hameedi 1988; Colonell and Niedoroda 1989). A third, 2-km causeway--Niakuk --has been proposed for the eastern end of Prudhoe Bay.

The individual and cumulative effects of causeways on coastal fish communities present long-standing issues (Craig and Griffiths 1981; Norton 1989). The concerns center on fish passage around the structures and possible adverse habitat changes that may affect population productivity. Habitat modifications (i.e., changes in temperature and salinity regimes) are caused by causeway-induced deflections of currents and entrained waters away from the coast. During easterly winds this sometimes results in an enhanced discontinuity in the brackish coastal band. The discontinuity occurs when marine water is present sufficiently close to shore to be upwelled in the lee of a causeway. The altered thermohaline structure produced by deflection of brackish water offshore is temporally conservative and may persist as much as 65 km downstream of the perturbing structure (Ross 1988).

Petroleum exploration and production activities in the Beaufort Sea also introduce the potential for marine oil spills resulting from blowouts, subsea pipeline failures, human error, or ice-related events. A total of 24 oil spills larger than 1,000 barrels were predicted to occur over the lifetime of OCS Sale 97 and then existing federal and state leases; of those, one was expected to exceed 100,000 barrels (MMS 1988).

OBJECTIVES

In 1988, NOAA's Alaska Office participated in stock identification research (RU 682) on arctic char in the coastal Beaufort Sea. The NOAA participation involved collection of arctic char from offshore areas. The "offshore component" to RU 682 was

considered advantageous because (1) it provided greater geographic coverage to the study than was possible from inshore work alone, and (2) it provided additional information on fish habitat use in areas where few data are currently available.

The goal of this study was to improve the information base on arctic fish habitat use by augmenting the meager offshore data. While collection of arctic char was of primary interest, useful information on other species would be obtained. This information can be coupled with OCS oil spill or other development scenarios to evaluate potential effects of the perturbations on fish in the coastal waters. Specific objectives for the FY 88 field work were:

1. Determine the spatial-temporal distributions, relative abundances, habitat associations and degree of intermixing of North Slope arctic char stocks in the coastal waters of the Alaskan Beaufort Sea.

2. Determine the spatial–temporal distributions, distributions, relative abundances, and habitat associations of other dominant coastal fishes of the Alaskan Beaufort Sea.

While the primary objective was being addressed in cooperative research with the FWS, our intent was to investigate the onshore-offshore dimension of anadromous char migratory behavior. Our supposition was that anadromous char occupy the entirety of the coastal brackish water habitat, but do not habitually venture into the colder, more saline marine waters. The offshore survey would complement other coastal sampling programs (e.g., FWS) and furnish a broader spatial perspective of habitat use than heretofore available.

STUDY AREA

Areal Considerations

The study area consisted of the eastern portion of the Alaskan Beaufort Sea coastal zone extending from the Colville River to the Canadian border (Figure 4). Highly variable ice and weather conditions precluded station sampling along predetermined transects and it was therefore necessary to emphasize "areal" sampling within hydrographically-defined coastal, transitional, and marine fish habitats. The study area was subdivided into four "coastal sections" (A = Harrison Bay, B = Stefansson Sound, C = Camden Bay, D = Barter Island-Demarcation Point; Figure 5) to establish priority sampling areas. Although somewhat arbitrary, this partitioning was based primarily on areal proximity to major char-producing rivers of the region (e.g., Colville, Sagavanirktok, Kavik, Canning, Hulahula, Aichilik, Egaksrak, and Kongakut). The coastal area to be surveyed essentially encompassed the known summer range of the species in Alaskan Beaufort waters. Coastal sections B–D (western, central, and eastern portions of the char coastal range) were judged to be of highest sampling priority.

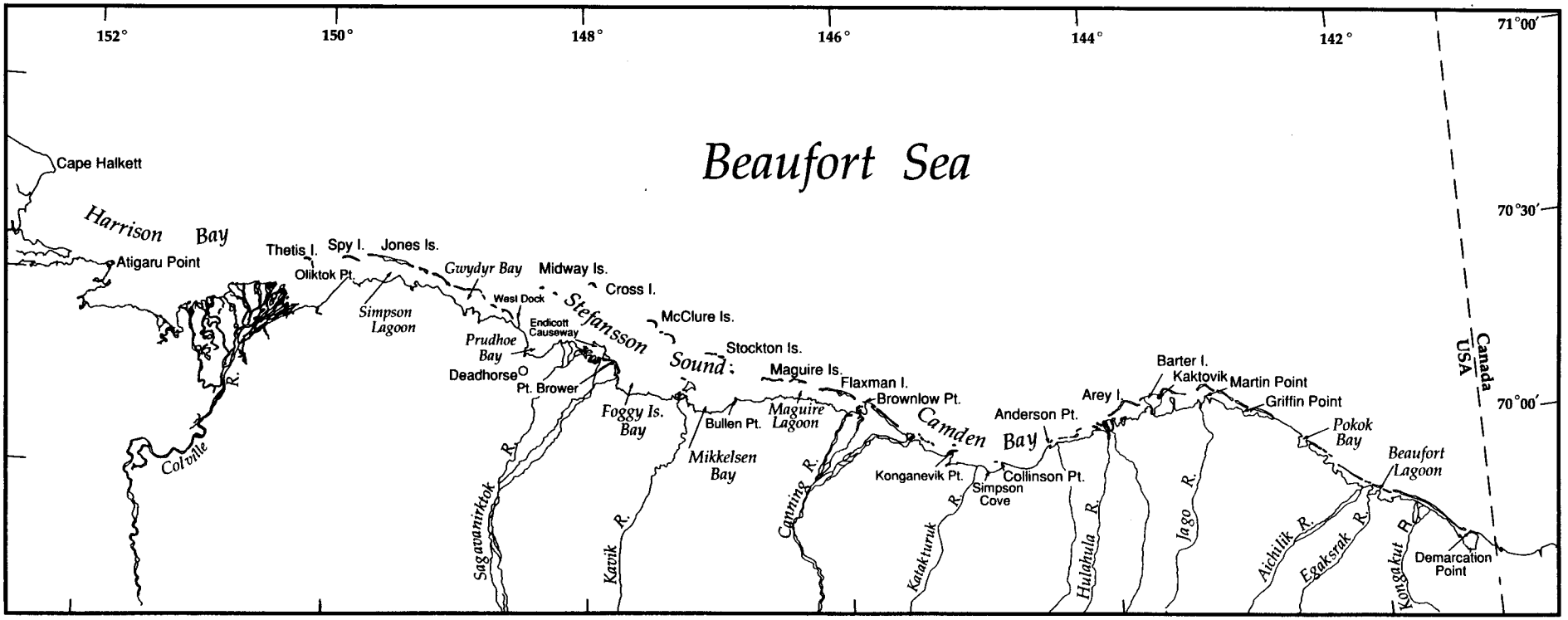


Figure 4.--Beaufort Sea study area.

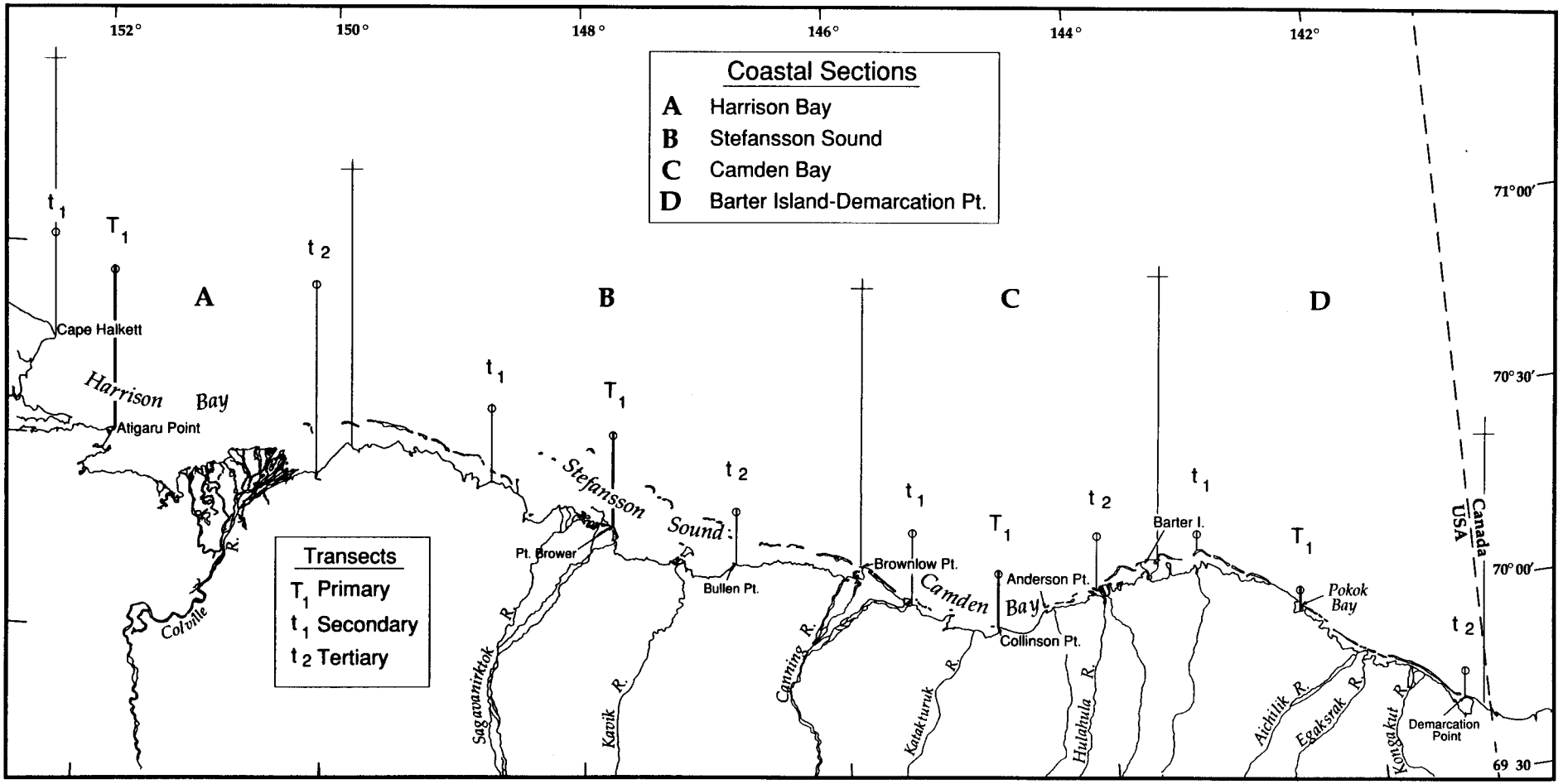


Figure 5.--Location of study area sections and sampling transects.

Sampling Strategy

Although station sampling along established transects was initially proposed it was also recognized that prevailing ice conditions might render such a plan infeasible. The planning was necessary, however, to organize our strategy as to priority of offshore areas to be sampled. Within each coastal section, primary sampling transects were identified off Atigaru Point, Point Brower, Collinson Point, and Pokok Bay (Figure 5). Initially, offshore sampling would be conducted at selected stations beginning at an inshore station (5 m) extending perpendicular to the coast and into marine waters. If these primary sampling sites were successfully occupied, opportunistic sampling would be conducted within the coastal section to provide a broader perspective to the offshore effort.

The intent of field sampling was not only to obtain arctic char from offshore locations but to sample fish from various "habitats" defined by water property characteristics. Three 15-day cruises were tentatively scheduled for field work in 1988. Our strategy was to conduct offshore sampling in two "sections" during each cruise, with an anticipated minimum of 50 seine sets per period.

METHODS

Stock Identification Requirement

Sampling requirements for arctic char stock identification investigations were determined in consultation with the Division of Fisheries, FWS, Anchorage, Alaska. A target of 200 arctic char per sampling period was selected based on the following rationale: (1) as many as 20 populations might be represented in offshore samples, (2) a minimum of 10 individuals per population was required for GSI stock recognition, and (3) collection of larger numbers of arctic char would not be permitted by the State of Alaska.

Other arctic fish investigators were to provide additional mixed stock samples (200 fish/collection) to RU 682 from their coastal sampling sites (Everett and Wilmot, in prep.): FWS--three collections from Kaktovik; North Slope Borough--two collections from Harrison Bay; LGL Research Associates--two collections from the Endicott Causeway; and Canadian Department of Fisheries and Oceans--two collections from Phillips Bay. In addition, Canadian scientists agreed to provide two samples of 50 fish each for GSI baseline development for the Big Fish and Rat River stocks. A total of 2,700 arctic char were to be obtained in 1988.

The NOAA stock identification objective relative to offshore sampling involved collection and delivery of preserved char tissues to the FWS in Anchorage for GSI analysis. Ideally, the entire sample would be collected at one location at a single point in time. In order to contend with expected low fish densities offshore, a protracted acquisition period (as long as 5 days) was adopted. After initial captures were made, additional sampling for arctic char would occur near the original collection site. A similar collection strategy

had been used successfully by the FWS in 1987 (Everett et al. 1988). Conceptually, stock identifications and intermixing could still be estimated, although some resolution in the stock predictions might be lost with respect to time and areal composition of the catch.

Precision and accuracy in GSI are related not only to sample size but also the total number of loci screened and the amount of genetic divergence observed in the populations being studied. Genetic baselines for 15 populations of arctic char had been electrophoretically determined prior to the 1988 field season (Everett et al. 1988). Simulation analysis of artificially created "mixed stocks" composed of known baselines indicated: (1) highest accuracy in the GSI occurs when the mixture is composed of an individual stock and (2) lowest accuracy occurs when many stocks contribute to the mixture.

Fish Sampling

Three survey cruises were completed by NOAA in 1988: Cruise 1, 30 July–12 August; Cruise 2, 17–28 August; and Cruise 3, 1–9 September. NOAA's 36-ft aluminum vessel "1273," which was configured as a drum seiner, and a 17-ft skiff were employed for seining. The NOAA vessel possesses several attributes that are useful for working in the Beaufort Sea: (1) it has an ice-reinforced hull; (2) it has a shallow draft (4 ft); and (3) its size is well suited for onshore–offshore transits between barrier islands and the exposed coastal sea. Active sampling methods (purse seining) were chosen in 1988 to (1) conduct offshore sampling in ice infested waters, and (2) provide samples allowing the direct relation of fish catch to known (at the time of capture) environmental conditions.

Prior to each cruise, an aircraft reconnaissance of the study area was conducted to determine which "sections" could be fished with least hinderance from ice. Upon arrival at a fishing site, the station location was determined from Loran C or SatNav fixes. The accuracy of the positions is approximately 0.5 km. Depth was determined by fathometer. Inshore gillnetting locations were determined from SatNav fixes and by dead reckoning from navigation charts.

The primary sampling gear was a 150-m-long by 7.3-m-deep purse seine designed to sample small schooling fish in shallow waters (Martin et al. 1986). The net dimensions (stretched-mesh) were: seine body, 19 mm; and bunt, 6.3 mm. This net is well suited to the Arctic because target species tend to be relatively small, seldom exceeding 700 mm FL. Winds exceeding 10–13 m/sec would prohibit seining.

The purse seine was set across the current and held open for 10 or 20 minutes in a large semicircle before closing. All sets were blind. Although use of an electronic fish finder to locate schools of fish had been planned, damage to the transducer precluded its use. When arctic char were captured additional sets were made in that vicinity to obtain as many fish as possible.

Gillnets were fished off beaches when "1273" was anchored or during periods when wind, fog, or ice prevented seining. The 46.2-m-long gillnets had panels of variable mesh

size (25, 50, 75, 100, and 150 mm), constructed of floating (monofilament) and Uroko Ultra sinking (multi-strand blend, little twist) web. Generally, three shackles of net were fished together. The shoreward end of the gillnet was anchored to the beach and the net extended perpendicularly to the coast. A sinking gillnet was usually fished closest inshore to reduce hazards to migratory waterbirds which tend to swim close and parallel to the shoreline. The gillnets were fished for variable periods, often overnight. However, where amphipod predation on netted fish was great, the nets were tended as often as every 2 hr to remove accumulated fish or debris. Frequent checking also reduced mortalities of netted fish.

At most fishing stations a small dredge was fished to provide information about species composition of the shallow water benthos. The dredge, which was fabricated in the field, also provided an index of species abundance. Dredge samples were sieved through a 1-mm-mesh screen and dominant organisms were identified. A list of invertebrate species by station is presented in Appendix A.

Selected fish were subjected to a detailed taxonomic analysis involving various meristic and morphological measures and counts. The species studied include arctic char, least and arctic ciscoes, rainbow smelt, and fourhorn sculpin (see Appendix B). All captured fish were examined for tags, tag scars, or other marks indicating previous capture or predation attempts. Tagging wounds and scars were reported as described by Fruge (1988).

A few zooplankton samples were collected with a 20-cm-diameter bongo sampler equipped with paired 120- and 333-μm-mesh nets. The sampler was towed near the surface for 10 minutes at a speed of about 0.5 m/sec. Conventional double oblique tows were not possible due to the shallow depths we were restricted to. Zooplankton samples were washed down onboard and preserved in buffered formalin. Zooplankton sampling was accompanied by Secchi disc readings to determine the depth of light penetration.

Physical Data

Thermohaline structure was recorded at each seine station with a portable conductivity–temperature–depth instrument (Applied Microsystems CTD–12) having an internal recording capability. The instrument's depth, temperature, and salinity sensors are accurate to within 0.10 m, 0.03°C, and 0.2 ppt, respectively. The CTD stores data in an internal memory and records eight samples of temperature, conductivity, and pressure per second. During oceanographic casts, the CTD instrument's sensors were held just below the sea surface and allowed to equilibrate, then the instrument was slowly lowered to within about 0.5 m of the bottom. Upon completion of the cast, CTD data were downloaded to a Zenith laptop portable computer, reviewed for accuracy, and stored on minidiskettes for processing.

Other physical measurements were taken in concert with oceanographic casts. Surface temperatures were measured with a bucket thermometer, which was held just

below the sea surface and allowed to equilibrate for a few minutes before being read. Wind speed and direction also were estimated.

Satellite Imagery

Visible band and thermal satellite images were acquired from the Geophysical Institute of the University of Alaska (OCSEAP RU 716). NOAA Advanced Very High Resolution Radiometer (AVHRR) and Landsat Multi-Spectral Scanner (MSS) scenes were obtained for 13 clear days during summer 1988. The images were used for assessment of summer ice conditions and fish habitat availability. The ground spatial resolution of the AVHRR sensor is 1.1 km at nadir. The MSS instrument has a nominal ground resolution of 79 m × 79 m.

Fish Sample Processing

Seine and gillnet catches were sorted to species, counted, and individually measured. In the few instances of large reported catches, catch size was estimated using a bulk sample approach. In such instances, the total weight (rather than individual weights) was obtained and length frequency information was collected from a representative subsample of the catch. Fork length (mm) and wet weight measurements (g) were taken immediately after fish capture. For consistency, weight observations were recorded by the same individual throughout the summer.

Fish weights were measured with Chatillion IN-15 sliding scale (0.1 kg accuracy) and Salter #235 hanging dial (1 g) instruments. Concerns about the accuracy of the sliding scale instrument were addressed later in a calibration test using a NEXUS balance (0.1 g accuracy). The results identified a tendency for sliding scale weights to be heavy by an average factor of 2%. Therefore, all fish weights determined by the IN-15 were corrected to reflect this difference.

Information on sex and maturity state was collected from fish that were not sacrificed. The following classification was used:

Sex	*Spawning Condition*	*Index*
M/F	Immature	1
	Will probably spawn in 2 yrs	2
	Will probably spawn within 1 yr	3
	Will probably spawn this year	4
	Has spawned once. Eggs are immature and will not spawn for 2 yr	5
	Has spawned once. Will spawn again within 1 yr	6

Maturity state is based on an assessment of gonadosomal development (Nielsen and Johnson 1983). Size, coloration, and remnant structures provide qualitative indicators of various stages of fish maturity. In immature fish the testes and ovaries are very poorly developed and translucent. As fish mature the gonads occupy increasing portions of the ventral cavity and are opaque (M/F 2) to white (M/F 3).

Additional processing was performed on arctic char and coregonids. Samples of heart, eye, and muscle tissue were excised from all arctic char and immediately placed on dry ice. Tissue acquisition and preservation methods described by Everett (1988) were followed. In addition, some tissues of arctic ciscoes and least ciscoes were retained for use in other genetic studies planned by the FWS.

Ages of the dominant anadromous fish were estimated using established age–length keys reported in the scientific literature. The sources of all size-at-age relationships employed are documented at appropriate places in the text. Otoliths were removed from 42 arctic char, 90 arctic ciscoes, and 28 least ciscoes, stored in glycerine, and sent to the FWS for processing. The otoliths are representative of the entire size range of fish sampled. These samples are being aged and archived by the FWS as part of their developing database on Alaskan arctic fishes.

The food habits of selected arctic char were visually examined. The fish that were examined were either those being collected for GSI or those for which detailed taxonomic work was being performed. The analysis involved observations of prey species composition and stomach fullness.

Analytical Procedures

Fisheries Data

Catches (total numbers of fish) from 10- and 20-min sets were transformed [ln (x+1)] and compared for differences in catch by set time fished. No significant differences (Student's t, $P < 0.05$) were found and thus catch data were pooled for subsequent analysis. Catch per unit of effort (CPUE) is presented as catch per set for seine data. Gillnet catches have been standardized to 10-hr set periods. Fish densities estimated from the seine catches are presented as numbers of fish per 100 m^2 surface area. The density estimates assume a surface area of approximately 1,800 m^2 fished during each seine set (i.e., the area of a circle with a circumference of 150 m).

Length frequency analyses were performed to determine size and approximate age composition of species sampled. Fork length frequencies were plotted for the major species captured by total catch and gear-type employed. Because of the small numbers of fish involved, the widths of length increments depicted in frequency histograms (horizontal axis) were chosen by Statgraphics software. This presentation varies from traditional methods involved in more detailed modal analysis (Anderson and Gutreuter 1983).

Weight–length relationships were described for four anadromous species. The regression model used was:

$$\ln (W) = \ln (a) + b \ln (L) + \xi,$$

where a and b are constants, L is the fork length (mm), W the wet weight (g), and ξ the error term. Standard correlation analysis was used to describe the association between weight and length.

Condition factors (Kn) were computed for the dominant anadromous species to provide a general index of fish well-being (Anderson and Gutreuter 1983). This index is routinely calculated in Beaufort Sea fish studies (e.g., Fruge et al. 1989; LGL 1989) as an easily obtained indicator of population growth vis-à-vis ambient environmental conditions. A Kn value of 1 depicts an "average" fish. Condition factors were calculated using the method of LeCren (1951):

$$Kn = W/aL^b,$$

where W and L are as above, and a and b are the coefficients determined from regression analysis.

A chi-square (χ^2) goodness-of-fit analysis (Sokol and Rohlf 1969) was used to investigate habitat utilization by fish. The χ^2 analysis is often used to relate animal occurrence to habitat-type in exploratory research (Green 1979) and is commonly employed (e.g., Brown and Winn 1988). The null hypothesis tested is that fish frequency of occurrence does not differ significantly between habitats. If an organism spends proportionately more or less time in a habitat than expected the inference would be that it is preferred or avoided. Habitat-types were hydrographically defined. In a practical (large-scale) sense, three types (brackish, transitional, and marine) can be delineated in the coastal Beaufort Sea. Porter and Church (1987) note that the impact of areal boundaries on inferential analysis is unimportant in regularly distributed (vs. aggregated pattern) habitat-types.

Prior to the field season we anticipated seining at 150 stations. Assuming that the fishing would be quite evenly distributed in three habitat-types, the power of the χ^2 statistic (P = 0.05, 2 df) would be about 90% (Cohen 1977). The sample size would be large enough to detect a significant difference in 90% of the cases. With this power a Type II error (beta) would be expected about 10% of the time. A testing power of 80% is commonly used in inferential analysis, and, in this instance, would require sampling at 100 or more stations.

Physical Data

CTD data were quality controlled and processed by conventional methods. Sensor readings were converted to engineering units and pressure sorted into 0.1-m bins. Data in each bin were then averaged to derive the temperature and conductivity for that

pressure. Empty bins were filled by a value derived from interpolating between closest non-empty bins. Salinity and density were calculated and stored along with temperature as a function of depth. Data recorded during the lowering of the instrument were primarily used for analyses in order to minimize turbulence-induced effects on the sensors due to passage of the instrument through the water. Plots of temperature, salinity, and density (sigma-t) versus depth and plots of temperature vs. salinity were examined to detect erroneous data and to categorize stations in terms of thermohaline structure and properties (see Appendix C). Due to the frequency of suspected erroneous readings at the sea surface, 1-meter data are used in the following discussions to represent conditions at the sea surface.

RESULTS

Genetic Stock Identification

A total of 1,209 arctic char were obtained as the result of collaborative sampling efforts in 1988. Samples were collected as follows (in total numbers of fish per indicated coastal site): 615, Endicott Causeway; 91, Mikkelsen Bay; 378, Kaktovik; and 127, Phillips Bay. The Mikkelsen Bay sample was provided by NOAA. Preliminary analysis suggests that the Mikkelsen Bay char represented a mixed aggregate of stocks from the Ivakshek (40%), Babbage (23%), Firth (16%), Egaksrak (11%), Hulahula (6%), and Lupine/Ribdon (3%) rivers (Everett and Wilmot, in prep.). Although confidence levels are not presented here, the authors feel that the GSI reasonably accounts for 79% of the stock mixture.

Physical Oceanography

A total of 45 CTD casts were obtained in the coastal region between Thetis and Barter islands (Figure 6) in conjunction with purse seining. Cast depths ranged from 2 to 13 m. Coastal water (temperature = >2°C, salinity = <17.5 ppt, sigma-t = <14), marine water (temperature = <1°C, salinity = >28 but <32 ppt, sigma-t = >23), and transitional waters (temperature = –1 to 2°C, salinity = 17.5–28 ppt, sigma-t = 14–23) were observed (Figures 7 and 8). Temperatures at 1 m ranged from about –1.0°C to 6.6°C, while salinities were between 0.8 and 28.7 ppt. However, most observations from the 1-m depth were in the temperature and salinity ranges of 2–7°C and 10–15 ppt, respectively, and thus were classified as coastal water. Coastal water prevailed throughout the water column at many stations inside the barrier islands (e.g., in Stefansson Sound), which were relatively shallow.

With few exceptions (discussed below), marine waters commonly occurred at depths greater than 6 m. Marine waters were observed only at stations in the Camden Bay area. Due to the presence of sea ice, no CTD casts were made far enough offshore to reach purely marine waters.

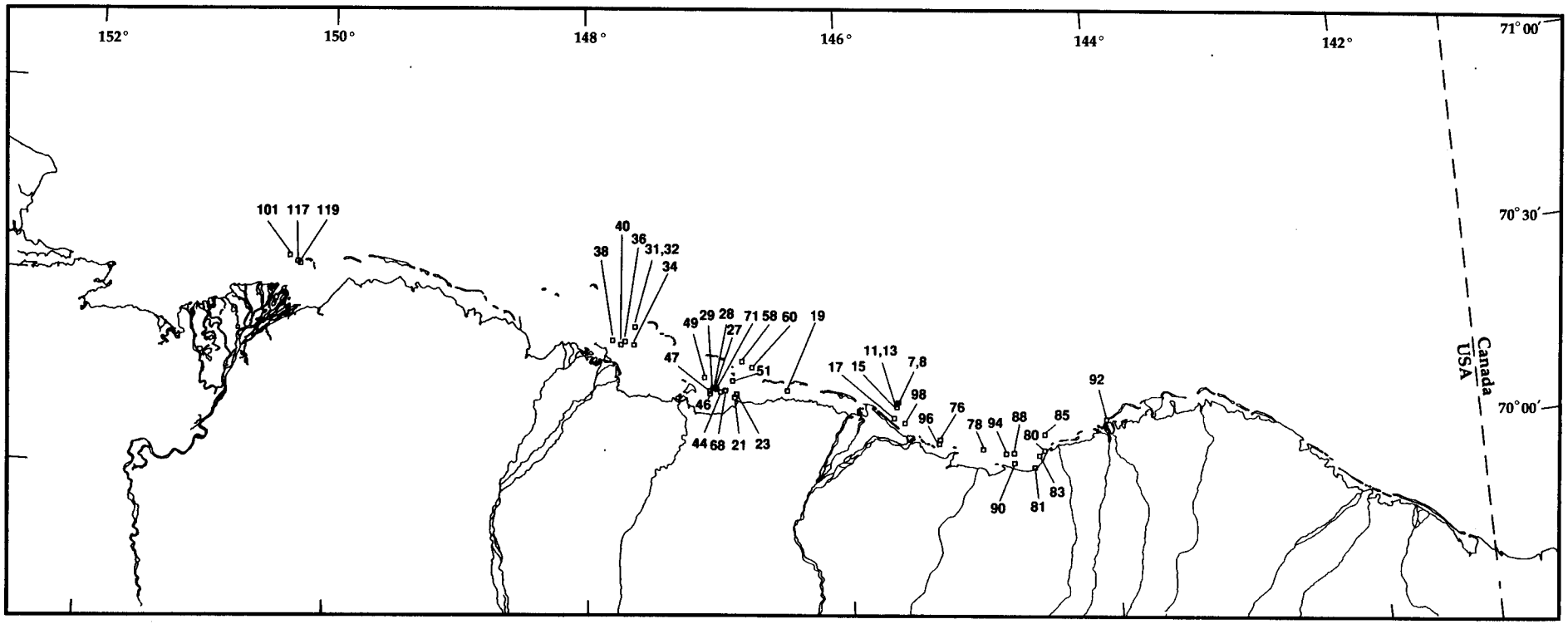


Figure 6.---Location of offshore hydrographic profiling stations (CTD casts) in 1988.

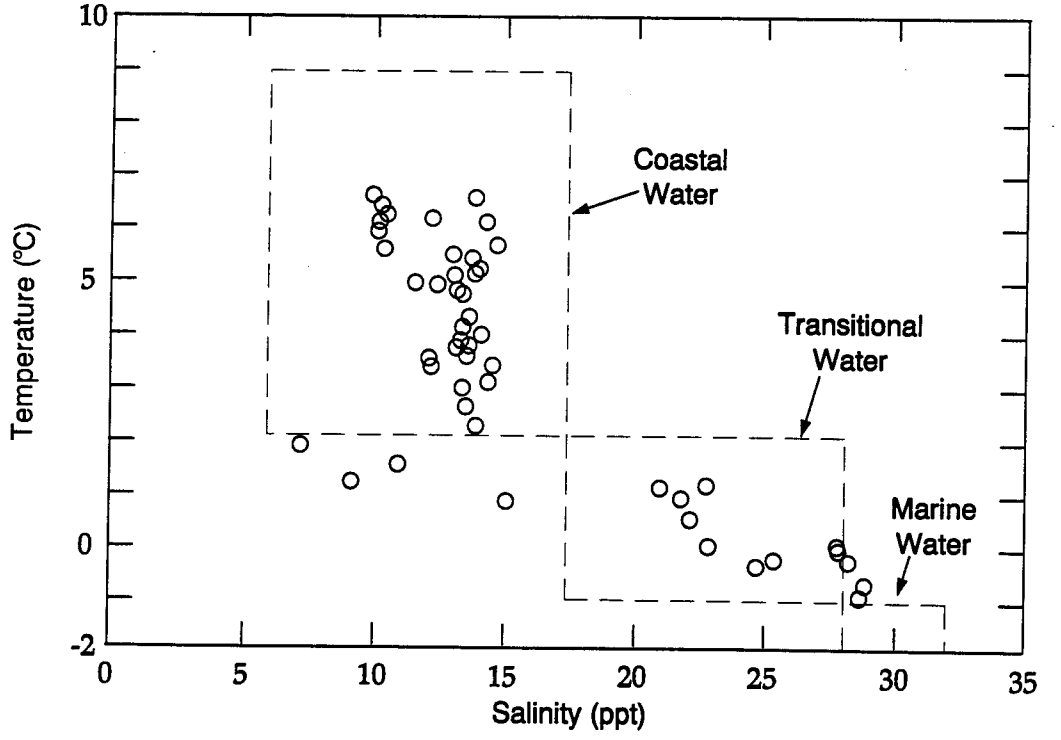


Figure 7.---One-meter temperature–salinity values, all stations combined.

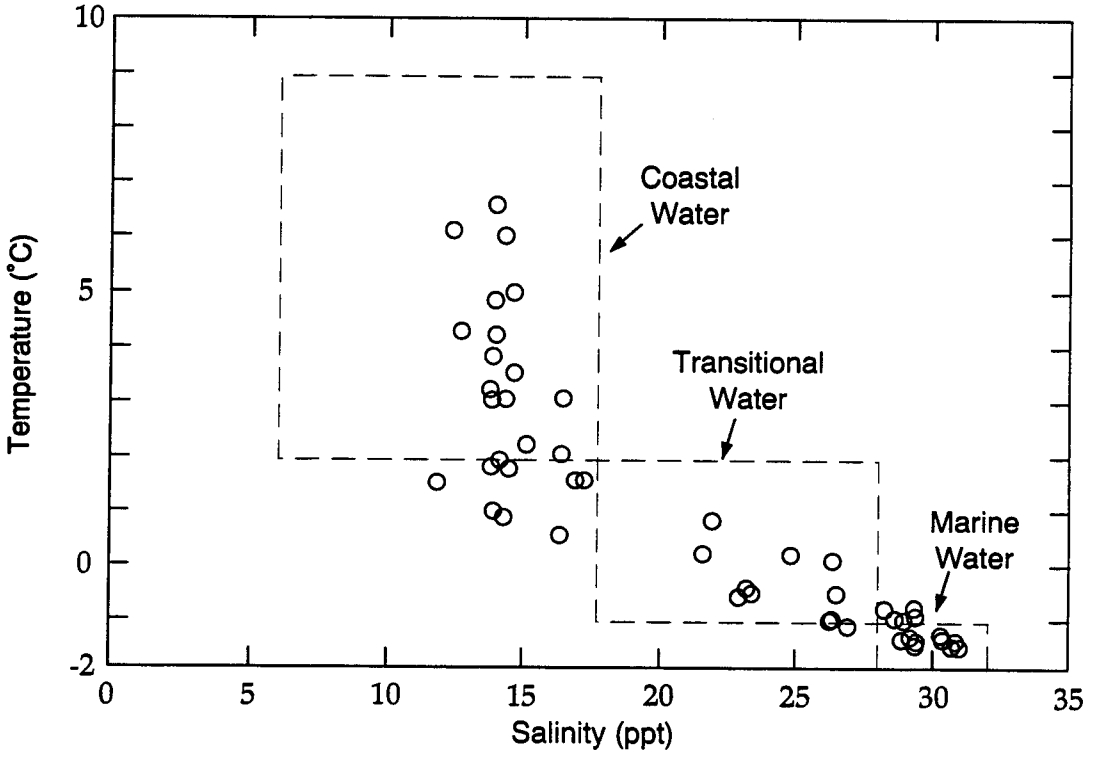


Figure 8.---Bottom temperature–salinity values, all stations combined.

