THE EFFECTS OF WATER TEMPERATURE ON THE SEASONAL DISTRIBUTION AND GROWTH OF WALLEYE POLLOCK, *THERAGRA CHALCOGRAMMA* (PALLAS), IN THE SOUTHEAST BERING SEA

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A

THESIS

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ABSTRACT

The distribution and growth of walleye pollock, *Theragra chalcogramma* (Pallas), were studied in relation to bottom water temperatures, in an area between latitude 54°30'N and 57°30'N and longitude 160°W and 170°W, from the data collected from 1976 to 1980.

The annual variations of bottom temperature distribution, including mean temperature, are described. It is found that temperature boundaries regulate spawning aggregation areas and feeding distribution of adult pollock. Young pollock were distributed in a wider temperature range and revealed a clearer feeding migration pattern than the adults.

The weight growth for walleye pollock aged 2 to 4 was determined. The growth rate varied with age, sex and year. The relative growth rate was related to the initial weight of the fish and the mean temperature. Additional seasonal variations in the length-weight relationship and condition factor were observed.

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CHAPTER 1

INTRODUCTION

The southeastern Bering Sea draws attention because of its high biological productivity. It is here that one of the most productive fisheries in the world is located. Because of its abundance and importance in food webs, the walleye pollock (*Theragra chalcogramma* [Pallas]) has been used as an example for studies of mass and energy transfer in the Bering Sea ecosystem. It is recognized that a knowledge of growth rates and growth increments for walleye pollock is essential for formulating models of energy flow in the pollock associated system (Nishiyama, 1979).

As poikilothermal animals, the body temperature of fishes is regulated by water temperature. Changes in the metabolic rates and distribution patterns of fishes are closely related to changes in the temperature of their surroundings (Nikolsky, 1963). However, the extent of the effects of temperature on fishes depends on their physiological condition, state of nourishment, and maturity (Laevastu and Hela, 1970).

Marine fishes have been shown to perceive small temperature changes (Fry and Hochachka, 1970). For example, the whiting (*Gadus merlangus* [L.]) can sense a temperature change as small as 0.03°C (Bull, 1936). If walleye pollock are capable of perceiving such small temperature changes, they may select those habitats where suitable temperature ranges bring better growth and survival, depending on their physiological status. The present study was initiated to investigate the relationships between water temperature and distribution and growth of walleye pollock in the southeastern Bering Sea.

A Biological Review of Walleye Pollock

The walleye pollock is the most abundant fish and constitutes the largest fishery resource in the Bering Sea. Between 1970 and 1978 the average biomass was estimated at about six and one-half million metric tons (Bakkala *et al.*, 1979). Catch statistics indicate that the yearly harvest of walleye pollock is approximately one million metric tons, or about 80% of the total catch of ground fish in this area (Forrester, 1981). Besides being used by men, walleye pollock are also used by many marine mammals (Harry and Hartley, 1981), sea birds (Hunt *et al.*, 1981) and other fishes (Smith, 1981).

The population structure of walleye pollock in the Bering Sea has been studied by Maeda (1972), Serobaba (1978), and Grant and Utter (1980). It was concluded that several stocks exist and yet it is difficult to separate them due to their intermingling during seasonal migrations. Nevertheless, studies of catch patterns indicate that the walleye pollock caught southeast of the Pribilof Islands in the eastern Bering Sea is a unit stock (Maeda, 1972). The present study is focused on this stock.

In response to seasonal changes in water temperature, walleye pollock show a general on- and off-shelf movement in the southeastern Bering Sea. Maeda (1972) defined the migration as: 1) a spawning migration from March to May; 2) a feeding migration from June to September; and 3) an overwintering migration from October to February. In the spawning season the fish are north of Unimak Island and then move onto the shelf north of the Pribilof Islands in the feeding season. For the overwintering migration, they move down to the continental slope and to the shelf edge south of the Pribilof Islands. Although this general migration pattern is consistent from year to year, there are differences. For example, walleye pollock were abundant in the inner shelf in the relatively warm years of 1965-1970, but in the cold years of 1971-1975, they were only found in abundance on the outer shelf (Smith *et al.*, 1976). Since walleye pollock are distributed near the bottom over the continental shelf, the differences were considered to be related to the yearly fluctuations in bottom temperatures. Thus, bottom water temperature is used in this study.

The size distributions of walleye pollock also varied from year to year. Maeda (1972) found that the average size of walleye pollock sampled in 1968 (June-September) decreased seaward. By contrast, the average length of walleye pollock increased seaward in 1975 (August-October) (Kaimmer *et al.*, 1976) and in 1976 (April-June) (Bakkala and Smith, 1978). The discrepancy has not yet been fully explained, but it is presumed that the distribution pattern of walleye pollock varies with fish size in conjunction with sexual maturity.

The growth of walleye pollock has been studied (Yamaguchi and Takahashi, 1972; Chang, 1974). A pollock reaches a fork length about

17 cm by age 1; and from age 1 to 4, it grows an average of 8 cm per year. Beyond age 4, growth rate is much reduced. However no studies have beeen done examining the yearly or seasonal variations and relating them to environmental factors. In the present study the weight growth of the age 2-4 fishes are studied in relation to water temperature, because they are the main component in the fishery and because they exhibit a relatively rapid growth. Additionally, their length-weight relationship and condition factor are also examined.

A Hydrographic Review of the Southeastern Bering Sea

Due to its various origins, the water in the southeastern Bering Sea can be divided into three categories: oceanic water, shelf water and coastal water (Takenouti and Ohtani, 1974). The saltier and warmer oceanic water is derived from the Alaska Stream and the Bering Sea Basin. The coastal water is dominated by less salty and colder water, resulting from both ice melting and from fresh water runoff near the coast. The shelf water is equilibrated, showing properties intermediate between the oceanic and coastal water masses. Because the net flow is very slow over the shelf (Kinder and Schumacher, 1981), only two energy sources, wind and tidal motion, are able to affect the hydrographic structure significantly (Coachman and Charnell, 1979).

The Bering Sea is mainly influenced by the subarctic climate. As a result of the seasonal fluctuation, wind energy causes mixing from the surface to 10-20 m in spring and summer, and to 50-60 m in winter

(Coachman and Charnell, 1979). The effective upward penetration distance of turbulent energy generated by tidal shear appears to be 30-50 m (Coachman and Charnell, 1979). Hence, having been mixed by wind and tidal stirring and by thermocline convection driven by surface cooling and freezing in winter, the winter turnover reaches 100-200 m, and bottom temperature may drop below -1.0°C in cold years (Takenouti and Ohtani, 1974). In summer, seaward from the 50 m isobath, the tidal energy is insufficient to overcome the surface buoyancy, and a thin pycnocline is formed at 20-25 m. The bottom temperature remains between -1°C and 4°C, conditioned by the severity of previous winter and storms which mix the water column. Shoreward of the 50 m isobath, tidal and wind mixing overlap, and the bottom temperature can reach 10°C.

The effects of yearly climatic fluctuations on the sea surface temperature have been described (Niebauer, 1980). It is speculated that the bottom water temperature is similarly influenced. Based on the data collected by the International Pacific Halibut Commission (IPHC), Bakkala (1979) calculated the mean bottom water temperature along the Alaska Peninsula from 1966 to 1978, and showed yearly fluctuations. Currently, no detailed study is being conducted on the annual bottom water temperature fluctuations in the southeastern Bering Sea.

Another major environmental feature of the Bering Sea is the formation of ice pack which covers the continental shelf in the eastern and northern sections during late winter and spring. The ice edge begins to intrude into the northern Bering Sea in November, and reaches its maximum southern extension in late March. At its most southward extent the ice sometimes covers the continental shelf to the Pribilof Islands. In April and May the ice edge begins to retreat and by July the Bering Sea is free of ice. The area of the outer shelf between the Pribilof Islands and Unimak Island is generally ice free throughout the year because of the intrusion of warmer Pacific Ocean water (Favorite, 1974). This provides a wintering habitat and spawning ground for walleye pollock and other commercially important fish species.

CHAPTER 2

MATERIALS AND METHODS

Study Area and Data Sources

The study area is located north of the Unimak Pass and southeast of the Pribilof Islands, between latitude 54°30'N and 57°30'N and longitude 160°W and 170°W (Fig. 1). This area is the main habitat of the walleye pollock population in the southeastern Bering Sea. Extensive data have also been collected in this area. About 80% of the study area is on the continental shelf and the remaining area is characterized by slope and deep water areas (Fig. 1).

Analyses of bottom water temperatures and biological data were made for the years 1976-1980. Temperature data were from various oceanographic data bases and cruise reports, including those from the University of Alaska, Processes and Resources of the Bering Sea Shelf (PROBES: a research project funded by the National Science Foundation), National Marine Fisheries Service (NMFS), International Pacific Halibut Commission (IPHC), Hokkaido University (Japan) and the Far Seas Fisheries Research Laboratory (Japan). Biological data were from three data bases of the Northwest and Alaska Fisheries Center (NWAFC, NMFS): the baseline survey program, the U.S. observers' reports and the commercial catch statistics.

The baseline survey program contains both temperature and biological data collected over the five-year period from a total of 432 sampling stations, whereas the observers' reports included only biological information from 556 sampling stations (Table 1). The

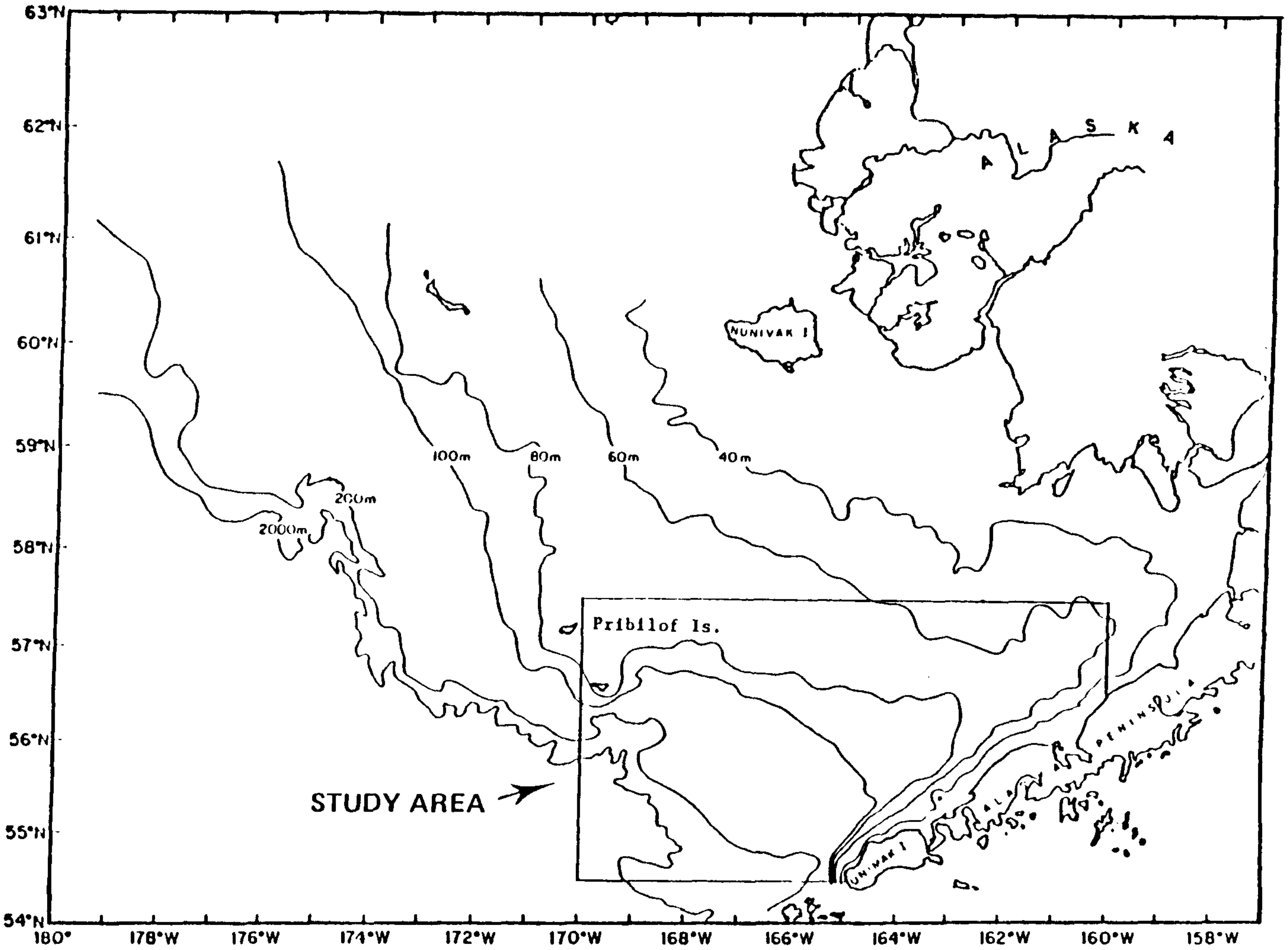

Figure 1. Bathymetry of the eastern Bering Sea and study area. Depth contours in meters.

Table 1. Number of stations sampled by the baseline survey program (S) and the U.S. observers' reports (O), 1976-1980.

Month	1976		1977		1978		1979		1980	
	S	O	S	O	S	O	S	O	S	O
Jan	0	0	0	0	0	0	0	14	0	6
Feb	0	0	0	0	0	0	0	0	0	3
Mar	0	1	0	0	0	0	0	3	0	1
Apr	11	0	0	1	0	4	0	0	0	15
May	24	11	0	0	0	0	44	3	63	10
Jun	41	16	10	5	0	53	95	16	33	3
Jul	12	14	9	27	0	32	56	23	7	21
Aug	0	0	0	19	0	53	27	20	0	2
Sep	0	4	0	12	0	38	0	28	0	11
Oct	0	5	0	14	0	22	0	22	0	0
Nov	0	0	0	10	0	3	0	10	0	0
Dec	0	0	0	0	0	0	0	1	0	0

baseline survey data were used in the analysis of the temperature effects on the seasonal distribution of walleye pollock. Because surveys were not conducted in winter, no data were available to describe the wintering distribution of walleye pollock. The age composition, mean length and weight, growth rate, length-weight relationship and condition factors were determined from data contained in observers' reports which were generally collected throughout each year. The commercial catch statistics provide catch and effort statistics on the walleye pollock fishery. The yearly landings and the catch per unit effort were determined from this data source.

Bottom Water Temperatures

Bottom water temperatures were contoured at 0.5°C intervals by means of the Surface II Graphic System (Sampson, 1978). However, at stations where the depth was more than 200 m, the water temperature at 200 m was used. The sea bottom area covered by water of each one-degree interval was measured and given in percentage to the study area. This is designated "temperature area" in this study.

Catch Data

Catch and fishing effort (the duration of fishing in hours) targeted on walleye pollock were given in a statistical block base. Each block is an area of one-half degree of latitude by one degree of longitude. In this study, catch-effort records of all the fishing vessels were used for a catch per unit effort (CPUE) calculation. The CPUE of walleye pollock in this study area was calculated from:

$$\text{CPUE} = \frac{\Sigma(C_i/E_i)}{\Sigma i} \qquad (1)$$

where C_i and E_i are the catch (metric tons) and fishing effort (hours), respectively, in the statistical block i, and CPUE is metric tons/hour.

Length-Weight Relationships

Length-weight relationship was determined from the allometric growth equation (Ricker, 1975):

$$W = aL^b \quad \text{or} \quad \log W = \log a + b \log L \qquad (2)$$

where W is wet weight of fish in grams, L is fork length in centimeters, and a (initial growth coefficeint) and b (relative growth coefficient) are constants determined by the least square method. Due to the lack of information on maturity in the observers' reports, the length-weight relationship was not established for fish captured during spawning season. The relationship for fish captured during feeding and wintering seasons were determined by combining data collected, respectively, from June to September, and October to December. Data were not sufficient to establish the relationship for 1976 and 1980 wintering seasons. The length-weight relationships of respective age-sex groups were also determined. A covariance analysis was used to compare the differences in the relationships between seasons and sexes.

Condition Factors

The condition factor K of a fish was calculated following Le Cren (1951):

$$K = W/aL^{b} \tag{3}$$

where W is wet weight (g) of fish, L is fork length (cm), a and b are the initial and relative growth coefficients of a given age-sex pollock. Yearly condition factors are calculated by combining data collected between June and September.

Fish Density

Assuming that fish are distributed uniformly over a given area and that there is no difference in catch due to the height of the nets employed, the fish density was calculated as the number of fish per 10^4 square meters, by using the following equation:

$$\text{Density} = \frac{N}{W \times D} \tag{4}$$

where N is the number of fish caught in a trawl, W is the mean effective path width of fishing gear, and D is the fishing distance. Unsatisfactory trawls, involving for example, nets hung up or ripped during trawling, were excluded from this calculation.

Growth

Maeda (1972) studied the feeding habits of walleye pollock and concluded that energy is accumulated mainly during the period from June to September. After transforming the body weights to logarithms, linear growth curves were established against the Julian Day, using the least squares method. Based on these equations, weight increments in the feeding season (June 1-September 30) and in the transitional season (spawning and wintering seasons, October 1-May 31), as well as annual weight increment (from age 2 to age 3, from age 3 to age 4) were calculated. Growth from June 1 (t_o) to September 30 (t_1) is expressed in:

1. Weight increment: $\Delta W = W_{t_1} - W_{t_o}$
2. Relative growth rate: $\Delta W/W_{t_o}$
3. Daily weight increment (growth rate): $\Delta W/121$

Where W_{t_o} and W_{t_1} are the fish weights at June 1 and September 30, respectively, and 121 is the length (days) of the feeding season.