Transitional waters formed by the mixture of coastal and marine waters were present at many stations. At deeper stations occupied in Camden Bay during the early part of the open-water season, transitional water frequently coincided with a pronounced pycnocline separating the coastal and marine water masses (Figure 9). In the latter part of the open-water season, transitional-type waters were prevalent throughout the water column at widely scattered stations. That thermohaline structure can be attributed to a combination of seasonal cooling, decreased freshwater input, and wind mixing.

Local changes of water properties were evident in areas where stations were occupied on several occasions. In Mikkelsen Bay seven CTD casts made in a 5.5-km area during the period 4–12 August illustrate relatively short-term fluctuations (Figure 10). The first cast (B04026) appears to reflect conditions immediately after a strong wind event, as temperature and salinity were essentially invariant throughout the water column. Casts B03041, B03043, and B03045 represent conditions 5 days later. Note the warmer surface temperatures and thermal stratification. Salinity, however, remained little changed from the previous observation. In isolation, the observations are suggestive of in situ warming due to insolation. However, a storm event with a westerly wind component exceeding 10 m/sec occurred on 7 August (Hale 1989). Such an event would be expected to vigorously mix the entire water column in Mikkelsen Bay. Perhaps the altered thermohaline structure resulted from advection of the Sagavanirktok River plume to the area by easterly-flowing, wind-driven currents. Large changes in both temperature and salinity structures are evident in casts B03067, B03070, and B03072, made on 11–12 August. While temperatures at 1 m remained much the same as during the prior observations, near-bottom temperatures were markedly lower than those previously observed. Similarly, 1-m salinities were little changed, while near-bottom salinities were considerably higher than previously. Pronounced thermoclines and haloclines were present between 2 and 3 m. Evidently, the near-bottom water had been displaced by transitional waters sometime between 9 and 11 August. Wind records from a meteorological station at Camden Bay showed a prevalence of moderate winds with about a 5 m/sec easterly component during that period (Hale 1989). Offshore movement of surface waters and compensatory onshore movements of sub-surface waters would be expected under such conditions, thus promoting stratification.

The seasonal evolution of regional thermohaline structure is reflected in CTD data from Camden Bay. During early August (casts C01006-014), a pronounced two-layer stratification was prevalent in the bay (Figure 9). A 5-m-thick surface layer composed of coastal water having temperatures and salinities of 5–6°C and 10–11 ppt, respectively, overlay marine water having temperatures and salinities of less than –1.0°C and greater than 28 ppt, respectively. The pycnocline occupied the 5–9-m depth zone. In late August (C04087, C04089, C04093) thermohaline stratification was very weak. Near-surface temperatures and salinities were 0–1°C and 23–28 ppt, respectively. Near-bottom temperatures were –1 to 0°C, while salinities were 25–28 ppt. Thus during the 3 weeks between the initial and second samplings, the nearshore waters in Camden Bay had changed from the early open-water season thermohaline structure to the more marine-like structure that typifies coastal waters in the latter portion of the open-water season.

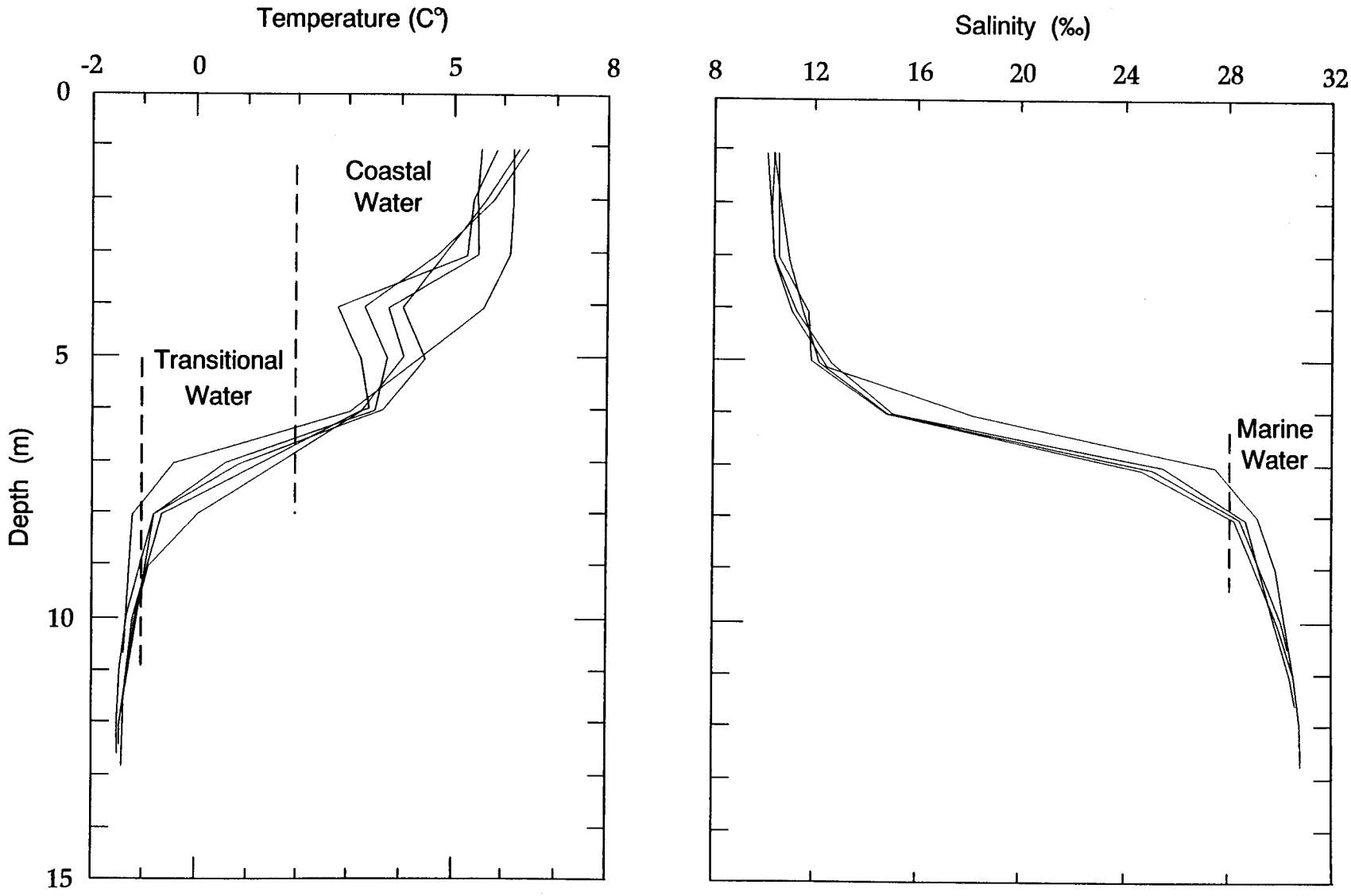


Figure 9.--Temperature and salinity profiles, western Camden Bay, 2–3 August 1988.

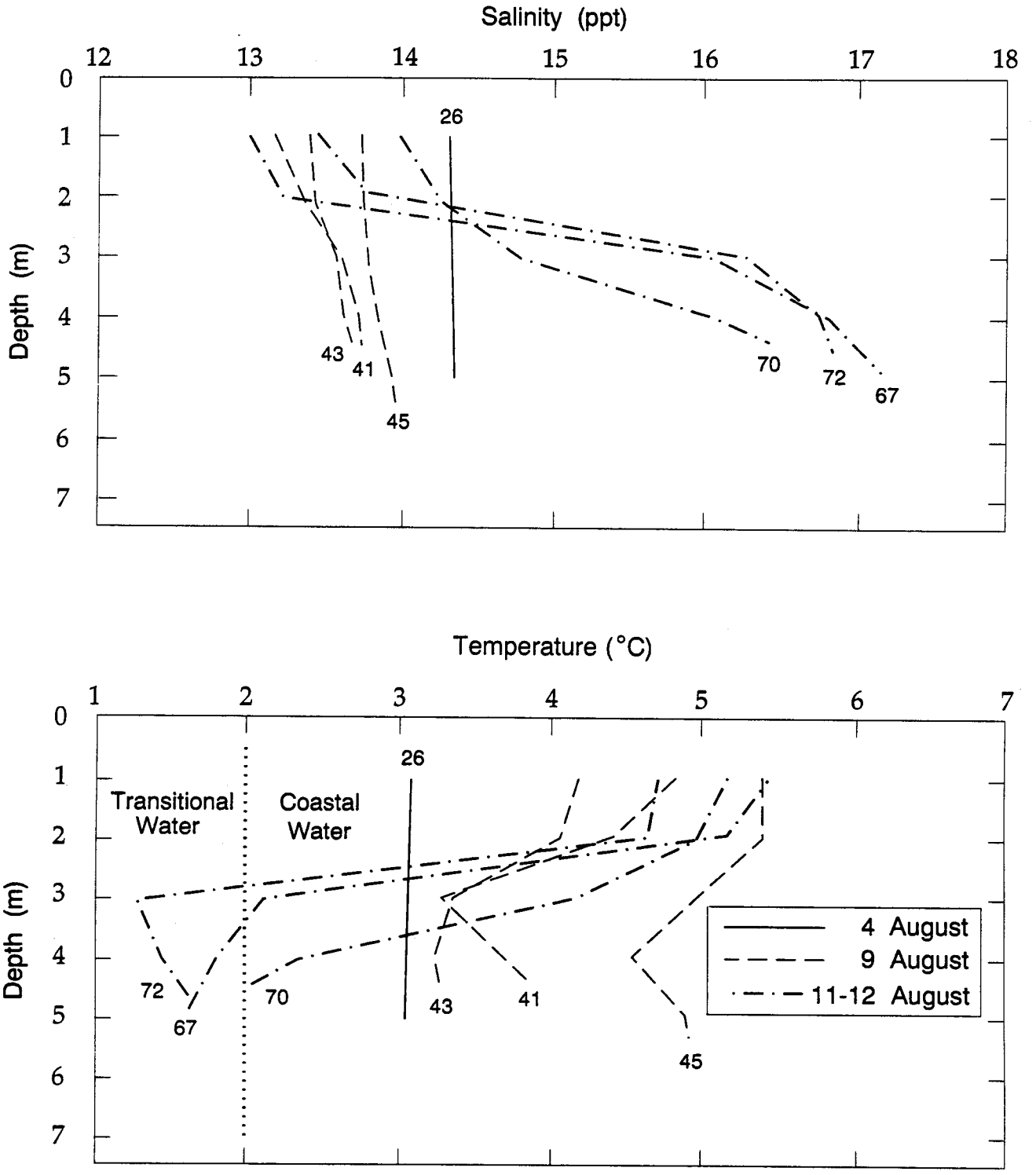


Figure 10.—Salinity and temperature profiles, Mikkelsen Bay (profiles identified by last two digits of cast number).

Local, as well as regional-scale, processes also may have been influential in producing the late August thermohaline structure. Sustained winds with a moderately strong easterly component occurred during the 3-day period just prior to these casts. The bathymetry and configuration of the eastern end of Camden Bay appear conducive to inshore upwelling during easterly winds, which might explain the cold, saline water observed there in late August. Thermohaline properties at the sea surface (temperature = −0.97°C, salinity = 28.63 ppt) approached those of marine waters just off the beach in eastern Camden Bay (C04082).

Four CTD casts were made in juxtaposition to each other west of Thetis Island between 27 August and 3 September. Because of the proximity of this area to the Colville River, one would expect the local water characteristics to be strongly influenced by river outflow. This would be especially noticeable during periods of peak river discharge in early summer. Observed late summer, short-term fluctuations of salinity structure in this area were considerable. Surface waters were quite cold, reflecting the onset of seasonal cooling. One-meter temperatures ranged between 1°C and 1.25°C. In contrast, 1-m salinities fluctuated markedly. They decreased from 21–23 ppt to 1–9 ppt during the observational period. Near-bottom temperatures at all stations were between −1°C and 0°C, while salinities decreased from 28 ppt to 23 ppt over the same interval. The temperature–salinity data suggested the presence of transitional water overlying marine water on 27 August. The marine intrusion was not evident during the subsequent sampling, when the entire water column was occupied by fresher waters. Also worth noting is the fact that our operational definitions of water masses were becoming less useful with the onset of autumn and associated rapid cooling of surface water. A few weeks earlier the low-salinity waters observed near Thetis Island almost certainly would have been classified as coastal waters.

Catch Summary

Purse Seine

During 1988, pack ice was seldom more than 4 to 5 km offshore of the coastal barrier islands. East of Barter Island, prevailing winds kept the ice close to the mainland throughout July and August. This prevented access to several of our proposed sampling areas. The nearshore presence of the pack ice also confined raft ice to a narrow corridor between the beach and the pack throughout the summer. In Camden Bay this corridor was only 10–13 km wide during periods of greatest open water availability. The raft ice moved on- and offshore throughout the summer in response to local winds and often impeded our movements and fishing efforts.

Most seining occurred in three general areas: eastern Stefansson Sound (outer Mikkelsen Bay), in Camden Bay, and near the Colville Delta (Figure 11, Appendix D). Other sites were located near the Endicott Causeway and offshore of Barter Island.

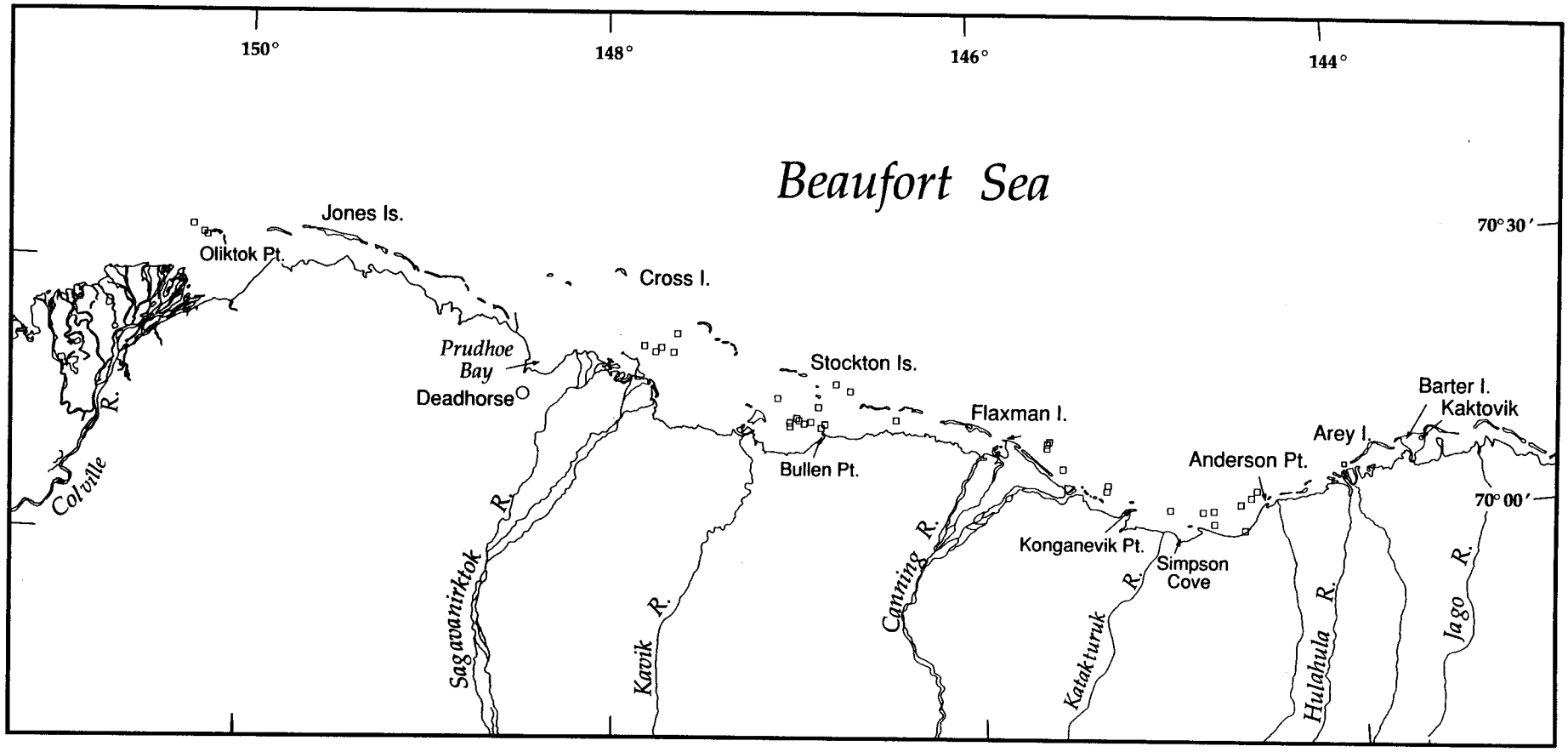


Figure 11.--Purse seine station locations in 1988 (□ designates station location).

A total of 42 seine sets were successfully completed; 17 of these were water hauls (catch = 0). Numerous other set attempts were aborted during the summer due to high winds, ice, or other adverse fishing conditions (e.g., fog, hanging the net). In several instances, small catches were associated with the aborted sets. These "aborted catches" have not been considered in the total identified above. They were, however, considered as "successful sets" by Thorsteinson et al. (1989) for preliminary evaluations of habitat use in an analysis employing presence/absence data.

The distribution of the 42 completed sets included 28 sets during Cruise 1, 12 during Cruise 2, and only 2 sets during Cruise 3. The observed trend of decreasing sampling effort with time reflects the storm and ice conditions encountered in 1988. Offshore habitats were mostly inaccessible after August 15. In September, ice coverage of 90–100% in nearshore waters restricted our sampling to inshore fishing near Oliktok Point.

A total of 3,549 fish were captured in the purse seine (Table 1). This represents an average catch rate of 84.5 fish/set. Not unexpectedly, a few sets produced the greatest catches. This is indicative of the low densities and patchy distributions of fish in offshore waters. Capelin and arctic cod were numerically predominant, comprising 74.4% and 23.5% of the total catch, respectively. Of the anadromous species taken in the seine, the arctic char was most abundant, representing 1.5% of the catch. Only three arctic ciscoes (one per cruise) were captured by the seine.

Table 1 provides a summary of selected environmental information associated with the seine catch data. Correlation analysis indicates a relatively strong association between total seine catch and sea surface temperature ($r = 0.64$) and more moderate associations with station depth ($r = 0.48$) and depth of upper layer ($r = 0.43$). The total seine catch was weakly associated with near-bottom temperatures ($r = 0.21$) and negatively correlated with the mean temperature of the upper layer ($r = -0.04$) and near-bottom salinities ($r = -0.32$). The upper layer generally consisted of coastal water lying above the pycnocline.

When anadromous fish were encountered, the average conditions of pelagic habitats were relatively warm (3–5°C) and of intermediate salinities (14–24 ppt). Not unexpectedly, marine species (e.g., capelin and arctic cod) were found in greatest numbers at stations possessing cooler temperatures and higher salinities than their anadromous counterparts prefer.

Although we were unable to affix a depth of capture to seine-caught fish it is likely that the arctic char and arctic ciscoes were present in the upper layer. A vertical positioning of anadromous fish in the upper water column is supported by several pieces of circumstantial evidence. First, the largest catches of anadromous fish in surface-bottom gillnet fishing in Camden Bay have typically been reported from the upper 2.4 m (Fruge et al. 1989). Second, coastal waters are extremely turbid and visibility conditions beneath 2 m can be expected to be poor. In 1988 we found an average depth of light penetration to be 2.31 m (range = 0.5–3.99 m, n = 6) at several offshore stations (depth range =

Table 1.--Active capture and environmental summary, 1988 (42 sets; 3,549 fish captured).

	Arctic char	Arctic cisco	Rainbow smelt	Snailfish	Ninespine stickleback	Pacific sandlance	Capelin	Sculpin[1]	Arctic cod
GENERAL									
Total number of sets with fish	2	3	1	6	1	1	6	4	21
Total number of fish captured	52	3	1	10	1	3	2,640	4	835
% occurrence in catch	1.5	t[2]	t	t	t	t	74.4	t	23.5
CPUE (catch/set)	1.18	0.07	0.02	0.23	0.02	0.07	60	0.09	18.98
ENVIRONMENTAL									
Depth (m)									
Mean station depth	5	4.75	—	4.5	—	5.17	5.71	5.2	6.42
Range of depths sampled	5	4.5–5.0	—	4.0–5.0	—	—	4.58–8.0	4.5–6.0	4.0–13.0
Mean upper layer	5	—	—	3.8	—	—	4.17	5	5.37
Temperature (°C)									
Mean sea surface temperature (SST)	4.35	3.95	—	4.5	—	—	2.76	5.3	4.78
Range of SSTs measured	3.1–5.6	3.1–4.8	—	3.0–5.6	—	—	−0.2–5.6	4.5–6.7	1.0–10.2
Mean temperature of upper layer	3.35	3.95	—	3.5	—	—	2.08	3.57	3.55
Temperature range of upper layer	3.1–3.6	3.1–4.8	—	0.9–5.9	—	—	−0.3–3.6	2.6–4.1	−0.3–3.6
Mean sea bottom temperature	2.35	1.1	—	1.64	—	—	0.3	1.77	1.64
Sea bottom temperature range	1.6–3.1	−0.9–3.1	—	0.5–6.1	—	—	−0.7–1.6	0.9–3.3	−1.4–6.5
Salinity (ppt)									
Mean salinity of upper layer	14.4	19.2	—	8.72	—	—	14.82	12.43	14.17
Salinity range of upper layer	14.2–14.6	14.2–24.2	—	0.6–14.6	—	—	5.2–25.7	12.0–13.3	0.6–28.0
Mean sea bottom salinity	15.75	21.6	—	13.4	—	—	22.47	14.1	17.68
Sea bottom salinity range	14.3–17.32	14.3–28.9	—	0.5–23.2	—	—	17.2–29.2	13.7–14.3	0.5–30.8

[1]Sculpin includes fourhorn sculpin, arctic hookear sculpin, and arctic staghorn sculpin.

[2]trace, <1%.

5.5–11.6 m). Prey visibility can be expected to be a major determinant of successful predation for visual feeders. Finally, the existing information on environmental preferences of anadromous fish suggests they favor coastal brackish conditions (Craig 1989a).

The three cruises provide a temporal framework (early, middle, late) for making seasonal comparisons of the relative abundances of dominant fish species (Tables 2–4). In addition to the pelagic species sampled, several demersal species, such as sculpins, were regularly captured when the seine dragged bottom. Early in the season, arctic cod were the most abundant (mean 17.0 fish/set) and most frequently captured species in exposed coastal waters (e.g., in Camden Bay, seaward of the Endicott Causeway, and off Barter Island). For example, densities of more that 17 cod/100 m^2 were observed on 5 August (B02038) near Pt. Brower. The hydrographic profile accompanying this set (B02037) indicated surface-to-bottom temperatures of 5.8°C to <1°C and salinities of 4 to 15 ppt over this depth range. The stratified conditions indicate the mixing of marine and brackish waters and the influence of Sagavanirktok River waters. A freshening of surface layers would be expected under the westerly wind conditions experienced on this date.

Fifty-two arctic char were captured in the offshore seining of Cruise 1. On the afternoon of 11 August, 48 fish (2.67 fish/100 m^2) were captured in a set in outer Mikkelsen Bay (B03069). This station (5.5-m) was located approximately 5 km due north of the nearest shoreline. Temperature and salinity data (B03067) indicated stratification (2-layer) with a thermocline located at 2 m. The surface temperature was 5.42°C and the bottom temperature was 1.61°C. Salinities were of intermediate character, being 13 ppt near the surface and >17 ppt at depth. Because the seine fished in both coastal and transitional waters, it is not possible to unequivocally associate the arctic char with a particular suite of habitat attributes.

Strong winds prevented offshore sampling during most of Cruise 2. During the early portion of the survey period (18–22 August), seining was attempted in Camden Bay. This was a period of marine intrusion into the bay and the catch was dominated by juvenile capelin (density = >10 fish/100 m^2), jellyfish (unknown spp.), and to a far lesser extent, arctic cod. The catches were reported from cold waters (–0.4°C to –1.9°C) from depths of 8–10 m (e.g., C03091 and C03092). Winds were steady from the southwest at 2.5–5 m/sec. On 25 August the vessel moved to Thetis Island in search of open water in the western portion of the study area. Strong winds (>10 m/sec) and poor visibility (fog) resulted in the conduct of one successful set (with no fish) in 4 days.

Poor weather and heavy ice conditions stymied offshore sampling throughout Cruise 3 (1–9 September). Ice coverage in nearshore waters outside of the barrier islands varied from 80 to 100%. Only two seine sets were possible and both occurred on 3 September. Both sets were made at midday at stations (A03117 and A03119) located near the ice front west of Thetis Island. Station depths were 5.0 and 5.5 m, respectively. While the two stations were located only 1.25 km apart the oceanographic conditions at each were markedly different. Temperature data from satellite images obtained on 3 September reflect widespread influence of the Colville River in the area where sampling occurred.

Table 2.—Purse seine catch summary for Cruise 1.[1]

Species	# sets with fish	Catch[2]				Density[3]		
		Σ	Mean	SD	Range	Mean	SD	Range
Capelin	2	2	0.07	0.26	0–1	0.004	0.016	0–0.06
Arctic cod	15	477	17.04	58.36	0–307	0.946	3.243	0–17.06
Arctic char	2	52	1.86	9.08	0–48	0.103	0.505	0–2.67
Snailfish	3	7	0.25	0.85	0–4	0.014	0.047	0–0.39
Sculpins	4	4	0.14	0.36	0–1	0.009	0.021	0–0.21
Arctic cisco	1	1	0.04	0.19	0–1	0.002	0.011	0–0.06
All	16	543	19.4	60.58	0–312	1.072	3.332	0–17.14

[1]28 sets including 12 water hauls.

[2]Σ = total numbers caught; mean = average catch/set; range in fish/set.

[3]Mean = average number of fish/100 m²; range in fish/100 m².

Table 3.—Purse seine catch summary for Cruise 2.[1]

Species	# sets with fish	Catch[2]				Density[3]		
		Σ	Mean	SD	Range	Mean	SD	Range
Capelin	2	722	60.20	193.20	0–672	3.34	10.72	0–37.3
Arctic cod	4	4	0.33	0.49	0–1	0.02	0.03	0–0.06
Arctic cisco	1	1	0.08	0.29	0–1	0.005	0.017	0–0.06
Snailfish	1	1	0.08	0.29	0–1	0.005	0.017	0–0.06
Ninespine stickleback	1	1	0.08	0.29	0–1	0.005	0.017	0–0.06
All	6	729	60.75	193.02	0–672	3.38	10.71	0–37.3

[1]12 sets including 5 water hauls.

[2]Σ = total numbers caught; mean = average catch/set; range in fish/set.

[3]Mean = average number of fish/100 m²; range in fish/100 m².

Table 4.—Purse seine catch summary for Cruise 3.[1]

Species	# sets with fish	Catch[2]				Density[3]		
		Σ	Mean	SD	Range	Mean	SD	Range
Capelin	2	1,916	958.0	1,142.7	150–1,766	53.2	63.5	8.3–98.1
Arctic cod	2	354	177.0	244.7	4–350	9.8	13.6	0.2–19.4
Snailfish	2	2	1.0	0	1	0.06	0	0.6
Arctic cisco	1	1	0.5	0.7	0–1	0.03	0.04	0–0.06
Sand lance	1	3	1.5	2.1	0–3	0.08	0.12	0–0.17
Rainbow smelt	1	1	1.0	0.7	0–1	0.03	0.04	0–0.06
All	2	2,277	1,113.5	1,355.5	155–1,916	61.9	69.2	8.6–106.4

[1]Total of 2 sets.

[2]Σ = total numbers caught; mean = average catch/set; range in fish/set.

[3]Mean = average number of fish/100 m^2; range in fish/100 m^2.

At station A03117 the fishing was conducted in a relatively ice-free area adjacent to the pack. The water column was stratified (2 layers), with an upper mixed layer 2 m thick. The water in the upper layer was cold (1.07°C) and very fresh (0.77 ppt). At depth the water was −0.42°C and relatively saline (23.16 ppt). In contrast, at station A03119 the seine was fished in an area bounded on three sides by ice. The water column was mixed, with temperatures ranging from 1.27 to −0.49°C (surface to bottom) and salinities from 9.15 to 23.18 ppt. Juvenile capelin (<100 mm) were abundant at both stations, with mean densities of >60 fish/100 m^2. While the fish densities reported at A03117 and A03119 were the highest we observed in 1988 there was an order of magnitude difference in the apparent abundance between them (i.e., 8 vs. 98 fish/100 m^2, respectively).

The seine catch at A03119 provided a "snapshot" of arctic fish interactions along the outer Colville Delta in early fall. Capelin, arctic cod, Pacific sandlance, and arctic ciscoes were feeding on an apparent swarm of mysids. Rainbow smelt were also present and may have been feeding on mysids or the smaller fish. Haldorson and Craig (1984) reported that rainbow smelt were one of the most abundant fish species in the Colville Delta in fall and winter months. Although the autumnal abundance of this species has been attributed to reproductive and wintering requirements, the actual timing of the onshore population movement may be more precisely linked to migrational or other life history patterns of capelin and arctic cod.

Satellite Data

Thermal imagery from satellite observations indicates offshore surface waters to be of heterogeneous composition, with a predictable trend of warmest waters next to the coast and coldest waters nearest the ice pack. Satellite scenes from the afternoon of 11 August indicate a patchwork of warmer surface temperatures throughout eastern Stefansson Sound. The satellite images suggest warmest SSTs (>5.0°C) in the general offshore area where 48 char were captured in one set. Coastal conditions in Camden Bay on the afternoon of 14 August, prior to the marine intrusion later that month, suggest very high SSTs (>7°C) widely distributed across the bay. Satellite photos show that ice was relatively far offshore on this date and thus may have had a reduced effect on surface temperature conditions. The influence of Colville river water on coastal habitats in Simpson Lagoon and Harrison Bay is indicated in thermal images from 3 September. In these pictures the surface boundaries between warm (0.6°C) and cold (−0.9 and −1.4°C) waters are quite distinct, with warmer waters banded near the coast.

Gillnetting

A total of 389 fish were captured by gillnetting. Gillnets were fished most extensively at Bullen and Oliktok points in 1988 (Figure 12, Table 5). At each location gillnetting was resorted to only when it became clear that seining alone would not provide the sample size needed for GSI analysis of arctic char. Although set times varied by date and area, an average set time (all locations) was 5 hr. Sampling at Thetis Island was

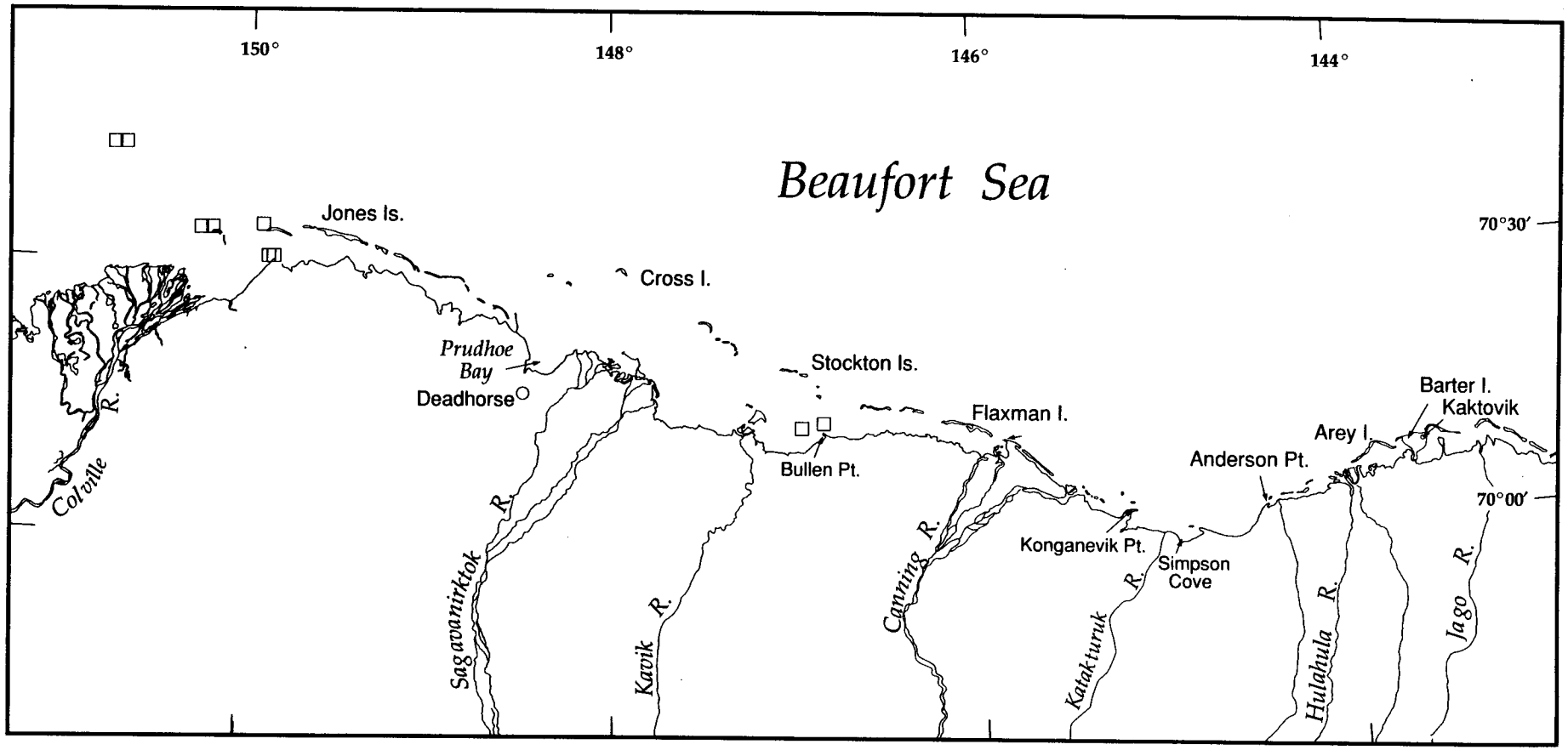


Figure 12.--Gillnet fishing locations in Stefansson Sound (□ designates net location).

Table 5.—Summary of 1988 gillnet catch.[1]

Species	Bullen Point (9–11 August)			Thetis Island (26–28 August)			Oliktok Point (1–6 September)		
	Σ	CPUE[2]	% species composition	Σ	CPUE	% species composition	Σ	CPUE	% species composition
Arctic char	37	6.27	16.7	—	—	—	2	0.16	1.2
Arctic cisco	123	20.85	55.7	1	0.30	25.0	78	6.23	47.6
Least cisco	56	9.49	25.3	—	—	—	35	2.79	21.3
Broad whitefish	3	0.51	1.4	—	—	—	6	0.48	3.7
Rainbow smelt	—	—	—	—	—	—	8	0.64	4.9
Fourhorn sculpin	2	0.34	0.9	2	0.60	50.0	17	1.36	10.4
Arctic cod	—	—	—	1	0.30	25.0	4	0.32	2.4
Unknown whitefish	—	—	—	—	—	—	14	1.12	8.5
All	221	37.5	—	4	1.20	—	164	13.09	—

[1]Total effort: 59 hr at Bullen Point, 33.5 hr at Thetis Island, 125.25 hr at Oliktok Point.

[2]CPUE expressed as number of fish/10-hr set.

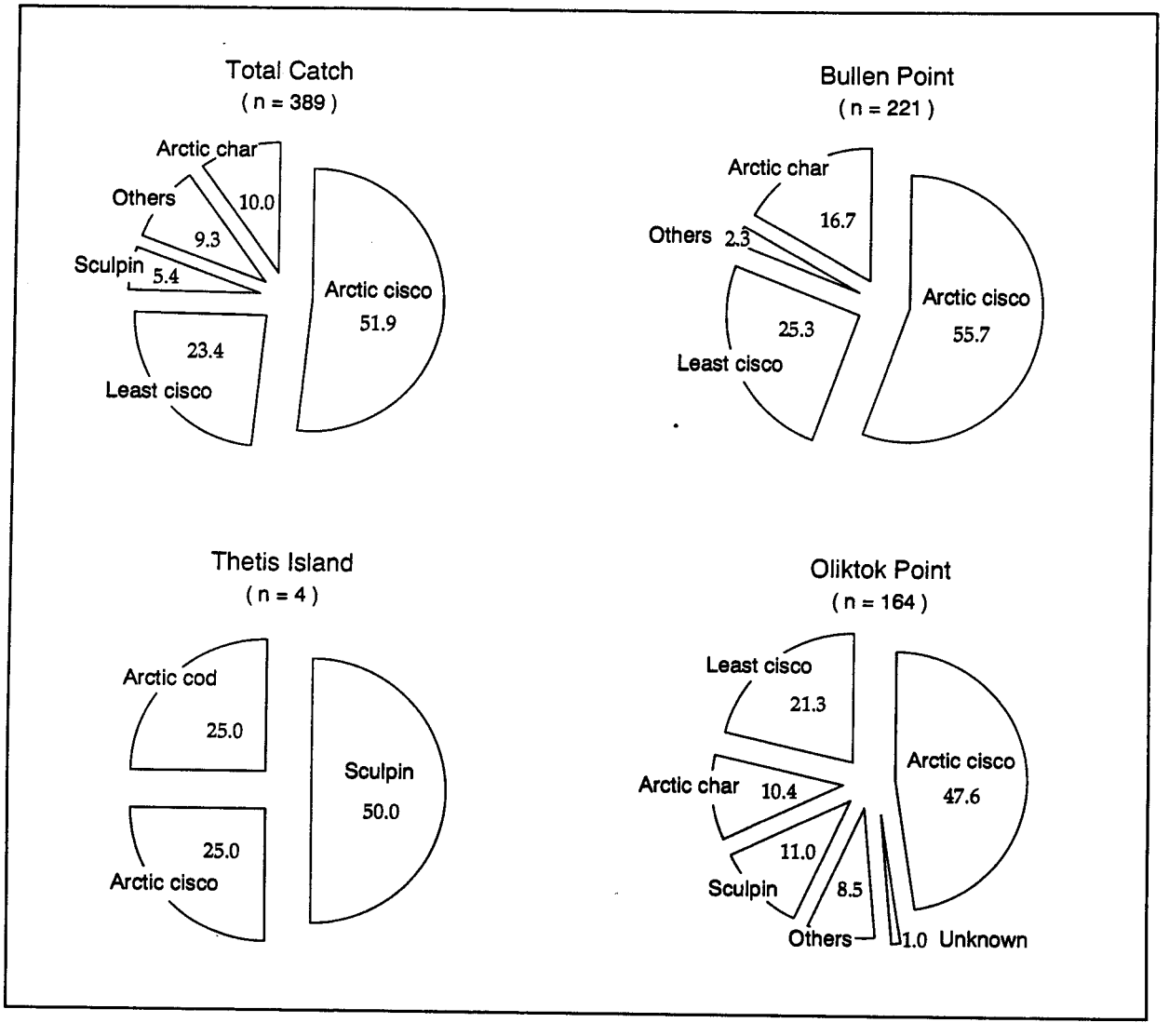


Figure 13.--Percent species composition of gillnet catches: total catch, Bullen Point, Thetis Island, and Oliktok Point.

conducted during several "weather" days in late August when wind, fog, and ice conditions prevented safe vessel operation. Arctic char and least and arctic ciscoes were the most abundant species at Bullen and Oliktok points (Figure 13). Only one arctic cisco was captured in over 33 hr of gillnetting at Thetis Island.

Arctic char were quite abundant at Bullen Point in early August 1988 (CPUE = 6.27). Thirty-seven char were captured between August 9 and 11. These were included with the fish taken farther offshore by seine as part of the Mikkelsen Bay GSI sample. Only two fish were captured at Oliktok Point after September 1 (CPUE = 0.16). The major pulse of arctic char had apparently moved into the Colville River during the latter part of August (LGL 1989). The CPUE values shown in Table 5 reflect an approximate three-fold greater relative abundance of fish in early August than 1 month later.

Temperature conditions were probably most responsible for the observed differences in relative fish abundance. Sea surface temperatures at gillnet sites were measured at the beginning and end of each set. In August, the nets were fished for widely varying periods (6.75–17.7 hr). During the first half of August, sea surface temperatures at fishing sites varied between 4.0 and 6.6°C. In September, nets fished at Oliktok Pt. were checked more frequently, usually at 2- and 4-hr intervals. Between 1 and 6 September, daily variations in surface temperatures ranging from −0.5°C at 0700, to a high of 1.5°C at 1300, to 0.7°C at 2000 were observed. After 1 September, easterly winds produced a continually dropping sea level along the western side of the point. This also may have influenced inshore use. Fish were captured on both sides of the net and it was therefore difficult to assess direction of movement.

Inshore changes in temperature and salinity structure due to wind-induced mixing may have been reflected in our catches. For example, a storm on the evening of 10 August had a westerly wind component of approximately 10 m/sec (Hale 1989). Gillnet catches rose from an average CPUE of 3.75 fish/hr to 7.81 fish/hr before and during the storm, respectively. Fish movements have been reported in response to a variety of storm events. Fechhelm et al. (1989) reported inshore movements of anadromous fish in delta areas during periods of marine intrusion. Others have suggested offshore movements away from the immediate coastlines during periods of strong wave action (Craig and Haldorson 1981).

Species Characterizations

Length and weight data for fish collected in 1988 are shown in Table 6. Note that only seine-caught arctic char have been separated from gillnet catches in this table. All but three arctic ciscoes and one rainbow smelt were collected at inshore stations. All of the least ciscoes and broad whitefish were taken by gillnets fished at Bullen and Oliktok points. The species composition of the gillnet catches is depicted in the pie charts in Figure 13.

Capelin, snailfish, Pacific sandlance, sticklebacks, and sculpins (other than fourhorn sculpin) were captured exclusively by the seine. The vast majority of arctic cod (>99%) were also captured in the offshore fishing. Fourhorn sculpin were captured by both gears. While never abundant, they appeared with regularity in most areas fished.

Species discussions are presented below for the anadromous fishes and dominant marine fishes sampled in 1988. All lengths are rounded to the nearest millimeter, reflecting the precision of our measurements. Emphasis was placed on the acquisition of biological data from anadromous species. Of these, the arctic char and two cisco species were most abundant in our catches. A more limited amount of data was obtained for broad whitefish and rainbow smelt. Finally, of the several marine species that were captured offshore, arctic cod and capelin were numerically most abundant and are therefore the focus of our discussions.

Table 6.—Length/weight statistics, all samples combined.

Species	Length (mm)					Weight (g)				
	N	Min	Max	Mean	SD	N	Min	Max	Mean	SD
Arctic char (all)	91	158	561	267.6	78.5	43	39.2	1,716.9	336.3	439.4
Arctic char (seine)	52	197	365	230.4	31.4	16	39.2	392.4	118.4	104.8
Arctic cisco (all)	200	84	383	333.4	76.6	97	9.8	1,687.5	440.6	323.7
Least cisco	89	103	388	284.0	67.0	33	9.8	657.3	278.2	193.7
Broad whitefish	8	320	445	368.9	45.6	3	524.9	833.9	672.0	155.0
Rainbow smelt	4	133	252	219.5	57.5	3	51.0	179.5	119.3	64.6
Liparid snailfish	10	21	79	58.8	20.9	—	—	—	—	—
Ninespine stickleback	1	—	—	75.0	—	—	—	—	—	—
Pacific sandlance	3	75	76	75.7	0.6	—	—	—	—	—
Capelin	570	38	84	52.4	7.6	—	—	—	—	—
Sculpins										
Fourhorn sculpin	22	93	245	179.6	30.7	6	39.2	147.2	78.5	53.4
Arctic hookear sculpin	1	—	—	54.0	—	—	—	—	—	—
Arctic staghorn sculpin	1	—	—	82.0	—	—	—	—	—	—
Arctic cod	541	22	147	75.7	20.5	—	—	—	—	—

Length Frequencies

Arctic char ranged in length (FL) from 158 to 561 mm in the combined seine and gillnet catches (Figure 14). Seine-caught arctic char ranged from 197 to 365 mm in size ($\bar{x}$ = 230.4 mm). Gillnet-caught char were larger and ranged in length from 158 to 561 mm ($\bar{x}$ = 317.5 mm). All but two fish captured with gillnets were from Bullen Point. The char gilnetted at Bullen Point (n = 37) in early August were larger (range 158 - 561 mm, $\bar{x}$ = 318.8 mm) than those captured at Oliktok Point (n = 2) in September (234 mm and 348 mm, $\bar{x}$ = 291 mm).

Size at Age

Fish ages were estimated from the age-length relationship for arctic char described by Fruge et al. (1989). The data used in their analysis were obtained from fish captured in coastal waters of the eastern Beaufort Sea during 1988. Judging from their analysis, most seined arctic char were age 3+. Some may have been younger, perhaps age 2+. Most fish were <240 mm FL. This small size suggests that 1988 was their first summer at sea. The larger seine-caught char (i.e., fish >240 mm, but <370 mm) were probably age 4+ or older (up to 7 yr). Length frequency data suggest that the gillnetted char comprise several age groups ranging from 2 to >10 yr. Considering the observed length frequency distribution and size of the sample mean, the greatest number of gillnetted char were probably immatures between 4 and 6 yr old. Fish of other ages were probably represented but in much lower numbers.

Length–Weight Relationship and Condition

The following regression model described the allometric growth relationship (Figure 15) of arctic char in our combined-gear catches:

$$\ln (W) = 1.04 \times 10^{-6} + 3.35 \ln (L)$$

$$\begin{aligned} \text{SE (a)} &= 0.1823 \\ \text{SE (b)} &= 0.2115 \\ r &= 0.931 \\ n &= 41 \end{aligned}$$

Arctic char collected during the period 4–10 August were used to calculate a condition factor, Kn, = 1.10.

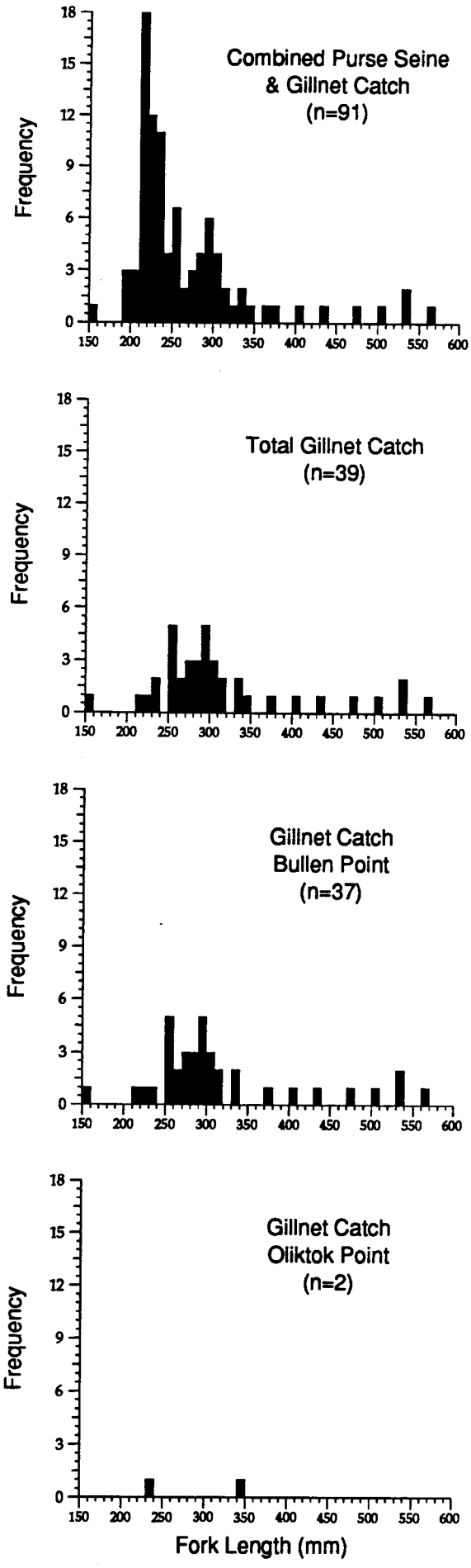


Figure 14.--Arctic char length frequencies: combined gear catch, total gillnet catch, Bullen Point gillnet catch, and Oliktok Point gillnet catch.

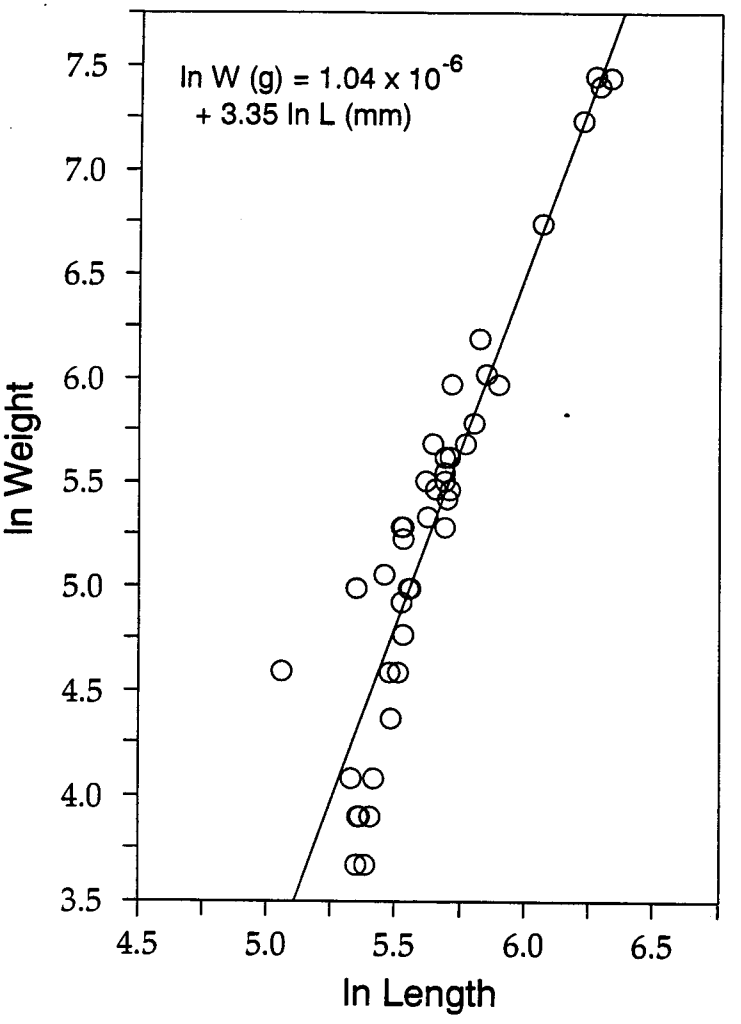


Figure 15.--Weight–length regression for arctic char.

Reproductive Status

Of 88 arctic char for which a maturity index was assigned, 84 were immature (Table 7). These fish were determined to be at least 3 yr away from first spawning. Two females (530 mm and 538 mm) were classified as F3 fish and they were probably 1 yr away from their first spawning. Only two females (401 mm and 432 mm) appeared to have spawned in the previous year (F5).

Sex Ratio

An overall sex ratio (males:females) of 1:1.6 was observed in combined gear catches. The ratio was 1:1.7 in seined char and 1:1.3 in gillnetted fish. In 1980, Craig and Griffiths (1981) reported a sex ratio of 1:1.4 for Sagavanirktok River char.

Table 7.—Length/weight statistics of three anadromous species by selected maturity state.

Maturity index	Length (mm)					Weight (g)				
	N	Min	Max	Mean	SD	N	Min	Max	Mean	SD
Arctic char										
M1	34	197	377	256.6	48.3	35	10	700	197.7	155.3
F1	50	158	503	247.1	51.7	24	40	1,410	222.1	279.2
F3	2	530	538	534.0	5.7	4	390	1,750	1,125.0	682.5
F5	2	401	432	416.5	21.9	—	—	—	—	—
Arctic cisco										
M1	25	111	367	240.9	80.5	21	10	700	187.1	200.2
M2	21	311	375	357.5	14.6	14	500	720	608.6	61.8
M3	4	355	379	357.8	9.5	2	550	700	625.0	106.1
M5	4	347	418	383.8	31.5	3	510	1,720	1,036.7	520.0
F1	24	120	375	231.0	59.2	23	10	600	153.5	161.6
F2	27	334	409	374.4	16.9	23	400	950	703.9	124.5
F3	5	352	391	372.5	13.6	—	—	—	—	—
F5	4	378	431	399.8	25.5	3	690	1,250	930.0	560.0
F6	3	363	379	370.7	8.0	3	560	750	650.0	95.4
Least cisco										
M2	2	220	388	304.0	118.8	—	—	—	—	—
M3	5	278	297	288.4	7.7	—	—	—	—	—
F2	19	233	381	308.4	44.6	9	310	670	463.3	107.2
F3	16	250	345	300.1	33.2	—	—	—	—	—

In the single seine catch of 48 char (B03064) from outer Mikkelsen Bay the sex ratio was 1:1.6. This catch was composed of an apparent school of immature char with average lengths of 220 mm in males and 224.5 mm in females. It may therefore be representative of the larger population. The data may reflect a differential rate of mortality between the sexes or that more females of this size/age class migrate to sea.

Only one other seine set resulted in the catch of arctic char. On 4 August, four larger char (one male 365 mm long, and three females averaging 306 mm) were captured off Bullen Point (B03027).

The sex ratio observed in gillnet-caught char was also variable. In an overnight set at Bullen Point (B03054) on 9 August a ratio of 1:1.5 was observed (n = 20). Two nights later at the same site (B03075) 10 char were captured and the ratio was 1:1. At B03054 the males possessed a mean length of 291.3 mm versus 339.5 mm in females. By comparison the males sampled at B03075 were longer ($\bar{x}$ = 333.6 mm) and the females shorter ($\bar{x}$ = 279.2 mm).

Food Habits

Fifteen arctic char collected in eastern Stefansson Sound during the period 4–12 August were examined for gut contents. Four char ($\bar{x}$ = 320.8 mm) taken at a 6-m depth station (B03027) were gorged on lipariid larvae. The stomachs were fully distended and larvae literally poured from their mouths at the slightest provocation. One fish had also been consuming copepods. On 11 August at another offshore (5.5-m depth) location (B03069) six char ($\bar{x}$ = 228.7 mm) had been feeding on yearling arctic cod and mysids. Closer inshore, five char ($\bar{x}$ = 348 mm) collected at gillnet stations B03062 (8/10) and B03075 (8/12) were feeding on young-of-the-year and yearling arctic cod, as well as mysids. Only one char was examined at Oliktok Point in September; it had been eating yearling arctic cod.

Arctic Cisco

Length Frequencies

Arctic ciscoes ranged in length from 84 mm to 383 mm (Figure 16). The average length of arctic ciscoes (both sexes and sampling gears combined) was 333.4 mm. Only three fish were captured by seining; one during each cruise. The first was captured in eastern Stefansson Sound (B03027) in early August (FL = 375 mm), the second (FL = 84 mm) at a 5.5-m deep station in Camden Bay (CO4081) on 21 August, and the third near Thetis Island (A03119) in early September (FL = 146 mm). The small size of the cisco taken in Camden Bay is indicative of a young-of-the-year fish.

In early August 122 arctic ciscoes were captured by gillnetting at Bullen Point. An additional 75 fish were captured at Oliktok Point in early September. The fish from Bullen Point were larger (range = 283–430 mm, $\bar{x}$ = 356 mm, SD = 23.8 mm) than those

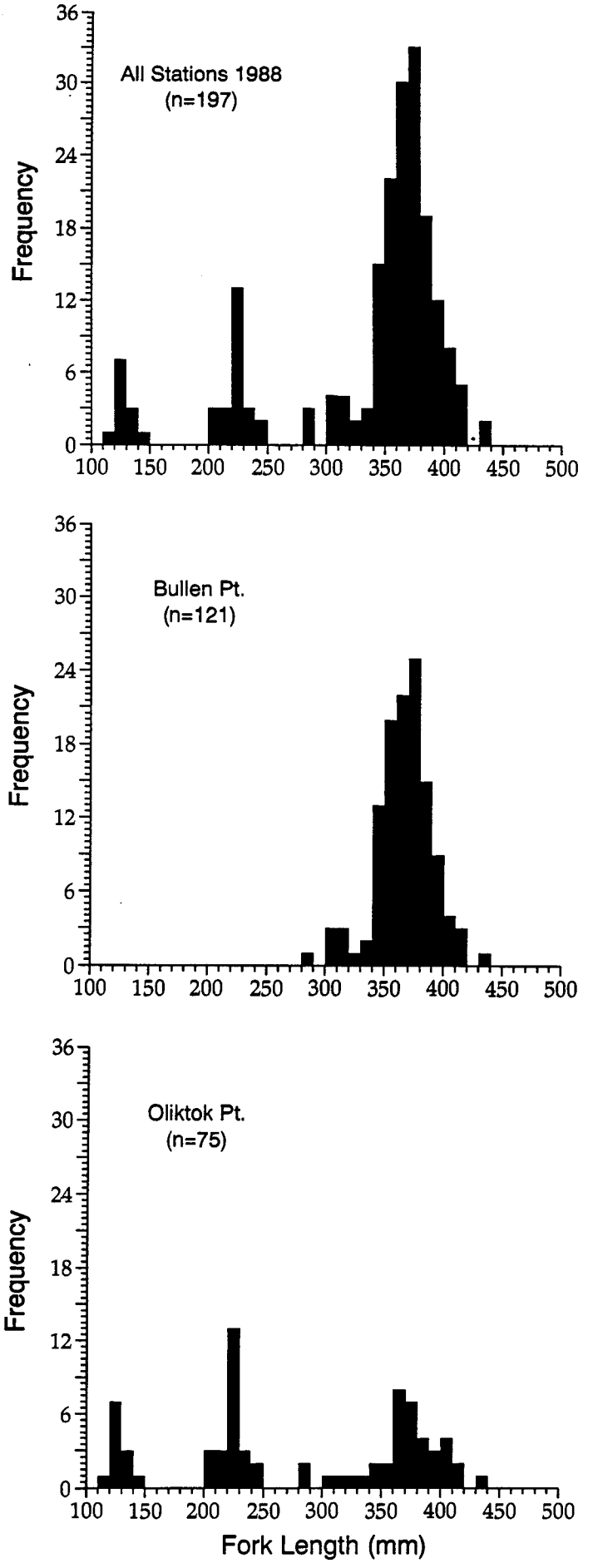


Figure 16.--Arctic cisco length frequencies: total gillnet catch, Bullen Point catch, and Oliktok Point catch.

at Oliktok Point (range = 111–431 mm, $\bar{x}$ = 285.6 mm, SD = 97.2 mm). Figure 16 indicates that the larger cohort observed at Bullen Point was still present in coastal waters a month later.

Size at Age

Cohort analysis and aging studies conducted by LGL (1989) on arctic ciscoes captured in 1988 identified the following size groupings and corresponding ages:

Cohort	*FL Range*	*Age*
Cohort I	68–114 mm	0+
Cohort II	108–168 mm	1+
Cohort III	142–230 mm	2+
Cohort IV	>230 mm	>3+

Applying this classification to our combined catch data (n = 200), it can be seen that the catch comprised the following cohorts (in numbers of fish):

	Cohort			
Area	*I*	*II*	*III*	*IV*
Offshore	1	0	1	1
Bullen Pt.	0	0	0	122
Oliktok Pt.	1	10	19	45

An inspection of average size-at-age data for arctic ciscoes collected in Simpson Lagoon (Craig and Haldorson 1981) indicates that fish > 200 mm were age 3+. Fish of lengths between 340 mm and 400 mm were aged anywhere from 6 to 12+ yr. If this relationship is considered in view of (1) our observed length frequencies, (2) information on maturity state (described below), and (3) age of first spawning (50% at age 8; see Craig 1989a), then the majority of ciscoes in our collection (340–400 mm) were ages 5–7. The age–length relationships for arctic ciscoes from Harrison and Prudhoe bays in 1988 (LGL 1989) suggest the likelihood of them being older fish (>7 yr).

Length–Weight Relationship and Condition

The following regression model described the length–weight relationship (Figure 17) for arctic ciscoes in our 1988 sample:

$$\ln (W) = 5.81 \times 10^{-8} + 3.91 \ln (L)$$

$$\begin{aligned} SE\ (a) &= 0.4055 \\ SE\ (b) &= 0.08883 \\ r &= 0.977 \\ n &= 97 \end{aligned}$$

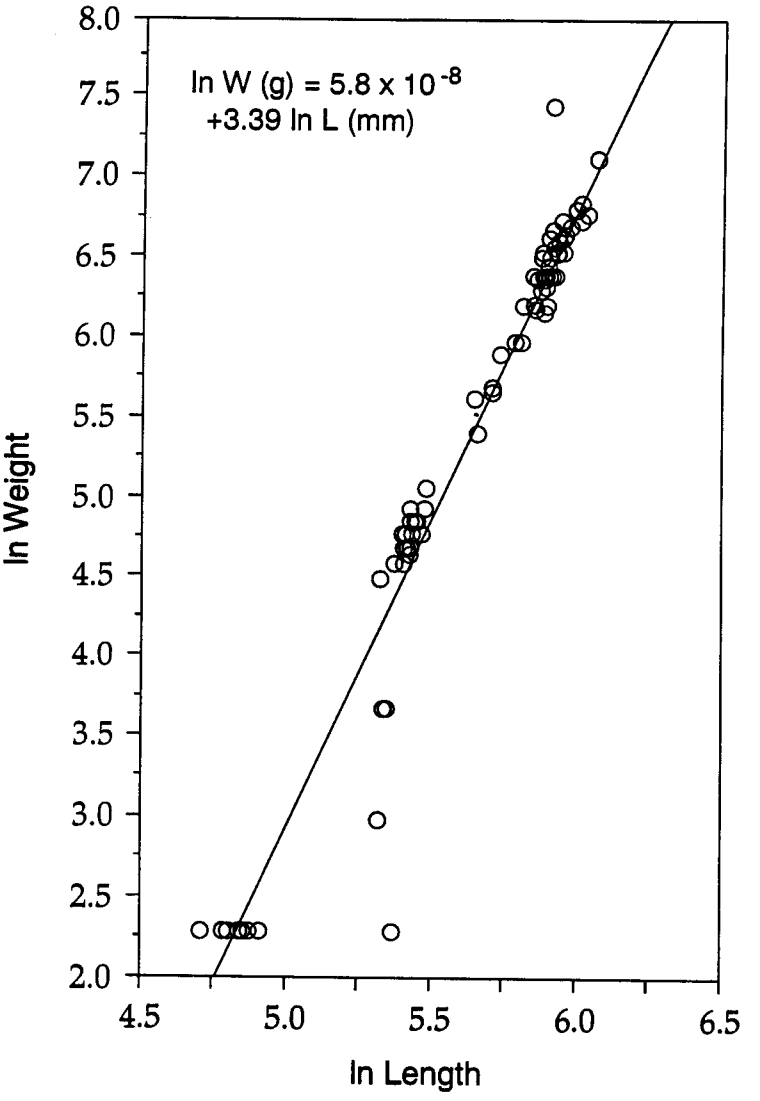


Figure 17.--Weight–length regression for arctic cisco.

The high value of b is suspicious and may reflect a selectivity bias of the gillnet for larger fish. Gillnet selectivity has been reported in Simpson Lagoon (Craig 1989a) and in Camden Bay (Fruge et al. 1989). Only 10 fish < 200 mm long were captured by our gillnets in 1988 (5% of the catch). Carlander (1969) notes that regression slopes > 3.5 cannot apply over a wide range of lengths without profound changes in body form.

Condition factors (Kn) were calculated for "early" (4–10 August) and "late" (2–6 September) portions of the open-water season. Mean Kn values of 1.06 and 1.02 were computed for the respective periods. No significant difference (Student's t, $P < 0.05$) was found between time periods.

Reproductive Status

Many ciscoes were released alive and thus only length measurements were obtained from a portion of the sample. Table 7 shows maturity state information from 117 fish. Although the 84-mm fish was not sexed it was obviously immature. The majority of ciscoes examined were immature and would not have spawned in 1988. Eleven fish appeared to have spawned previously.

Sex Ratio

An overall sex ratio (male:female) of 1:1.2 was observed in the combined catch data. Sex ratios were also compared between Bullen and Oliktok points. A ratio of 1.2:1 was found in the Bullen Point sample and 0.7:1 at Oliktok Point.

Food Habits

The stomach contents of 10 fish were examined from the Oliktok Point sample. In order of relative importance the diet was found to consist of mysids, unidentified larval fish, and young-of-the-year arctic cod. Several stomachs were noted as being 100% full (but not distended). These fish had been feeding on mysids. One fish displayed scars that were apparently the result of a seal attack.

Least Cisco

Length Frequencies

Least cisco lengths ranged from 103 to 388 mm (Figure 18). The average length was 333.4 mm. Least ciscoes were collected exclusively by gillnetting and large fish (>200 mm) were more heavily represented than smaller individuals in the catch. LGL (1989) fyke net data show fish in the 180–350-mm size range were most abundant in Prudhoe Bay in 1988 and our data are consistent with this observation.

Early and late season size comparisons are possible between least cisco catch data from Bullen and Oliktok points. Fifty-six fish captured during Cruise 1 at Bullen Point ranged in size from 220 to 345 mm ($\bar{x}$ = 288.2 mm, SD = 29.5 mm). Thirty-three fish sampled at Oliktok Point during Cruise 3 ranged from 103 to 388 mm ($\bar{x}$ = 276.9 mm, SD = 85.8 mm). Of the small fish (six fish < 200 mm) captured at Oliktok Point, all were less than 150 mm long (range = 103–146 mm).