CHAPTER 3

RESULTS

Bottom Water Temperatures

To investigate yearly bottom water temperature variations from 1976 to 1980, the isothermal distribution, "temperature area" and mean temperature in June of each year are determined and compared.

The bottom temperature contours in the study area are plotted in Figures 2 and 3. In 1976, the mid-shelf region (50-100 m in depth) was primarily covered by cold water below 0°C (Fig. 2-A). The -1°C isotherm reached as far south as 56°15'N. Warm water (3-3.5°C) was found only in the vicinity of Unimak Island, and the 3°C isotherm was found seaward of the 200 m isobath. A sharp temperature gradient was found along the 80-100 m isobaths.

The temperature structures in 1977, 1978 and 1980 were similar (Figs. 2-B, 2-C and 3-B). No cold waters below 1°C were found in the study area. The outer shelf (100-200 m) and slope area (> 200 m) were dominated by the 3.5-4°C warm water. The 3.5°C isotherm ran parallel with the 80-100 m isobaths. Temperatures gradually decreased shoreward and no distinguishable temperature gradient was noticeable on the shelf.

In 1979, the waters in the study area were warmer than in other years, with waters as warm as 4-5.5°C occurring widely on the mid-shelf and along the north side of the Alaska Peninsula (Fig. 3-A). Temperatures of the slope area were above 4°C, but there was a pocket of 3.5°C water covering a large area on the mid-shelf. In contrast

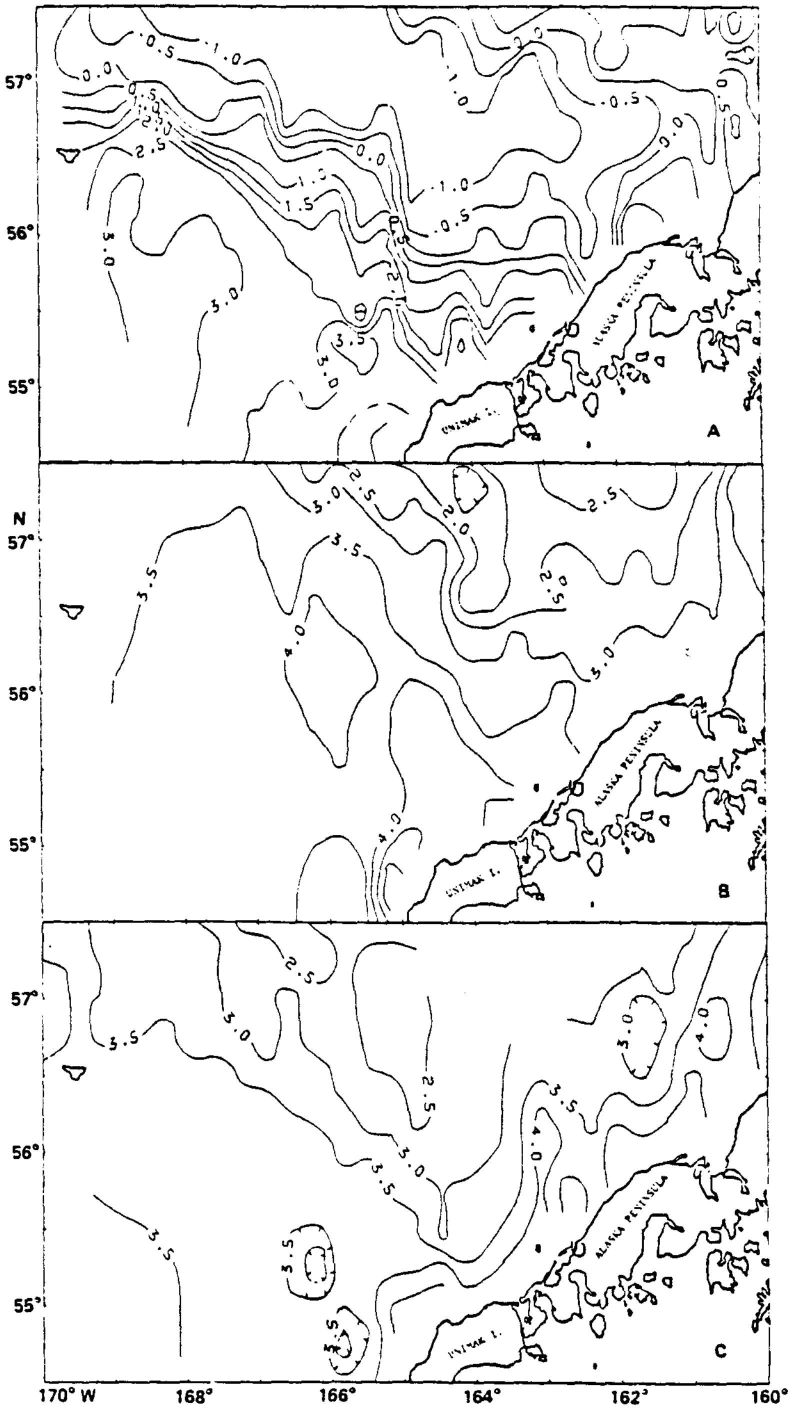

Figure 2. Bottom temperature (°C) contours in the southeastern Bering Sea during June 1976 (A), 1977 (B), and 1978 (C).

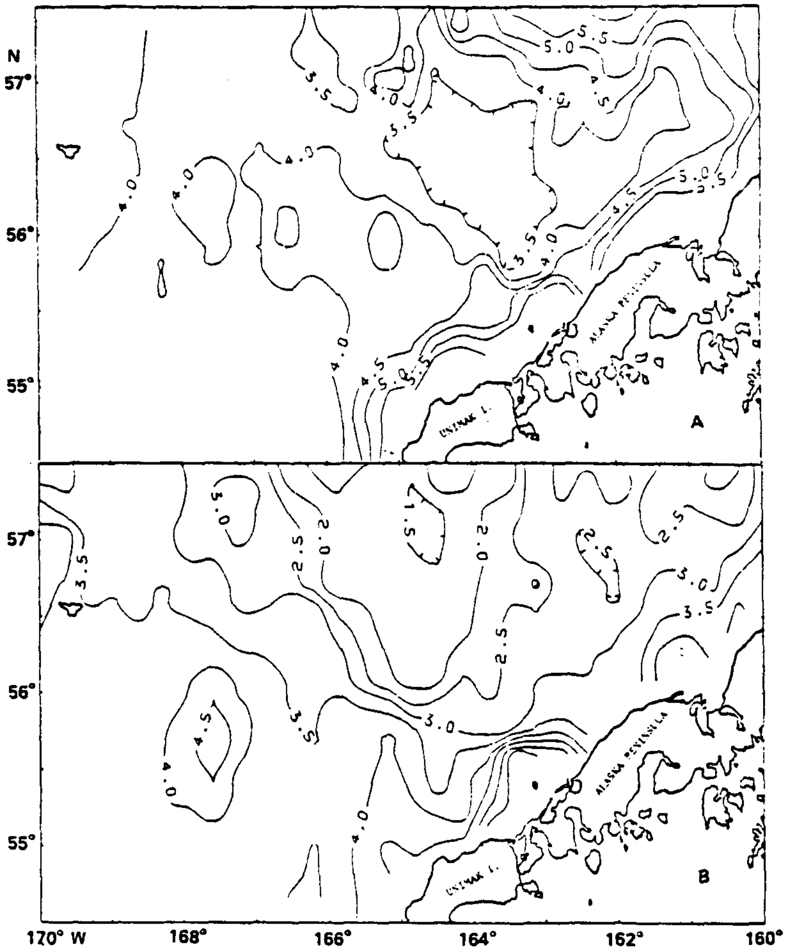

Figure 3. Bottom temperature (°C) contours in the southeastern Bering Sea during June 1979 (A) and 1980 (B).

to other years, a temperature gradient was evident along the Alaska Peninsula instead of along the slope, and no waters below 3°C existed.

The "temeprature area" demonstrates more clearly the characteristic temperature conditions for 1976 to 1980 (Table 2). In 1976 waters of -1.5°C to 0.9°C covered 60% of the study area. From 1977 to 1980, the cold waters were not present and the study area was covered by relative warm waters. In 1977 and 1978, 97% of the study area was covered by waters ranging from 2°C to 4.9°C. In 1979, 86% of the study area was covered by waters of 3-4.9°C. In 1980, 85% of the study area was in the temperature range 2-4.9°C. It is noted that the predominant temperature was 3-3.9°C throughout these years, except during 1976.

After eliminating high temperatures recorded near the coast (< 50 m), mean temperatures were calculated and presented in Table 3. These mean temperatures ranged from a low of 0.92°C in 1976 to a high of 4.15°C in 1979. The mean temperatures were similar for 1977, 1978 and 1980. Student's t-tests indicate that the mean temperatures of the three years were not significantly different ($P < 0.05$) between any two years compared, except between 1977 and 1980 ($t = 1.153$, $0.10 < P < 0.20$).

These three temperature features (isothermal distribution, "temperature area" and mean temperature) clearly illustrate that bottom temperature fluctuated from year to year. It is concluded that the coldest year was 1976 and the warmest year was 1979, whereas the remaining years had average temperatures.

Table 2. "Temperature area" values in the southeastern Bering Sea, expressed as a percent of the total study area covered by various water temperature ranges for the month of June, 1976-1980.

Temperature range, °C	Year				
	1976	1977	1978	1979	1980
-1.5 - -1.1	16.8	0	0	0	0
-1.0 - -0.1	32.7	0	0	0	0
0 - 0.9	10.3	0	0	0	0
1 - 1.9	10.0	3.7	2.4	0	14.2
2 - 2.9	19.8	26.7	28.5	0	31.3
3 - 3.9	10.2	56.6	61.1	49.8	43.1
4 - 4.9	0.2	12.5	7.8	36.5	10.1
5 - 6.0	0	0.5	0.2	13.7	1.5
Total	100.0	100.0	100.0	100.0	100.0

Table 3. Bottom water temperature range (°C) and mean temperature ± one standard deviation (SD) in June for 1976 to 1980 in the southeastern Bering Sea.

Year	Range	Mean ± SD (*N*)
1976	-1.5 - 4.3	0.92 ± 1.65 (183)
1977	1.0 - 5.5	3.26 ± 0.86 (94)
1978	2.0 - 5.5	3.46 ± 0.64 (170)
1979	3.2 - 6.0	4.15 ± 0.64 (206)
1980	1.3 - 5.8	3.11 ± 1.06 (149)

Relative Abundance

To compare the relative abundance of the walleye pollock biomass from 1976 to 1980, the catch and CPUE were calculated. The yearly landings varied from 3.20×10^5 mt to 4.78×10^5 mt (Appendix Table A-1). The landing decreased 33% from 1976 to 1977, but then gradually recovered toward 1980. Although there was fishing throughout the year, approximately 85% of the total landings were harvested in the five months from June to October (Appendix Table A-1 and Fig. 4-A), which corresponds to the feeding season. These catches are also reflected in the high CPUE for these months (Appendix Table A-2 and Fig. 4-B). The mean CPUE for these months was 9.54, 6.71, 6.64, 6.08 and 6.03 (mt/hr) from 1976 to 1980. Note that the CPUE was also exceptionally high in 1976 but steadily declined in the following years.

Age Composition

The walleye pollock catch consisted of 16 age groups from 1976 to 1980 (Appendix Table B-1). Despite yearly fluctuations (Fig. 5), there was three dominant age groups: age 4 in 1976, age 2 in 1979 and age 3 in 1980. These reflect the strong brood years of 1972 and 1977.

Numerically, fishes of age 2-4 dominate the catch, representing 57% of those caught in the five years under consideration (Appendix Table B-1). Fishes of age 5-7 were the second largest group, comprising 27% of the catch. Fishes above age 8 constituted only 16%

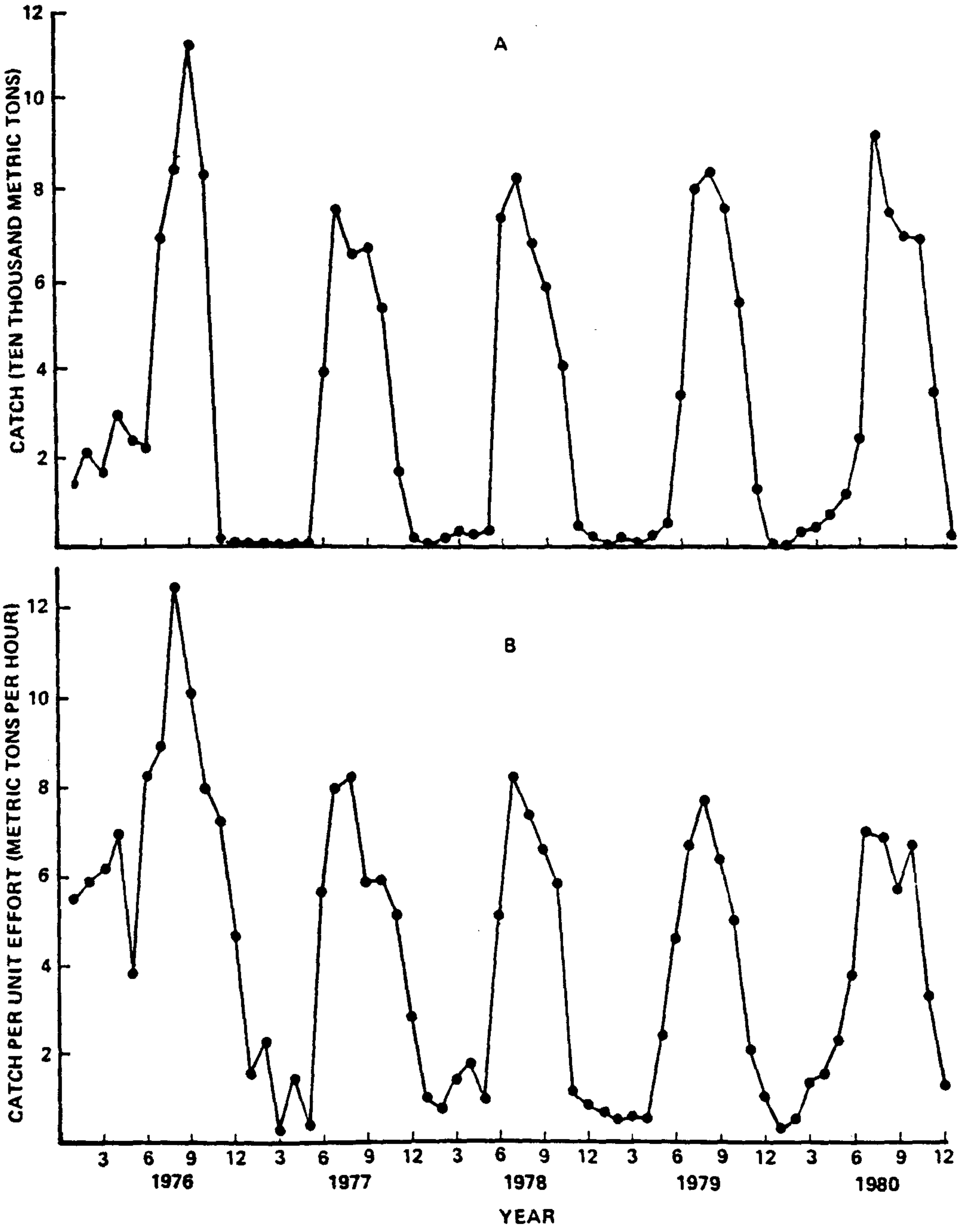

Figure 4. Monthly catch (A) and catch per unit effort (B) of walleye pollock in the southeastern Bering Sea, 1976-1980.