Size at Age

Fish ages were estimated using the age–length relationship described for least ciscoes in Simpson Lagoon (Craig and Haldorson 1981). The fact that all fish examined

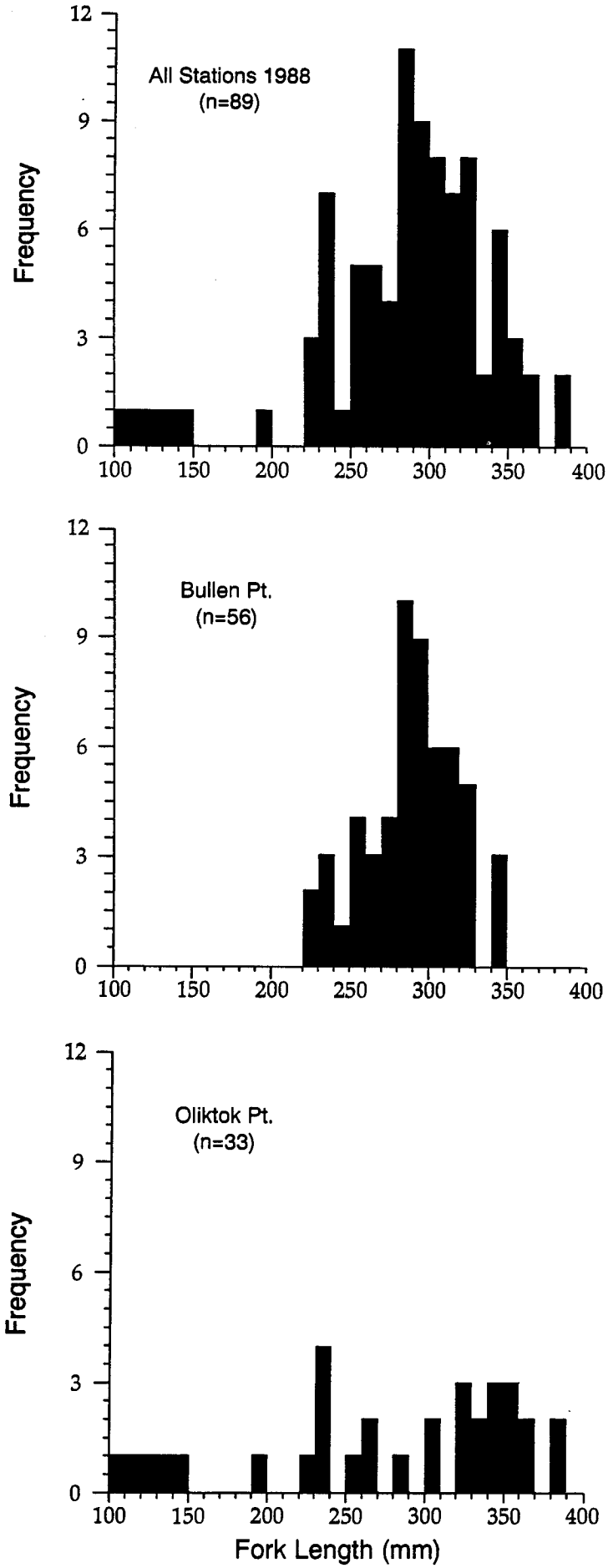


Figure 18.—Least cisco length frequencies: total gillnet catch, Bullen Point catch, and Oliktok Point catch.

were immatures (Table 7) suggests probable ages of 5–9 yr. Without actual verification of age (from otoliths or scales) this result is speculative. The Simpson Lagoon data show great variability in age at a particular size. Considering the imprecise nature of our gonadosomal index, it is possible that these least ciscoes were older (i.e., 10+ or more). Of the small fish (<150 mm) from Oliktok Point, five were likely age 2+ and one could have been age 3+.

Length–Weight Relationship and Condition

The length–weight regression (Figure 19) for least cisco in 1988 was:

$$\ln (W) = 3.278 \times 10^{-7} + 3.59 \ln (L)$$

$$SE(a) = 0.9555$$
$$SE(b) = 0.4714$$
$$r = 0.976$$
$$n = 33$$

The large value of the regression slope b (i.e., >3.5) may reflect the selectivity bias of the gillnets described previously.

A mean condition factor (Kn) of 1.08 was calculated for fish measured during Cruise 3. This index corresponds to fish condition observed during the late portion of the open-water season (n = 33). All fish on which this index is based were captured at Oliktok Point. There were not enough independent measures of length and weight taken at Bullen Point to compute a Kn in similar fashion. However, it was possible to estimate Kn for the "early" season using the sample mean $\bar{W}$ in conjunction with the regression-determined value for L. The total (bulk) weight of 52 least ciscoes sampled at Bullen Point was 12,850 g ($\bar{x}$ = 247.12 g). The calculated mean length is 293 mm. These values produce an estimated Kn of 1.05. The statistical difference between condition factors during early and late periods was not evaluated.

Reproductive Status

All fish examined (42 total) were immature and would not spawn in 1988. One-half of the least ciscoes were considered to be 1 yr away from spawning. The remaining 21 fish examined were estimated to be at least 2 yr from spawning. The six fish < 150 mm were at least 4–5 yr from sexual maturity.

Sex Ratio

Of 44 fish from which data were collected, females outnumbered males by a factor of 4.5. Sex ratios (male:female) were 1:3.7 at Bullen Point and 1:10 at Oliktok Point. Because of the small sample sizes these ratios should be viewed with caution.

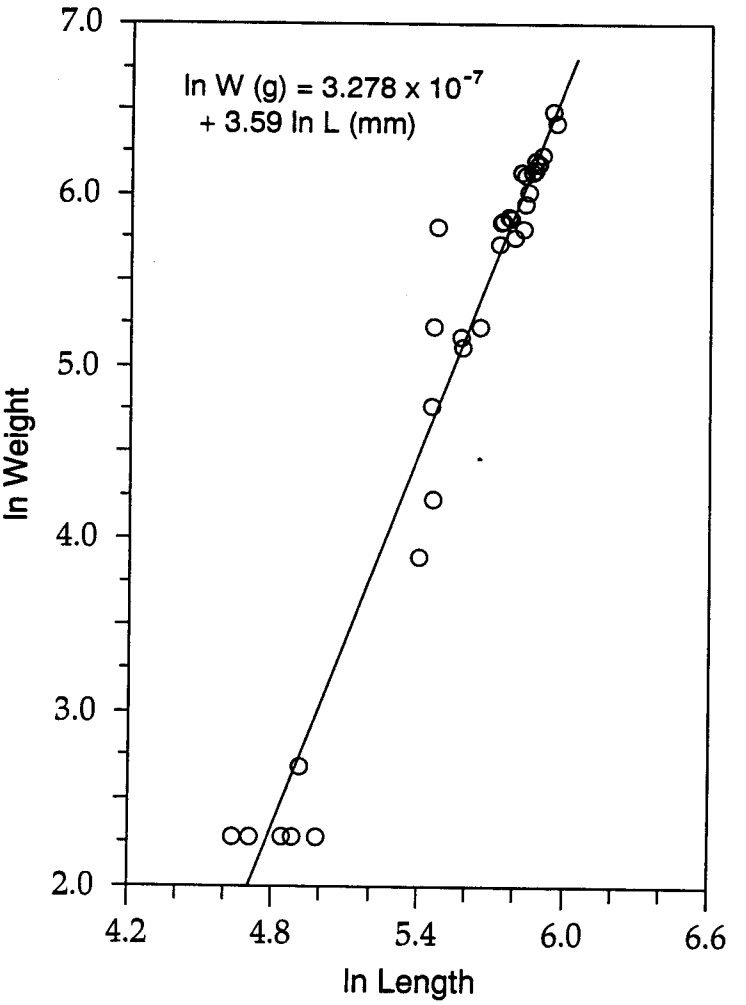


Figure 19.—Weight–length regression for least cisco.

Food Habits

The stomach contents of two least ciscoes captured at Oliktok Point were evaluated for food habits information. Both fish had been feeding on mysids and amphipods. These foods appeared to be of about equal importance in the least cisco diets.

Broad Whitefish

Length Frequencies

Only eight broad whitefish were captured in 1988 and all were taken by gillnetting. Three were captured at Bullen Point and five at Oliktok Point. Fish ranged in length from 320 to 445 mm (Figure 20). The average length of fish collected at Bullen Point was 342 mm versus 385 mm in the Oliktok Point sample.

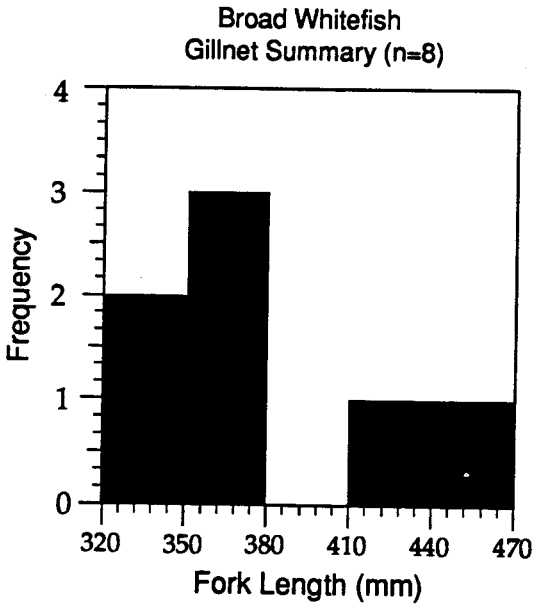


Figure 20.--Broad whitefish length frequencies, all stations combined.

LGL (1989) identified four cohorts of broad whitefish in Prudhoe and Harrison bays. Cohort IV (>230 mm) broad whitefish were abundant in their sampling near the Kuparuk River west of West Dock, at Heald Point, and in Foggy Island Bay. This cohort was the only one represented in our sampling.

Size at Age

The age–length relationship described for broad whitefish from Prudhoe Bay in 1988 (LGL 1989) was used to estimate age. Fish taken at Bullen Point ranged in length from 324 to 364 mm. This suggests probable ages of 7–9 yr. Oliktok Point fish were larger, ranging in size between 320 and 445 mm. These fish were probably 8–12 yr old.

Length–Weight Relationship

Regression analysis of the small sample of broad whitefish suggests the following relationship between length and weight variables (Figure 21):

$$\ln (W) = 2.067 \times 10^{-4} + 2.52 \ln (L)$$

$$SE(a) = 0.9327$$
$$SE(b) = 0.4267$$
$$r = 0.986$$
$$n = 6$$

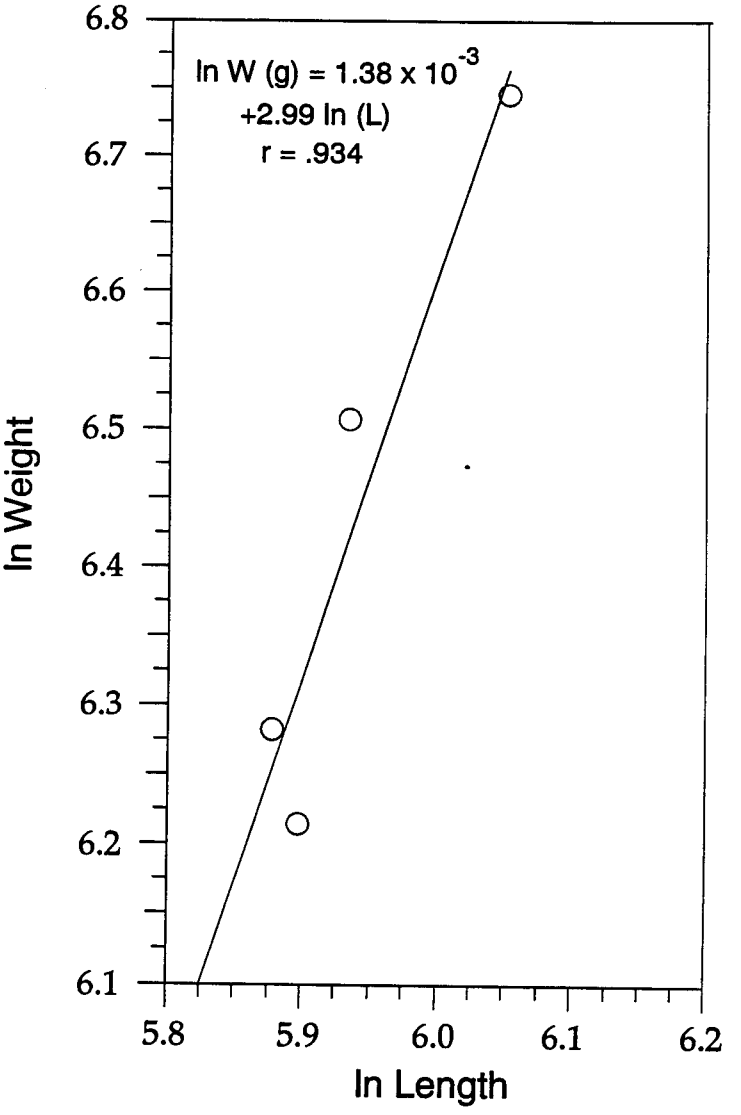


Figure 21.--Weight-length regression for broad whitefish.

Mean condition factors (Kn) of 0.78 for the "early" period at Bullen Point (n = 3) and 0.99 for the "late" period at Oliktok Point (n = 3) are suggested by our sample. Given the small sample sizes, these Kn values should not be construed as representative of the population. LGL (1989) suggests that larger broad whitefish may have dispersed more widely in 1988 than has been observed in previous years. The Kn values may reflect poorer environmental conditions (relatively cool temperatures and high salinities) for growth in 1988.

Reproductive Status

Four fish were examined for maturity condition with the following results: M1 - 320 mm; M2 - 425 mm; F1 - 338 mm; and M1 - 324 mm.

Other

The small sample does not lend itself to presentation of sex ratios. No food habits information was collected.

Rainbow Smelt

Rainbow smelt were observed only in catches from Harrison Bay. A total of eight rainbow smelt were captured in gillnets fished at Oliktok Point during Cruise 3. Five fish were devoured by predatory amphipods while hanging in the net, leaving only skeletal remains. The three remaining fish and one additional smelt captured in the seine were measured for length. Gillnet-captured fish had lengths of 252 mm, 246 mm, and 247 mm and weighed 120 g, 183 g, and 130 g, respectively. These fish had been feeding on mysids at the time of their capture or while they were trapped in the net. The 247-mm smelt was an immature female (F2) that probably would not spawn for 2 yr. This was the only specimen from which information on sexual maturity was obtained. The seine-caught smelt was a small fish (133 mm) that was captured at an offshore station near the Colville Delta (A03119).

Arctic Cod

Length Frequencies

Arctic cod ranged in size from 22 to 147 mm long (Figure 22). The average length was 76 mm. The length frequencies are clearly bimodal with peaks between 25–30 mm and 80–90 mm in the September 3 sample (n = 350) taken at a station seaward of the Colville Delta (A03119). Conversely, in a large sample (n = 309) taken earlier in the season (August 5) in eastern Stefansson Sound (B02038), the distribution of measured lengths was unimodal, peaking midway between 60 and 90 mm. In two periods of offshore sampling in Camden Bay (1–2 August and 18–22 August) no cods < 60 mm or > 95 mm were captured (n = 40). Fish > 100 mm long were apparently few at offshore stations located between the Endicott Causeway and Bullen Point in August as well as in Harrison Bay in early September.

Houghton and Whitmus (1988) report catching 695 arctic cod and 13,141 gadid larvae between 17 August and 3 September in Prudhoe and Foggy Island bays. The mean length of the 304 cod measured was 90 mm (SD = 15mm). More than 1,000 lengths were obtained from postlarval fish. Their mean length was 36 mm (SD = 24 mm).

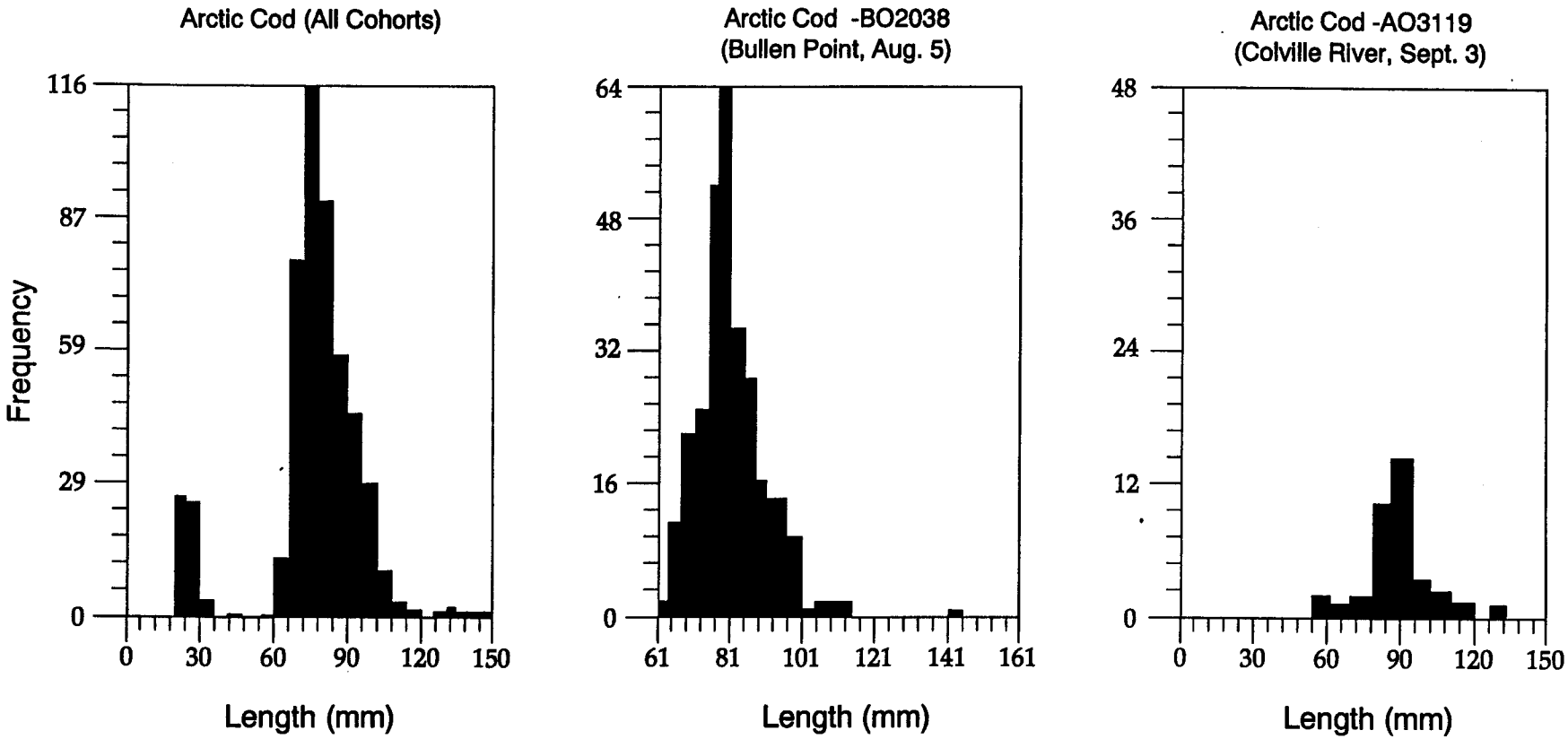


Figure 22.--Arctic cod length frequencies: all cohorts; offshore Bullen Point, 5 August; and Colville Delta, 3 September.

Size at Age

Age and growth relationships have been described for arctic cod in coastal Beaufort Sea waters between the Colville Delta and the Sagavanirktok River (Craig et al. 1982). Arctic cod < 60 mm were young-of-the year, 60–110-mm fish were age 1+, and 110–150-mm fish were age 2+ (or possibly 3+).

Capelin

Length Frequencies

Capelin ranged in size from 38 to 84 mm and averaged 52 mm long (Figure 23). The fish were all captured at stations of approximately 5.0-m depths near large river mouths. On 11 August two capelin ($\bar{x}$ = 64 mm) were captured off Bullen Point east of the Sagavanirktok River (BO3068-69). In sampling conducted off the Canning River in Camden Bay on 22 August, an estimated 675 capelin ($\bar{x}$ = 63 mm, range = 50–84 mm) were captured in the seine. More than 1,900 capelin were captured on 3 September at two stations off the Colville Delta (A03117 and A03119). These fish ranged in size from 38 to 80 mm and averaged 69 mm (n = 201) and 63 mm (n = 340), respectively.

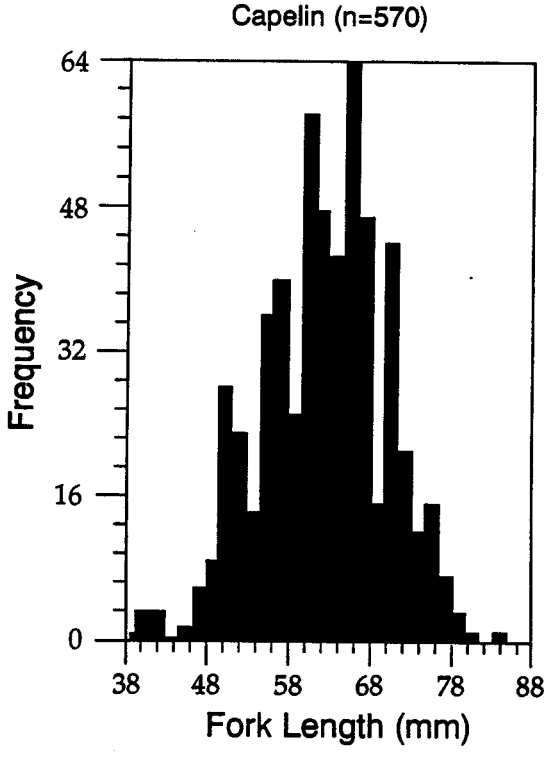


Figure 23.—Capelin length frequencies, all cohorts.

Houghton and Whitmus (1988) caught nearly 16,500 capelin in Prudhoe and Foggy Island bays in late August 1988. The mean length of the 480 fish measured was 61 mm (SD = 7 mm).

Size at Age

Pahlke (1985) described age–length relationships for capelin in the Kodiak, Togiak, and Nome areas. Only one fish smaller than 110 mm FL was included in his analysis. Age composition, average length, and average weight were significantly different between study areas and varied from year to year. At a given age, males were larger than females. The capelin ranged in age from 2 to 4 yr, with age 3 predominant. Most of the small (>40 mm) fish were probably yearling fish. It is possible that the capelin < 40 mm reported here, and by Houghton and Whitmus (1988), were young-of-the-year fish.

Other Species

Small numbers of several other species were collected in 1988. Incidental catches included three Pacific sandlance, ten lipariid snailfish, one ninespine stickleback, and 22 sculpins. Length–weight information on these species is provided in Table 6.

The Pacific sandlance were captured off of the Colville Delta in an area where the seafloor is composed of coarse-grained sands. The only sandlance examined for gut contents had been feeding on mysids. Nine snailfish were captured near the Boulder Patch in Stefansson Sound. One was seined in Camden Bay. Houghton and Whitmus (1988) reported high densities of larval snailfish in offshore stations in Foggy Island Bay. One ninespine stickleback was captured in a westward-facing set (5.5-m depth) in eastern Camden Bay on 21 August (CO4081). The stickleback capture occurred after several days of sustained easterly winds (a period of upwelling) and sea surface temperatures were very cold (–0.4°C) at the capture site.

Fourhorn sculpins were captured in both gears at sampling stations located throughout the study area. Two other sculpin species, the arctic hookear and arctic staghorn sculpins, were captured at offshore stations near the Boulder Patch. Of the fourhorn sculpins examined for maturity condition, one fish (FL = 181 mm) appeared to have spawned during the preceding year. Two other fourhorn sculpins (a 203-mm male and a 198-mm female) were considered to be immature fish 2 yr away from spawning. Amphipods were observed in the guts of fourhorn sculpins captured at Bullen and Oliktok points.

Amphipod predation on net-caught fish from the west side of Oliktok Point was extreme. Even though nets were checked every 2 hr, several whitefish were rendered unidentifiable to species.

Tagged Fish

Four tagged fish, one broad whitefish and three least ciscoes, were captured at Oliktok Point. Unfortunately, their poor condition after gilling precluded release. Information on the tags was given to the Division of Fisheries, FWS, Anchorage, Alaska, and is tabulated below:

Fish	*Date*	*Tag type*	*Number*	*Scar*
Least	9/2	Blue Floy anchor	LGLFRBK 043696	Abscessed
Broad	9/4	(Tag lost earlier in year)		Open wound
Least	9/6	Yellow dart	WCC8217526	Fair
Least	9/6	Red dart	Environo 15827	Good

It was noted that the LGL-marked fish had eggs measuring 1 mm in diameter.

Zooplankton

Seven surface bongo tows were completed in 1988. The stations selected for plankton sampling were located seaward of the barrier islands of Stefansson Sound (B04025, B04025, and A03136), off the Colville Delta (A03115), offshore Barter Island (D01002), and in the deeper waters of Camden Bay (C04086). The purpose of the sampling was only to obtain information about the presence/absence of zooplankton species (and their sizes) at several offshore locations. Secchi disc readings taken at the plankton stations indicated an average depth of light penetration to be 2.31 m (range = 0.5–3.99 m, SD = 1.39).

The zooplankton samples have not been sorted. However, the sample collected beyond the McGuire Islands in eastern Stefansson Sound on 8 August contains an unidentified larval fish (suspected gadid). The sample collected off the Colville Delta on 3 September is full of mysids.

Archival Specimens

Voucher specimens of several fish species were sent to the California Academy of Sciences to be incorporated into the OCSEAP collection. The species sent include capelin, rainbow smelt, arctic cod, snailfish, arctic hookear sculpin, and arctic staghorn sculpin.

Habitat Use

Of the purse seine sets that were successfully completed, 27 occurred in coastal waters, 14 in transitional waters, and 1 in oceanic waters (Figure 24). The number of successful sets per sampling period was 30, 10, and 2, respectively. No fish were captured at the oceanic station, so it has been dropped from analysis herein. Assuming that these

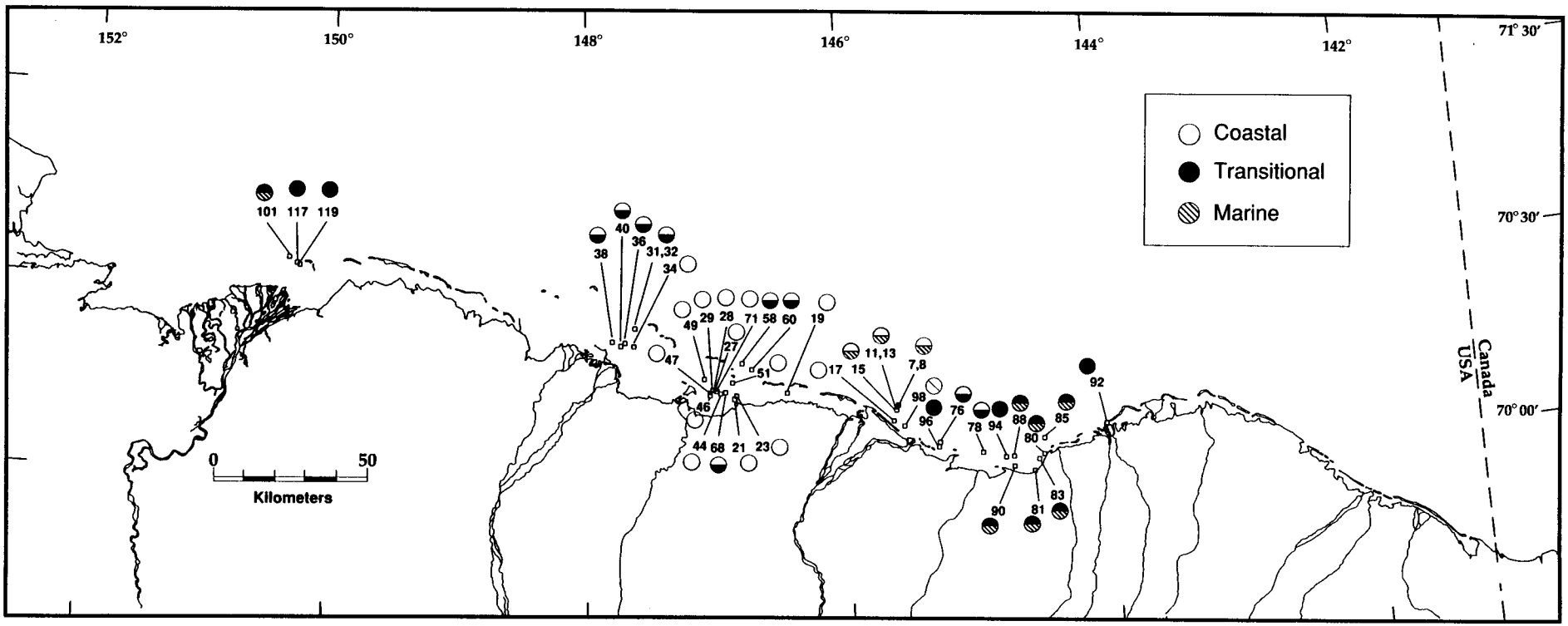


Figure 24.--Distribution of coastal, transitional, and marine water masses in the 1988 seine sampling program (water masses identified by numeric portion of the cast number).

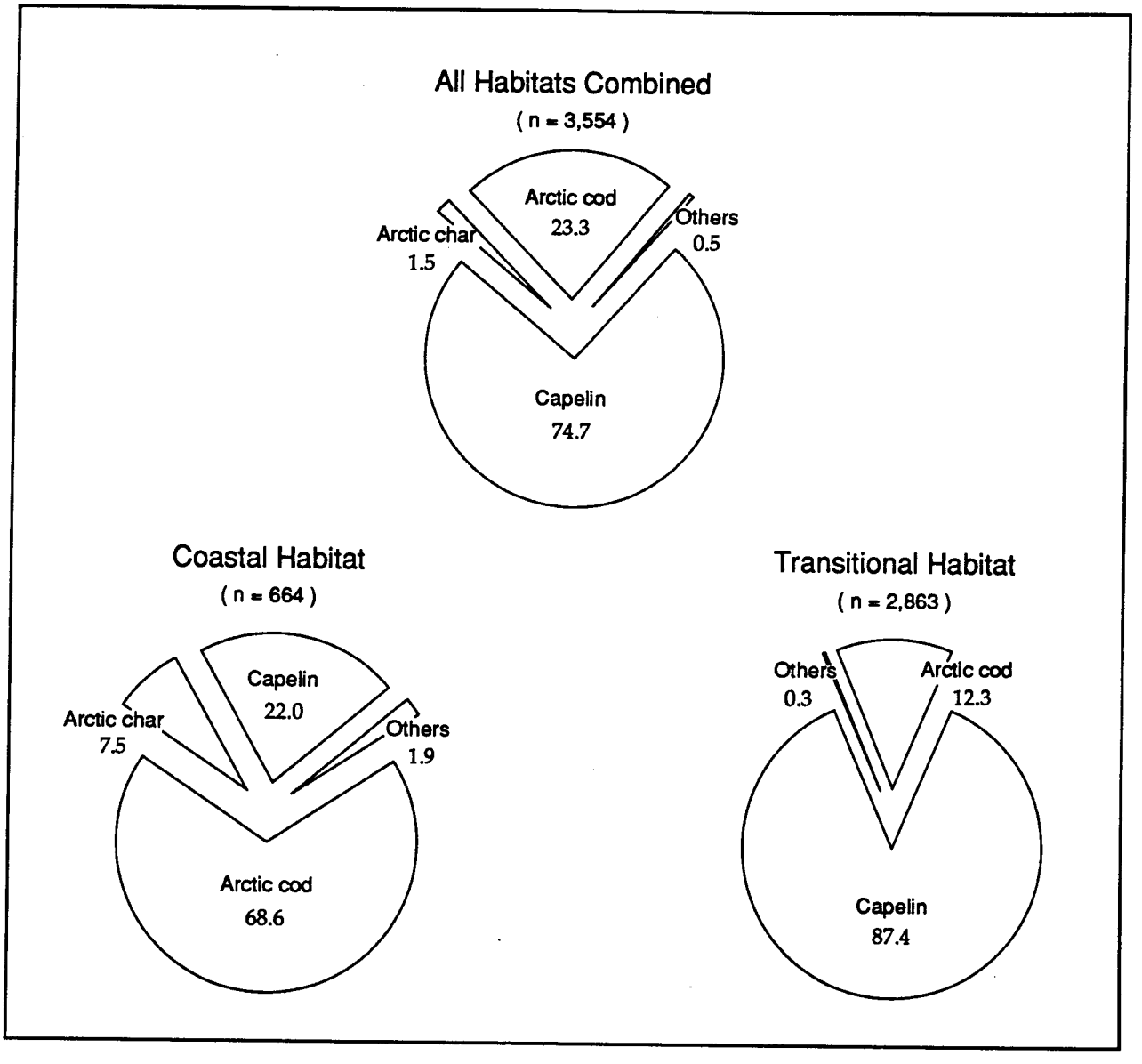


Figure 25.--Percent species composition of seine catch by hydrographically defined habitat-type: all habitats combined, coastal habitat, and transitional habitat.

water masses reflect habitat-types, the seine catch was distributed (% composition) as shown in Figure 25. The total number of fish (3,554) includes a small number of fish reported in aborted hauls. The category "Others" refers to the small catches (combined seine catch <5%) of snailfish, sculpins, arctic cisco, Pacific sandlance, stickleback, and rainbow smelt.

Contrary to expectation, no anadromous fish were caught at six stations in coastal waters having temperatures > 6°C. The mean surface temperature at coastal water stations during 1988 was 5.6°C. This average temperature is biased toward conditions in

early August when most sampling occurred. This was also the only period during which anadromous fish were captured by seining.

The physical properties of the upper mass (waters above the pycnocline) were described because of its known utilization by anadromous species. Test gillnet fishing in Camden Bay (Fruge et al. 1989) demonstrated consistently higher catches of arctic char and other anadromous fish in the upper 2.4 m. Presumably, this pattern of use can be extrapolated to other coastal areas of the Beaufort Sea. However, it is recognized that actual depth of occurrence will depend on temperature and salinity conditions at a given location, and activity of the fish.

The ranges of temperature and salinity values presented above for the upper water mass represent depth-integrated means for these parameters. In four cases, the inclusion of deepwater stations in the coastal category reflects the depth of the upper mass (essentially coastal water) being deeper than the seine. A result of this action is a disproportionate effect on the bottom temperature and salinity characteristics of the coastal habitat. If these stations are excluded from the temperature and salinity calculations, the means above are 1.9°C and 15.1 ppt, respectively.

Chi square (χ^2) analysis was used to test the null hypothesis that there was no significant difference ($P < 0.05$) in the frequencies of fish occurrence in coastal and transitional waters. Occurrence data were weighted by effort expended in each habitat type. Observed and expected occurrences of fish by habitat are shown below.