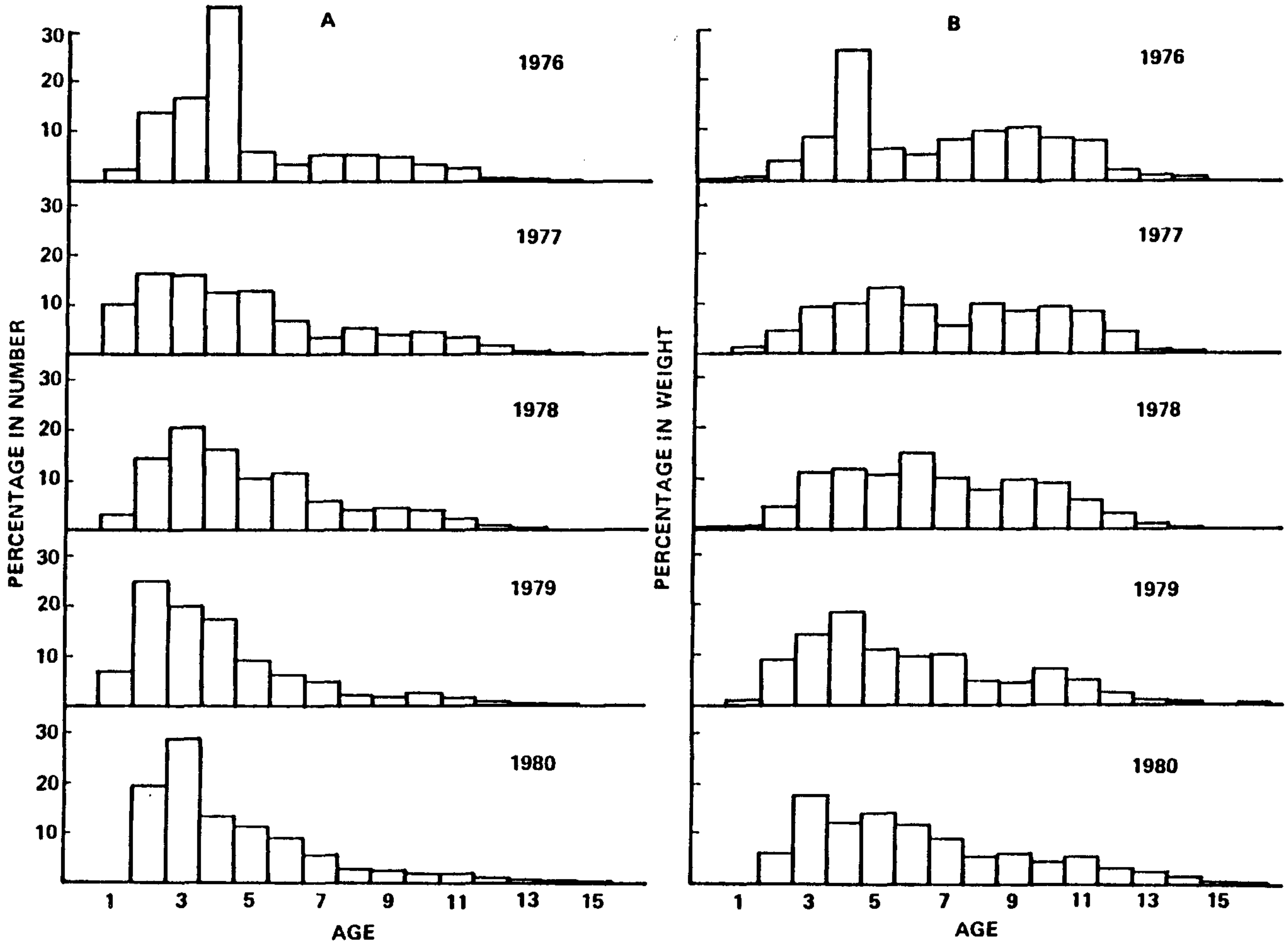

Figure 5. Age composition of walleye pollock as percent of total number (A) and total weight (B) in commercial catch for the southeastern Bering Sea, 1976-1980.

of the catch. However, in terms of biomass, the older age groups represented a substantial proportion of the catch, and fishes above age 8 constituted 36% of the catch. In fact, the age 8-12 fishes decreased in weight from 40% in 1976 to 24% in 1980 (Appendix Table B-1, Fig. 5-B), corresponding to the decrease in number from 17% in 1976 to 10% in 1980 (Fig. 5-A). It appears that older fish have decreased in the commercial catch since 1976, and it was particularly noticeable in 1979 and 1980.

The mean fork length and wet weight of fishes for ages 1 to 7 captured in the feeding season are summarized in Table B-2 (Appendix). The length of fish aged 1 to 7 increased from 1976 to 1980 (Fig. 6-A), except that fish aged 5 and 6 were relatively constant in length. Similarly the weight of the fishes aged 2-7 increased from 1976 to 1980 (Fig. 6-B), except for fish aged 4 in 1978 and age 5-7 in 1979. The results suggest that in general the fish experiencing cold years (1971-1976) were slimmer than the fish experiencing fewer cold years.

Length-Weight Relationships

The coefficients of the length-weight relationships of walleye pollock in the feeding season and in the wintering season from 1976 to 1980 are summarized in Tables 4 and 5, respectively. The covariance analyses indicate that except for age 3 females, the relative growth coefficient b is significantly different ($P < 0.05$) between the feeding season and wintering season in 1979 (Table 6). Since the large value b implies a greater increase of body weight in proportion

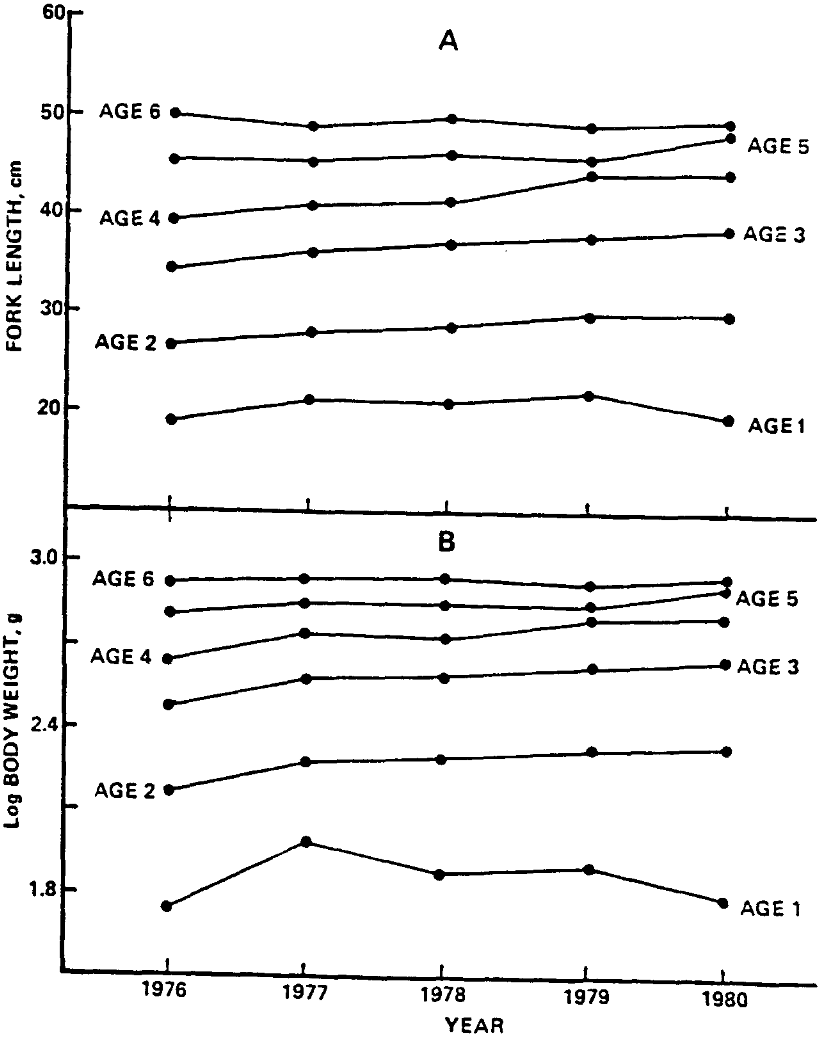

Figure 6. Mean fork length (A) and wet weight (B) for walleye pollock aged 1 to 7 in the southeastern Bering Sea, 1976-1980.

Table 4. Coefficients of the length-weight relationships for walleye pollock aged 2 to 4 captured during the feeding season (June-September), 1976-1980. Least squares fit the equations $W = aL^b$ (W = wet weight; L = fork length). N = sample size; r^2 = the coefficient of determination.

Year	Age	Sex	N	Range (cm)	Mean Length (cm)	Mean Weight (g)	$a \cdot 10^{-1}$	b	r^2
1976	2	F	166	20-35	26.3	149	0.1429	2.8131	0.845
1977	2	F	167	21-37	28.0	193	1.9018	2.0671	0.592
1978	2	F	354	17-40	28.5	208	0.0595	3.1054	0.855
1979	2	F	232	21-39	30.0	221	0.4235	2.5048	0.769
1980	2	F	84	25-37	30.3	228	0.1418	2.8299	0.826
1976	3	F	197	26-40	34.3	299	0.1409	2.8137	0.775
1977	3	F	154	27-45	36.2	392	0.2863	2.6469	0.798
1978	3	F	474	28-47	37.3	416	0.1902	2.7544	0.795
1979	3	F	218	30-47	38.0	441	0.0687	3.0352	0.805
1980	3	F	97	33-46	39.2	473	0.6479	2.4225	0.847
1976	4	F	387	32-49	39.6	449	0.4341	2.5096	0.803
1977	4	F	126	32-49	41.5	583	1.0739	2.3043	0.859
1978	4	F	420	31-51	41.6	559	0.1608	2.7984	0.840
1979	4	F	162	35-55	44.8	672	0.4057	2.5483	0.804
1980	4	F	20	40-50	45.8	700	3.9162	1.9566	0.611
1976	2	M	93	21-36	27.3	162	0.1124	2.8829	0.877
1977	2	M	162	22-37	28.1	201	0.5866	2.4310	0.805
1978	2	M	334	20-40	28.8	215	0.0690	3.0633	0.841
1979	2	M	245	18-39	30.0	226	0.3022	2.6104	0.814
1980	2	M	87	24-36	30.1	223	0.2143	2.7100	0.850

Table 4. Continued.

Year	Age	Sex	N	Range (cm)	Mean		$a \cdot 10^{-1}$	b	r^2
					Length (cm)	Weight (g)			
1976	3	M	158	28-41	34.3	300	0.1300	2.8374	0.792
1977	3	M	162	29-45	36.0	387	0.3217	2.6163	0.839
1978	3	M	495	25-45	36.7	391	0.2334	2.6944	0.805
1979	3	M	197	31-48	37.6	430	0.3176	2.6151	0.728
1980	3	M	87	30-46	38.4	448	0.3668	2.5756	0.880
1976	4	M	350	31-47	38.9	434	0.7909	2.3486	0.764
1977	4	M	122	32-49	40.3	541	0.5957	2.4610	0.856
1978	4	M	357	31-52	41.1	538	0.2926	2.6371	0.844
1979	4	M	160	33-54	43.4	620	0.4756	2.5076	0.807
1980	4	M	25	38-50	43.4	623	1.6340	2.1837	0.667

Table 5. Coefficients of the length-weight relationships for walleye pollock aged 2 to 4 captured during the wintering season (October-December), 1976-1980. Least squares fit the equation W = aL^b (W = wet weight; L = fork length). N = sample size; r^2 = the coefficient of determination.

Year	Age	Sex	N	Range (cm)	Mean Length (cm)	Mean Weight (g)	$a \cdot 10^{-1}$	b	r^2
1977	2	F	12	25-33	29.2	204	0.3702	2.5474	0.767
1978	2	F	88	18-39	29.3	221	0.0385	3.2160	0.929
1979	2	F	97	24-40	32.7	265	0.0176	3.4058	0.899
1977	3	F	51	29-43	37.4	441	0.1154	2.9061	0.867
1978	3	F	92	28-45	36.2	394	0.1207	2.8865	0.903
1979	3	F	53	32-47	42.2	495	0.0196	3.3595	0.798
1977	4	F	28	36-49	41.2	587	0.6405	2.4493	0.880
1978	4	F	63	33-49	41.3	560	0.2678	2.6669	0.839
1979	4	F	64	37-55	46.7	763	0.0744	2.9962	0.746
1977	2	M	60	20-35	29.0	208	0.0704	3.0437	0.921
1978	2	M	49	22-37	30.8	241	0.0222	3.3664	0.922
1979	2	M	70	24-39	32.8	266	0.0271	3.2808	0.927
1977	3	M	21	31-42	38.2	469	0.7938	2.3812	0.789
1978	3	M	97	28-46	36.2	387	0.1572	2.8079	0.892
1979	3	M	49	29-48	40.3	505	0.0479	3.1215	0.844
1977	4	M	33	35-49	40.5	550	0.6164	2.4514	0.736
1978	4	M	64	32-50	40.6	549	0.1291	2.8689	0.917
1979	4	M	50	37-51	44.5	651	0.0144	3.4251	0.839

Table 6. Analysis of covariance for the difference on the length-weight relationships ($W = aL^b$) between the feeding season (June-September) and the wintering season (October-December) for 1977 to 1979. df = degree of freedom; F = the variance ratio; P = the probability of wrongly rejecting the null hypothesis.

Year	Age	Sex	Slope			Intercept		
			df	F	P	df	F	P
1977	2	F	175	0.58	0.449	176	0.11	0.739
1978	2	F	438	0.76	0.383	439	13.07	0.000***
1979	2	F	353	28.98	0.000***	354	5.95	0.015*
1977	3	F	201	1.46	0.228	202	2.03	0.156
1978	3	F	562	1.06	0.304	563	2.35	0.125
1979	3	F	267	1.51	0.220	268	7.85	0.005**
1977	4	F	150	0.52	0.471	151	1.46	0.228
1978	4	F	479	0.63	0.430	480	1.98	0.161
1979	4	F	222	4.00	0.047*	223	1.16	0.282
1977	2	M	218	14.88	0.000***	219	11.87	0.001**
1978	2	M	379	2.79	0.096	380	19.76	0.000***
1979	2	M	311	15.00	0.000***	312	17.67	0.000***
1977	3	M	179	0.49	0.484	180	4.46	0.036*
1978	3	M	588	0.82	0.367	589	0.94	0.332
1979	3	M	242	4.03	0.046*	243	1.58	0.210
1977	4	M	151	0.00	0.967	152	0.00	0.952
1978	4	M	417	2.54	0.112	418	9.27	0.003**
1979	4	M	206	15.20	0.000***	207	1.71	0.192

* significance level $0.01 < P < 0.05$
** significance level $0.001 < P < 0.01$
*** significance level $P < 0.001$

to the length, the result suggests that in the warm year (1979) the growth took place over an extended period even after the feeding season. The length-weight relationships for pollock of each age-sex group are summarized in Table 7. The relative growth coefficient is not statistically different between sexes ($P > 0.06$) (Table 8).

Condition Factors

The condition factor has been considered as an indicator of the nutritional status of fish (Weatherley, 1972). For the months data were available, monthly means of the condition factor were calculated for each age-sex group from years 1976 to 1980. The monthly means are plotted in Figure 7, which indicates seasonal changes in the condition factors. The condition factors are low in the wintering season, and high in the feeding season. For example, the condition factor of four-year females (Appendix Table C-3) in 1976 steadily increased from 0.85 in May to 1.07 in September, and then decreased to 0.96 in October. A similar tendency is seen in other age-sex groups, though the pattern of the seasonal change varies from year to year, with large changes in the condition factor observed in the spawning and wintering seasons.

To examine yearly fluctuations, a mean yearly condition factor was calculated for the feeding season. The lowest and highest yearly condition factors were observed in 1976 and 1977 (Appendix Table C-7 and Fig. 8). From 1978 to 1980, the yearly condition factor decreased in age 2 fish, whereas it leveled off in the age 3 and 4 fishes.

Table 7. Coefficients of the length-weight relationships for walleye pollock aged 2 to 4. Least squares fit the equation $W = aL^b$ from data collected from 1976 to 1980 (W = wet weight; L = fork length). N = sample size; r^2 = the coefficient of determination.

Age	Sex	N	$a \cdot 10^{-2}$	b	r^2
2	F	1,350	1.1201	2.8964	0.808
2	M	1,219	1.3830	2.8417	0.835
2	pooled	2,569	1.2158	2.8758	0.820
3	F	1,521	0.6469	3.0468	0.838
3	M	1,441	0.8906	2.9588	0.829
3	pooled	2,962	0.7576	3.0034	0.834
4	F	1,492	1.2850	2.8505	0.835
4	M	1,349	1.7290	2.7726	0.820
4	pooled	2,841	1.4913	2.8115	0.829

Table 8. Analysis of covariance for the difference on the length-weight relationships ($W = aL^b$) between female and male walleye pollock from data collected from 1976 to 1980. *df* = degree of freedom; *F* = the variance ratio; *P* = the probability of wrongly rejecting the null hypothesis.

Age	Slope			Intercept		
	df	*F*	*P*	*df*	*F*	*P*
2	2,564	1.06	0.303	2,565	15.08	0.000*
3	2,958	3.18	0.075	2,959	0.54	0.462
4	2,836	1.97	0.161	2,837	2.70	0.101

* significance level $P < 0.001$

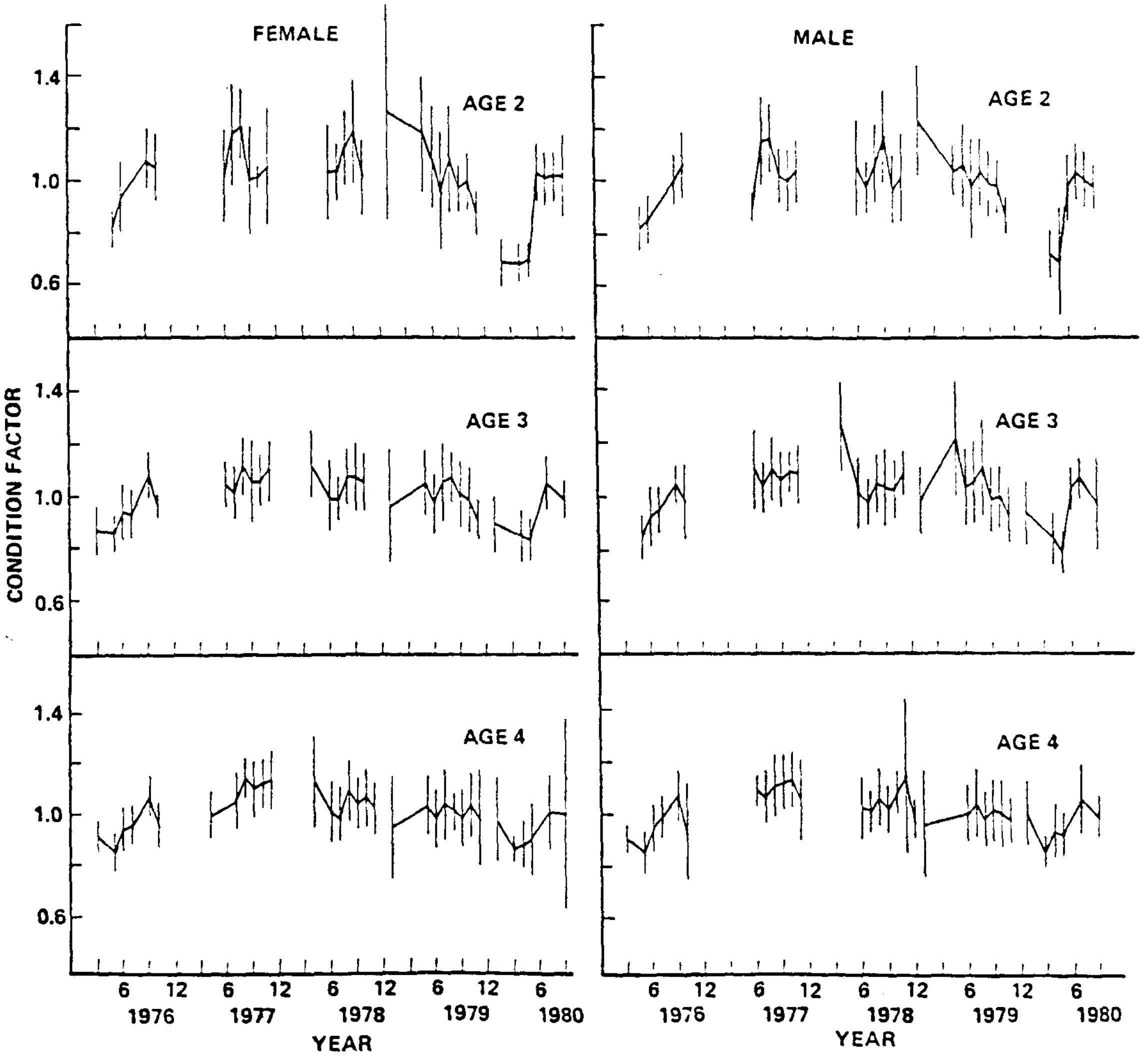

Figure 7. Monthly mean condition factors ± one standard deviation for walleye pollock aged 2 to 4 in the southeastern Bering Sea, 1976-1980.

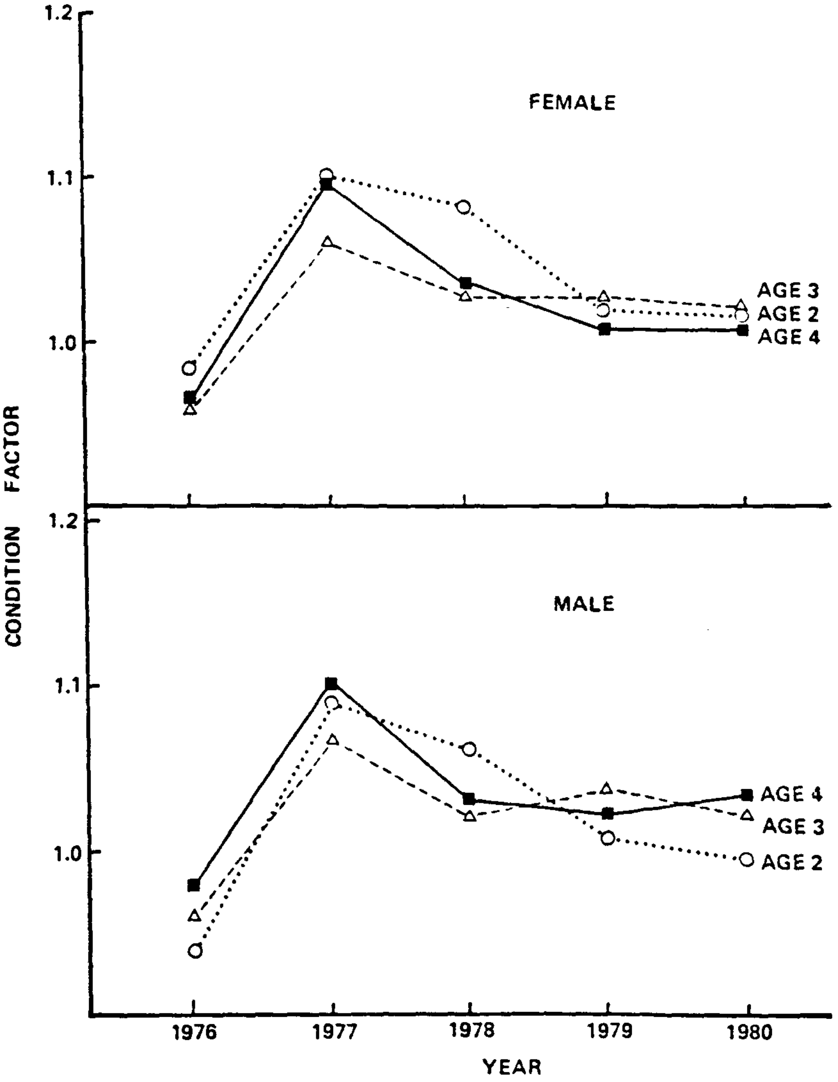

Figure 8. Yearly condition factors for walleye pollock aged 2 to 4 in the southeastern Bering Sea, 1976-1980.

Distribution Patterns

Since maturity information about walleye pollock was not recorded in the survey program, it is difficult to separate walleye pollock as to mature and immature. It is known that most walleye pollock mature at 31-32 cm fork length, though some as small as 24 cm have been found (Serobaba, 1971). Bakkala and Smith (1978) have also shown that 50 percent of the males are mature at 31 cm and that for females 34 cm is a maturation length. In the present study, fishes are seperated into adult (> 31 cm) and young (< 31 cm).

To study adult walleye pollock distribution, I have adopted Maeda's (1972) model of life history where he divided it into three seasons: spawning season (March-May), feeding season (June-September) and overwintering season (October-February). Because the lack of reproduction ability, it is assumed that the young fish reveal only a two-season (feeding and wintering) pattern. Therefore, to study young walleye pollock distribution I define the feeding season from April (the ice pack starts retreating) to September, and the overwintering season as October-March. The distributions of the adult and young fishes are separately studied, and due to insufficient data the distribution pattern of walleye pollock was examined for only spawning and feeding seasons.

1. Adult Walleye Pollock

A. Spawning Season

The distribution of adult walleye pollock in the spawning season is described in relation to the temperature in May for a cold year (1976), a warm year (1979) and an average year (1980).

In 1976, the 2°C isotherm extended from 55°N and 165°W northwest to 57°N and 169°W along the 100 m isobath (Fig. 9-A), and more than one-half of the study area was below 2°C, with warm waters (> 3°C) occurring only on the outer shelf. Eight stations were sampled in the area where temperatures were below 2°C. Only two stations yielded catches with low fish densities: 2.2 and 0.5 $N/10^4m^2$ (Fig. 9-A and Appendix Table D-1). By contrast, the average fish density was 116 $N/10^4m^2$ for sixteen stations sampled where temperatures ranged from 2°C to 3.9°C. High fish densities (> 30 $N/10^4m^2$) were found near the 3°C isotherm at around 56-56 30°N and 170°W; near the 2.5-3°C isotherm at around 55°N and 165-166°W; and near the 2°C isotherm at around 55°30'N and 166°W (Fig. 9-A).

In 1979 the stations occupied were primarily on the outer shelf, where temperatures ranged from 3-4.9°C (Fig. 9-B). The fish were widely distributed at the sampling stations. High fish densities were found at around 54°45'-55°30'N and 164-167°W, and at around 55°45'-56°30'N and 168-169°W. This indicates that the adults aggregate in deep waters when temperatures are mild in the spawning season.

In 1980, the 2°C isotherm appeared in the mid-shelf (Fig. 9-C) between the 80 m and 100 m isobaths. The stations were sampled from

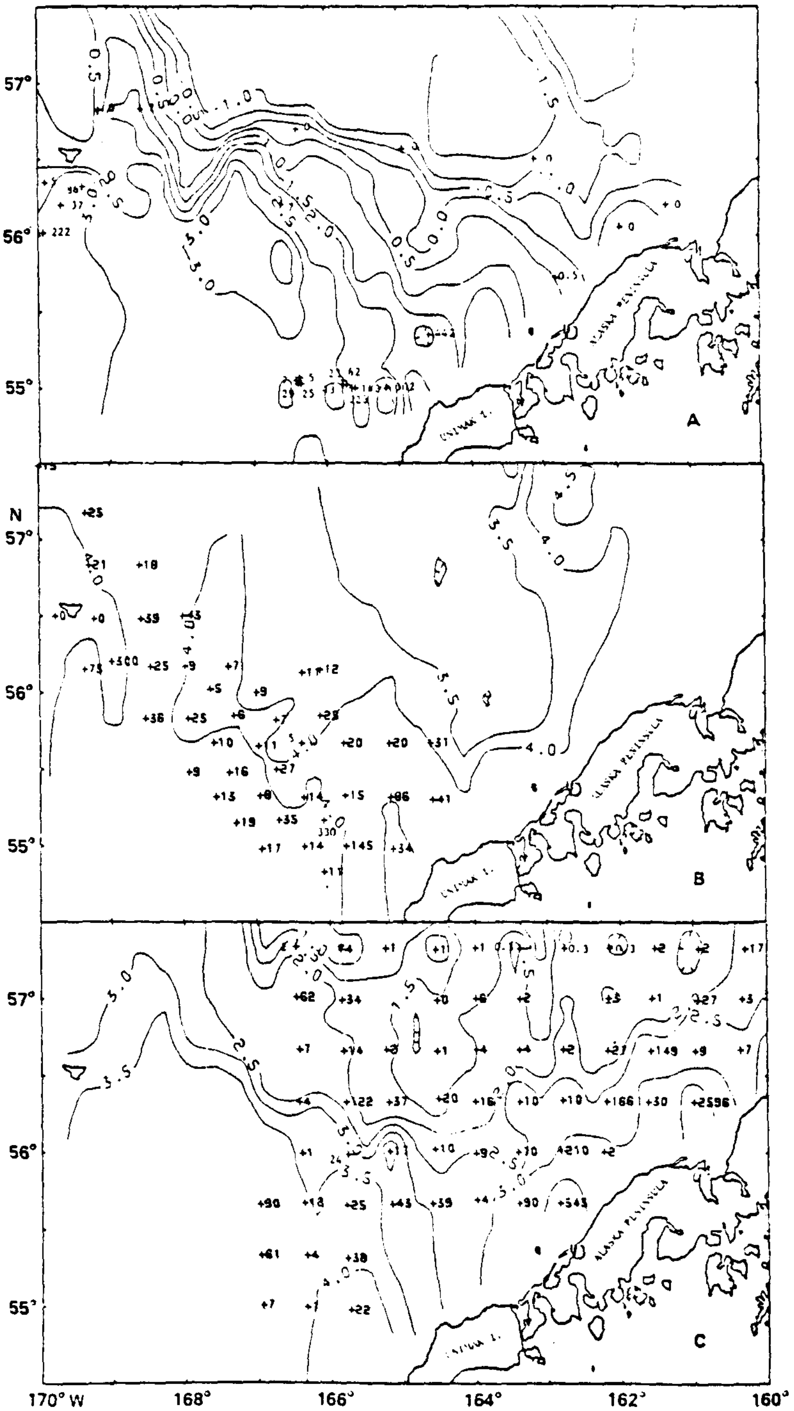

Figure 9. Bottom temperature contours and densities ($N/10^4m^2$) of adult walleye pollock in the southeastern Bering Sea during May 1976 (A), 1979 (B) and 1980 (C).

an area 55-57°30'N and 160-167°W with a temperature range of 0.5-4.4°C. Again fish densities were low where temperatures were below 2°C (Fig. 9-C). The average fish density was 8.7 $N/10^4m^2$ where temperatures ranged from 0°C to 1.9°C, and 104 $N/10^4m^2$ where the temperature was 2-4.4°C (Appendix Table D-1). Note that fish aggregations were found in 3°C water near the Alaska Peninsula, where densities were very low in 1976.

Although sampling stations were not taken in the same general areas in all three years, from the evidence presented it appears that adult walleye pollock are aggregated at areas where temperatures rise above 2°C. Throughout the three years the mean density was high in the 3.5-3.9°C temperature range (Appendix Table D-1).

B. Feeding Season

Figure 10 and Table D-2 (Appendix) represent the temperature-density relationship for adult walleye pollock during the feeding season. In 1976, stations were sampled from the temperature range of -1.5°C to 4.4°C (Fig. 10-A). High fish densities (> 30 $N/10^4m^2$ or $>$ 1.5 in logarithmic form) were found at the 0.5-3.9°C temperature range. In contrast, water temperatures at the stations were above 3°C (Fig. 10-B) in 1979. The highest fish densities were found in the temperature range of 3.5-3.9°C, though the adults were abundant within a wide temperature range of 3-7.4°C. In 1977 and 1980, the temperature range at the stations was intermediate between those of 1976 and 1979, ranging from 2°C to 6.4°C, and more fish were found at 2-4.4°C (Fig. 10-C).

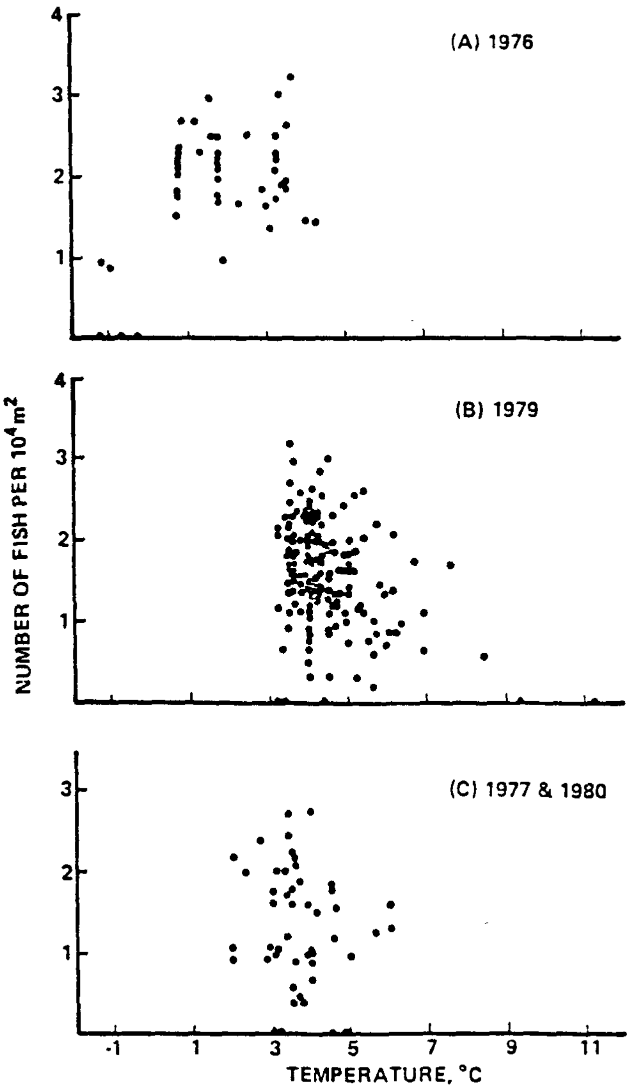

Figure 10. The temperature-density plot of adult walleye pollock in the feeding season (June-September) of 1976 (A), 1979 (B) and 1977 & 1980 (C).

This evidence indicates that adults tend to favor the temperature range of 2-4.4°C, though they were found at a temperature range of -1.2°C to 8.4°C. Note that fish densities are relatively symmetrically distributed in the temperature range 0.5-7.0°C with the mode at about 3.5°C, when the four years data are combined.

The densities of adult walleye pollock in the feeding season are examined for June 1976 and June-August 1979. In June 1976, the fish were concentrated on the outer shelf in warm temperatures (Fig. 11-A), bounded by the 0.5°C isotherm extending from 55°30'N 162°W northwestly to 57°N and 170°W. Only two out of eight stations sampled from the -1.5°C to -0.1°C temperature range resulted in fish caught. The fish densities were 7.6 and 6.4 $N/10^4m^2$ (Appendix Table D-3). In the temperature range of 0.5°C to 4.4°C, the average fish density was 185 $N/10^4m^2$. No stations were within the 0°C and 0.5°C temperature range. The 0-0.5°C water appears to have acted as a boundary for the adult pollock feeding season distribution in 1976.

In June 1979, the stations were sampled over the entire study area where temperatures range from 3.5 to 5.9°C (Fig. 12-A). The fish were widely distributed. In July, stations were sampled on the mid-shelf where temperatures range from 4°C to 5.9°C (Fig. 12-B). Again, the fish were widely distributed. In August, sampling stations were not established over the entire area (Fig. 12-C); however, low fish densities were found at the temperatures above 6°C around 56°30'-57°N and 160-161°W between the 60-80 m isobaths. The fish densities were high at the 12 stations along the 4°C isotherm along the slope.