	Coastal		*Transitional*	
Species Group	*Observed*	*Expected*	*Observed*	*Expected*
All species	17	16.5	8	8.5
Anadromous fish	2	2.6	2	1.4
Estuarine group	6	7.3	4	3.7
Marine fish	14	12.5	5	6.5

The "anadromous fish" group consists of arctic char, arctic cisco, rainbow smelt, and ninespine stickleback. The "marine group" includes arctic cod and sculpins. The "estuarine" grouping is an arbitrary clustering of the remaining species. No statistical difference in habitat utilization by the all species group ($\chi^2 = 0.056$, 1 df) or marine group ($\chi^2 = 0.526$, 1 df) was evident in our data. There were insufficient data to conduct χ^2 tests on anadromous and estuarine groups.

Although anadromous species were encountered offshore in our purse seining and in tow-netting by others (Houghton and Whitmus 1988), the limited sampling effort and small sample sizes preclude definitive conclusions about observed inshore–offshore distributions and habitat use. For example, if our sample was 50 stations, distributed in coastal, transitional, and oceanic habitats, the power of the χ^2 test ($P < 0.05$, df = 2) would have been 70%. The corresponding "effect" of habitat on fish frequency of occurrence

would be 40% of the mean. The sample would be large enough to show a significant difference equal to 40% of the mean in about 70% of the cases. At this power, a Type II error would be committed 30% of the time.

DISCUSSION

The summer of 1988 was characterized as a "heavy ice year." Breakup occurred on the North Slope in mid- to late July but the ice pack remained close inshore throughout the "open water" season. From the perspective of requirements for offshore seining, the open-water period was even more abbreviated, extending from 1 August to 10 September.

Vessel movements were restricted in 1988 by harsh environmental conditions. While we were able to seine throughout the zone of maximal brackish water influence discussed by Craig (1989a), ice and frequently bad weather, as well as the long distances and travel times required to reach prospective fishing grounds, had an adverse effect on the number of stations we were able to occupy.

Length frequency information from the anadromous fish species captured in the seine indicate that larger-sized fish (400-mm range) were sampled by the gear. Size-related avoidance problems have been reported for many other active sampling gears but were not apparent with the seine. For example, Isakson et al. (1986) reported gear avoidance by juvenile salmon (FL > 140 mm) in exploratory tow net fishing in Bristol Bay. Similar gear avoidance by arctic species may also be reflected in the size composition of the tow net catches of Houghton and Whitmus (1988). The use of a "round haul" technique in conjunction with electronic fish finding methods may improve the efficiency of the seine operation from what occurred in 1988. The potential for tactile as well as visual avoidance would be reduced by this sampling approach.

Although the magnitude of active sampling effort was less than anticipated in 1988, the analysis of fish habitat use that we employed can be readily adapted to multiyear data sets. This approach has recently been used by Rose and Leggett (1989) in a study of Atlantic cod abundance patterns relative to water mass distributions and prey density fields in the North Atlantic. Frequency of occurrence data collected in different years are statistically comparable as long as the hydrographic definitions used in habitat characterization remain consistent. If electronic gear is used to locate fish, hydrographic casts would need to be completed after the seine set to reduce bias associated with frequency of habitat-type sampled; i.e., these would be "blind" seine sets with respect to knowledge of the water mass sampled.

Hale (1989) analyzed meteorological and oceanographic data sets acquired by the FWS in 1988 from three coastal locations in the ANWR segment of the eastern Beaufort Sea. The data were acquired from 6 August through 13 September. His analysis showed winds to be predominantly from the east (60%) with westerly winds occurring about 30% of the time. Mean wind speeds of 5 m/sec were reported. A comparison of nearshore and

lagoonal hydrographic data sets shows that water temperatures rarely exceeded 7°C in coastal bays and lagoons during 1988. Little vertical stratification was observed in shallower portions of lagoons and protected bay environments. Salinities were generally less than 9 ppt at these locations.

More exposed sampling sites, such as Bullen Point, may have been subject to greater habitat variability resulting from wind-induced mixing. Offshore coastal stations (5–10 m deep) inside the barrier islands, or more exposed locations, tended to be stratified in two layers. In many instances, the waters overlying the pycnocline were of similar temperature and salinity composition to those much closer to the coast. This feature of the two-layer system provides a possible offshore extension of the more limited brackish water available to anadromous fish.

Storms dominated the open-water period after mid-August, and this may have shortened the period of seasonal use of exposed coastline by anadromous fish. A comparison of 1987 and 1988 fyke net catches at Collinson Point in Camden Bay (unpublished FWS catch statistics) shows a marked increase in arctic char catches (142 vs. 543 fish, respectively) in the latter year. The concept of increased use of protected bays and lagoons by fish during unfavorable conditions is intuitively appealing.

Arctic char were the primary target of our offshore purse seining. Their relative availability must therefore be considered in view of the success, or lack thereof, of the offshore sampling effort. Catch statistics from the eastern Beaufort Sea (Fruge et al. 1989) show greatest relative abundance of char in coastal waters from mid-July to mid-August 1988. LGL (1989) reported peak char abundance in Prudhoe Bay in early (around 15 July) and late (around 1 September) periods in 1988. The peaks in CPUE observed by LGL were attributed to (1) their sampling near major char rivers, and (2) the wide-ranging dispersal of char during summer months. Essentially, these CPUE peaks coincide with arctic char departures from and returns to freshwater habitats. LGL (1989) also reported very low catches of arctic char in the Harrison, Phillips, and Mckinley bay regions for similar summer periods in 1988. In the latter instances, the apparently reduced abundance of arctic char was explained by physiographic characteristics of the species' distribution.

In light of the above, two points are clear: (1) the coastal residency period for most char was 1.5 months in 1988, and (2) there was a reduced availability of arctic char in coastal waters after September 1. Spawning fish of the year were not expected, or encountered, in catches after mid-August. Arctic char were captured in offshore seining only during the first half of August. Considering the seasonal availability of the species, and the logistical constraints imposed on offshore fishing in 1988, our catches indicate that seining is a practical sampling method for arctic char in the arctic marine environment.

Craig (1989a) indicated that the primary brackish water habitat of char extends some 2–10 km from the coast. The presence of arctic char beyond the inshore habitat may reflect directed movements related to feeding. Certain seine data support this. Four char

(297–365 mm long) captured in outer Mikkelsen Bay on 4 August appeared to be actively feeding, as they were satiated with larval snailfish. The water column there was well mixed (5-m depth, 3°C temperature, and 13–14 ppt salinity). On 11 August, 48 smaller char (range = 197–283 mm, $\bar{x}$ = 220 mm) were captured in seining 5 km offshore in Mikkelsen Bay. This may have been their first year at sea. These fish had undigested mysids and young-of-the-year arctic cod in their stomachs and may have been actively pursuing prey when captured. On this date the water column was stratified, with water temperatures and salinities in the upper layer of >5°C and 13 ppt, respectively.

Our results support an existing conceptual model of lagoonal/coastal use by arctic char (Irvine and Meyer 1989). Arctic char may undertake daily (or otherwise intermittent) excursions into offshore areas in search of food. Larval fish and young aged arctic cod and capelin may be a relatively more abundant food resource offshore, especially in the "early" season prior to the first marine intrusion. After feeding at offshore sites, the char may return to warmer inshore waters for enhanced metabolism or protection from storm events. Metabolic benefits of warmer temperatures also may be achieved via fish occupation of upper water layers which, in many instances, possess water property characteristics similar to inshore waters. With respect to new information, the apparent schooling of relatively large numbers of small char in offshore areas was an unexpected result. Perhaps it reflected interspecific competition for a limited inshore food resource.

The Mikkelsen Bay char sample served as a "blind test" of the GSI, as no information was provided to the FWS regarding "location of catch." The GSI's recognition of Sagavanirktok and Canning river fish, and proportionately higher assignments of these stocks to the mixture, is a confirmation of the validity of this technique. Arctic char from the eastern Beaufort Sea and Canada were also indicated in the sample. This is reasonable in light of known physiographic distributions and migration rates of char. The result is also supported by tag return data. The smaller-sized char in the large offshore sample (48 fish) were probably Sagavanirktok or Canning River fish undertaking their first seaward migration.

Our seining and gillnet fishing activities offer little new information about anadromous fish distributions. Length frequency data for arctic char, arctic and least ciscoes, and broad whitefish were similar to those reported by others (Fruge et al. 1989; LGL 1989). Arctic and least ciscoes of intermediate sizes (200–325 mm and 175–275 mm, respectively) were not abundant in our sampling. Like Houghton and Whitmus (1988), we captured very few small (<100 mm) arctic cisco at the offshore stations. Fruge at al. (1989) also reported a paucity of young-of-the-year arctic ciscoes along the ANWR coast. LGL (1989) indicated that 1988 was a poor recruitment year for the species.

Length frequency data obtained for arctic char captured in eastern Stefansson Sound are suggestive of the bimodal trend reported by LGL (1989). These authors offer two possible explanations for the observed bimodality. The first relates to energetics. A significant fraction of energy intake of immature anadromous char is presumably devoted to somatic growth rather than accumulation of fat reserves for overwintering. Overwinter-

ing mortality due to depletion of fat reserves may be higher among immature fish than adults, especially during winters when conditions during the preceding growth season were suboptimal. The second explanation relates to density dependence. Dillinger and Gallaway (1989) suggest that recurrent bimodal length frequency distributions of broad whitefish observed near Prudhoe Bay during the period 1975–88 may have resulted from high densities of large fish using critical freshwater overwintering and rearing habitats in some years. Large fish are presumed to exclude smaller fish from the preferred habitats. It follows that during years when exclusion of small fish occurs, relatively high mortalities of those age classes would result as the immature fish would be forced to use less hospitable habitats.

The bimodal size distribution of arctic char may also be a reflection of differential mortality related to feeding mode. Gallaway (1988) suggests that once char attain a certain size and morphology threshold and are able to feed on arctic cod, they have access to an often abundant food resource unavailable to smaller char. Small capelin reported in abundance offshore also may be an important food resource. Piscivory may confer significant energetic advantages over planktivory in terms of energy expended per unit of energy captured, thereby effectively reducing size-related mortality.

A probable consequence of the heavy sea ice coverage in 1988 was reduced use of coastal habitats by andromous fish. Preliminary data of the FWS indicate a 10-fold reduction in total catch in 1988 relative to that in 1987. This was so despite a doubling of fishing effort in 1988. Cooler water temperatures and frequent storms probably resulted in the physical disruption and decrease of inshore habitat quality and accessibility. Fechhelm et al. (1989) found that colder temperatures and increased salinities may block migratory pathways of anadromous fish. From a population perspective, growth parameters could be affected by cooler temperatures and reduced feeding opportunities.

Such effects are not readily apparent in Kn values reported for arctic char or arctic and least ciscoes in 1988 (Fruge et al. 1989; this report). In Norway, Berg and Berg (1989) found that the earliest portion of the "open water season" corresponded to the period of greatest seasonal growth in arctic char. The temperature and salinity regimes reported by Hale (1989) for shallow water environments after mid-August are not unlike conditions reported by Schmidt et al. (1989) at fish overwintering sites. With respect to char, most fish had returned to freshwater habitats by early September. LGL (1989) noted a significant difference in the regression slopes of the weight–length relationships for broad whitefish in "early" and "late" periods of 1988. This was related to colder temperatures and higher salinities in autumn.

Young-of-the year (larvae to 30–40-mm juveniles) and yearling (60–90 mm) arctic cod were abundant in eastern Stefansson Sound during 1988 (Houghton and Whitmus 1988; this report). This is a known spawning ground nursery area significant for arctic cod (Craig et al. 1982; Craig 1984). The presence of young-of-the year juveniles near the Colville Delta in the seine sampling suggests the possibility of another spawning location in the western part of the study area.

Expatriate biota from the Chukchi Sea may be transported as far east as Harrison Bay during periods of extended westerly winds. Arctic cod hatched in the Chukchi Sea could potentially be transported to this region. Fish-of-the-year were observed in catches in the northeastern Chukchi Sea during early September 1989; this area could be a potential source of young-of-the-year cod observed off the Colville Delta (W. Barber, Univ. Alaska Fairbanks, pers. commun.).

However, it seems more probable that the small cods observed in the September sampling originated in eastern Stefansson Sound. If one assumes (1) that cod spawn in spring some 167 km east of the Colville Delta, and (2) average summer conditions of 5 m/sec easterly winds and 15.4 cm/sec currents prevail, it would take 7–19 days for a passively drifting "particle" to be transported into Harrison Bay. This scenario factors no west winds into the transport process. West winds, which occur about 30% of the time, tend to be stronger than east winds, and thus their effect on a passively drifting organism (in the opposite direction) would be greater. It is therefore not unrealistic to imagine an "estuarine transport" period encompassing the entire open-water period in which young cod are moved by currents from one end of the lagoon to the other. Mortality of post-spawners (2- and 3-yr-old fish) is apparently great, as few fish of older age groups (>120 mm) are reported in the various 1988 catch data (Houghton and Whitmus 1988; Fruge et al. 1989; this report).

A large number of very small capelin (<100 mm) were captured at several offshore locations in 1988 (Houghton and Whitmus 1988; this report). Spawning by capelin had previously been reported in Prudhoe Bay (Bendock 1979), and may also occur in Demarcation Bay (R. Bailey, FWS, pers. commun.). Subsistence use records indicate the species is present in coastal waters near Barrow during August but it is not known whether spawning occurs at this time. Large capelin are apparently rarely captured in coastal fish sampling (see, e.g., Craig and Haldorson 1981; Fruge et al. 1989). Although this may be an artifact of the sampling gears and areas fished, it is more likely a reflection of this species' requirements for offshore transitional or marine habitats.

In 1988 capelin were the most abundant fish we captured in pelagic habitats near the Canning, Sagavanirktok, and Colville deltas. Perhaps capelin spawn along the margins of these large river deltas and their larvae are subsequently transported offshore at the time of hatch. Alternatively, we think it more likely that spawning occurs farther offshore along the outer beaches of the barrier islands. Beach and offshore spawning are probable, the magnitude of either being related to the density of the spawning biomass. This hypothesis is consistent with Bendock's (1979) observations in Prudhoe Bay and what has been reported in the Northwest Atlantic (e.g., Carscadden et al. 1989).

The timing of capelin reproduction in the southeastern Beaufort Sea is poorly defined. It may occur in several waves at various times and places throughout the summer (Pahlke 1985). However, it is likely that reproduction is keyed in time and space to other events associated with spring breakup (e.g., warming temperatures and increasing food resources; see Chambers and Leggett 1989). Eggs hatch near mid-July and larval fish

may be transported inshore under west wind conditions associated with the disintegration of the strong front between coastal and marine waters. A similar transport mechanism involving wind-regulated water mass replacement and transport of larval fish has been suggested for capelin off the coast of Newfoundland (Frank and Leggett 1982). In this case, the onshore transport would carry larvae into coastal "safe sites" where survival may be enhanced. Fish acoustically detected by Moulton and Tarbox (1987) along the leading edge of the front near Prudhoe Bay may have been capelin.

The hypothesized onshore transport (and possible movement of age 1 fish) of capelin would link early life history development in the species to favorable temperature and food conditions in the more protected nearshore zone. As indicated parenthetically above, it is not known whether the capelin overwinter in coastal waters or offshore. Existing information on the food habits of the capelin (Pahlke 1985) indicates copepods and euphausiids are their primary prey. As such, the species provides a trophic link similar to that described for arctic cod between the zooplankton and apex vertebrate consumers in the arctic. There is no reason that this fish would not be an important food resource for anadromous char and cisco species utilizing offshore habitats.

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Appendix A
Molluscs Collected in the Beaufort Sea in 1988

BIVALVIA

Astarte montagui (Dillwyn, 1817)
Axinopsida orbiculata (G. O. Sars, 1878)
Boreacola vadosa Bernard, 1979
Crytodaria kurriana Dunker, 1862
Diplodonta aleutica Dall, 1901
Hiatella arctica (Linnè, 1767)
Liocyma fluctuosa (Gould, 1841)
Lyonsia arenosa (Möller, 1842)
Macoma calcarea (Gmelin, 1791)
Macoma crassula (Deshayes, 1855)
Macoma moesta alaskana Dall, 1900
Musculus (Musculus) corrugatus (Stimpson, 1851)
Musculus (Musculus) discors (Linnè, 1767)
Musculus (Musculus) niger (Gray, 1824)
Mya (Mya) pseudoarenaria Schlesch, 1931
Nucula tenius (Montagu, 1808)
Pandora (Pandorella) glacialis Leach in Ross, 1819
Portlandia arctica (Gray, 1824)
Tellina nuculoides (Reeve, 1854)
Thyasira equalis (Verrill & Bush, 1897)
Tridonta borealis (Schumacher, 1817)
Yoldiella (Yoldiella) intermedia (M. Sars, 1865)

GASTROPODA

Admete sp. #850
Amauropsis islandica (Gmelin, 1791)
Boreoscala greenlandica (Perry, 1811)
Buccinum angulosum Gray, 1839
Colus dautzenbergi Dall, 1916
Cylichna occulata (Michaels, 1841)
Diaphana minuta (Brown, 1827)
Margarites giganteus (Leach, 1878)
Natica (Cryptonatica) russa Gould, 1859
Neptunea borealis (Philippi, 1850)
Neptunea heros (Gray, 1850)
Odostomia (Menestho) albula (Fabricius, 1780)
Odostomia (Menestho) castanea (Möller, 1842)33
Oenopota novajasemliensis (Leche, 1878)
Oenopota rosea (G.O. Sars, 1878)
Oenopota simplex (Middendorff, 1849)
Oenopota sp. #679
Oenopota sp. #843
Philine polaris Aurvillius, 1885
Polinices pallida (Broderip & Sowerby, 1829)
Retusa sp. #844
Velutina undata Brown in Smith, 1839
Velutina velutina (Müller, 1776)

1988 COLLECTION STATIONS.
BEAUFORT SEA, ARCTIC OCEAN, NOAA-OAS

88-1 B04:019; 4:VIII:88; 70 12.6'N, 146 27.6'W; 4.5m
- Oenopota novajasemliensis - 2
- Musculus discors - 1
- Musculus niger dead
- Liocyma fluctuosa - 15
- Pandora glacialis dead
- Crytodaria kurriana dead
- Musculus corrugatus - 4
- Axinopsida orbiculata - 1

88-2 B04:021; 4:VIII:88; 70 11.5'N, 146 52.3'W; 4.5m
- Oenopota novajasemliensis dead
- Musculus niger - 2
- Liocyma fluctuosa - 2
- Tridonta borealis dead
- Macoma moesta alaskana dead
- Astarte montagui dead
- Portlandia arctica dead

88-3 B04:022; 4:VIII:88; 70 12.0'N, 146 51.7'W; 6.5m
- Cylichna occulata dead
- Oenopota novajasemliensis - 6
- Odostomia albula - 5
- Musculus discors - 1
- Liocyma fluctuosa - 4
- Tridonta borealis - 4
- Macoma calcarea dead
- Astarte montagui - 6
- Portlandia arctica - 1
- Diplodonta aleutica - 1

88-4 B04:026; 4:VIII:88; 70 13.1'N, 146 59.8'W; 6.0m
- Retusa sp. #844 dead
- Liocyma fluctuosa - 1
- Astarte montagui dead

88-5 B02:030; 5:VIII:88; 70 22.6'N, 147 38.3'W; 8.75m
- Margarites giganteus - 1
- Buccinum angulosum - 1
- Natica russa dead
- Cylichna occulata - 1
- Diaphana minuta - 4
- Oenopota novajasemliensis - 4
- Gn. sp. - 1
- Liocyma fluctuosa - 4
- Tridonta borealis - 1
- Pandora glacialis - 1
- Astarte montagui - 3
- Portlandia arctica dead
- Lyonsia arenosa dead
- Axinopsida orbiculata - 1

88-6 B02:033; 5:VIII:88; 70 19.7'N, 147 39.0'W; 7m
Polinices pallida dead
Diaphana minuta - 3
Oenopota novajasemliensis - 18
Oenopota sp. - 1
Tellina nuculoides - 35
Tridonta borealis dead
Pandora glacialis - 3
Macoma moesta alaskana - 1
Astarte montagui - 1
Portlandia arctica - 1
Macoma crassula - 3
Lyonsia arenosa - 5

88-7 B02:035; 5:VIII:88; 70 20.5'N, 147 43.1'W; 7.5m
Polinices pallida - 2
Philine polaris - 1
Diaphana minuta - 1
Oenopota novajasemliensis - 4
Liocyma fluctuosa - 10
Tridonta borealis - 1
Pandora glacialis - 1
Crytodaria kurriana - 36
Astarte montagui - 8
Portlandia arctica - 25
Macoma crassula - 1

88-8 B02:037; 5:VIII:88; 70 20.8'N, 147 48.3'W; 5.5m
Diaphana minuta dead
Oenopota novajasemliensis - 5
Liocyma fluctuosa - 11
Tridonta borealis - 1
Crytodaria kurriana dead
Astarte montagui - 3
Portlandia arctica - 2

88-9 B02:038; 5:VIII:88; 70 20.8'N, 147 48.5'W; 5m

88-10 Bullen PT.; 8:IX:88; 70 10.8'N, 146 58.1'W; 2.5m
Amauropsis islandica - 1
Neptunea heros dead
Buccinum angulosum dead
Cylichna occulata - 5
Diaphana minuta - 24
Musculus discors dead
Liocyma fluctuosa - 2
Tridonta borealis dead
Crytodaria kurriana - 3
Yoldiella intermedia - 5
Boreacola vadosa _ 87

88-11 Bullen Pt.; 9:VIII:88; 70 11.5'N, 146 58.6'W; 2.5m

88-12 B03:044; 9:VIII:88; 70 12.0'N, 146 58.3'W; 5.5m
Cylichna occulata - 1
Diaphana minuta - 1
Oenopota novajasemliensis - 12
Odostomia albula - 7
Liocyma fluctuosa - 12
Tridonta borealis - 5
Macoma moesta alaskana - 1
Astarte montagui - 4
Portlandia arctica - 9

88-13 B03:046; 9:VIII:88; 70 12.4'N, 147 03.0'W; 6.0m
Natica russa - 4
Polinices pallida - 9 + egg case
Philine polaris - 10
Cylichna occulata - 10
Diaphana minuta - 17
Oenopota novajasemliensis - 141
Odostomia albula - 32
Admete sp. #850 - 7
Liocyma fluctuosa - 46
Tridonta borealis - 64
Macoma moesta alaskana - 8
Astarte montagui - 65
Portlandia arctica - 20
Macoma crassula - 5
Lyonsia arenosa - 3
Axinopsida orbiculata - 2
Yoldiella intermedia - 2

88-14 B03:049; 9:VIII:88; 70 15.4'N, 147 06.1'W; 7.0m; Mud
Polinices pallida dead
Philine polaris - 3
Cylichna occulata - 1
Oenopota novajasemliensis - 13
Odostomia albula - 5
Odostomia castanea - 1
Retusa sp. #844 - 2
Liocyma fluctuosa - 10
Tridonta borealis - 9
Macoma calcarea - 1
Macoma moesta alaskana - 2
Astarte montagui - 25
Portlandia arctica - 9
Diplodonta aleutica - 1

88-15 9:VIII:88; 70 15.0'N, 146 57.7'W; 4m; Sand
Cylichna occulata - 3
Oenopota novajasemliensis - 2
Liocyma fluctuosa - 9
Astarte montagui - 1
Musculus corrugatus dead
Boreacola vadosa - 4

88-16 B03:051; 9:VIII:88; 70 13.9'N, 146 53.0'W; 4.5m; S-M
Boreoscala greenlandica - 1
Oenopota simplex - 11
Polinices pallida - egg case
Philine polaris - 1
Cylichna occulata - 34
Diaphana minuta - 10
Oenopota rosea - 1
Oenopota novajasemliensis - 4
Musculus niger dead
Liocyma fluctuosa - 234
Tridonta borealis - 9
Macoma calcarea - 6
Crytodaria kurriana - 9
Astarte montagui dead
Musculus corrugatus - 17
Portlandia arctica - 3
Axinopsida orbiculata - 3

88-17 B03:058; 10:VIII:88; 70 16.9'N, 146 46.3'W; 10.0m; G
Liocyma fluctuosa - 4
Axinopsida orbiculata - 1

88-18 B03:059; 10:VIII:88; 70 15.8'N, 146 41.9'W; 7.0m; G
Oenopota novajasemliensis - 1

88-19 B03:068; 11:VIII:88; 70 12.3'N, 146 56.1'W; 6m; M-S
Margarites giganteus - 1
Neptunea heros - 2
Velutina undata - 1
Oenopota simplex - 1
Polinices pallida - 1
Neptunea borealis dead
Oenopota rosea - 1
Oenopota novajasemliensis - 31
Odostomia albula - 5

88-20 B03:069; 11:VIII:88; 70 12.5'N, 146 59.6'W; 5.5m;

88-21 B03:071; 11:VIII:88; 70 12.3'N, 147 01.4'W; 5.5m;

88-22 B03:072; 11:VIII:88; 70 12.6'N, 146 59.7'W; 5.5m; Mud
Polinices pallida - 1
Philine polaris - 1
Diaphana minuta - 2
Oenopota novajasemliensis - 49
Musculus discors - 2
Liocyma fluctuosa - 22
Tridonta borealis - 4
Pandora glacialis - 3
Macoma moesta alaskana - 2
Astarte montagui - 4
Musculus corrugatus - 1
Portlandia arctica - 2
Macoma crassula - 1

88-23 B03:073; 11:VIII:88; 70 12.6'N, 146 59.7'W; 5.5m; Mud
Cylichna occulata - 7
Diaphana minuta - 3
Liocyma fluctuosa - 1
Tridonta borealis - 1
Portlandia arctica - 2
Axinopsida orbiculata - 1
Yoldiella intermedia - 155

88-24 17:VIII:88; 70 27.4'N, 148 34.7'W; 9m; Mud
Philine polaris - 1
Cylichna occulata - 2
Diaphana minuta - 2
Oenopota novajasemliensis - 13
Odostomia albula - 1
Liocyma fluctuosa - 11
Macoma calcarea - 5
Crytodaria kurriana - 1
Macoma moesta alaskana - 2
Astarte montagui - 2
Portlandia arctica - 13
Axinopsida orbiculata - 45

88-25 18:VIII:88; 70 11.7'N, 146 13.0'W; 1.6m; Mud
Amauropsis islandica - 1
Cylichna occulata - 1
Diaphana minuta - 2
Crytodaria kurriana dead
Portlandia arctica - 7

88-26 C02:075; 18:VIII:88; 70 03.5'N, 145 18.4'W; 8.0m; Sand
Margarites giganteus - 2
Oenopots simplex - 2
Philine polaris - 2
Cylichna occulata - 4
Diaphana minuta - 6
Oenopota novajasemliensis - 2
Liocyma fluctuosa - 86
Tridonta borealis - 1
Musculus corrugatus - 10
Mya pseudoarenaria - 3
Portlandia arctica - 5
Macoma crassula - 8
Lyonsia arenosa - 1
Axinopsida orbiculata - 28
Boreacola vadosa - 6
Pisidium idahoense dead (freshwater)

88-27 19:VIII:88; 69 58.6'N, 144 50.8'W; 2.6m; Mud
Polinices pallida egg case
Cylichna occulata - 1
Liocyma fluctuosa - 1
Crytodaria kurriana - 35
Yoldiella intermedia - 24

88-28 Simpson 20:VIII:88; 69 58.6'N, 144 52'W; 3.1m; Mud
Cylichna occulata - 39
Diaphana minuta - 27
Portlandia arctica - 2

88-29 C03:079; 21:VIII:88; 69 59.6'N, 144 32.0'W; 5.5m; Mud
Diaphana minuta - 3
Oenopota novajasemliensis - 6
Liocyma fluctuosa - 8
Macoma moesta alaskana - 13
Mya pseudoarenaria - 1
Portlandia arctica - 10
Axinopsida orbiculata - 7
Yoldiella intermedia - 2

88-30 C03:081; 21:VIII:88; 69 58.6'N, 144 36.3'W; 5.5m; Mud
Cylichna occulata - 1
Diaphana minuta - 2
Oenopota novajasemliensis - 4
Liocyma fluctuosa - 12
Tridonta borealis - 1
Macoma moesta alaskana - 8
Mya pseudoarenaria - 1
Portlandia arctica - 1
Macoma crassula - 1
Axinopsida orbiculata - 1

88-31 C03:083; 21:VIII:88; 69 59.7'N, 144 33.6'W; 7.0m; Mud
Polinices pallida egg case
Diaphana minuta - 3
Oenopota novajasemliensis - 23
Odostomia albula - 3
Liocyma fluctuosa - 66
Tridonta borealis - 11
Pandora glacialis - 2
Macoma moesta alaskana - 6
Mya pseudoarenaria - 9
Portlandia arctica - 142
Macoma crassula - 2
Lyonsia arenosa - 21
Axinopsida orbiculata - 9

88-32 C03:085; 21:VIII:88; 70 01.5'N, 144 35.3'W; 10.0m; Mud

Natica russa - 1
Polinices pallida - 1
Philine polaris - 2
Diaphana minuta - 2
Oenopota novajasemliensis - 23
Odostomia albula - 1
Liocyma fluctuosa - 13
Pandora glacialis - 1
Macoma calcarea - 1
Astarte montagui - 6
Musculus corrugatus - 3
Mya pseudoarenaria - 3
Portlandia arctica - 4
Macoma crassula - 1
Axinopsida orbiculata - 4

88-33 C03:088; 21:VIII:88; 70 00.7'N, 144 46.3'W; 10.0m; Mud

Colus dautzenbergi - 1
Oenopots simplex - 2
Polinices pallida - 3
Philine polaris - 26
Cylichna occulata - 1
Diaphana minuta - 9
Oenopota novajasemliensis - 118
Odostomia albula - 1
Oenopota sp. #843 dead
Admete sp. #850 - 9
Liocyma fluctuosa - 39
Nucula tenius - 1
Tridonta borealis - 13
Pandora glacialis - 15
Macoma moesta alaskana - 19
Astarte montagui - 54
Musculus corrugatus - 17
Mya pseudoarenaria - 13
Portlandia arctica - 12
Macoma crassula - 8
Lyonsia arenosa - 18
Axinopsida orbiculata - 2
Yoldiella intermedia - 1

88-34 C03:090; 21:VIII:88; 69 59.3'N, 144 46.8'W; 8.5m; Mud
Polinices pallida dead
Philine polaris dead
Diaphana minuta - 2
Oenopota novajasemliensis - 16
Oenopota sp. #679 - 1
Odostomia albula - 1
Liocyma fluctuosa - 34
Nucula tenius dead
Tridonta borealis - 12
Pandora glacialis - 1
Macoma calcarea - 4
Macoma moesta alaskana - 9
Astarte montagui - 27
Mya pseudoarenaria dead
Portlandia arctica - 5
Macoma crassula - 11
Axinopsida orbiculata - 1
Thyasira equalis dead

88-35 C03:092; 22:VIII:88; 70 00.9'N, 144 03.2'W; 8.0m; Mud
Diaphana minuta - 1
Oenopota novajasemliensis - 1
Liocyma fluctuosa - 32
Tridonta borealis - 2
Portlandia arctica - 24
Axinopsida orbiculata - 5

88-36 C03:094; 22:VIII:88; 70 00.6'N, 147 49.7'W; 8.5m; Mud
Oenopots simplex - 2
Polinices pallida dead
Philine polaris - 1
Diaphana minuta - 7
Oenopota novajasemliensis - 27
Odostomia albula - 2
Musculus discors - 2
Hiatella arctica - 1
Liocyma fluctuosa - 54
Tridonta borealis - 6
Pandora glacialis - 4
Macoma moesta alaskana - 21
Musculus corrugatus - 1
Mya pseudoarenaria - 1
Portlandia arctica - 21
Macoma crassula - 4
Lyonsia arenosa - 22
Axinopsida orbiculata - 1

88-37 C01:095; 22:VIII:88; 70 02.4'N, 145 17.4'W; 6m; Gravel
Velutina velutina - 1
Cylichna occulata - 2
Diaphana minuta - 7
Oenopota novajasemliensis - 1
Musculus discors - 27
Liocyma fluctuosa - 17
Pandora glacialis - 3
Astarte montagui - 3
Axinopsida orbiculata - 2
Boreacola vadosa - 3

88-38 C01:098; 22:VIII:88; 70 06.0'N, 145 33.8'W; 8.5m; Sand
Cylichna occulata - 27
Liocyma fluctuosa - 32
Macoma calcarea - 1
Macoma moesta alaskana - 1
Mya pseudoarenaria - 2
Portlandia arctica - 2
Axinopsida orbiculata - 24

88-39 Thetis 26:VIII:88; 70 03.1'N, 150 08.9'W; 1.8m; Mud
Crytodaria kurriana - 9

88-40 A03:101; 27:VIII:88; 70 34.0'N, 150 18.1'W; 7.0m; Mud
Cylichna occulata - 2
Liocyma fluctuosa - 8
Pandora glacialis - 1

88-41 A03:102; 28:VIII:88; 70 33.2'N, 150 11.5'W; 0.6-1.8m; G
Amauropsis islandica dead

88-42 Thetis 28:VIII:88; 70 32.0'N, 150 12.9'W; 4m; Mud
Crytodaria kurriana - 4
Portlandia arctica - 19

88-43 Thetis 28:VIII:88; 70 35.1'N, 150 15.1'W; 10m; Mud
Diaphana minuta - 2
Oenopota novajasemliensis - 9
Oenopota sp. #843 dead
Liocyma fluctuosa - 6
Tridonta borealis dead
Macoma calcarea - 1
Portlandia arctica - 56
Lyonsia arenosa - 11
Axinopsida orbiculata - 20
Yoldiella intermedia - 3

88-44 Oliktok 2:IX:88; 70 31.2'N, 149 52.8'W; 2.5m, Mud
Polinices pallida - 1
Crytodaria kurriana - 1
Yoldiella intermedia - 48

88-45 A03:114; 3:IX:88; 70 33.4'N, 150 18.0'W; 5.5m; Mud
Crytodaria kurriana - 2
Portlandia arctica - 4
Yoldiella intermedia - 1

88-46 A03:119; 3:IX:88; 70 32.8'N, 150 14.0'W; 5.5m; Mud
Yoldiella intermedia - 4

88-47 Pingok 8:IX:88; 70 34.8'N, 149 36.1'W; 10.5m; Mud
Portlandia arctica - 3
Axinopsida orbiculata - 2

88-48 Simpson C.; 18:VIII:88; 69 58.6'N, 144 50.7'W; beach drift

88-49 Behind Stump Is.; 70 25'N, 148 37'W; 1.2-1.8m; 16:Viii:88
Cylichna occulata dead
Oenopota novajasemliensis - 1
Valvata sincera dead (freshwater)
Liocyma fluctuosa - 1
Crytodaria kurriana - dead
Portlandia arctica - 1

Appendix B
Fish Data: Meristics and Counts

1. Specimen 1266
2. Area Beaufort Sea*
3. Species Arctic Cisco
4. Date 4/8/88
5. * 70° 13.1' N; 147° 00.1'W
6. Sex/Condition F1
7. Scale Card
8. Scale#
9. Weight (g) 600
10. Fork Length 375 mm
11. Standard Length 343 mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length
15. Body Length
16. Head Length 69.0 mm
17. Maxillary Len. 20.3 mm
18. Maxillary Depth
19. Lower Jaw Len. 27.6 mm
20. Eye Diameter 13 mm
21. Obit Length 15 mm
22. Snout-Nostril 16.5 mm
23. Snout-Maxillary
24. Snout-Anterior Obit Length
25. Snout-Occip
26. Snout-Dorsal 161.6 mm
27. Snout-Adipose 274 mm
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 272 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Pseudobranchia **
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 25.1 mm
42. Interorbital Width 17.9 mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 79.2 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/ posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 49.6 mm
55. Pelvic Length 49.3 mm
56. Anal Fin Length
57. Anal Height (anterior/ posterior)
58. Dorsal Fin Rays 12
59. Caudal Rays (forked) 16
60. Pectoral Rays 18
61. Pelvic Rays 12
62. Anal Rays 13
63. InOrb Shape - Convex
64.
65.
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 96 + 93+3
71. Pores, Std.Len.
72. Scales, Lateral Line 99
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal 13
76. Scales, Ventral 14
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 8/8
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 47 + 17+1+29
82. Gill Rakers, 2nd Arch 45
83. Gill Raker Len. 8.9 mm
84. Gill Raker Space
85. Pyloric Caeca
86. Vertebra 75
87. Physical Condition
88. Gill Slit 4th - 14.0 mm
89. Vomer Width 0
90. Palatine Length 0
91.
92. Food
93.
94. Max Extends - mid eye
95.