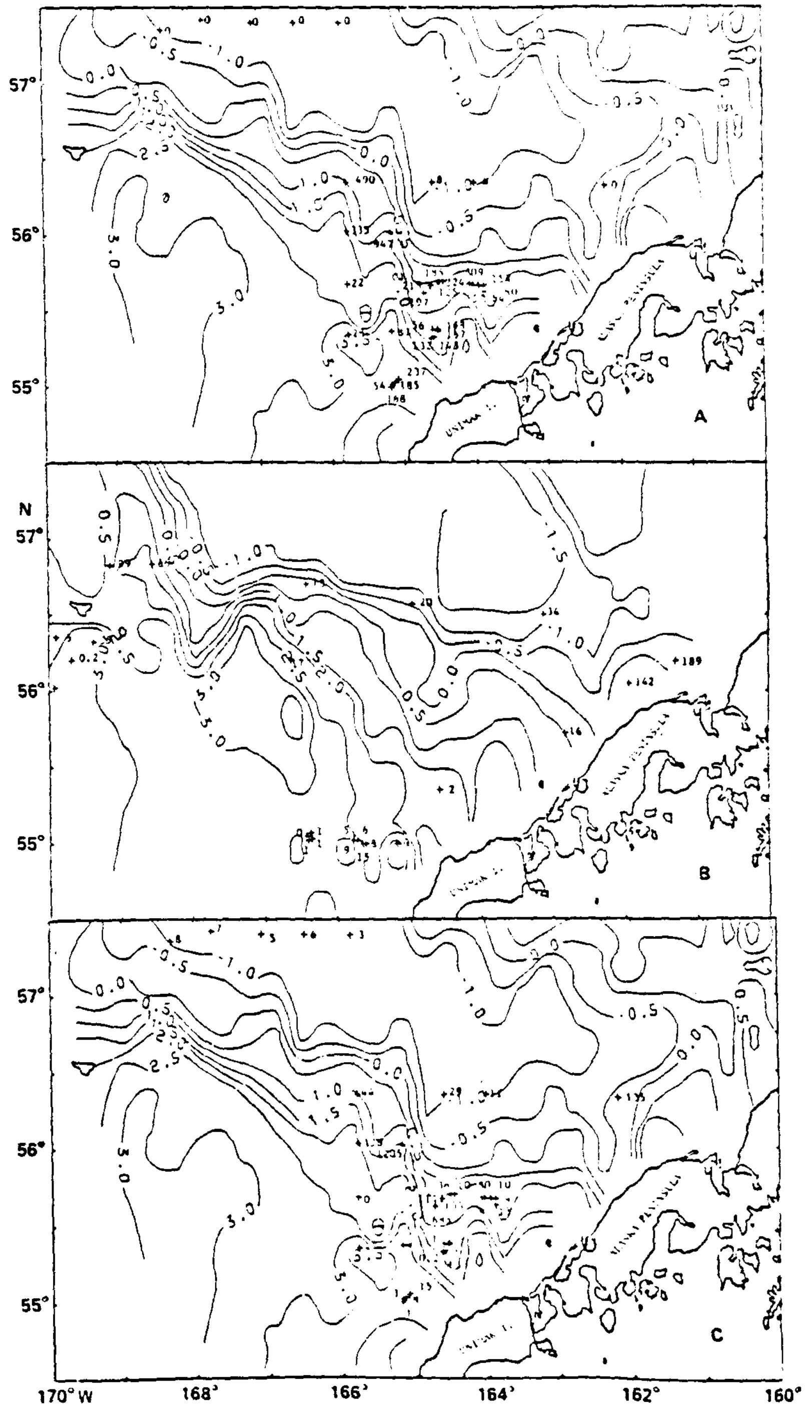

Figure 11. Bottom temperature contours and densities ($N/10^4m^2$) of adult walleye pollock in the southeastern Bering Sea during June 1976 (A), and young walleye pollock during May (B) and June (C) 1976.

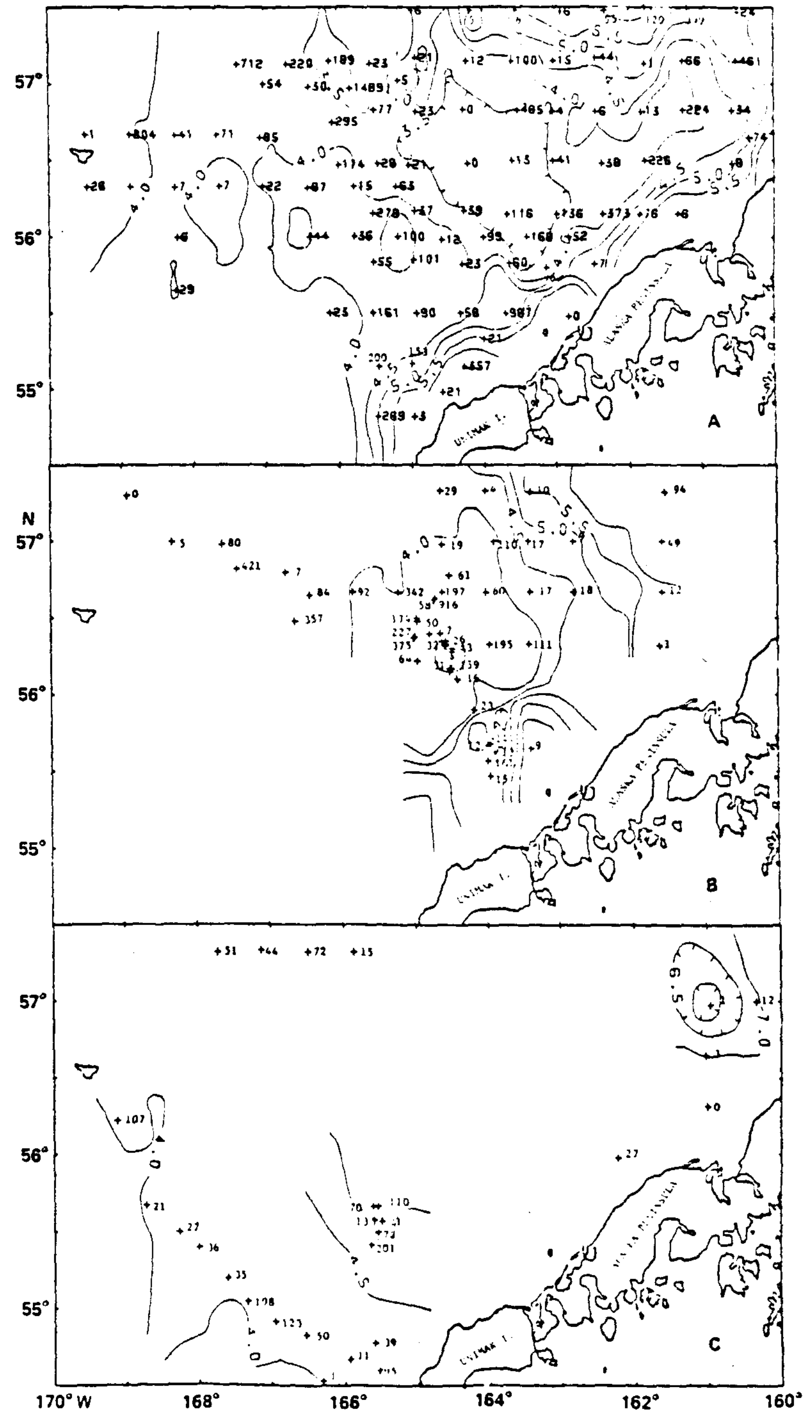

Figure 12. Bottom temperature contours and densities ($N/10^4 m^2$) of adult walleye pollock in the southeastern Bering Sea during June (A), July (B) and August (C) 1979.

In contrast with the 1976 feeding season distributions, adults were widely distributed on the shelf in the temperature range 3.5-5.9°C in 1979. The abundant fish found in the slope area in August indicate that a significant number of adult walleye pollock did not migrate onto the mid-shelf in the feeding season.

2. Young Walleye Pollock

Young walleye pollock were abundant in the temperature range of -0.5°C to 4.4°C in 1976, 3.5-7.9°C in 1979 and 1.5-5.9°C in 1977 and 1980 (Fig. 13 and Appendix Table D-4). The highest temperature where young were encountered was 11.2°C, and the lowest temperature was -1.2°C. This temperature-density relationship is similar to that found for adults (Fig. 10 and Appendix Table D-2), except that relative abundance occurs over a wider temperature range.

In 1976, young walleye pollock were found at stations with temperatures below -0.1°C (Appendix Table D-3, Figs. 11-B and 11-C), temperatures in which adults were not found (Figs. 9-A and 11-A). The difference of adult and young distributions suggest that young pollock can penetrate into cold waters during feeding. In addition, in May the average fish density was 68.1 $N/10^4m^2$ in the temperature range of -1.5°C to 0.4°C, 46.1 $N/10^4m^2$ in 0.5-2.4°C, and 6.3 $N/10^4m^2$ in 2.5-4.4°C (Appendix Table D-3). This may suggest that low temperatures are not unfavorable to the young fish.

Young walleye pollock distribution is shown for May through August 1979 in Figure 14. In May, the fish were widely distributed.

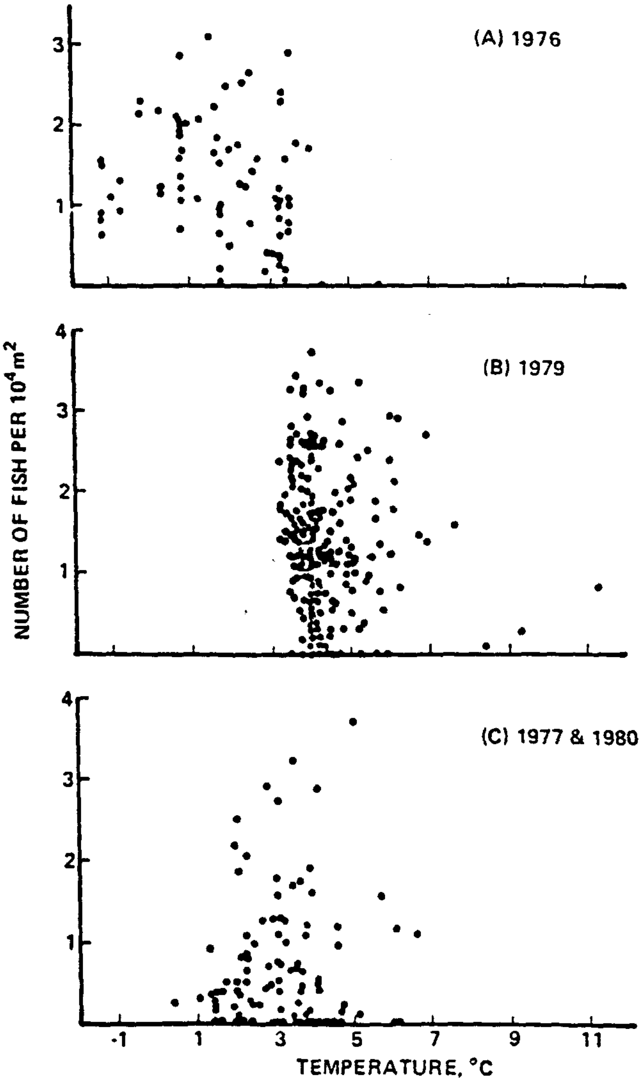

Figure 13. The temperature-density plot of young walleye pollock in the feeding season (June-September) of 1976 (A), 1979 (B), and 1977 & 1980 (C).

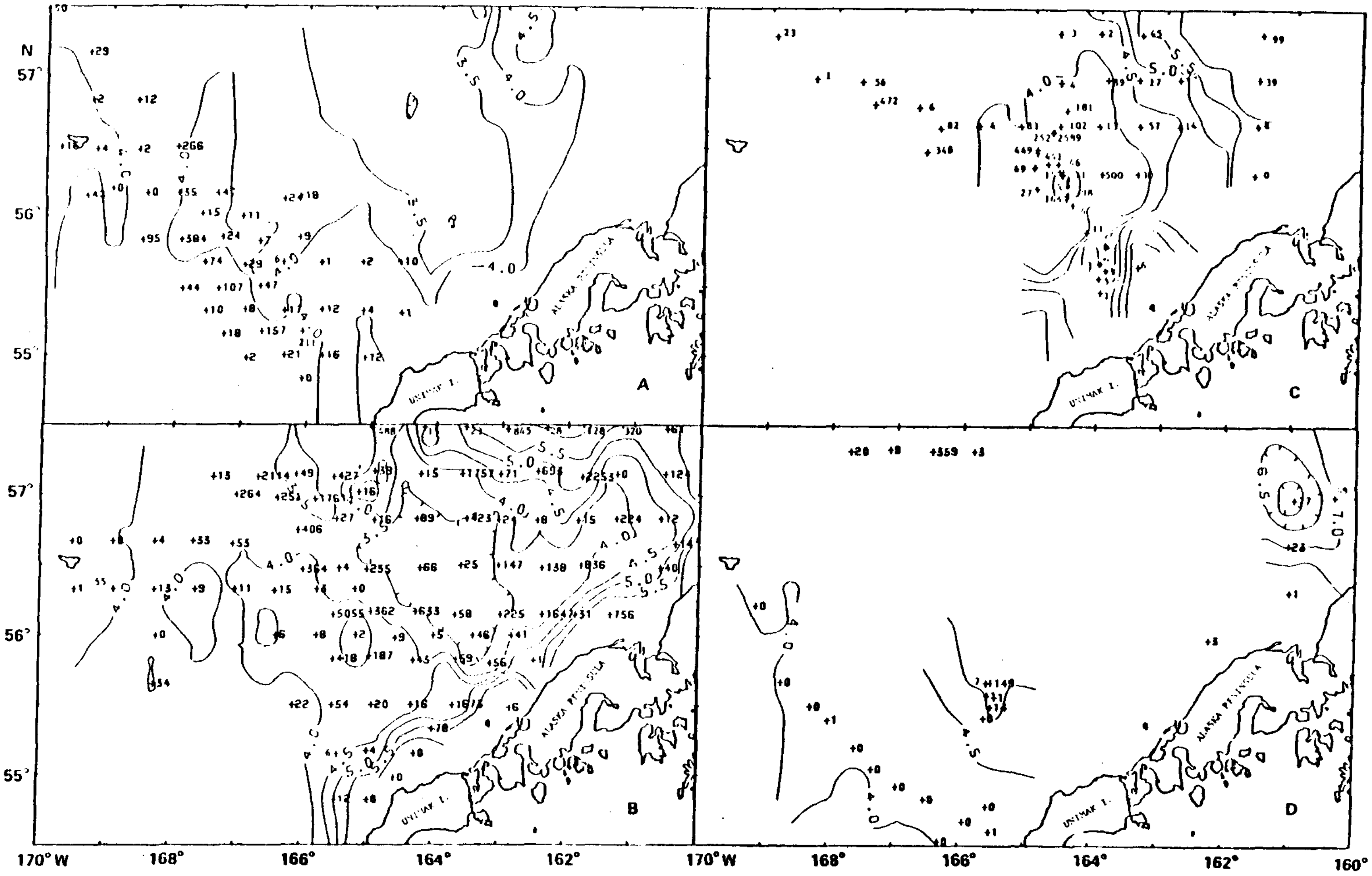

Figure 14. Bottom temperature contours and densities ($N/10^4 m^2$) of young walleye pollock in the southeastern Bering Sea during May (A), June (B), July (C) and August (D) 1979.

on the outer shelf (Fig. 14-A) in the temperature range 3.5-4.9°C. Note that fish densities were low in shallow waters. By contrast, in June low fish densities were found in deep water (Fig. 14-B), though the fish were widely distributed on the shelf where temperatures ranged from 3.5°C to 5.9°C. In July, the fish were widely distributed on the mid-shelf in temperature range 4-5.9°C (Fig. 14-C). Although no stations were sampled over the outer shelf, it is presumed that the abundance there was low, judging from the fish densities observed in June and August. In August, three stations were sampled on the mid-shelf with temperature above 6°C, where young pollock were abundant, adults were rare (Fig. 12-C). However, only three out of eighteen stations sampled from the outer shelf and slope area with temperature range 4-4.5°C had noticeable fish densities 7, 14 and 149 $N/10^4m^2$, the fish densities of the remaining stations were in the range between 0 and 1 $N/10^4m^2$. The absence of young fish on the outer shelf and slope area is apparent.

This evidence indicates that the young fish inhabited the outer shelf and gradually moved onto the mid-shelf as summer advanced. It is unlikely that young pollock inhabit the outer shelf during summer. Compared with the distribution of the adults (Fig. 12), the feeding migration of young walleye pollock is quite obvious.

Growth

For the respective age and sex groupings Table 9 summarizes the intercepts (*a*) and slopes (*b*) of the growth curves. From these values,

Table 9. Coefficients of growth curves for walleye pollock aged 2 to 4 in the feeding season (June-September), 1976-1980. Least squares fit the linear equation logW = *a*T + *b* (W = wet weight; T = the Julian Day). *N* = sample size.

Year	Age	Sex	*N*	$a \cdot 10^{-3}$	*b*
1976	2	F	166	2.3376	1.6664
1977	2	F	169	1.4430	1.9297
1978	2	F	354	2.8732	1.6846
1979	2	F	232	1.7297	1.9410
1980	2	F	84	1.3720	2.0378
1976	3	F	197	1.4870	2.1735
1977	3	F	154	0.7419	2.4107
1978	3	F	474	1.2788	2.3395
1979	3	F	218	0.6846	2.4787
1980	3	F	97	0.5261	2.5522
1976	4	F	387	1.6151	2.3302
1977	4	F	126	0.2042	2.7088
1978	4	F	420	0.5306	2.6191
1979	4	F	162	0.8991	2.6190
1980	4	F	20	1.1610	2.5828
1976	2	M	93	1.2282	1.9064
1977	2	M	163	1.6623	1.8989
1978	2	M	334	2.3739	1.7992
1979	2	M	245	2.0892	1.8782
1980	2	M	87	1.2069	2.0631
1976	3	M	158	1.3798	2.1896
1977	3	M	162	0.8869	2.3786
1978	3	M	495	0.9947	2.3708
1979	3	M	197	1.1519	2.3737
1980	3	M	87	0.8587	2.4530
1976	4	M	350	1.2683	2.3844
1977	4	M	122	0.2794	2.6567
1978	4	M	357	0.0863	2.6986
1979	4	M	160	0.9793	2.5727
1980	4	M	25	1.1308	2.5403

the weight growth in the feeding season was calculated. Figure 15 clearly illustrates that there are yearly fluctuations in growth during the feeding season for the three age groups. The weight increment varied between 51-163 g for age 2 fish; 68-134 g for age 3 fish and 13-220 g for age 4 fish (Table 10). Correspondingly, the growth rates were different for each year.

The yearly fluctuations in growth rate exhibit different patterns according to the age of the fish (Fig. 16). In particular, age 4 fish show a distinct fluctuation over the years. In 1976, it was the highest in fish aged 2, 3 and 4, whereas in 1977 and 1978 it was lower than those of age 2 and 3 fishes. Thereafter, it increased gradually, and again exceeded that of the age 2 and 3 fishes in 1979 and 1980. It is noticeable that since 1978 the fluctuation pattern has reversed between the age 4 fish and the age 2 and 3 fishes. The multi-year fluctuation patterns of the age 2 and 3 fishes were similar, throughout the five years the magnitude of the fluctuation did not change greatly. Attempts were made to analyze the relations between growth rate and temperature, and yearly condition factor. However, no satisfactory relationships were found.

The relative growth rate (RGR $=\Delta W/W_{t_0}$) was in the range of 0.02 and 1.23, with a considerable variation by age and year (Table 10). Figure 17 shows that there is an inverse relation between the relative growth rate and the initial weight (W_{t_0}), the fish weight at the beginning (June 1) of the feeding season. A least squares regression analysis was performed for age 2, 3 and 4 fishes, respectively (Table 11).

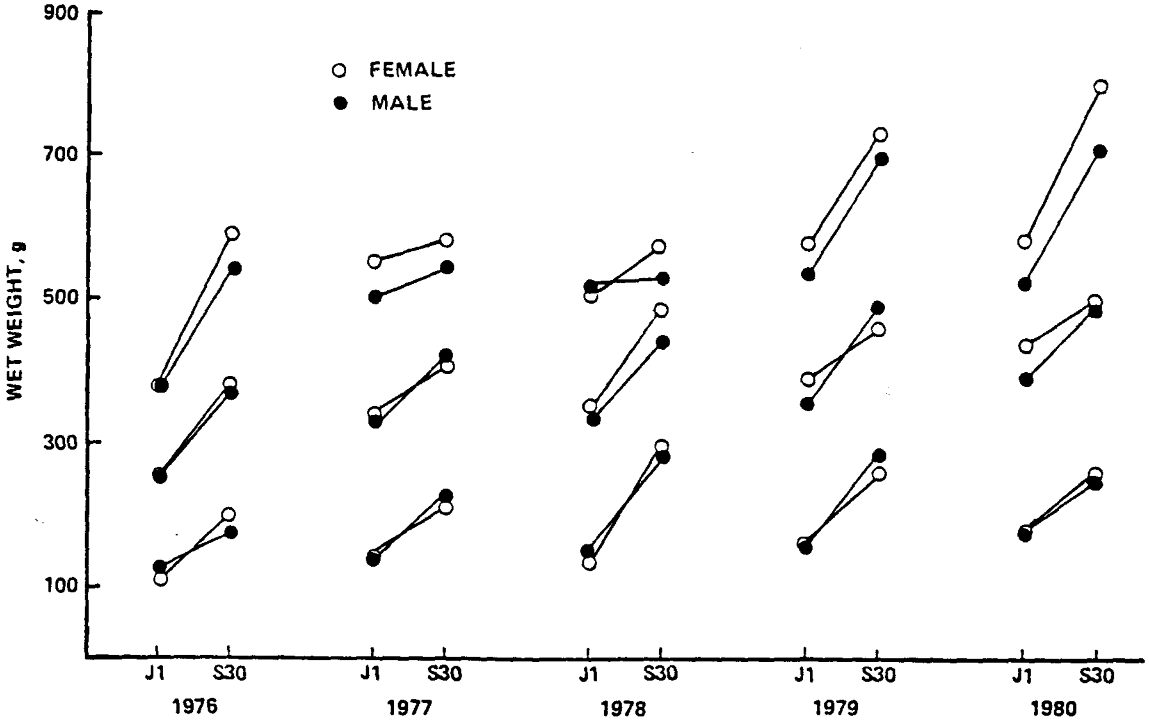

Figure 15. The increase of wet weight of walleye pollock in the southern Bering Sea from June 1 (J1) to September 30 (S30), 1976-1980. From top to bottom are ages 4, 3, and 2 fishes, respectively.

Table 10. Growth for walleye pollock aged 2 to 4 in the feeding season (June-September, or 121 days), 1976-1980. *N* = sample size; W_{t_o} = wet weight at June 1; W_{t_1} = wet weight at September 30; ΔW = weight increment ($W_{t_1} - W_{t_o}$); ΔW/121 = growth rate; $\Delta W/W_{t_o}$ = relative growth rate.

Year	Age	Sex	*N*	Weight (g)		ΔW (g)	ΔW/121 ($g \cdot day^{-1}$)	$\Delta W/W_{t_o}$
				W_{t_o}	W_{t_1}			
1976	2	F	166	106	203	97	0.80	0.92
1977	2	F	167	141	211	70	0.58	0.49
1978	2	F	354	133	296	163	1.35	1.23
1979	2	F	232	161	260	99	0.82	0.62
1980	2	F	84	177	259	82	0.68	0.47
1976	3	F	197	252	381	129	1.07	0.51
1977	3	F	154	334	411	77	0.63	0.23
1978	3	F	474	343	490	147	1.21	0.43
1979	3	F	218	383	464	81	0.67	0.21
1980	3	F	97	429	497	68	0.56	0.16
1976	4	F	387	378	593	215	1.77	0.57
1977	4	F	126	550	582	32	0.27	0.06
1978	4	F	420	502	581	80	0.66	0.16
1979	4	F	162	571	733	163	1.34	0.28
1980	4	F	20	576	796	220	1.82	0.38
1976	2	M	93	124	175	51	0.42	0.41
1977	2	M	162	142	226	84	0.69	0.59
1978	2	M	334	145	282	136	1.13	0.94
1979	2	M	245	158	282	125	1.03	0.79
1980	2	M	87	177	248	71	0.58	0.40

Table 10. Continued.

Year	Age	Sex	*N*	Weight (g)		ΔW (g)	ΔW/121 (g·day^{-1})	ΔW/W_{t_o}
				W_{t_o}	W_{t_1}			
1976	3	M	158	252	370	118	0.97	0.47
1977	3	M	162	327	418	92	0.76	0.28
1978	3	M	495	333	440	107	0.88	0.32
1979	3	M	197	355	489	134	1.11	0.38
1980	3	M	87	384	488	104	0.86	0.27
1976	4	M	350	379	539	161	1.33	0.42
1977	4	M	122	501	541	41	0.34	0.08
1978	4	M	357	515	528	13	0.10	0.02
1979	4	M	160	528	694	166	1.37	0.31
1980	4	M	25	517	708	191	1.58	0.37

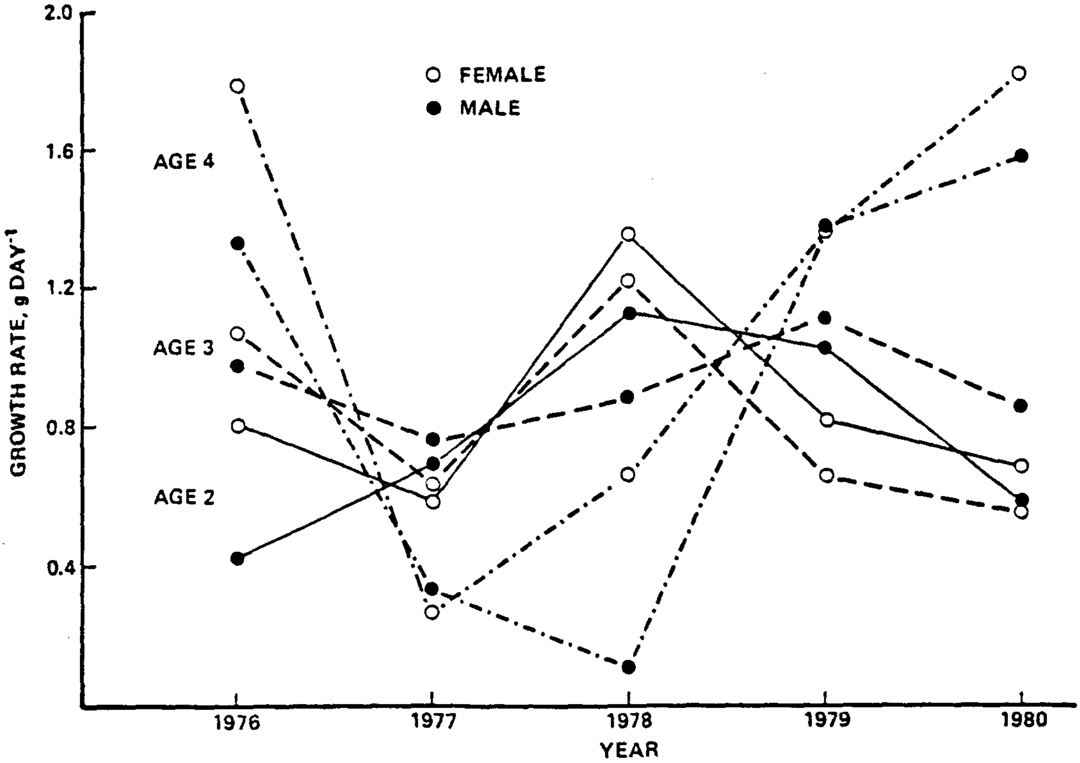

Figure 16. Growth rates for walleye pollock aged 2 to 4 in the southeastern Bering Sea during the feeding season (June-September), 1976-1980.

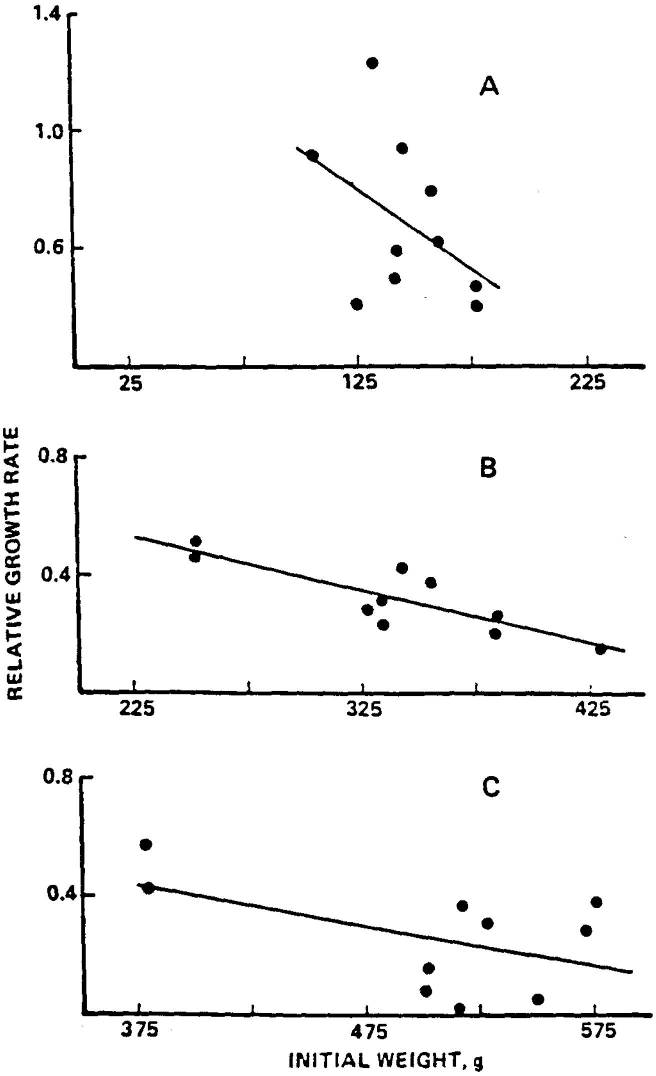

Figure 17. The relative growth rates for ages 2 (A), 3 (B) and 4 (C) walleye pollock at various initial weights.

Table 11. Regressions of the relative growth rate (RGR) and the initial weight (W_{t_0}) for walleye pollock aged 2 to 4, with and without the introducing of the temperature correction factor (c). *N* = sample size; r^2 = the coefficient of determination; *P* = the probability of wrongly rejecting the null hypothesis.

Regression of W_{t_0} to	Age	*N*	$a \cdot 10^{-2}$	*b*	r^2	*P*
RGR	2	10	-0.5400	1.4763	0.196	0.200
	3	10	-0.1773	0.9270	0.701	0.003*
	4	10	-0.1292	0.9145	0.254	0.138
RGR/c	2	10	-1.4280	2.9000	0.619	0.007*
	3	10	-0.4491	1.9391	0.785	0.000**
	4	10	-0.3730	2.2261	0.594	0.009*

* significance level $0.001 < P < 0.01$
** significance level $P < 0.001$

The value of slope a decreased from age 2 to age 4, showing the difference of the age specific growth characteristics. The coefficient of determination shows that the regression explains 19.6 percent of the total variation in relative growth rate for the age 2 fish, 70.1 percent for the age 3 fish and 25.4 for the age 4 fish. The initial weight is related to the relative growth rate in the age 3 fish at the 95% level, and in the age 2 and 4 fishes at the 80% level.

The effects of the initial weight on the weight increment (WI) in the feeding season is given by the equation:

$$WI = (aW_{t_o} + b) \cdot W_{t_o} \qquad (5)$$

It is presumed that temperature also affects growth rate and subsequently the weight increment. The temperature effects on the growth are introduced as correction factor c. Thus, equation 5 is rewritten:

$$WI = (aW_{t_o} + b) \cdot W_{t_o} \cdot c \qquad (6)$$

Maximum growth is assumed to occur at an optimum temperature. The value c = 1 is given at the maximum growth, and c = 0 where growth does not occur. In this examination negative growth is not taken into consisderation.

Since the densities of the walleye pollock are relatively symetrically distributed with the mode at 3.5°C (Figs. 10 and 13), and since the mean densities of the young were low at the temperature below -0.5°C in 1976 and above 7.5°C in 1979 (Table D-4), it is assumed that the optimum temperature for the growth of walleye pollock is 3.5°C, and that zero growth occurs at -0.5°C and 7.5°C. Thus, the hypothesized growth condition is expressed on the sine curve (Fig. 18). The equation of the sine curve is given by:

$$c = \mathit{Sin}\ (22.5T + 11.25) \tag{7}$$

Based on this equation, the temperature correction factors were calculated (Table 12). After dividing the relative growth rate by the temperature correction factor, the regressions on initial weight are recalculated (Table 11) and plotted in Figure 19. It is clear that the introduction of the temperature correction factor has significantly improved the regressions, particularly for the age 2 fish.

Table 13 summarizes the weight increments of walleye pollock in the feeding season and transitional season, as well as the annual weight increment. On the average, the fish weight increased about 222 g from age 2 to age 3, and 210 g from age 3 to age 4. The weight increment in the transitional season varied between 73-169 g for the age 2 fish and 28-169 g for the age 3 fish. Note that the weight increments in the transitional season are not necessarily smaller than those in the feeding season.