1. Specimen 1267
2. Area Beaufort Sea*
3. Species Arctic char
4. Date 4/8/88
5. * 70° 13.1'N;147° 00.1'W
6. Sex/Condition M1
7. Scale Card
8. Scale#
9. Weight (g)
10. Fork Length 375 mm
11. Standard Length 343 mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length 406 mm
15. Body Length
16. Head Length 69.0 mm
17. Maxillary Len. 25.2 mm
18. Maxillary Depth
19. Lower Jaw Len. 36.2 mm
20. Eye Diameter
21. Orbit Length 14.8 mm
22. Snout-Nostril 15.8 mm
23. Snout-Maxillary
24. Snout-Anterior Orbit Length
25. Snout-Occip
26. Snout-Dorsal 141.4 mm
27. Snout-Adipose 274 mm
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 244 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Pink Spot Dia. - 3.5 mm
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 25.6 mm
42. Interorbital Width 23.3 mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 79.2 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 42.2 mm
55. Pelvic Length 39.1 mm
56. Anal Fin Length
57. Anal Height (anterior/posterior)
58. Dorsal Fin Rays 15
59. Caudal Rays (forked) 17
60. Pectoral Rays 15
61. Pelvic Rays 11
62. Anal Rays 14
63. InOrbit Shape - Convex
64.
65.
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 146 = 140+6
71. Pores, Std.Len.
72. Scales, Lateral Line
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal
76. Scales, Ventral
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 11/11
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 22
82. Gill Rakers, 2nd Arch 22 = 10+1+11
83. Gill Raker Len. 6.8 mm
84. Gill Raker Space
85. Pyloric Caeca 34
86. Vertebra 69
87. Physical Condition
88. Depth Collected-6m
89. Gill Slit 4th - 16.4 mm
90. Vomer Width - 4.3 mm
91. Palatine Length - 11.3 mm
92. Food
93.
94. Max. Extends- Rear Orbit
95. Pseudobranchia - ++

1. Specimen 1268
2. Area 1-m depth, Bullen Pt
3. Species Arctic char
4. Date 10/08/88
5.
6. Sex/Condition F3
7. Scale Card
8. Scale#
9. Weight (g) 1000
10. Fork Length 558 mm
11. Standard Length 504 mm
12. Mid-Eye Length
13. Rear Orbit Len.
14. Total Length 587 mm
15. Body Length
16. Head Length 103.3 mm
17. Maxillary Len. 43.0 mm
18. Maxillary Depth
19. Lower Jaw Len. 64.9 mm
20. Eye Diameter 17.3 mm
21. Orbit Length 18.9 mm
22. Snout-Nostril 28.3 mm
23. Snout-Maxillary
24. Snout-Anterior Orbit Length
25. Snout-Occip
26. Snout-Dorsal 227 mm
27. Snout-Adipose 419 mm
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 368 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Pink Spot Dia. 5.0 mm
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 36.7 mm
42. Interorbital Width 34.4 mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 101 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 70.8 mm
55. Pelvic Length 61.1 mm
56. Anal Fin Length
57. Anal Height (anterior/posterior)
58. Dorsal Fin Rays 12
59. Caudal Rays (forked) 17
60. Pectoral Rays 15
61. Pelvic Rays 10
62. Anal Rays 11
63. Pseudobranchia ± 25
64.
65.
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 136 = 128+8
71. Pores, Std.Len.
72. Scales, Lateral Line
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal
76. Scales, Ventral
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 11/11
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 21 = 8+1+12
82. Gill Rakers, 2nd Arch 21
83. Gill Raker Len. 9 mm
84. Gill Raker Space
85. Pyloric Caeca 35
86. Vertebra
87. Physical Condition
88. Pseudobranchia - ± 25
89. Gill Slit 4th -18.3 mm
90. Vomer Width - 6.5 mm
91. Palatine Width - 3.0 mm
92. Food
93. Palatine Teeth - 12
94. Paltine Length - 19.4 mm
95. Max. Extends - Post Orbit

1. Specimen 1269
2. Area Bulkley R.
3. Species Arctic Cisco
4. Date 10 / August / 1988
5.
6. Sex/Condition F3
7. Scale Card
8. Scale#
9. Weight (g) 1000
10. Fork Length
11. Standard Length 396 mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length 469 mm
15. Body Length
16. Head Length 79.3 mm
17. Maxillary Len. 21.9 mm
18. Maxillary Depth
19. Lower Jaw Len. 31.0 mm
20. Eye Diameter 12.9 mm
21. Obit Length 17.8 mm
22. Snout-Nostril 15.5 mm
23. Snout-Maxillary
24. Snout-Anterior Obit Length
25. Snout-Occip
26. Snout-Dorsal 193.7 mm
27. Snout-Adipose 331 mm
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 308 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Pseudobranchia ++ very short
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 29.7 mm
42. Interorbital Width 19.5 mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 95 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/ posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 57.6 mm
55. Pelvic Length 56.0
56. Anal Fin Length
57. Anal Height (anterior/ posterior)
58. Dorsal Fin Rays (2) 12
59. Caudal Rays (forked) 17
60. Pectoral Rays 16
61. Pelvic Rays 12
62. Anal Rays (2) 13
63. InOrbit Shape - Convex
64.
65.
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 89 + 3
71. Pores, Std.Len.
72. Scales, Lateral Line
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal 11
76. Scales, Ventral 11
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 9/9
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 16 + 11 + 28 = 45
82. Gill Rakers, 2nd Arch 18 + 1 + 27 = 46
83. Gill Raker Len. 11.4 mm
84. Gill Raker Space
85. Pyloric Caeca 99
86. Vertebra 35 + 5 + 23 = 63
87. Physical Condition
88. Gill Slit 4th - 15.8 mm
89. Vomer Width - 0
90. Palatine Len - 0
91. Depth Collected - 2m
92. Food
93.
94. Max Extends - mid eye
95.

1. Specimen 1670
2. Area Bullen Point
3. Species Least Cisco
4. Date 10/08/88
5. Depth Captured 2-m
6. Sex/Condition F3
7. Scale Card
8. Scale#
9. Weight (g)
10. Fork Length 340 mm
11. Standard Length 314 mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length 383 mm
15. Body Length
16. Head Length 63.2 mm
17. Maxillary Len. 19.5 mm
18. Maxillary Depth
19. Lower Jaw Len. 25.6 mm
20. Eye Diameter 13.3 mm
21. Obit Length 17.4 mm
22. Snout-Nostril 11.7 mm
23. Snout-Maxillary
24. Snout-Anterior Obit Length
25. Snout-Occip
26. Snout-Dorsal 137.8 mm
27. Snout-Adipose 268 mm
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 237.7 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Max. Extends - mid eye
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 24.6 mm
42. Interorbital Width 14.2 mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 74 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/ posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 56.8 mm
55. Pelvic Length 54.8 mm
56. Anal Fin Length
57. Anal Height (anterior/ posterior)
58. Dorsal Fin Rays 14+2+12
59. Caudal Rays (forked) 17
60. Pectoral Rays 16
61. Pelvic Rays 13
62. Anal Rays 2+15 = 17
63. In Orb Shape - Convex
64.
65.
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 84+3C
71. Pores, Std.Len.
72. Scales, Lateral Line
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal 10
76. Scales, Ventral 10
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 8/8
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 15+1+32 = 48
82. Gill Rakers, 2nd Arch 17+1+30 = 48
83. Gill Raker Len. 10.0 mm
84. Gill Raker Space
85. Pyloric Caeca 90
86. Vertebra 34+5+23 = 62
87. Physical Condition
88. Gill Slit 4th = 12.9
89. Vomer Width = 0
90. Palatine Len = 0
91.
92. Food
93.
94. Pseudobranchia ± 69
95.

1. Specimen 1671
2. Area Bulbon Point
3. Species Broad Whitefish
4. Date 10 | 08 | 88
5. Depth Captured 2-m
6. Sex/Condition F1
7. Scale Card
8. Scale#
9. Weight (g)
10. Fork Length 367 mm
11. Standard Length 340 mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length 409 mm
15. Body Length
16. Head Length 64.5 mm
17. Maxillary Len. 13.9mm x7.4
18. Maxillary Depth
19. Lower Jaw Len. 20.6mm
20. Eye Diameter 11.7mm
21. Obit Length 15.4mm
22. Snout-Nostril 15.5mm
23. Snout-Maxillary
24. Snout-Anterior Obit Length
25. Snout-Occip
26. Snout-Dorsal 153 mm
27. Snout-Adipose 283 mm
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 260 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Max Extends - Front Orbit
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 24.6mm
42. Interorbital Width 20.5mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 79 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/ posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 38.3mm
55. Pelvic Length 36.7 mm
56. Anal Fin Length
57. Anal Height (anterior/ posterior)
58. Dorsal Fin Rays 3+12=15
59. Caudal Rays (forked) 17
60. Pectoral Rays 16
61. Pelvic Rays 12
62. Anal Rays 3+14 = 17
63. In Orbit Shape - Convex
64.
65.
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 84+2C
71. Pores, Std.Len.
72. Scales, Lateral Line 86
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal 11
76. Scales, Ventral 9
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 9/8
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 7+1+13 = 21
82. Gill Rakers, 2nd Arch 6+1+10 = 17
83. Gill Raker Len. 4.1 mm
84. Gill Raker Space
85. Pyloric Caeca 149
86. Vertebra
87. Physical Condition
88. Gill Slit 4th - 14.0
89. Vomer Width 0
90.
91.
92. Food
93.
94. Pseudobranchia +
95.

1. Specimen 1672
2. Area Bulkan Point
3. Species Arctic Cisco
4. Date 10/08/88
5. Depth Captured 2-m
6. Sex/Condition F2
7. Scale Card
8. Scale#
9. Weight (g)
10. Fork Length 412 mm
11. Standard Length 378 mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length 448 mm
15. Body Length
16. Head Length 70.7 mm
17. Maxillary Len. 19.5 mm
18. Maxillary Depth
19. Lower Jaw Len. 31.2 mm
20. Eye Diameter 11.5 mm
21. Obit Length 16.1 mm
22. Snout-Nostril 14.3 mm
23. Snout-Maxillary
24. Snout-Anterior Obit Length
25. Snout-Occip
26. Snout-Dorsal 174 mm
27. Snout-Adipose 324 mm
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 303 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Max Extends - Front Pupil
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 26.7 mm
42. Interorbital Width 18.5 mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 99 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 51.3 mm
55. Pelvic Length 18.7 mm
56. Anal Fin Length
57. Anal Height (anterior/posterior)
58. Dorsal Fin Rays 3+13=16
59. Caudal Rays (forked) 17
60. Pectoral Rays 16
61. Pelvic Rays 12
62. Anal Rays 2+13=15
63. In Orbit Shape - Convex
64. Pseudobranchia -
65.
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line
71. Pores, Std.Len.
72. Scales, Lateral Line 98
73. Scales (1st power above L.L.) 93+0C
74. Scales, Occip.
75. Scales, Dorsal 11
76. Scales, Ventral 10
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 8/8
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 15+1+27=43
82. Gill Rakers, 2nd Arch 18+1+28=47
83. Gill Raker Len. 9.8 mm
84. Gill Raker Space
85. Pyloric Caeca 147
86. Vertebra
87. Physical Condition
88. Gill Slit 4th - 15.9
89. Vomer Width - 0
90. Palatine Length - 0
91.
92. Food
93.
94.
95.

1. Specimen 1273
2. Area Prudhoe Bay
3. Species Arctic Char
4. Date 8/23/88
5.
6. Sex/Condition F15
7. Scale Card
8. Scale#
9. Weight (g)
10. Fork Length 580 mm
11. Standard Length 523 mm
12. Mid-Eye Length 550mm
13. Rear Obit Len. 540 mm
14. Total Length 607 mm
15. Body Length 541 mm
16. Head Length 105 mm
17. Maxillary Len. 47.9 mm
18. Maxillary Depth 9.2 mm
19. Lower Jaw Len. 69 mm
20. Eye Diameter 15 mm
21. Obit Length 21.1 mm
22. Snout-Nostril 20.5 mm
23. Snout-Maxillary 58.4 mm
24. Snout-Anterior Obit Length 29.8 mm
25. Snout-Occip 65 mm
26. Snout-Dorsal 218 mm
27. Snout-Adipose 437 mm
28. Snout-Pectoral 100 mm
29. Snout-Pelvic 254 mm
30. Snout-Anal 386 mm
31. Dorsal-Adipose 211.5 mm
32. Pectoral-Pelvic 165.6 mm
33. Pelvic-Anal 132.7 mm
34. Pelvic Caudal 268 mm
35. Dorsal Caudal Length 44.3 mm
36. Ventral Caudal Length 57.2 mm
37. Caudal Peduncle Len 96.5
38. Mid-Eye Depth 49.3 mm
39. Occiput Depth 67.3 mm
40. Dorsal Fin Depth 125 mm
41. Caudal Peduncle Depth 39.2 mm
42. Interorbital Width 38.0 mm
43. Mid-eye Width 44.3 mm
44. Occiput Width 53.1 mm
45. Body Width 70.2 mm
46. Caudal Peduncle Width 30.5 mm
47. Circumference 123 mm
48. Dorsal Fin Length 68.0 mm
49. Dorsal Height (anterior/posterior) 61.2/25.3
50. Adipose Base Length 5.7 mm
51. Adipose Height 6.5 mm
52. Adipose Length 17.5 mm
53. Caudal Fin Length (minimum/maximum) 57.2/78.5
54. Pectoral Length 70.2 mm
55. Pelvic Length 64.6 mm
56. Anal Fin Length 48.9 mm
57. Anal Height (anterior/posterior) 61.5/23.8
58. Dorsal Fin Rays 3+12+15
59. Caudal Rays (forked) 17
60. Pectoral Rays 14
61. Pelvic Rays 9
62. Anal Rays 2+11= 13
63. Spot Dig. 3-6.3 mm
64. Slit behind 4th gill 19.3 mm
65.
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 143
71. Pores, Std.Len. 135 +8c
72. Scales, Lateral Line
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal 48
76. Scales, Ventral 48
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 11/11
80. Pores, Lower Jaw 71
81. Gill Rakers 1st Arch 22 = 10+1+11
82. Gill Rakers, 2nd Arch 22 = 9+1+12
83. Gill Raker Len. 10.8 mm
84. Gill Raker Space 1.7 mm
85. Pyloric Caeca 35
86. Vertebra 35+5+28 = 68
87. Physical Condition 2
88. Vomer W 5.2 mm
89. Palatine L 21.6 mm
90. Vomer Teeth 5
91. Palatine Teeth 18
92. Food 1 Arctic Cod
93. Tongue Teeth 8/10
94.
95.

1. Specimen 1274
2. Area Prudhoe Bay
3. Species Arctic Char
4. Date 8/23/88
5.
6. Sex/Condition F 15
7. Scale Card
8. Scale#
9. Weight (g)
10. Fork Length 533 mm
11. Standard Length 483 mm
12. Mid-Eye Length 515 mm
13. Rear Obit Len. 503 mm
14. Total Length 563 mm
15. Body Length 504 mm
16. Head Length 99.9 mm
17. Maxillary Len. 41.5 mm
18. Maxillary Depth 8.7 mm
19. Lower Jaw Len. 62.9 mm
20. Eye Diameter 14.5 mm
21. Obit Length 19.7 mm
22. Snout-Nostril 18.7 mm
23. Snout-Maxillary 51.7 mm
24. Snout-Anterior Obit Length 25.4 mm
25. Snout-Occip 59.2 mm
26. Snout-Dorsal 208 mm
27. Snout-Adipose 396 mm
28. Snout-Pectoral 99.0 mm
29. Snout-Pelvic 255 mm
30. Snout-Anal 366 mm
31. Dorsal-Adipose 125.4 mm
32. Pectoral-Pelvic 152 mm
33. Pelvic-Anal 118.5 mm
34. Pelvic Caudal 250.5 mm
35. Dorsal Caudal Length 46.3 mm
36. Ventral Caudal Length 62.6 mm
37. Caudal Peduncle Len 94.8
38. Mid-Eye Depth 49.0 mm
39. Occiput Depth 58.5 mm
40. Dorsal Fin Depth 115 mm
41. Caudal Peduncle Depth 36.7 mm
42. Interorbital Width 33.3 mm
43. Mid-eye Width 41.0 mm
44. Occiput Width 50.7 mm
45. Body Width 63.7 mm
46. Caudal Peduncle Width 22.5 mm
47. Circumference 106 mm
48. Dorsal Fin Length 56.3 mm
49. Dorsal Height (anterior/posterior) 54.7/21.5
50. Adipose Base Length 5.9 mm
51. Adipose Height 9.0 mm
52. Adipose Length 22.5 mm
53. Caudal Fin Length (minimum/maximum) 50/77.5
54. Pectoral Length 73.4 mm
55. Pelvic Length 64.2 mm
56. Anal Fin Length 42.3 mm
57. Anal Height (anterior/posterior) 56.0/19.5
58. Dorsal Fin Rays 15+3+12
59. Caudal Rays (forked) 17
60. Pectoral Rays 14
61. Pelvic Rays 9
62. Anal Rays 3+10= 13
63. Vomer W 6.0mm
64. Vomer Teeth 8
65. ~~Pink Spot Dia. 5.5 mm~~
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter 1.8 mm
70. Pores, Lateral Line 137
71. Pores, Std.Len. 132 mm
72. Scales, Lateral Line
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal
76. Scales, Ventral
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 12/12
80. Pores, Lower Jaw 6/7
81. Gill Rakers 1st Arch 24 = 1+1+12
82. Gill Rakers, 2nd Arch 26 = 1+1+14
83. Gill Raker Len. 9.2 mm
84. Gill Raker Space 2.4 mm
85. Pyloric Caeca 33
86. Vertebra 33+6+28 = 67
87. Physical Condition 2
88. Palatine Length 20.6 mm
89. Palatine Teeth 21
90. Slit behind 4th gill 19 mm
91.
92. Food
93.
94.
95.

1. Specimen 1275 a
2. Area Prudhoe Bay
3. Species Arctic Char
4. Date 24/08/88
5.
6. Sex/Condition M 15
7. Scale Card
8. Scale#
9. Weight (g)
10. Fork Length 579 mm
11. Standard Length 529 mm
12. Mid-Eye Length 548 mm
13. Rear Obit Len. 537 mm
14. Total Length 615 mm
15. Body Length 555 mm
16. Head Length 119.4 mm
17. Maxillary Len. 53.5 mm
18. Maxillary Depth 7.2 mm
19. Lower Jaw Len. 85.5 mm
20. Eye Diameter 13.3 mm
21. Obit Length 22.4 mm
22. Snout-Nostril 28.1 mm
23. Snout-Maxillary 73.0 mm
24. Snout-Anterior Obit Length 36.4 mm
25. Snout-Occip 79.8 mm
26. Snout-Dorsal 242 mm
27. Snout-Adipose 436 mm
28. Snout-Pectoral 117.0 mm
29. Snout-Pelvic 276 mm
30. Snout-Anal 399 mm
31. Dorsal-Adipose 204.8 mm
32. Pectoral-Pelvic 159.1 mm
33. Pelvic-Anal 124.5 mm
34. Pelvic Caudal 262.7 mm
35. Dorsal Caudal Length 52.8 mm
36. Ventral Caudal Length 61.3 mm
37. Caudal Peduncle Len 95.6
38. Mid-Eye Depth 50.2 mm
39. Occiput Depth 72.2 mm
40. Dorsal Fin Depth 134 mm
41. Caudal Peduncle Depth 43.7 mm
42. Interorbital Width 38.7 mm
43. Mid-eye Width 46.5 mm
44. Occiput Width 55.7 mm
45. Body Width 72 mm
46. Caudal Peduncle Width 26.1 mm
47. Circumference
48. Dorsal Fin Length 63.5 mm
49. Dorsal Height (anterior/ posterior) 61.0/29.8
50. Adipose Base Length 11.2 mm
51. Adipose Height 9.4 mm
52. Adipose Length 24.7 mm
53. Caudal Fin Length (minimum/maximum) 52/91.3
54. Pectoral Length 82.8 mm
55. Pelvic Length 74.8 mm
56. Anal Fin Length 45.6 mm
57. Anal Height (anterior/ posterior) 63.5/24.8
58. Dorsal Fin Rays 14 = 3 + 11
59. Caudal Rays (forked) 17
60. Pectoral Rays 14
61. Pelvic Rays 10
62. Anal Rays 13
63. Vomar w/teeth 8.4/7.0
64. Palatine w/teeth 21.7/14
65. Tongue Teeth 5/7
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 137
71. Pores, Std.Len. 133
72. Scales, Lateral Line
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal
76. Scales, Ventral
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 14/12
80. Pores, Lower Jaw 7/7
81. Gill Rakers 1st Arch 23 = 9+1+13
82. Gill Rakers, 2nd Arch 23 = 10+1+12
83. Gill Raker Len. 10.0 mm
84. Gill Raker Space 3.1 mm
85. Pyloric Caeca 31 mm
86. Vertebra 67
87. Physical Condition 2
88. Pink Spot Dia. 4.8 mm
89. Slit Behind 4th gill 22.8mm
90.
91.
92. Food 9 Arctic cod
93. 1 Least Cisco
94.
95.

1. Specimen 12756
2. Area Thetis Island
3. Species Buchara Sculpin
4. Date 27/08/88
5. Depth Cp. 1-m
6. Sex/Condition F3
7. Scale Card
8. Scale#
9. Weight (g)
10. Fork Length 191 mm
11. Standard Length 162 mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length 191 mm
15. Body Length
16. Head Length 59.3 mm
17. Maxillary Len. 23.9 mm
18. Maxillary Depth
19. Lower Jaw Len. 27.4 mm
20. Eye Diameter 8.6 mm
21. Obit Length 12.0 mm
22. Snout-Nostril
23. Snout-Maxillary
24. Snout-Anterior Obit Length
25. Snout-Occip
26. Snout-Dorsal 58.3 mm
27. Snout-Adipose
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 104.7 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Pec Drd II L 100.9 mm
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 6.5 mm
42. Interorbital Width 7.0 mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 38 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 43.8 mm
55. Pelvic Length 27.4 mm
56. Anal Fin Length
57. Anal Height (anterior/posterior)
58. Dorsal Fin Rays VIII + 13 (1st 3 Rectimate)
59. Caudal Rays (forked) 7+7+8
60. Pectoral Rays
61. Pelvic Rays I 3
62. Anal Rays 15
63. In Orbit Shape - Concave
64. Max Extends - Past Orbit
65. D interspace 6.6 mm
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 33
71. Pores, Std.Len.
72. Scales, Lateral Line
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal Σ 47
76. Scales, Ventral Σ 27
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 2+4 = 6/6
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 1+0+6 = 7
82. Gill Rakers, 2nd Arch 0+0+6 = 6
83. Gill Raker Len. spiny nub
84. Gill Raker Space
85. Pyloric Caeca 10
86. Vertebra 12+2+28 = 42
87. Physical Condition
88. Gill Sl. 4th - Pore
89. Pseudobranchia 23
90. O. Spine Ray 1 26.2 ± 5.3
91. Lateral Scales +
92. Food
93. Branchio membr. - Free fold
94. LL Canal - Pore/Fade under
95. tip of D
96. Vomer Width - 4.8 m
97. Palatine Length - 0
98. Coloration - Orange, Br. lower
99. eggs - purple

1. Specimen 1276
2. Area Thetis Island
3. Species Fourhorn Sculpin
4. Date 28/08/88
5. Depth of Capture - 1m
6. Sex/Condition F2
7. Scale Card
8. Scale#
9. Weight (g)
10. Fork Length 185mm
11. Standard Length 157.5mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length 187mm
15. Body Length
16. Head Length 53.0 mm
17. Maxillary Len. 22.9 mm
18. Maxillary Depth
19. Lower Jaw Len. 24.9 mm
20. Eye Diameter 8.2 mm
21. Obit Length 12.6 mm
22. Snout-Nostril 13.0 mm
23. Snout-Maxillary
24. Snout-Anterior Obit Length
25. Snout-Occip
26. Snout-Dorsal 56.4mm
27. Snout-Adipose
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 94.5mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Pre D #II - 95.8 mm
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 5.8 mm
42. Interorbital Width
43. Mid-eye Width
44. Occiput Width
45. Body Width 32.0 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/ posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 42.2mm
55. Pelvic Length 28.3mm
56. Anal Fin Length
57. Anal Height (anterior/ posterior)
58. Dorsal Fin Rays VIII+13
59. Caudal Rays (forked) 10+8+13 = 31
60. Pectoral Rays 17
61. Pelvic Rays I 3
62. Anal Rays 15
63. InObit Shape - Concave
64. Max Extends - Rear Orbit
65. D interspace 7.9 mm
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 37
71. Pores, Std.Len.
72. Scales, Lateral Line
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal Σ 66
76. Scales, Ventral Σ 14
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 2+4 = 6/6
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 1+0+6 = 7
82. Gill Rakers, 2nd Arch 0+0+7 = 7
83. Gill Raker Len. Spiny Nub
84. Gill Raker Space
85. Pyloric Caeca 8
86. Vertebra 11+4+28 = 43
87. Physical Condition
88. Gill Slit 4th - Pore
89. Pseudobranchia - 16
90. Branchio memb. - Free fold
91. LL Canal Parallels under Tip of D
92. Food
93. Vomer Width - 5.2mm
94. Palatine Width - 0
95. eggs - orange

1. Specimen 1277
2. Area Oliktok Point
3. Species Fourhorn Sculpin
4. Date 21/08/88
5. Capture Depth - 1m
6. Sex/Condition F3
7. Scale Card
8. Scale#
9. Weight (g)
10. Fork Length
11. Standard Length 211 mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length 246 mm
15. Body Length
16. Head Length
17. Maxillary Len. 26.4 mm
18. Maxillary Depth
19. Lower Jaw Len. 36.8 mm
20. Eye Diameter 10 mm
21. Obit Length 16.5 mm
22. Snout-Nostril 17.4 mm
23. Snout-Maxillary
24. Snout-Anterior Obit Length
25. Snout-Occip
26. Snout-Dorsal 81.7 mm
27. Snout-Adipose
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 131.8 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Pre Dorsal II - 129.5mm
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 8.9 mm
42. Interorbital Width 13 mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 38 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 42.2 mm
55. Pelvic Length 35.2 mm
56. Anal Fin Length
57. Anal Height (anterior/posterior)
58. Dorsal Fin Rays V III + 14
59. Caudal Rays (forked) +8+
60. Pectoral Rays 16
61. Pelvic Rays I 3
62. Anal Rays 14
63. In Orbit Shape - Concave
64. Max. Extends . 2ear Orbit
65. D interspace - 12.7 mm
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 44
71. Pores, Std.Len.
72. Scales, Lateral Line
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal
76. Scales, Ventral ± 80
77. Scales, Supra-pelvic ± 13
78. Scales around Caudal Peduncle
79. Branchiostegals 6/6
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 2+0+5=7
82. Gill Rakers, 2nd Arch 0+0+6=6
83. Gill Raker Len. Spiny Nub
84. Gill Raker Space
85. Pyloric Caeca 8
86. Vertebra 10+11+28=42
87. Physical Condition
88. Pseudobranchia - 15
89. D Spine L - 17.4 mm
90. Eye L - 34.5 mm
91. Branchio memb. - free fold
92. Food
93. Palatine Len - 0
94. Gill slit 4th - Pore
95. Dnot to C
96. Vomer Width - 7.6 mm

1. Specimen 1278
2. Area Oliktok Point
3. Species Rainbow Smelt
4. Date 04/09/88
5. _____
6. Sex/Condition _____
7. Scale Card _____
8. Scale# _____
9. Weight (g) _____
10. Fork Length _____
11. Standard Length 28 mm
12. Mid-Eye Length _____
13. Rear Obit Len. _____
14. Total Length skeleton only
15. Body Length _____
16. Head Length _____
17. Maxillary Len. 22 mm
18. Maxillary Depth _____
19. Lower Jaw Len. 29.4mm
20. Eye Diameter _____
21. Obit Length 13.0mm
22. Snout-Nostril _____
23. Snout-Maxillary _____
24. Snout-Anterior Obit Length _____
25. Snout-Occip _____
26. Snout-Dorsal _____
27. Snout-Adipose _____
28. Snout-Pectoral _____
29. Snout-Pelvic _____
30. Snout-Anal _____
31. Dorsal-Adipose _____
32. Pectoral-Pelvic _____
33. Pelvic-Anal _____
34. Pelvic Caudal _____
35. Dorsal Caudal Length _____
36. Ventral Caudal Length _____
37. _____
38. Mid-Eye Depth _____
39. Occiput Depth _____
40. Dorsal Fin Depth _____
41. Caudal Peduncle Depth _____
42. Interorbital Width 9.9mm
43. Mid-eye Width _____
44. Occiput Width _____
45. Body Width _____
46. Caudal Peduncle Width _____
47. Circumference _____
48. Dorsal Fin Length _____
49. Dorsal Height (anterior/ posterior) _____
50. Adipose Base Length _____
51. Adipose Height _____
52. Adipose Length _____
53. Caudal Fin Length (minimum/maximum) _____
54. Pectoral Length _____
55. Pelvic Length _____
56. Anal Fin Length _____
57. Anal Height (anterior/ posterior) _____
58. Dorsal Fin Rays 11
59. Caudal Rays (forked) _____
60. Pectoral Rays _____
61. Pelvic Rays _____
62. Anal Rays _____
63. _____
64. _____
65. _____
66. Liver Weight _____
67. Gonad Weight _____
68. Egg Number _____
69. Egg Diameter _____
70. Pores, Lateral Line _____
71. Pores, Std.Len. _____
72. Scales, Lateral Line _____
73. Scales (1st power above L.L.) _____
74. Scales, Occip. _____
75. Scales, Dorsal _____
76. Scales, Ventral _____
77. Scales, Supra-pelvic _____
78. Scales around Caudal Peduncle _____
79. Branchiostegals _____
80. Pores, Lower Jaw _____
81. Gill Rakers 1st Arch _____
82. Gill Rakers, 2nd Arch _____
83. Gill Raker Len. _____
84. Gill Raker Space _____
85. Pyloric Caeca _____
86. Vertebra 44+0+22=66
87. Physical Condition _____
88. _____
89. Vomer Width - 6.2 mm
90. Palatine Len - 14.8
91. Teeth P=12/13, V=2
92. Food _____
93. _____
94. _____
95. _____

1. Specimen 1279
2. Area Oliktok Point
3. Species Arctic Cisco
4. Date 04/09/88
5. Capture Depth - 1m
6. Sex/Condition M 6
7. Scale Card
8. Scale#
9. Weight (g) 880
10. Fork Length 418 mm
11. Standard Length 388 mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length 456 mm
15. Body Length
16. Head Length 74.0 mm
17. Maxillary Len. 20.2 mm X7.450
18. Maxillary Depth
19. Lower Jaw Len. 29.6 mm
20. Eye Diameter 13.2 mm
21. Obit Length 15.8 mm
22. Snout-Nostril 16.1 mm
23. Snout-Maxillary
24. Snout-Anterior Obit Length
25. Snout-Occip
26. Snout-Dorsal 185.8 mm
27. Snout-Adipose 327 mm
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 303 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. MAx. Extends - mideye
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 28.1 mm
42. Interorbital Width 21.7 mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 93.0 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/ posterior)
50. Adipose Base Length
51. Adipose Height 51.0 mm
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 47.6 mm
55. Pelvic Length
56. Anal Fin Length
57. Anal Height (anterior/ posterior)
58. Dorsal Fin Rays (3) 12=15
59. Caudal Rays (forked) 17
60. Pectoral Rays 17
61. Pelvic Rays 13
62. Anal Rays (2) 12=14
63. InOrbit Shape - Convex
64.
65.
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 98 + 1 C
71. Pores, Std.Len.
72. Scales, Lateral Line
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal 11
76. Scales, Ventral 11
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 8/9
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 15+1+24=40
82. Gill Rakers, 2nd Arch 19+1+27=47
83. Gill Raker Len. 12.2 mm
84. Gill Raker Space
85. Pyloric Caeca 129
86. Vertebra 35+8+22=65
87. Physical Condition
88. Pseudobranchia - 18
89. Gill Slit 4th - 16.3 mm
90. Vomer Width - 0
91. Palatine Len - 0
92. Food
93.
94.
95.