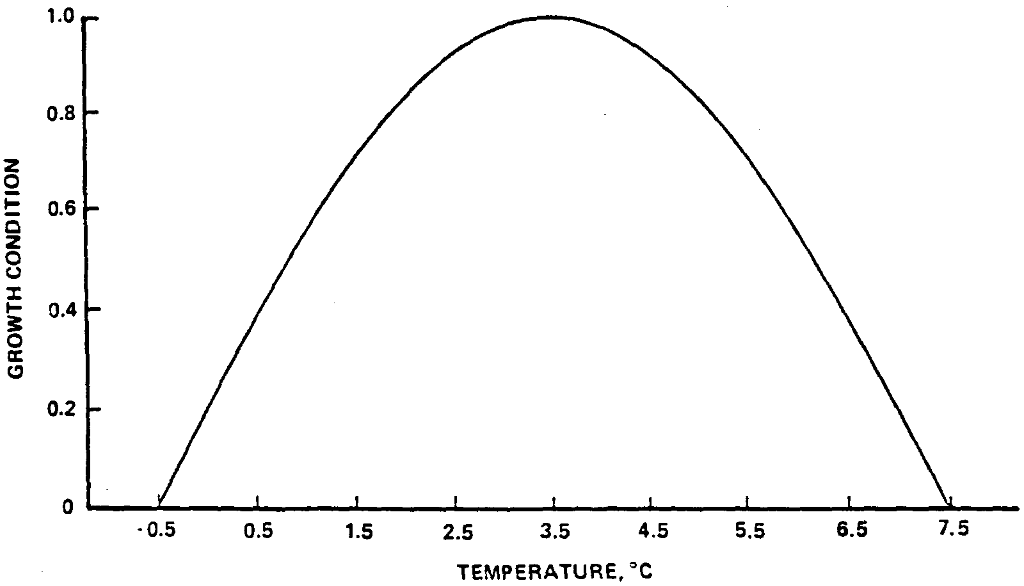

Figure 18. The hypothesized growth condition for walleye pollock at a temperature range of -0.5°C to 7.5°C.

Table 12. The temperature correction factor (c) for the growth condition of walleye pollock at a temperature range of -0.5°C to 7.5°C.

Temperature °C	Temperature Correction Factor
-0.5	0
0.5	0.38
1.5	0.71
2.5	0.92
3.5	1
4.5	0.92
5.5	0.71
6.5	0.38
7.5	0

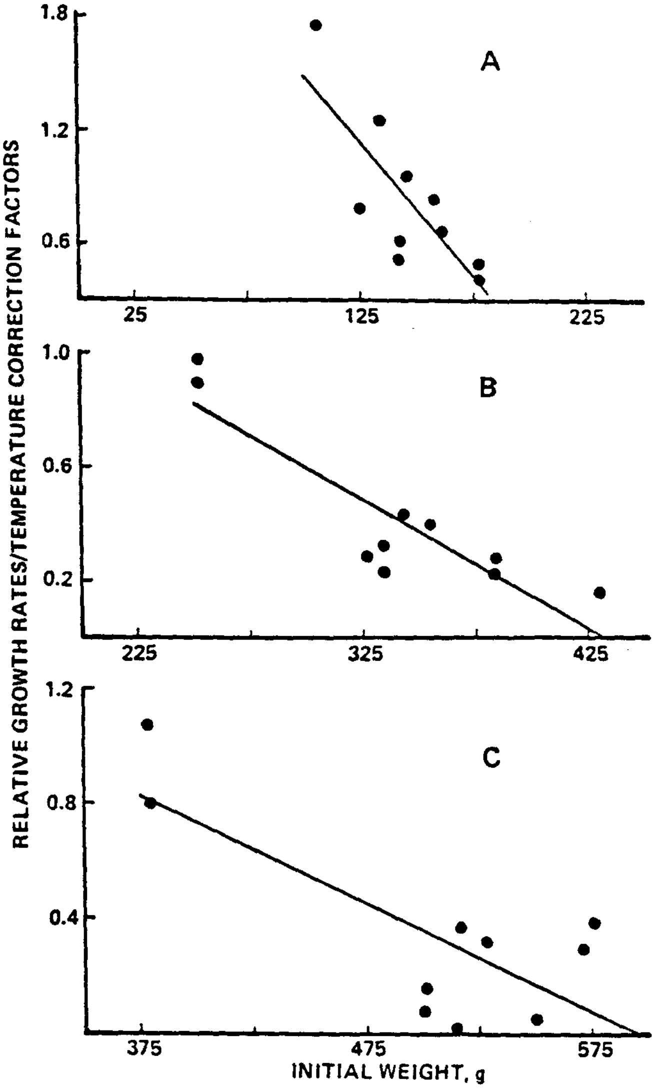

Figure 19. The relative growth rates for ages 2 (A), 3 (B) and 4 (C) walleye pollock corrected for the hypothesized growth condition at various initial weights.

Table 13. Weight increment (g) in the feeding season (June-September), in the transitional season (October-May), and annual increment for walleye pollock aged 2 to 4, 1976-1980.

Year		Age		Sex	Feeding Season	Transitional Season	Annual
from	to	from	to				
1976	1977	2	3	F	97	132	229
1977	1978	2	3	F	70	131	201
1978	1979	2	3	F	163	87	250
1979	1980	2	3	F	99	169	269
1976	1977	3	4	F	129	169	298
1977	1978	3	4	F	77	90	167
1978	1979	3	4	F	147	81	228
1979	1980	3	4	F	81	112	193
1976	1977	2	3	M	51	152	203
1977	1978	2	3	M	84	107	191
1978	1979	2	3	M	136	73	209
1979	1980	2	3	M	125	102	226
1976	1977	3	4	M	118	131	249
1977	1978	3	4	M	92	97	188
1978	1979	3	4	M	107	88	194
1979	1980	3	4	M	134	28	162

CHAPTER 4

DISCUSSION

The present study has illustrated annual fluctuations in bottom water temperatures and shown that these in turn affect the distribution of walleye pollock. Analysis of distribution patterns has revealed that in 1976 walleye pollock were congregated near a sharp temperature gradient, and that they were widely distributed in 1979 when temperature was high and temperature gradients were weak. From these results, it is inferred that temperature gradients form boundaries which determine the distribution of walleye pollock. It can be considered that in a cold year the restricted area of preferable temperatures has prevented the fish from distributing themselves widely. Consequently, it is highly likely that the highest CPUE and large landing in 1976 were caused by fish congregations. Such congregations appear to be advantageous for fishing.

There are differences in distribution patterns between the adult and young walleye pollock. The young fish were distributed in a wider temperature range and showed a clear on-shelf movement in the 1979 feeding season. Takahashi and Yamaguchi (1972) considered that the differences in distribution were due to differences in physiological requirements or adaptability to temperatures of adult and young fishes. However, such differences can be discussed in terms of feeding habits of walleye pollock. It is known that cannibalism represents a large fraction of total food intake of walleye pollock (Takahashi and Yamaguchi, 1972; Bailey and Dunn, 1979). In walleye pollock greater than

50 cm, more than 40% of the stomach content (by weight) consisted of smaller walleye pollock. Mito (1974) also showed that the occurrence of cannibalism ranged from 74 to 99% in walleye pollock larger than 40 cm. This indicates that small walleye pollock are subject to strong predation pressure from large walleye pollock when they occupy the same habitat. Therefore, it is conceivable that to avoid predation in the feeding season, young walleye pollock are forced to migrate into shallow waters, even though the temperature conditions are unfavorable. On the other hand, the distribution of adult walleye pollock is regulated by temperature conditions. They tend to remain in waters with the preferred temperature range and follow these waters onto the mid-shelf to search for food as summer advances. Additionally it is assumed that an on-shelf migration is not essential for adult walleye pollock, as far as they can find enough food organisms on the outer shelf. Such a case appears to be exemplified by their distribution pattern in 1979, when adults were found abundant on the outer shelf throughout the feeding season.

From late fall through winter, a cold water mass is formed on the shelf and develops southward as the season advances. It is assumed that the overwintering migration takes place in response to the southward development of this cold water mass. The evidence that young walleye pollock were more abundant than the adult walleye pollock in low temperatures, leads one to consider that adults move onto the outer shelf earlier than young fish. Again, to avoid predation, young walleye pollock may select relatively colder waters for overwintering where adults are few.

It is well known that the growth of fish is determined principally by the quality and quantity of food organisms, water temperature and density of the population. In reality, it is difficult to assess the magnitude of the influences caused by each factor, because of intermingling of these factors. In the present study, attempts are made to analyze the relation between ambient temperatures and initial weights and the growth of walleye pollock. Although a linear relation between the initial weight and relative growth rate is established, the statistical significance was less satisfactory. However, the development and introduction of the temperature correction factor yielded statistically significant results. This indicates that the influence of temperature on the growth can be eliminated from the initial weight-relative growth rate relationship by using this approach. It seems reasonable to assume that the fish tend to select an optimum temperature range which brings better growth. The present data suggest that the preferred temperature for walleye pollock is about 2-4.4°C. This study proposed an assumption that the growth rate of walleye pollock follows a sine function in the temperature range of -0.5°C to 7.5°C with the optimum at 3.5°C. The significant improvement of the regressions appear to support the validity of this temperature correction. However, the growth rates of walleye pollock at various temperatures must be determined in a laboratory.

The different distribution patterns of young and adult walleye pollock are considered to affect the growth differently, as the temperature conditions differ between areas. Since adult pollock inhabit areas of preferred temperature, their growth is likely to be under the influence of a relatively narrow range of temperatures. In contrast, young fish are exposed to a wide temperature range, so that their growth is influenced by varying temperatures.

Together with temperature, food supply has a significant influence on growth. It is known that in the Bering Sea zooplankton biomass fluctuates on a two or three year cycle (Motoda and Minoda, 1974), and that the relative importance of prey organisms of walleye pollock varies from year to year (Bailey and Dunn, 1979). Therefore, it is assumed that a yearly variation in abundance and composition of prey organisms of walleye pollock takes place in accordance with the zooplankton biomass fluctuations. Since the food composition of walleye pollock varies with the size of individual fishes (Takahashi and Yamaguchi, 1972; Bailey and Dunn, 1979), it is conceivable that the variation in the abundance and composition of the prey organisms will have different effects on the growth of different aged pollock. This may explain in part the different multi-year fluctuation patterns in the growth rate between the age 4 fish and the age 2 and 3 fishes.

One would expect that aggregation of fishes would lead to lower growth rate, because of less food portioning and greater intraspecific competition. However, this does not appear to be the case for

1976 when fish were highly aggregated. Instead, high weight increments were observed. The occurrence of cannibalism may be an explanation. It is possible that in 1976 walleye pollock obtained a considerable food supply through cannibalism, since a greater opportunity for cannibalism would have occurred due to congregations of the fish. The increased growth rate with age in 1976 is considered to have resulted from the fact that predacious ability increases with fish size. Based on this consideration, it is presumed that the population size of walleye pollock will decrease in cold years, not only because of the intensive fishing, but also because of the increased occurence for cannibalism.

The present study has clearly demonstrated that substantial growth occurs in the transitional season. It is well known that the feeding activity of fish is regulated by water temperatures, and that the temperature condition determines the duration of the feeding (Nikolsky, 1963). Consequently, it is reasonable to assume that the initiation and the length of the feeding season varies from year to year, depending on water temperature. Thus, an improved definition of the feeding season should be determined by temperature conditions. In addition, the bottom water temperature on the overwintering area usually remains 3-4°C throughout most of the year. It appears that this temperature does not prevent walleye pollock from feeding. To determine the growth of walleye pollock in winter, the relationship between food supply and food intake should be studied in relation to water temperature.

CHAPTER 5

SUMMARY

1. The distribution and growth of walleye pollock were studied in relation to bottom water temperature in the southeastern Bering Sea between latitude 54°30'N and 57°30'N and longitude 160°W and 170°W for the years 1976 to 1980.

2. Temperature data were from various oceanographic data base and cruise reports, including those from the University of Alaska, Processes and Resources of the Bering Sea Shelf (PROBES), National Marine Fisheries Service (NMFS), International Pacific Halibut Commission (IPHC), and Hokkaido University (Japan). Biological data were from the Northwest and Alaska Fisheries Center (NWAFC, NMFS).

3. Walleye pollock equal to or larger than 31 cm fork length were classified as adult whereas those less than 31 cm were classified as young. The adult life history is divided into a spawning season (March-May), a feeding season (June-September) and an overwintering season (October-February); and that of the young fish into a feeding season (March-September) and an overwintering season (October-February). The distribution patterns were separately examined for adult and young fishes.

4. Bottom water temperatures were studied by examining isothermal distribution, "temperature area" and mean temperature in June for 1976 to 1980. The yearly temperature fluctuations were found. The coldest year was 1976 and warmest was 1979. The temperatures of 1977, 1978, and 1980 fell in between those of 1976 and 1979.

5. Adult walleye pollock were found within a temperature range of -1.2°C to 8.4°C. In the spawning season, congregations of adult walleye pollock were found in areas where temperatures were above 2°C, and high densities were associated within the 3.5-3.9°C temperature range. In the feeding season, adult walleye pollock were restricted to the outer shelf, bounded by 0-0.5°C water in the cold year 1976. In 1979 they were rare on the mid-shelf with the temperature above 6°C. A very high catch and CPUE observed in 1976 were considered to have resulted from aggregations of fishes.

6. Young walleye pollock were found within a temperature range of -1.2°C to 11.2°C. Despite changes in temperature conditions between years, young walleye pollock were widely distributed over the study area during the feeding seasons.

7. The difference in distribution patterns of adult walleye pollock and young walleye pollock was discussed in terms of feeding habit. It is assumed that to avoid predation young walleye pollock are forced to move into the mid-shelf area in the early feeding season, where temperatures are usually cold. However, adults remain in preferred temperatures (2-4.4°C) on the outer shelf, as far as they can obtain enough food.

8. Seasonal changes in the length-weight relationship and condition factor were observed. The condition factor was relatively high in the feeding season and low in the wintering season. It was considered that the changes reflected variations in food supply between seasons.

9. It was assumed that the growth of walleye pollock took place during the feeding season (June-September). The growth rate varied with age, sex and year. A direct relationship between growth rate and the mean temperature was not found. However, the relative growth rate was related to the initial weight of the fish and the mean temperature.

10. Substantial weight increments of walleye pollock were observed in October-February. This indicates that the feeding season can not be simply determined by calendar months June to September. An improved definition of the feeding season should take temperature conditions into account, because temperature affects the feeding activity of fishes.

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APPENDIX A

Table A-1. Monthly commercial catch (metric tons) of walleye pollock in the southeastern Bering Sea, 1976-1980.

Month	Year				
	1976	1977	1978	1979	1980
Jan	14,017	983	521	1,019	894
Feb	21,343	973	2,238	2,292	4,024
Mar	16,635	17	3,436	1,105	5,050
Apr	29,438	537	2,953	2,647	7,840
May	23,781	34	3,956	5,531	12,635
Jun	22,208	39,160	73,667	34,174	24,722
Jul	69,081	74,933	82,673	80,436	92,593
Aug	84,123	64,942	67,943	84,007	75,216
Sep	112,055	66,851	57,794	76,130	70,178
Oct	83,085	52,948	40,609	55,324	69,507
Nov	1,311	17,151	5,089	13,758	35,066
Dec	1,168	1,697	2,347	1,011	2,719
Sum	478,245	320,226	343,226	357,434	400,444

Table A-2. Monthly catch per unit effort (metric tons per hour) of walleye pollock in the southeastern Bering Sea, 1976-1980.

Month	Year				
	1976	1977	1978	1979	1980
Jan	5.48	1.53	0.95	0.69	0.33
Feb	5.89	2.27	0.75	0.50	0.58
Mar	6.14	0.25	1.41	0.59	1.33
Apr	6.92	1.45	1.76	0.53	1.56
May	3.80	0.38	0.92	2.40	2.33
Jun	8.24	5.63	5.12	4.57	3.77
Jul	8.93	7.96	8.25	6.69	7.01
Aug	12.50	8.25	7.41	7.75	6.90
Sep	10.09	5.82	6.61	6.35	5.74
Oct	7.95	5.90	5.81	5.02	6.75
Nov	7.20	5.12	1.13	2.07	3.35
Dec	4.63	2.82	0.83	1.05	1.25

APPENDIX B

Table B-1. Age composition of walleye pollock as percent of total number and total weight in commercial catch for the southeastern Bering Sea, 1976-1980.

Year	Parameter	Age							
		1	2	3	4	5	6	7	8
1976	Number	2.46	13.71	16.72	35.10	5.73	3.49	5.22	5.22
	Weight	0.25	3.63	8.59	26.09	6.16	5.03	8.23	9.92
1977	Number	10.21	16.35	16.20	12.63	12.82	7.02	3.57	5.49
	Weight	1.36	4.58	9.34	10.29	13.37	9.91	5.90	10.49
1978	Number	3.21	14.54	20.70	16.21	10.50	11.66	5.91	4.24
	Weight	0.39	4.15	11.18	11.89	10.73	14.98	10.01	7.77
1979	Number	7.10	24.93	19.91	17.39	9.28	6.37	4.99	2.18
	Weight	1.01	9.22	14.24	18.62	11.18	9.70	9.99	4.80
1980	Number	0.41	19.58	28.75	13.35	11.29	9.03	5.68	2.81
	Weight	0.04	6.15	17.96	12.22	14.27	11.81	9.03	5.53
Average	Number	4.68	17.82	20.46	18.94	9.92	7.51	5.07	2.99
	Weight	0.61	5.55	12.26	15.82	11.14	10.29	8.63	7.70

Table B-1. Continued.