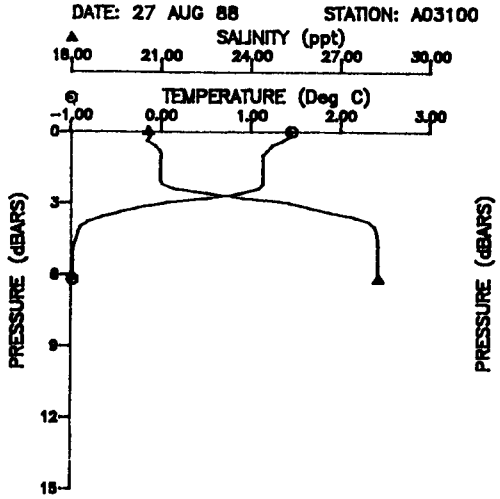
1. Specimen 1280
2. Area Oliktok Point
3. Species Rainbow Smelt
4. Date 04/09/88
5. Capture Depth - 1m
6. Sex/Condition F2
7. Scale Card
8. Scale#
9. Weight (g)
10. Fork Length 252 mm
11. Standard Length 231.5mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length 271.5 mm
15. Body Length
16. Head Length 54.3 mm
17. Maxillary Len. 21.9 mm
18. Maxillary Depth
19. Lower Jaw Len. 29.0 mm
20. Eye Diameter 10.1 mm
21. Obit Length 13.4 mm
22. Snout-Nostril 15.0 mm
23. Snout-Maxillary
24. Snout-Anterior Obit Length
25. Snout-Occip
26. Snout-Dorsal
27. Snout-Adipose
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 190.3 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Max. Extends - Rear Eye
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 12.3 mm
42. Interorbital Width 12.0 mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 40.2 mm
46. Caudal Peduncle Width 14.3 mm
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 36.7mm
55. Pelvic Length 32.0 mm
56. Anal Fin Length
57. Anal Height (anterior/posterior)
58. Dorsal Fin Rays 12
59. Caudal Rays (forked) 16
60. Pectoral Rays 12
61. Pelvic Rays 8
62. Anal Rays 15
63. In Orbit Shape - Convex
64.
65.
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 21/19
71. Pores, Std.Len.
72. Scales, Lateral Line 66
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal 8
76. Scales, Ventral 9
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 7/7
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 9+1+20 = 30
82. Gill Rakers, 2nd Arch 2+1+19 = 28
83. Gill Raker Len. 7.2 mm
84. Gill Raker Space
85. Pyloric Caeca 6
86. Vertebra 43+0+22=65
87. Physical Condition
88. Pseudobranchia - 14
89. Gill slit 4th - 11 mm
90. Vomer Width - 5.1 mm
91. Palatine Width - 15.8 mm
92. Food
93. Teeth V=3, P=13/14
94.
95.

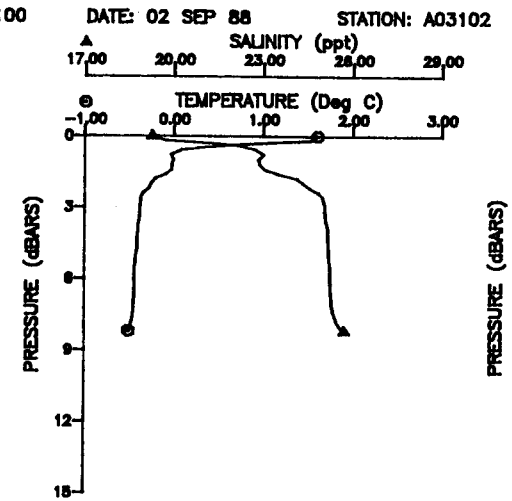
1. Specimen 1281
2. Area Oliktok Point
3. Species Broad Whitefish
4. Date 04/09/88
5. Capture Depth - 1m
6. Sex/Condition M2
7. Scale Card
8. Scale#
9. Weight (g)
10. Fork Length 427.5 mm
11. Standard Length 397 mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length 473 mm
15. Body Length
16. Head Length 73.9 mm
17. Maxillary Len. 15.1 x 2.6 mm
18. Maxillary Depth
19. Lower Jaw Len. 22.5 mm
20. Eye Diameter 13.1 mm
21. Obit Length 19.2 mm
22. Snout-Nostril 18.7 mm
23. Snout-Maxillary
24. Snout-Anterior Obit Length
25. Snout-Occip
26. Snout-Dorsal 179.2 mm
27. Snout-Adipose 329 mm
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 314 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Max Extends Front Orbit
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 32.7 mm
42. Interorbital Width 22.4 mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 87.2 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 65.5 mm
55. Pelvic Length 62.8 mm
56. Anal Fin Length
57. Anal Height (anterior/posterior)
58. Dorsal Fin Rays 15
59. Caudal Rays (forked) 17
60. Pectoral Rays 18
61. Pelvic Rays 11
62. Anal Rays 15
63. In Orbit Shape - Convex
64.
65.
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 95+2 = 97
71. Pores, Std.Len.
72. Scales, Lateral Line 97
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal 11
76. Scales, Ventral 9
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 8/8
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 8+1+13=22
82. Gill Rakers, 2nd Arch 6+1+11 = 18
83. Gill Raker Len. 3.5 mm
84. Gill Raker Space
85. Pyloric Caeca 178
86. Vertebra 37+5+20+62
87. Physical Condition
88. Pseudobranchia - 20
89. Vomer Width - 0
90. Palatine L. - 0
91.
92. Food
93.
94.
95.

1. Specimen 1282
2. Area Oliktok Point
3. Species Least Cisco
4. Date 04/09/88
5. Capture Depth - 1m
6. Sex/Condition F2
7. Scale Card
8. Scale#
9. Weight (g)
10. Fork Length 313 mm
11. Standard Length 286mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length 345 mm
15. Body Length
16. Head Length 54.3mm
17. Maxillary Len. 16.2 mm x6.0mm
18. Maxillary Depth
19. Lower Jaw Len. 25.0 mm
20. Eye Diameter 12.3 mm
21. Obit Length 14.8 mm
22. Snout-Nostril 10.8 mm
23. Snout-Maxillary
24. Snout-Anterior Obit Length
25. Snout-Occip
26. Snout-Dorsal 127.7 mm
27. Snout-Adipose 238.6 mm
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 218 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Max Extends - mideye
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 23.7mm
42. Interorbital Width 12.5mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 69.7 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/ posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 50.3 mm
55. Pelvic Length 50.4 mm
56. Anal Fin Length
57. Anal Height (anterior/ posterior)
58. Dorsal Fin Rays 15
59. Caudal Rays (forked) 16
60. Pectoral Rays 14
61. Pelvic Rays 11
62. Anal Rays 16
63. In Orbit Shape - Convex
64.
65.
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 74+1
71. Pores, Std.Len.
72. Scales, Lateral Line 76
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal 10
76. Scales, Ventral 8
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 8/8
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 14+1+39=54
82. Gill Rakers, 2nd Arch 16+1+29
83. Gill Raker Len. 10.2mm
84. Gill Raker Space
85. Pyloric Caeca 74
86. Vertebra 36+4+22=62
87. Physical Condition
88. Pseudobranchia - 23
89. Gill Slit 4th - 11.2 mm
90. Vomer Width 0
91. Palate Len 0
92. Food
93.
94.
95.

1. Specimen 1283
2. Area Oilkok Point
3. Species least Cisco
4. Date 06/09/88
5.
6. Sex/Condition ♀
7. Scale Card
8. Scale#
9. Weight (g) 670
10. Fork Length 381 mm
11. Standard Length 347.5 mm
12. Mid-Eye Length
13. Rear Obit Len.
14. Total Length 415.5 mm
15. Body Length
16. Head Length 67.5 mm
17. Maxillary Len. 19.2 X 7.4
18. Maxillary Depth
19. Lower Jaw Len. 27.4 mm
20. Eye Diameter 13.0 mm
21. Obit Length 17.4 mm
22. Snout-Nostril 16.0 mm
23. Snout-Maxillary
24. Snout-Anterior Obit Length
25. Snout-Occip
26. Snout-Dorsal 154.3 mm
27. Snout-Adipose 285 mm
28. Snout-Pectoral
29. Snout-Pelvic
30. Snout-Anal 268 mm
31. Dorsal-Adipose
32. Pectoral-Pelvic
33. Pelvic-Anal
34. Pelvic Caudal
35. Dorsal Caudal Length
36. Ventral Caudal Length
37. Max Extends - mideye
38. Mid-Eye Depth
39. Occiput Depth
40. Dorsal Fin Depth
41. Caudal Peduncle Depth 26.7 mm
42. Interorbital Width 15.7 mm
43. Mid-eye Width
44. Occiput Width
45. Body Width 80 mm
46. Caudal Peduncle Width
47. Circumference
48. Dorsal Fin Length
49. Dorsal Height (anterior/ posterior)
50. Adipose Base Length
51. Adipose Height
52. Adipose Length
53. Caudal Fin Length (minimum/maximum)
54. Pectoral Length 57.6 mm
55. Pelvic Length 51.6 mm
56. Anal Fin Length
57. Anal Height (anterior/ posterior)
58. Dorsal Fin Rays 15
59. Caudal Rays (forked) 17
60. Pectoral Rays 17
61. Pelvic Rays 12
62. Anal Rays 17
63. InOrbit Shape Convex
64.
65.
66. Liver Weight
67. Gonad Weight
68. Egg Number
69. Egg Diameter
70. Pores, Lateral Line 84 + 2
71. Pores, Std.Len.
72. Scales, Lateral Line 87
73. Scales (1st power above L.L.)
74. Scales, Occip.
75. Scales, Dorsal 10
76. Scales, Ventral 9
77. Scales, Supra-pelvic
78. Scales around Caudal Peduncle
79. Branchiostegals 9/9
80. Pores, Lower Jaw
81. Gill Rakers 1st Arch 17 + 1 + 30 = 48
82. Gill Rakers, 2nd Arch 18 + 1 + 30 = 49
83. Gill Raker Len. 9.0 mm
84. Gill Raker Space
85. Pyloric Caeca 81
86. Vertebra 35 + 6 + 22 = 63
87. Physical Condition
88. Pseudobranchia ++
89. Gill Slit 4th - 14.2 mm
90. Vomer Width - 0
91. Palatine Len - 0
92. Food
93. Condition - spotted
94.
95.

Appendix C
CTD Station Data


DATE: 27 AUG 88
STATION: A03100
SALINITY (ppt)
18,00 21,00 24,00 27,00 30,00
TEMPERATURE (Deg C)
-1,00 0,00 1,00 2,00 3,00
PRESSURE (dBARS)
0 3 6 9 12 15


DATE: 02 SEP 88
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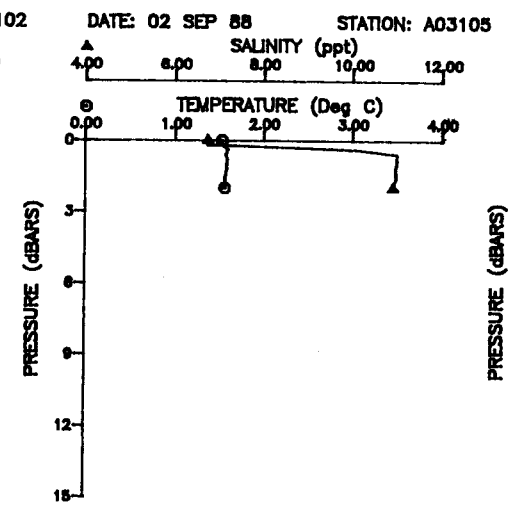
17,00 20,00 23,00 26,00 29,00
TEMPERATURE (Deg C)
-1,00 0,00 1,00 2,00 3,00
PRESSURE (dBARS)
0 3 6 9 12 15


DATE: 02 SEP 88
STATION: A03105
SALINITY (ppt)
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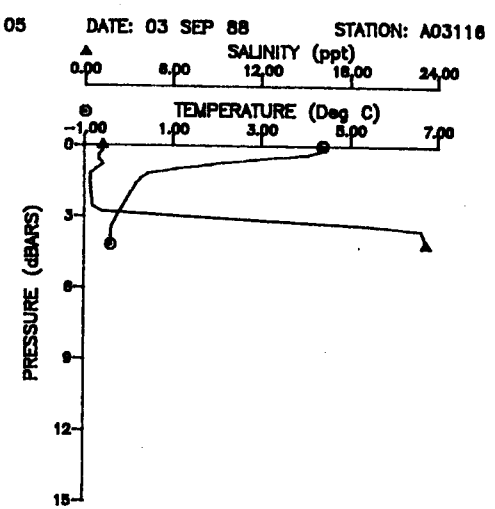
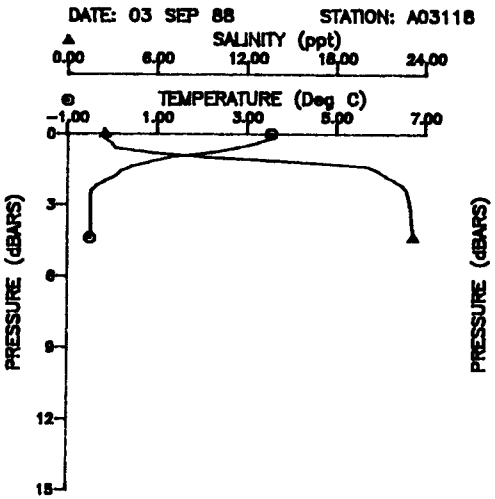
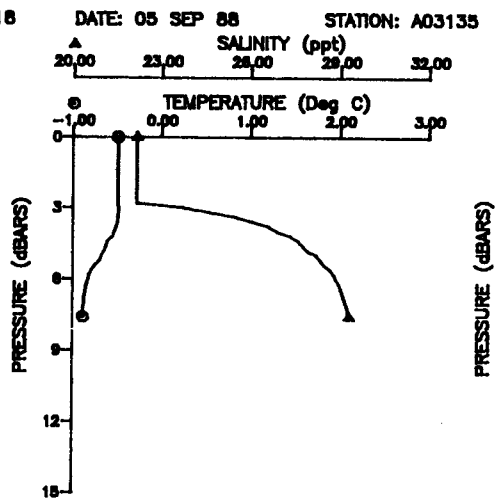
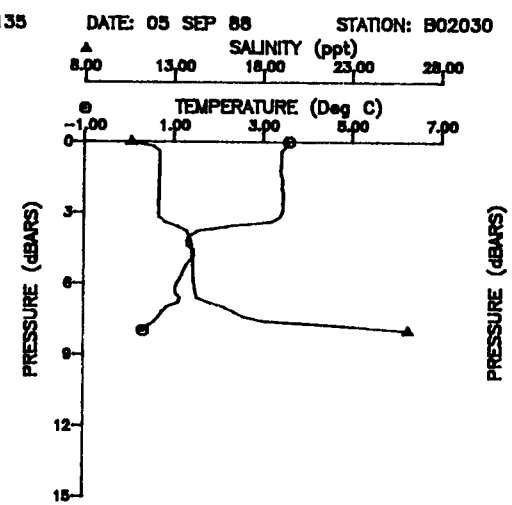
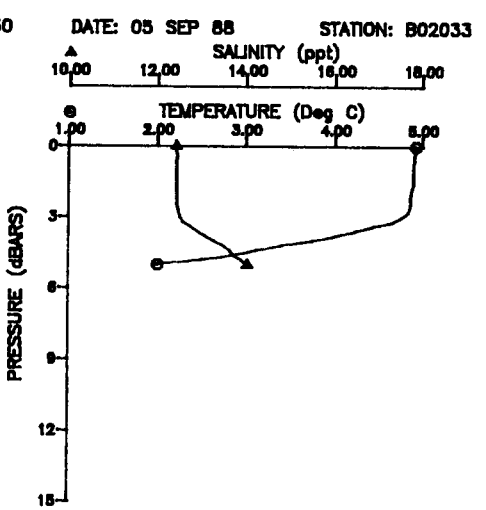
TEMPERATURE (Deg C)
0,00 1,00 2,00 3,00 4,00
PRESSURE (dBARS)
0 3 6 9 12 15

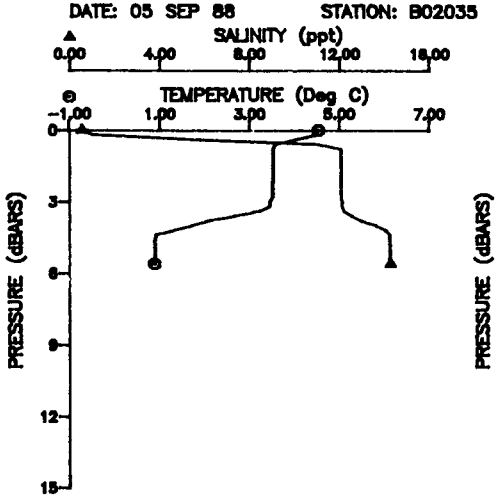

DATE: 03 SEP 88
STATION: A03116
SALINITY (ppt)
0,00 6,00 12,00 18,00 24,00
TEMPERATURE (Deg C)
-1,00 1,00 3,00 5,00 7,00
PRESSURE (dBARS)
0 3 6 9 12 15

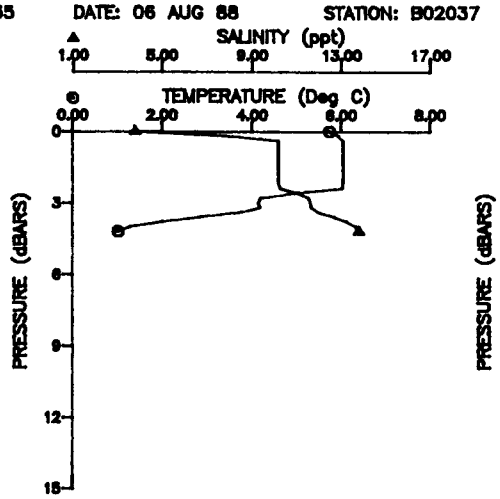

DATE: 03 SEP 88
STATION: A03116
SALINITY (ppt)
0,00 6,00 12,00 18,00 24,00
TEMPERATURE (Deg C)
-1,00 1,00 3,00 5,00 7,00
PRESSURE (dBARS)
0 3 6 9 12 15

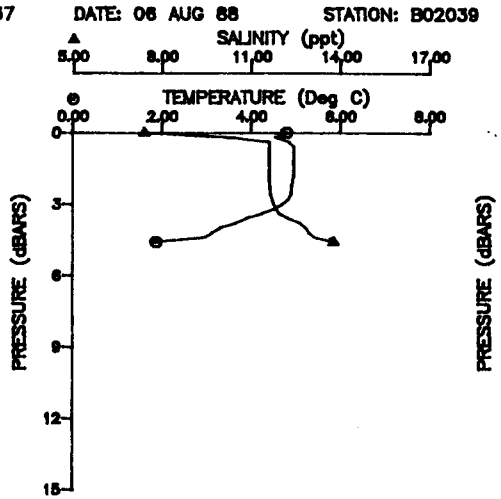

DATE: 05 SEP 88
STATION: A03135
SALINITY (ppt)
20,00 23,00 26,00 29,00 32,00
TEMPERATURE (Deg C)
-1,00 0,00 1,00 2,00 3,00
PRESSURE (dBARS)
0 3 6 9 12 15

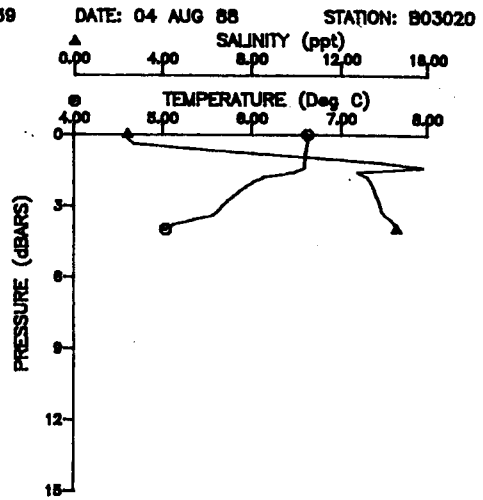

DATE: 05 SEP 88
STATION: B02030
SALINITY (ppt)
8,00 13,00 18,00 23,00 28,00
TEMPERATURE (Deg C)
-1,00 1,00 3,00 5,00 7,00
PRESSURE (dBARS)
0 3 6 9 12 15

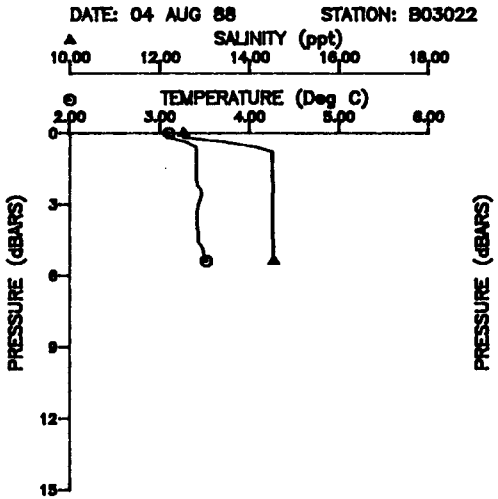

DATE: 05 SEP 88
STATION: B02033
SALINITY (ppt)
10,00 12,00 14,00 16,00 18,00
TEMPERATURE (Deg C)
1,00 2,00 3,00 4,00 5,00
PRESSURE (dBARS)
0 3 6 9 12 15

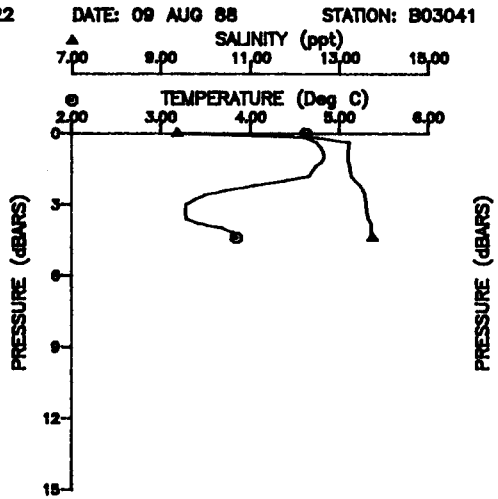

DATE: 05 SEP 88
STATION: B02035
SALINITY (ppt)
0.00 4.00 8.00 12.00 16.00
TEMPERATURE (Deg C)
-1.00 1.00 3.00 5.00 7.00
PRESSURE (dBARS)
0 3 6 9 12 15

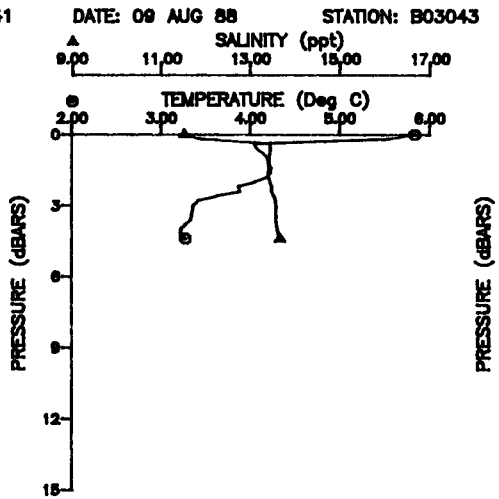

DATE: 06 AUG 88
STATION: B02037
SALINITY (ppt)
1.00 5.00 9.00 13.00 17.00
TEMPERATURE (Deg C)
0.00 2.00 4.00 6.00 8.00
PRESSURE (dBARS)
0 3 6 9 12 15

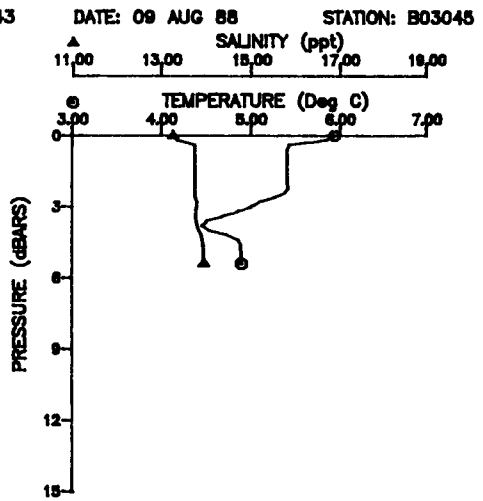

DATE: 06 AUG 88
STATION: B02039
SALINITY (ppt)
5.00 8.00 11.00 14.00 17.00
TEMPERATURE (Deg C)
0.00 2.00 4.00 6.00 8.00
PRESSURE (dBARS)
0 3 6 9 12 15

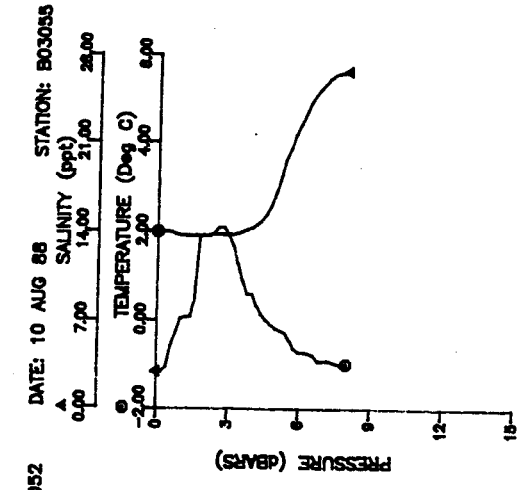

DATE: 04 AUG 88
STATION: B03020
SALINITY (ppt)
0.00 4.00 8.00 12.00 16.00
TEMPERATURE (Deg C)
4.00 5.00 6.00 7.00 8.00
PRESSURE (dBARS)
0 3 6 9 12 15

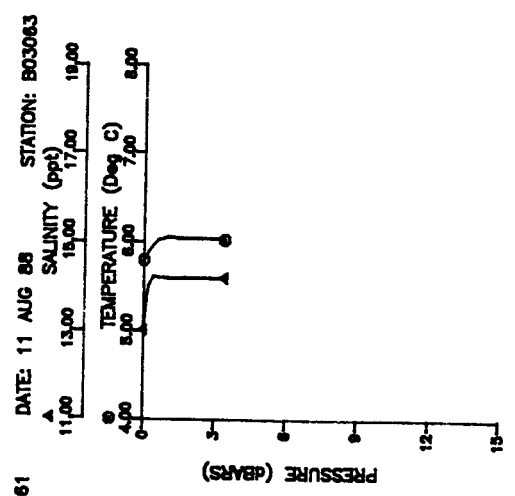

DATE: 04 AUG 88
STATION: B03022
SALINITY (ppt)
10.00 12.00 14.00 16.00 18.00
TEMPERATURE (Deg C)
2.00 3.00 4.00 5.00 6.00
PRESSURE (dBARS)
0 3 6 9 12 15

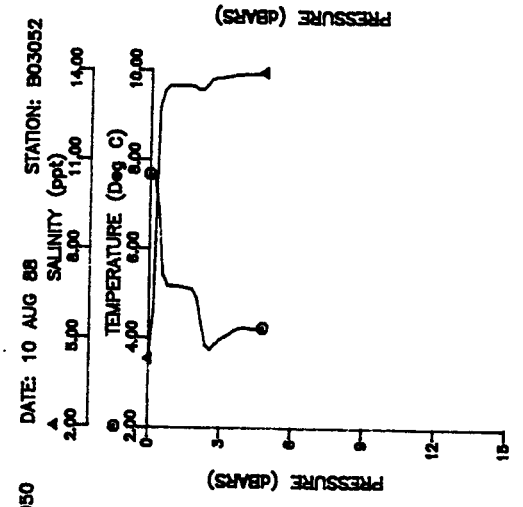

DATE: 09 AUG 88
STATION: B03041
SALINITY (ppt)
7.00 9.00 11.00 13.00 15.00
TEMPERATURE (Deg C)
2.00 3.00 4.00 5.00 6.00
PRESSURE (dBARS)
0 3 6 9 12 15

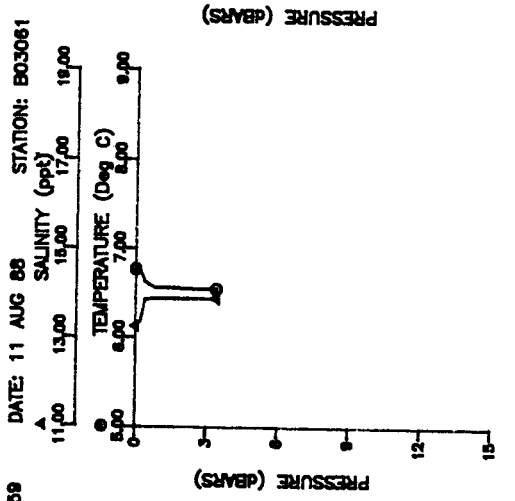

DATE: 09 AUG 88
STATION: B03043
SALINITY (ppt)
9.00 11.00 13.00 15.00 17.00
TEMPERATURE (Deg C)
2.00 3.00 4.00 5.00 6.00
PRESSURE (dBARS)
0 3 6 9 12 15

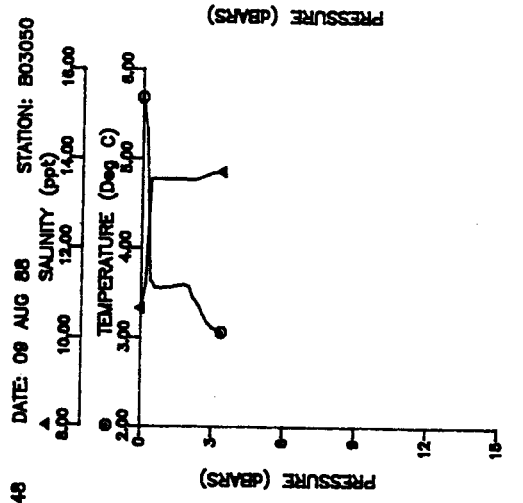

DATE: 09 AUG 88
STATION: B03045
SALINITY (ppt)
11.00 13.00 15.00 17.00 19.00
TEMPERATURE (Deg C)
3.00 4.00 5.00 6.00 7.00
PRESSURE (dBARS)
0 3 6 9 12 15

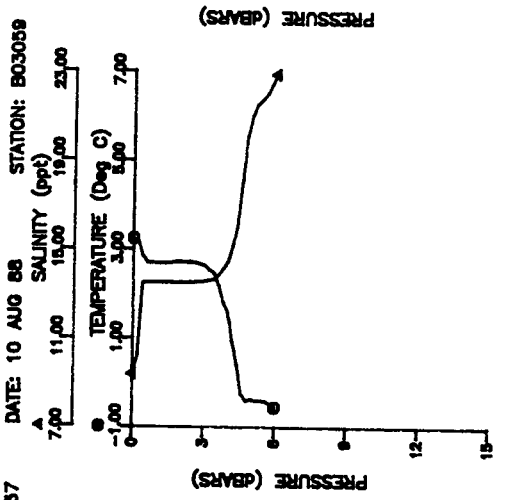

DATE: 10 AUG 88
STATION: B03055
SALINITY (ppt)
TEMPERATURE (Deg C)
PRESSURE (dBARS)

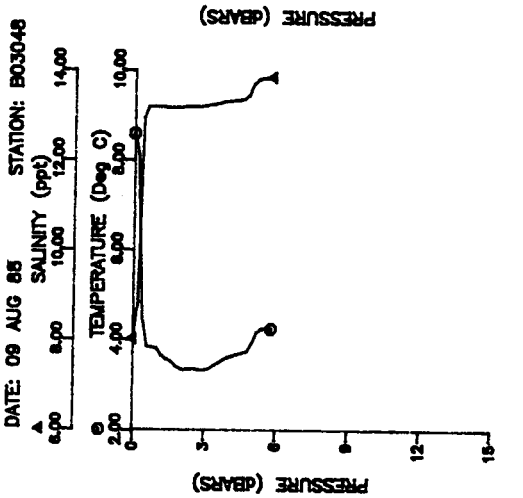

DATE: 11 AUG 88
STATION: B03063
SALINITY (ppt)
TEMPERATURE (Deg C)
PRESSURE (dBARS)

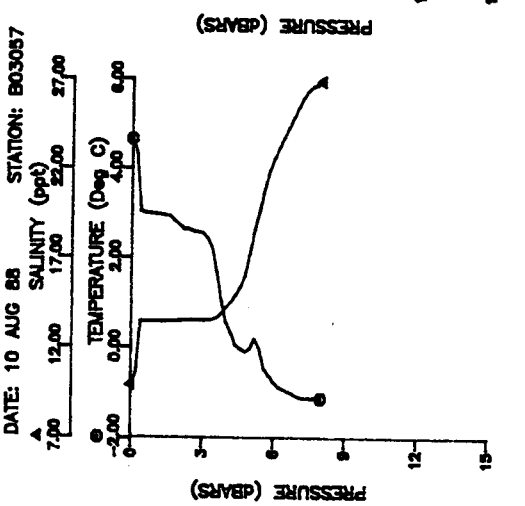

DATE: 10 AUG 88
STATION: B03052
SALINITY (ppt)
TEMPERATURE (Deg C)
PRESSURE (dBARS)

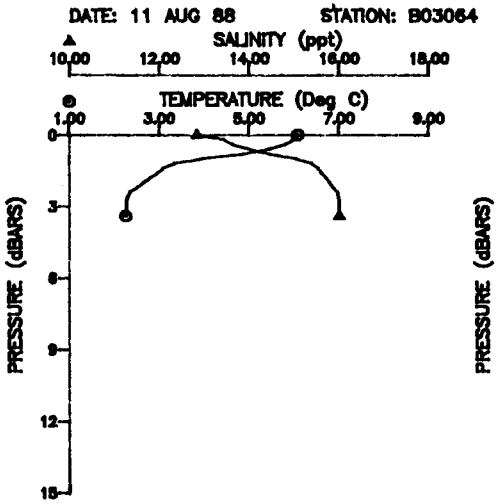

DATE: 11 AUG 88
STATION: B03061
SALINITY (ppt)
TEMPERATURE (Deg C)
PRESSURE (dBARS)

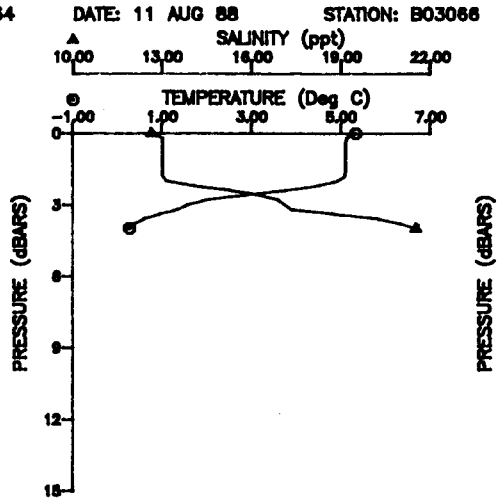

DATE: 09 AUG 88
STATION: B03050
SALINITY (ppt)
TEMPERATURE (Deg C)
PRESSURE (dBARS)

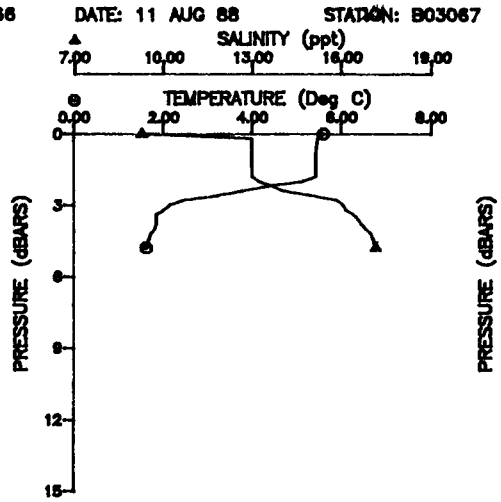

DATE: 10 AUG 88
STATION: B03059
SALINITY (ppt)
TEMPERATURE (Deg C)
PRESSURE (dBARS)

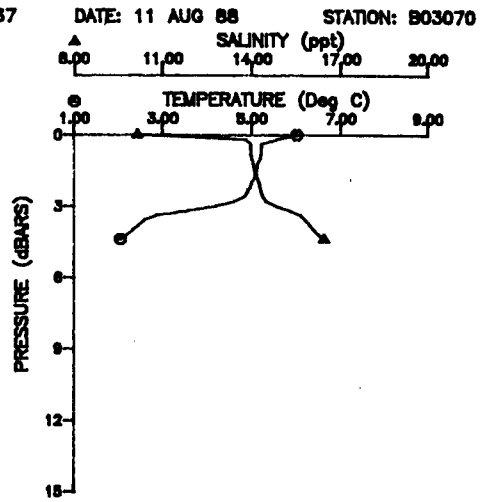

DATE: 09 AUG 88
STATION: B03048
SALINITY (ppt)
TEMPERATURE (Deg C)
PRESSURE (dBARS)

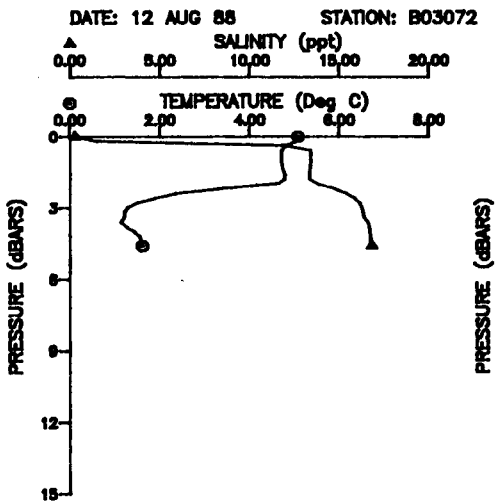

DATE: 10 AUG 88
STATION: B03057
SALINITY (ppt)
TEMPERATURE (Deg C)
PRESSURE (dBARS)

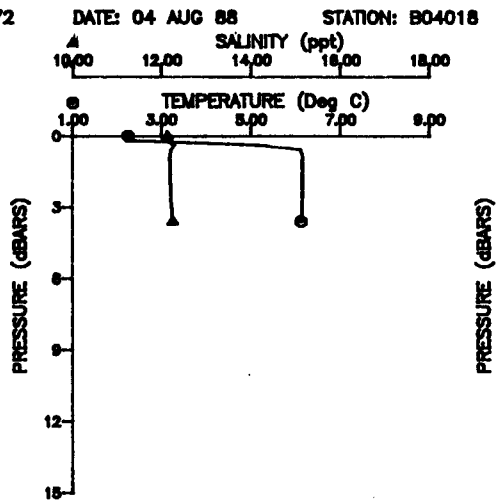

DATE: 11 AUG 88
STATION: B03064
SALINITY (ppt)
10.00 12.00 14.00 16.00 18.00
TEMPERATURE (Deg C)
1.00 3.00 5.00 7.00 9.00
PRESSURE (dBARS)
0 3 6 9 12 15

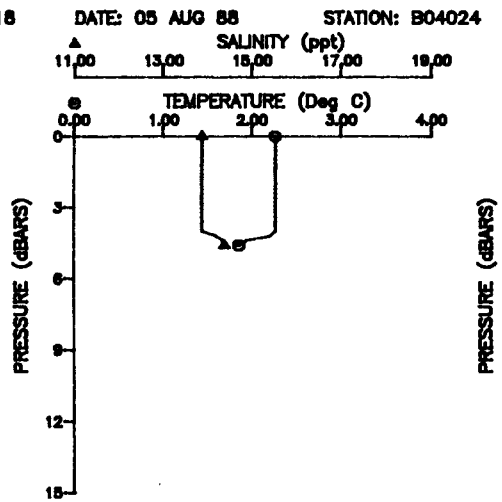

DATE: 11 AUG 88
STATION: B03066
SALINITY (ppt)
10.00 13.00 16.00 19.00 22.00
TEMPERATURE (Deg C)
-1.00 1.00 3.00 5.00 7.00
PRESSURE (dBARS)
0 3 6 9 12 15

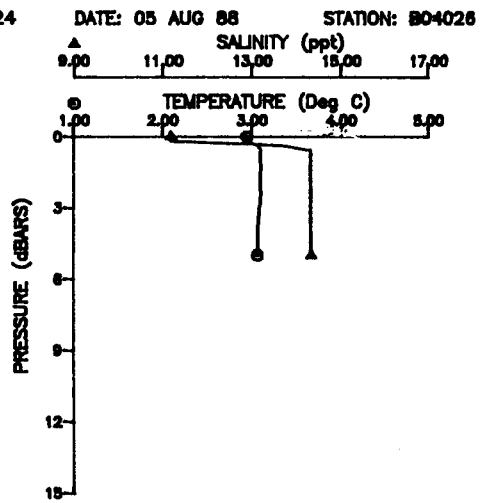

DATE: 11 AUG 88
STATION: B03067
SALINITY (ppt)
7.00 10.00 13.00 16.00 19.00
TEMPERATURE (Deg C)
0.00 2.00 4.00 6.00 8.00
PRESSURE (dBARS)
0 3 6 9 12 15

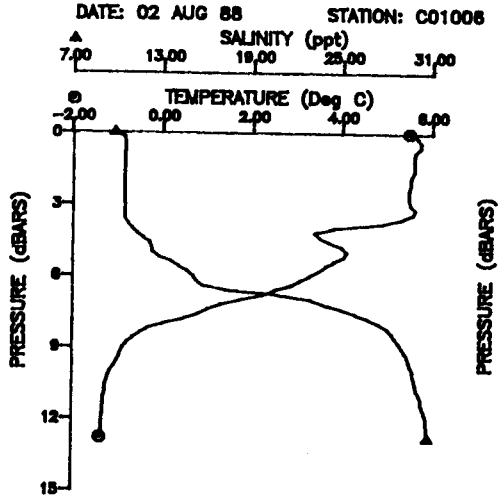

DATE: 11 AUG 88
STATION: B03070
SALINITY (ppt)
8.00 11.00 14.00 17.00 20.00
TEMPERATURE (Deg C)
1.00 3.00 5.00 7.00 9.00
PRESSURE (dBARS)
0 3 6 9 12 15

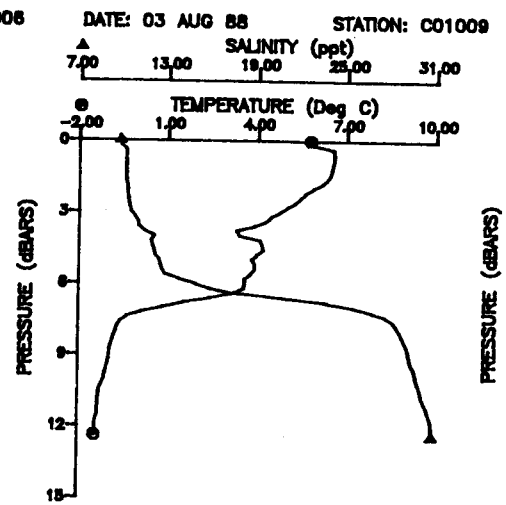

DATE: 12 AUG 88
STATION: B03072
SALINITY (ppt)
0.00 5.00 10.00 15.00 20.00
TEMPERATURE (Deg C)
0.00 2.00 4.00 6.00 8.00
PRESSURE (dBARS)
0 3 6 9 12 15

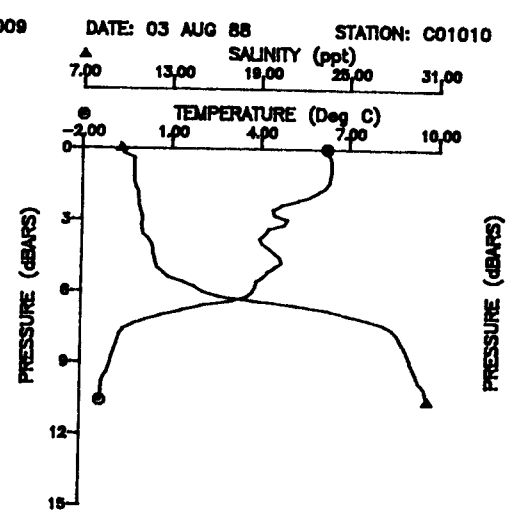

DATE: 04 AUG 88
STATION: B04018
SALINITY (ppt)
10.00 12.00 14.00 16.00 18.00
TEMPERATURE (Deg C)
1.00 3.00 5.00 7.00 9.00
PRESSURE (dBARS)
0 3 6 9 12 15

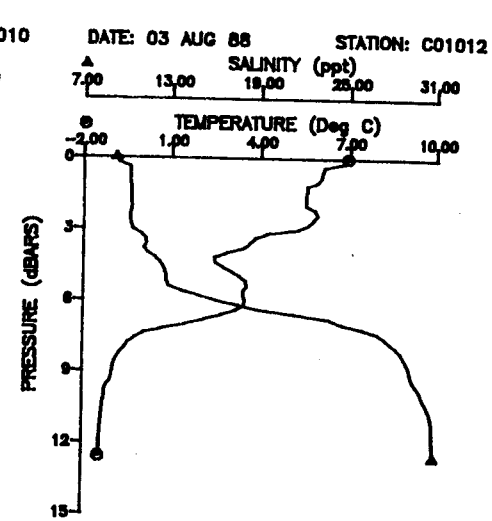

DATE: 05 AUG 88
STATION: B04024
SALINITY (ppt)
11.00 13.00 15.00 17.00 19.00
TEMPERATURE (Deg C)
0.00 1.00 2.00 3.00 4.00
PRESSURE (dBARS)
0 3 6 9 12 15

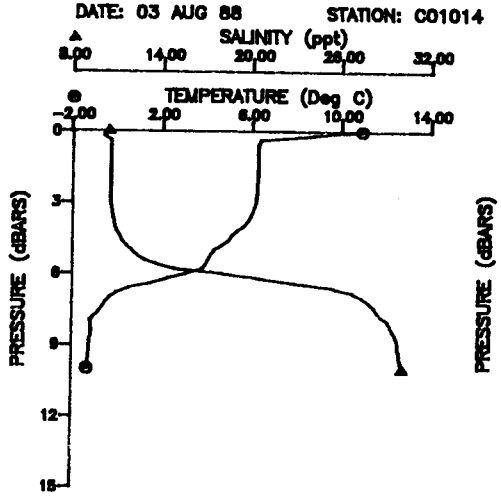

DATE: 05 AUG 88
STATION: B04026
SALINITY (ppt)
9.00 11.00 13.00 15.00 17.00
TEMPERATURE (Deg C)
1.00 2.00 3.00 4.00 5.00
PRESSURE (dBARS)
0 3 6 9 12 15

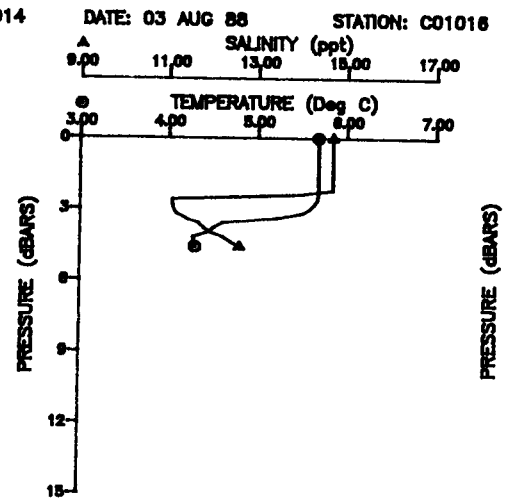

DATE: 02 AUG 88
STATION: C01006
SALINITY (ppt)
7.00 13.00 19.00 25.00 31.00
TEMPERATURE (Deg C)
-2.00 0.00 2.00 4.00 6.00
PRESSURE (dBARS)
0 3 6 9 12 15

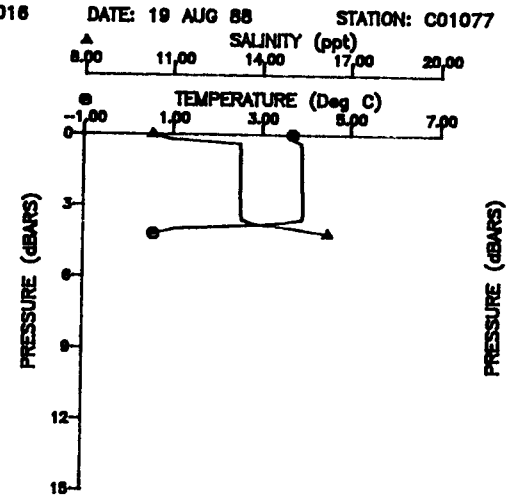

DATE: 03 AUG 88
STATION: C01009
SALINITY (ppt)
7.00 13.00 19.00 25.00 31.00
TEMPERATURE (Deg C)
-2.00 1.00 4.00 7.00 10.00
PRESSURE (dBARS)
0 3 6 9 12 15

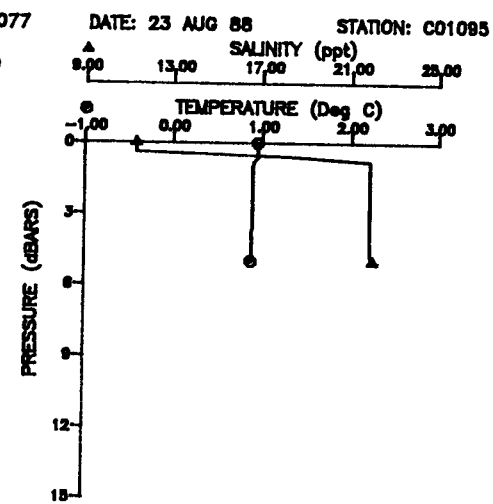

DATE: 03 AUG 88
STATION: C01010
SALINITY (ppt)
7.00 13.00 19.00 25.00 31.00
TEMPERATURE (Deg C)
-2.00 1.00 4.00 7.00 10.00
PRESSURE (dBARS)
0 3 6 9 12 15

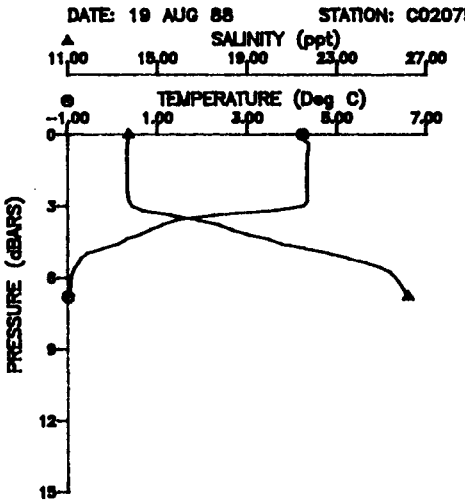

DATE: 03 AUG 88
STATION: C01012
SALINITY (ppt)
7.00 13.00 19.00 25.00 31.00
TEMPERATURE (Deg C)
-2.00 1.00 4.00 7.00 10.00
PRESSURE (dBARS)
0 3 6 9 12 15

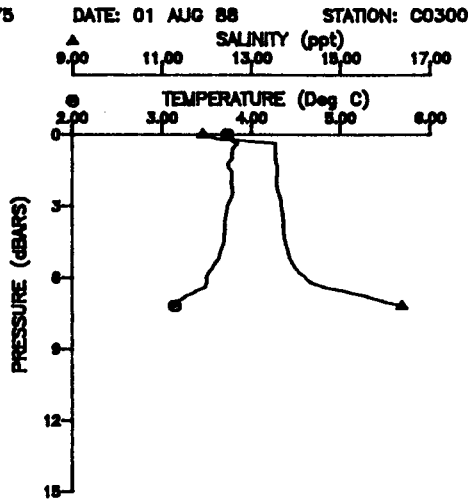

DATE: 03 AUG 88
STATION: C01014
SALINITY (ppt)
8.00 14.00 20.00 26.00 32.00
TEMPERATURE (Deg C)
-2.00 2.00 6.00 10.00 14.00
PRESSURE (dBARS)
0 3 6 9 12 15

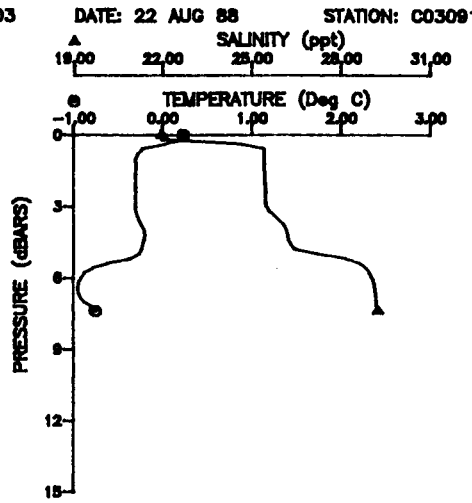

DATE: 03 AUG 88
STATION: C01016
SALINITY (ppt)
9.00 11.00 13.00 15.00 17.00
TEMPERATURE (Deg C)
3.00 4.00 5.00 6.00 7.00
PRESSURE (dBARS)
0 3 6 9 12 15

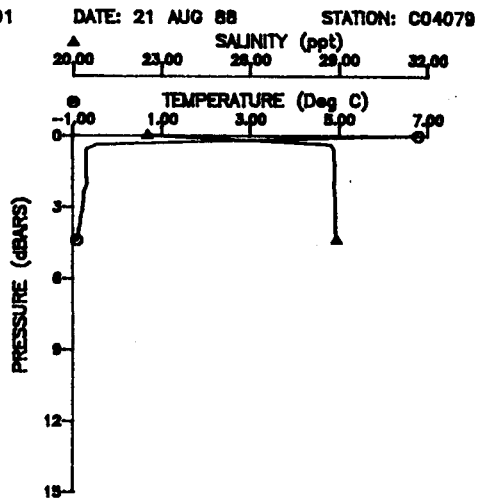

DATE: 19 AUG 88
STATION: C01077
SALINITY (ppt)
8.00 11.00 14.00 17.00 20.00
TEMPERATURE (Deg C)
-1.00 1.00 3.00 5.00 7.00
PRESSURE (dBARS)
0 3 6 9 12 15

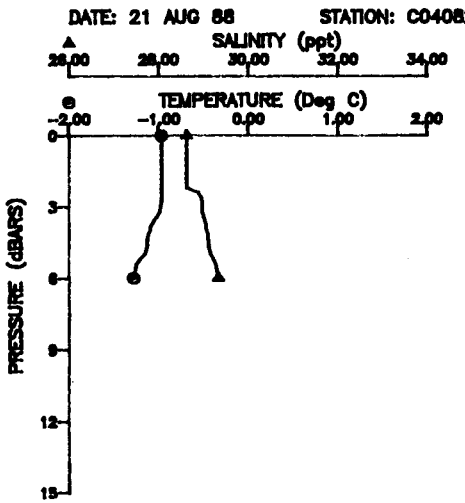

DATE: 23 AUG 88
STATION: C01095
SALINITY (ppt)
9.00 13.00 17.00 21.00 25.00
TEMPERATURE (Deg C)
-1.00 0.00 1.00 2.00 3.00
PRESSURE (dBARS)
0 3 6 9 12 15

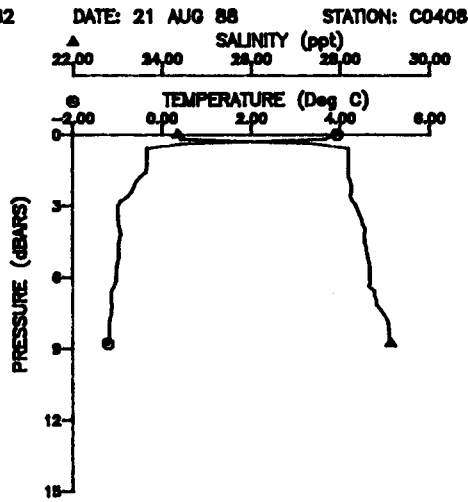

DATE: 19 AUG 88
STATION: C02075
SALINITY (ppt)
11.00 15.00 19.00 23.00 27.00
TEMPERATURE (Deg C)
-1.00 1.00 3.00 5.00 7.00
PRESSURE (dBARS)
0 3 6 9 12 15

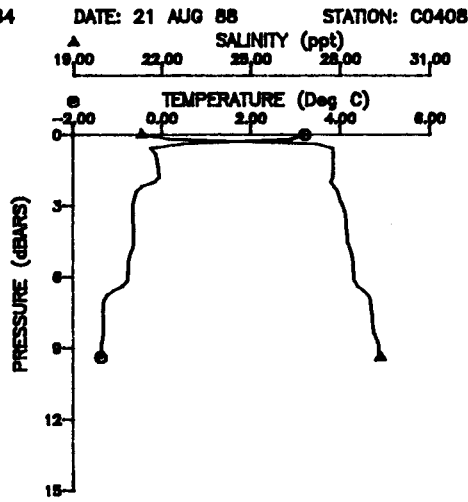

DATE: 01 AUG 88
STATION: C03003
SALINITY (ppt)
9.00 11.00 13.00 15.00 17.00
TEMPERATURE (Deg C)
2.00 3.00 4.00 5.00 6.00
PRESSURE (dBARS)
0 3 6 9 12 15

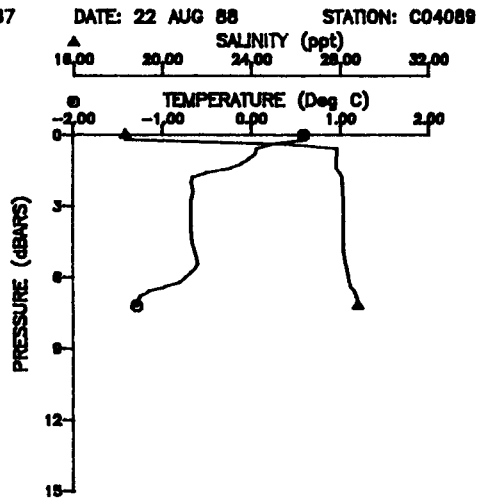

DATE: 22 AUG 88
STATION: C03091
SALINITY (ppt)
19.00 22.00 25.00 28.00 31.00
TEMPERATURE (Deg C)
-1.00 0.00 1.00 2.00 3.00
PRESSURE (dBARS)
0 3 6 9 12 15

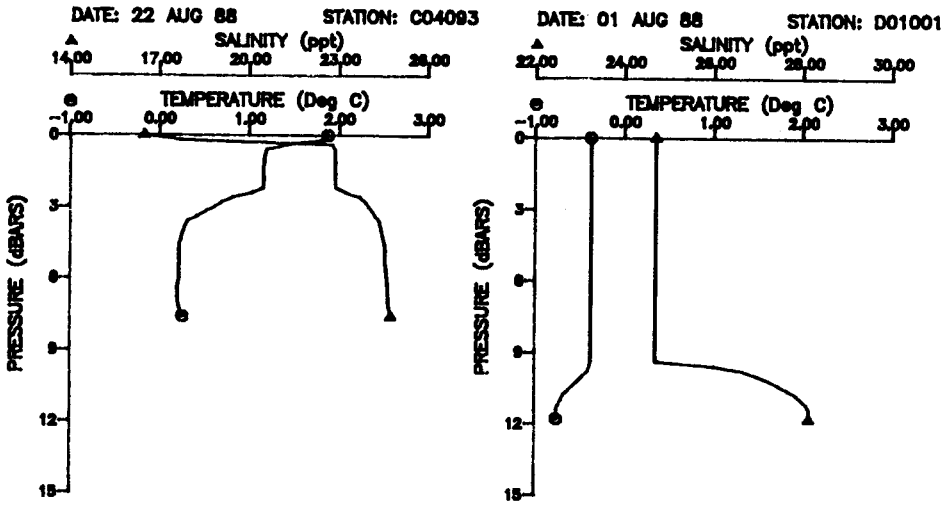

DATE: 21 AUG 88
STATION: C04079
SALINITY (ppt)
20.00 23.00 26.00 29.00 32.00
TEMPERATURE (Deg C)
-1.00 1.00 3.00 5.00 7.00
PRESSURE (dBARS)
0 3 6 9 12 15


DATE: 21 AUG 88
STATION: C04082
SALINITY (ppt)
28.00 28.00 30.00 32.00 34.00
TEMPERATURE (Deg C)
-2.00 -1.00 0.00 1.00 2.00
PRESSURE (dBARS)
0 3 6 9 12 15


DATE: 21 AUG 88
STATION: C04084
SALINITY (ppt)
22.00 24.00 26.00 28.00 30.00
TEMPERATURE (Deg C)
-2.00 0.00 2.00 4.00 6.00
PRESSURE (dBARS)
0 3 6 9 12 15


DATE: 21 AUG 88
STATION: C04087
SALINITY (ppt)
19.00 22.00 25.00 28.00 31.00
TEMPERATURE (Deg C)
-2.00 0.00 2.00 4.00 6.00
PRESSURE (dBARS)
0 3 6 9 12 15


DATE: 22 AUG 88
STATION: C04089
SALINITY (ppt)
16.00 20.00 24.00 28.00 32.00
TEMPERATURE (Deg C)
-2.00 -1.00 0.00 1.00 2.00
PRESSURE (dBARS)
0 3 6 9 12 15


DATE: 22 AUG 88
STATION: C04093
SALINITY (ppt)
14.00
17.00
20.00
23.00
26.00
TEMPERATURE (Deg C)
-1.00
0.00
1.00
2.00
3.00
PRESSURE (dBARS)
0
3
6
9
12
15
DATE: 01 AUG 88
STATION: D01001
SALINITY (ppt)
22.00
24.00
26.00
28.00
30.00
TEMPERATURE (Deg C)
-1.00
0.00
1.00
2.00
3.00
PRESSURE (dBARS)
0
3
6
9
12
15

Appendix D
Seine and Gillnet Fishing Locations

Station	Date	Gear	Fishing Location LAT (N)	LONG (W)	NAV
DO1002	8-01	BN	70 10.4	143 41.8	LC
CO1005	8-02	BN	70 9.3	145 38.9	LC
CO1007	8-02	PS	70 9.3	145 37.2	LC
CO1008	8-02	PS	70 9.3	145 37.2	LC
CO1011	8-02	PS	70 9.0	145 38.2	LC
CO1013	8-02	PS	70 8.9	145 38.5	LC
C01015	8-02	PS	70 8.5	145 38.5	LC
C01017	8-02	PS	70 7.5	145 40.1	LC
B04019	8-04	PS	70 12.6	146 27.6	LC
B03021	8-04	PS	70 11.5	146 52.3	LC
B03023	8-04	PS	70 11.8	146 51.6	LC
B04025	8-04	BN	70 15.0	146 51.0	LC
B04027	8-04	PS	70 13.1	147 00.2	LC
B04028	8-04	PS	70 13.1	147 00.5	LC
B04029	8-04	PS	70 12.9	147 00.9	LC
B02031	8-05	PS	70 22.5	147 38.4	LC
B02032	8-05	PS	70 22.5	147 38.4	LC
B02034	8-05	PS	70 19.7	147 39.1	LC
B02036	8-05	PS	70 20.4	147 43.2	LC
B02038	8-05	PS	70 20.8	147 48.9	LC
B02040	8-05	PS	70 20.0	147 45.3	LC
B03042	8-09	GN	70 11.6	146 58.4	LC
B03044	8-09	PS	70 12.1	146 58.3	LC
B03046	8-09	PS	70 12.0	147 03.0	LC
B03047	8-09	PS	70 12.5	147 03.0	LC
B03049	8-09	PS	70 15.4	147 06.2	LC
B03051	8-09	PS	70 13.9	146 52.9	LC
B03053	8-09	GN	70 11.6	146 58.4	DR
B03054	8-09	GN	70 10.6	146 51.6	DR
B03056	8-10	BN	70 16.5	146 48.6	LC
B03058	8-10	PS	70 16.9	146 46.3	LC
B03060	8-10	PS	70 15.8	146 42.2	LC
B03062	8-10	GN	70 11.6	146 51.7	DR
B03065	8-11	GN	70 12.5	146 59.6	DR
B03068	8-11	PS	70 13.3	146 56.2	LC
B03069	8-11	PS	70 12.5	146 59.6	LC
B03071	8-11	PS	70 12.9	147 01.4	LC
B03073	8-11	PS	70 12.6	146 59.8	LC
B03074	8-11	GN	70 12.6	146 59.7	LC
C02075	8-18	PS	70 03.5	145 18.4	SN
C01078	8-18	PS	70 01.9	144 59.6	LC
C04080	8-21	PS	69 56.6	144 32.0	SN
C04081	8-21	PS	69 58.5	144 36.3	SN

C04083	8-21	PS	69 57.7	144 33.6	LC
C04085	8-21	PS	70 01.5	144 35.4	LC
C04086	8-21	BN	70 01.5	144 38.8	LC
C04088	8-21	PS	70 00.7	144 46.4	LC
C04090	8-21	PS	69 58.8	144 46.8	LC
C03092	8-22	PS	70 00.9	144 03.2	LC
C04094	8-22	PS	70 00.6	144 49.6	LC
C01096	8-22	PS	70 02.9	145 19.1	LC
C01098	8-22	PS	70 06.0	145 33.8	LC
A03099	8-26	GN	70 33.1	150 08.8	DR
A03101	8-27	PS	70 34.0	150 18.3	LC
A03102	8-28	GN	70 33.2	150 11.5	DR
A03103	9-01	GN	70 30.9	149 53.8	DR
A03104	9-02	GN	70 30.9	149 52.0	DR
A03106	9-02	GN	70 30.8	149 52.0	DR
A03107	9-02	GN	70 30.8	149 52.0	DR
A03108	9-02	GN	70 30.8	149 52.0	DR
A03109	9-02	GN	70 30.8	149 52.6	DR
A03110	9-02	GN	70 30.8	149 52.8	DR
A03111	9-02	GN	70 30.8	149 52.6	DR
A03112	9-02	GN	70 30.8	149 52.6	DR
A03113	9-02	GN	70 30.8	149 52.0	DR
A03115	9-03	BN	70 33.4	150 17.5	LC
A03117	9-03	PS	70 33.1	150 15.2	LC
A03119	9-03	PS	70 32.8	150 14.1	LC
A03120	9-03	GN	70 30.7	149 52.7	DR
A03121	9-03	GN	70 30.7	149 52.5	DR
A03125	9-04	GN	70 30.7	149 52.5	DR
A03128	9-04	GN	70 30.7	149 52.7	DR
A03129	9-04	GN	70 30.7	149 52.5	DR
A03130	9-04	GN	70 30.7	149 52.5	DR
A03136	9-05	BN	70 34.3	149 34.4	LC
A03138	9-05	GN	70 30.7	149 52.5	DR
A03139	9-05	GN	70 30.7	149 52.5	DR
A03140	9-06	GN	70 30.7	149 52.5	DR
A03141	9-06	GN	70 30.7	149 52.5	DR
A03142	9-06	GN	70 34.3	149 53.9	DR
A03143	9-06	GN	70 30.7	149 52.5	DR
A03144	9-06	GN	70 30.7	149 52.5	DR
A03154	9-06	GN	70 34.5	149 53.9	DR

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

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