Year	Parameter	Age							
		9	10	11	12	13	14	15	16
1976	Number	4.96	3.42	2.79	0.70	0.29	0.18	0	0
	Weight	10.73	8.67	8.26	2.30	1.25	0.88	0	0
1977	Number	4.26	4.84	3.72	2.00	0.54	0.27	0.08	0
	Weight	8.93	9.96	9.06	4.73	1.20	0.73	0.15	0
1978	Number	4.53	4.23	2.56	1.20	0.40	0.08	0.03	0
	Weight	9.80	9.12	5.77	2.89	0.99	0.26	0.07	0
1979	Number	1.91	2.78	1.78	0.77	0.40	0.13	0.03	0.03
	Weight	4.46	7.34	5.06	2.51	1.00	0.47	0.11	0.28
1980	Number	2.60	1.92	1.98	1.16	0.82	0.48	0.14	0
	Weight	5.97	4.35	5.38	3.15	2.40	1.40	0.32	0
Average	Number	3.65	3.44	2.57	1.17	2.45	0.23	0.06	0.01
	Weight	7.98	7.89	6.71	3.12	1.37	0.75	0.13	0.06

Table B-2. Mean fork length (cm) and wet weight (g) ± one standard deviation (SD) for walleye pollock aged 1 to 7. *N* = sample size.

Age	Parameter	1976		1977		1978	
		Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)
1	Length	18.9 ± 2.30	(61)	21.2 ± 2.76	(156)	20.9 ± 3.51	(154)
	Weight	60 ± 22.7	(61)	102 ± 35.1	(156)	85 ± 47.7	(154)
2	Length	26.7 ± 3.25	(259)	28.0 ± 3.18	(329)	28.7 ± 3.27	(688)
	Weight	154 ± 61.6	(259)	197 ± 61.4	(329)	211 ± 80.4	(688)
3	Length	34.3 ± 2.49	(355)	36.1 ± 3.14	(316)	37.0 ± 3.13	(969)
	Weight	300 ± 66.6	(355)	390 ± 101.7	(316)	403 ± 103.6	(969)
4	Length	39.3 ± 2.74	(737)	40.9 ± 3.76	(248)	41.3 ± 3.65	(777)
	Weight	442 ± 86.6	(737)	562 ± 132.2	(248)	549 ± 144.7	(777)
5	Length	45.4 ± 3.97	(108)	45.2 ± 3.28	(241)	46.1 ± 4.65	(501)
	Weight	649 ± 163.6	(108)	720 ± 150.4	(241)	744 ± 235.6	(501)
6	Length	49.9 ± 3.71	(67)	48.8 ± 4.49	(115)	49.8 ± 4.71	(568)
	Weight	860 ± 220.0	(67)	904 ± 287.2	(115)	927 ± 283.9	(568)
7	Length	50.8 ± 4.50	(120)	52.3 ± 4.60	(52)	54.1 ± 5.70	(276)
	Weight	905 ± 254.2	(120)	1096 ± 329.8	(52)	1209 ± 458.8	(276)

Table B-2. Continued.

Age	Parameter	1979		1980	
		Mean ± SD	(*N*)	Mean ± SD	(*N*)
1	Length	22.2 ± 2.68	(119)	19.8 ± 2.77	(5)
	Weight	85 ± 28.2	(119)	68 ± 31.9	(5)
2	Length	30.0 ± 3.62	(477)	30.2 ± 2.79	(171)
	Weight	224 ± 75.5	(477)	225 ± 63.8	(171)
3	Length	37.8 ± 3.27	(415)	38.8 ± 2.98	(184)
	Weight	435 ± 120.0	(415)	461 ± 90.7	(184)
4	Length	44.1 ± 4.00	(322)	44.5 ± 3.07	(45)
	Weight	646 ± 166.5	(322)	657 ± 112.6	(45)
5	Length	45.7 ± 4.50	(178)	48.3 ± 4.53	(42)
	Weight	721 ± 206.7	(178)	859 ± 285.4	(42)
6	Length	49.1 ± 4.86	(131)	49.8 ± 5.02	(18)
	Weight	876 ± 291.7	(131)	929 ± 252.2	(18)
7	Length	53.9 ± 5.20	(95)	54.7 ± 6.70	(16)
	Weight	1162 ± 401.2	(95)	1248 ± 475.2	(16)

APPENDIX C

Table C-1. Monthly mean condition factors ± one standard deviation (SD) of the age 2 female walleye pollock, 1976-1980. *N* = sample size.

Month	1976		1977		1978		1979		1980	
	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)
Jan							1.26 ± 0.41	(17)		
Feb									0.69 ± 0.09	(23)
Mar										
Apr									0.68 ± 0.07	(14)
May	0.81 ± 0.07	(24)					1.17 ± 0.22	(11)	0.70 ± 0.07	(31)
Jun	0.94 ± 0.13	(114)	1.02 ± 0.18	(11)	1.03 ± 0.18	(107)	1.09 ± 0.19	(43)	1.03 ± 0.11	(14)
Jul			1.18 ± 0.19	(50)	1.03 ± 0.11	(115)	0.96 ± 0.22	(66)	1.01 ± 0.11	(25)
Aug			1.21 ± 0.13	(35)	1.13 ± 0.14	(53)	1.08 ± 0.21	(58)	1.02 ± 0.09	(15)
Sep	1.08 ± 0.11	(50)	1.00 ± 0.21	(71)	1.19 ± 0.20	(79)	0.97 ± 0.09	(65)	1.02 ± 0.15	(30)
Oct	1.05 ± 0.13	(24)	1.01 ± 0.04	(7)	1.01 ± 0.14	(88)	1.00 ± 0.11	(46)		
Nov			1.05 ± 0.22	(5)			0.88 ± 0.09	(51)		
Dec										

Table C-2. Monthly mean condition factors ± one standard deviation (SD) of the age 3 female walleye pollock, 1976-1980. *N* = sample size.

Month	1976		1977		1978		1979		1980	
	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)
Jan							0.96 ± 0.22	(16)	0.89 ± 0.11	(36)
Feb										
Mar	0.87 ± 0.09	(8)								
Apr					1.12 ± 0.18	(10)			0.85 ± 0.10	(56)
May	0.86 ± 0.07	(19)					1.05 ± 0.12	(10)	0.83 ± 0.08	(12)
Jun	0.94 ± 0.11	(99)	1.05 ± 0.09	(9)	1.00 ± 0.14	(164)	0.97 ± 0.11	(36)		
Jul	0.94 ± 0.09	(74)	1.02 ± 0.10	(47)	0.99 ± 0.08	(114)	1.05 ± 0.15	(86)	1.05 ± 0.10	(49)
Aug			1.11 ± 0.11	(48)	1.07 ± 0.11	(116)	1.07 ± 0.10	(35)		
Sep	1.08 ± 0.09	(24)	1.05 ± 0.16	(50)	1.07 ± 0.13	(80)	1.00 ± 0.13	(61)	0.98 ± 0.07	(40)
Oct	0.96 ± 0.05	(9)	1.06 ± 0.10	(28)	1.05 ± 0.11	(90)	0.99 ± 0.13	(45)		
Nov			1.10 ± 0.12	(23)			0.91 ± 0.07	(7)		
Dec										

Table C-3. Monthly mean condition factors ± one standard deviation (SD) of the age 4 female walleye pollock, 1976-1980. *N* = sample size.

Month	1976		1977		1978		1979		1980	
	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)
Jan							0.95 ± 0.19	(21)	0.98 ± 0.16	(24)
Feb										
Mar	0.92 ± 0.06	(16)							0.87 ± 0.05	(5)
Apr			1.00 ± 0.09	(5)	1.12 ± 0.17	(17)			0.89 ± 0.09	(26)
May	0.85 ± 0.07	(69)					1.03 ± 0.11	(6)	0.91 ± 0.14	(20)
Jun	0.94 ± 0.08	(175)			1.01 ± 0.12	(141)	0.98 ± 0.11	(33)		
Jul	0.96 ± 0.07	(177)	1.05 ± 0.11	(39)	0.98 ± 0.08	(83)	1.04 ± 0.13	(59)	1.01 ± 0.14	(11)
Aug			1.14 ± 0.08	(50)	1.09 ± 0.12	(118)	1.01 ± 0.07	(20)		
Sep	1.07 ± 0.08	(35)	1.10 ± 0.11	(33)	1.04 ± 0.10	(78)	0.99 ± 0.11	(50)	1.00 ± 0.36	(9)
Oct	0.96 ± 0.09	(8)	1.12 ± 0.09	(22)	1.07 ± 0.11	(54)	1.04 ± 0.13	(51)		
Nov			1.13 ± 0.11	(6)	1.02 ± 0.10	(7)	0.99 ± 0.18	(11)		
Dec										

Table C-4. Monthly mean condition factors ± one standard deviation (SD) of the age 2 male walleye pollock, 1976-1980. *N* = sample size.

Month	1976		1977		1978		1979		1980	
	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)
Jan							1.23 ± 0.21	(28)		
Feb										
Mar										
Apr									0.72 ± 0.09	(14)
May	0.83 ± 0.08	(32)					1.04 ± 0.09	(10)	0.69 ± 0.20	(16)
Jun	0.86 ± 0.09	(41)	0.90 ± 0.05	(7)	1.05 ± 0.17	(80)	1.06 ± 0.16	(40)	0.97 ± 0.12	(15)
Jul			1.15 ± 0.16	(59)	0.98 ± 0.10	(110)	0.98 ± 0.18	(88)	1.03 ± 0.11	(24)
Aug			1.17 ± 0.13	(28)	1.07 ± 0.15	(60)	1.04 ± 0.13	(49)	1.00 ± 0.11	(15)
Sep	1.01 ± 0.10	(51)	1.02 ± 0.10	(68)	1.17 ± 0.18	(84)	0.99 ± 0.13	(68)	0.98 ± 0.08	(33)
Oct	1.07 ± 0.13	(15)	1.00 ± 0.12	(50)	0.97 ± 0.13	(41)	0.98 ± 0.10	(30)		
Nov			1.04 ± 0.12	(10)	1.02 ± 0.17	(8)	0.86 ± 0.07	(38)		
Dec										

Table C-5. Monthly mean condition factors ± one standard deviation (SD) of the age 3 male walleye pollock, 1976-1980. *N* = sample size.

Month	1976		1977		1978		1979		1980	
	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)
Jan							0.99 ± 0.13	(16)	0.94 ± 0.12	(37)
Feb										
Mar										
Apr					1.27 ± 0.17	(9)			0.84 ± 0.10	(52)
May	0.86 ± 0.08	(18)					1.22 ± 0.22	(5)	0.79 ± 0.08	(11)
Jun	0.93 ± 0.11	(59)	1.11 ± 0.15	(7)	1.01 ± 0.13	(169)	1.03 ± 0.14	(43)	1.03 ± 0.08	(5)
Jul	0.95 ± 0.09	(76)	1.04 ± 0.10	(66)	0.98 ± 0.09	(113)	1.06 ± 0.16	(81)	1.07 ± 0.08	(43)
Aug			1.11 ± 0.12	(42)	1.05 ± 0.11	(123)	1.11 ± 0.18	(15)		
Sep	1.05 ± 0.07	(23)	1.07 ± 0.11	(47)	1.04 ± 0.14	(90)	0.99 ± 0.12	(58)	0.97 ± 0.18	(36)
Oct	0.98 ± 0.14	(17)	1.10 ± 0.08	(8)	1.03 ± 0.11	(87)	1.00 ± 0.12	(39)		
Nov			1.09 ± 0.11	(13)	1.09 ± 0.09	(10)	0.93 ± 0.10	(10)		
Dec										

Table C-6. Monthly mean condition factors ± one standard deviation (SD) of the age 4 male walleye pollock, 1976-1980. *N* = sample size.

Month	1976		1977		1978		1979		1980	
	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)	Mean ± SD	(*N*)
Jan							0.96 ± 0.20	(22)	1.00 ± 0.12	(23)
Feb										
Mar	0.91 ± 0.05	(21)							0.85 ± 0.06	(5)
Apr									0.94 ± 0.10	(22)
May	0.86 ± 0.08	(56)							0.92 ± 0.08	(21)
Jun	0.95 ± 0.09	(161)	1.09 ± 0.06	(6)	1.02 ± 0.12	(108)	1.00 ± 0.10	(41)		
Jul	0.99 ± 0.08	(160)	1.06 ± 0.10	(39)	1.01 ± 0.08	(76)	1.04 ± 0.13	(62)	1.06 ± 0.13	(14)
Aug			1.11 ± 0.12	(29)	1.07 ± 0.11	(100)	0.98 ± 0.10	(14)		
Sep	1.07 ± 0.10	(29)	1.12 ± 0.10	(48)	1.02 ± 0.09	(73)	1.02 ± 0.12	(43)	0.99 ± 0.08	(10)
Oct	0.94 ± 0.18	(6)	1.14 ± 0.11	(19)	1.09 ± 0.08	(49)	1.00 ± 0.13	(39)		
Nov			1.05 ± 0.15	(14)	1.06 ± 0.08	(10)	0.98 ± 0.09	(10)		
Dec					0.99 ± 0.07	(5)				

Table C-7. Yearly condition factors ± one standard deviation (SD) for walleye pollock aged 2 to 4, 1976-1980. *N* = sample size.

Year	Age	Sex	Mean ± SD	(*N*)
1976	2	F	0.98 ± 0.14	(166)
1977	2	F	1.10 ± 0.21	(167)
1978	2	F	1.08 ± 0.17	(354)
1979	2	F	1.02 ± 0.19	(232)
1980	2	F	1.02 ± 0.12	(84)
1976	3	F	0.96 ± 0.11	(197)
1977	3	F	1.06 ± 0.13	(154)
1978	3	F	1.03 ± 0.12	(474)
1979	3	F	1.03 ± 0.13	(218)
1980	3	F	1.02 ± 0.09	(97)
1976	4	F	0.96 ± 0.09	(387)
1977	4	F	1.10 ± 0.10	(126)
1978	4	F	1.03 ± 0.11	(420)
1979	4	F	1.01 ± 0.12	(162)
1980	4	F	1.01 ± 0.26	(20)
1976	2	M	0.94 ± 0.12	(93)
1977	2	M	1.09 ± 0.15	(162)
1978	2	M	1.06 ± 0.17	(334)
1979	2	M	1.01 ± 0.16	(245)
1980	2	M	1.00 ± 0.10	(87)
1976	3	M	0.96 ± 0.10	(158)
1977	3	M	1.07 ± 0.11	(162)
1978	3	M	1.02 ± 0.12	(495)
1979	3	M	1.04 ± 0.15	(197)
1980	3	M	1.02 ± 0.14	(87)
1976	4	M	0.98 ± 0.09	(350)
1977	4	M	1.10 ± 0.11	(122)
1978	4	M	1.03 ± 0.10	(357)
1979	4	M	1.02 ± 0.12	(160)
1980	4	M	1.03 ± 0.11	(25)

APPENDIX D

Table D-1. Abundance ($N/10^4 m^2$) of adult walleye pollock captured in May 1976, 1979 and 1980. Given are sample size (*N*), mean and range for fish densities at isotherms ranging from -1.1°C to 4.9°C. Data were unavailable where rows are blank.

Temperature °C	1976			1979			1980		
	N	Range	Mean	*N*	Range	Mean	*N*	Range	Mean
-1.5 - -1.1	1		0						
-1.0 - -0.6	1		0						
-0.5 - -0.1	1		0						
0 - 0.4	3	0 - 0.5	0.2				1		4.5
0.5 - 0.9	1		0				0		
1.0 - 1.4	0						7	0.3 - 27.4	7.4
1.5 - 1.9	1		2.2				10	0 - 37.0	10.0
2.0 - 2.4	2	6.5 - 441.9	224.2				15	0.2 - 166.4	30.1
2.5 - 2.9	1		4.9				7	2.3 - 148.9	34.5
3.0 - 3.4	10	5.1 - 225.3	84.1	1		15.3	9	1.6 - 209.7	48.6
3.5 - 3.9	3	23.2 - 502.4	189.6	18	8.1 - 330.5	41.3	10	4.4 - 2596.1	339.3
4.0 - 4.4				21	0.4 - 299.8	32.4	3	6.8 - 25.0	17.8
4.5 - 4.9				4	0.5 - 85.9	40.4			

Table D-2. Abundance ($N/10^4m^2$) of adult walleye pollock captured in the feeding season (June-September) 1976, 1979, and 1977 & 1980. Given are sample size (*N*), mean and range for fish densities at isotherms ranging from -1.5°C to 11.4°C. Data were unavailable where rows are blank.

Temperature °C	1976			1979			1977 & 1980		
	N	Range	Mean	*N*	Range	Mean	*N*	Range	Mean
-1.5 - -1.1	5	0 - 7.6	1.5						
-1.0 - -0.6	2	0 - 6.4	3.2						
-0.5 - -0.1	1		0						
0 - 0.4	0								
0.5 - 0.9	12	33.9 - 489.6	164.8						
1.0 - 1.4	2	197.4 - 474.1	335.7						
1.5 - 1.9	12	8.1 - 947.4	214.3						
2.0 - 2.4	1		45.6				4	7.2 - 151.2	67.0
2.5 - 2.9	2	66.9 - 335.0	200.9				2	7.4 - 247.3	127.3
3.0 - 3.4	10	22.1 - 1008.1	215.2	7	0 - 188.8	65.4	13	0 - 516.4	92.5
3.5 - 3.9	4	68.9 - 1675.5	561.4	44	7.2 - 1488.8	140.3	13	1.5 - 167.1	52.3
4.0 - 4.4	2	26.1 - 27.7	26.9	59	0 - 712.0	96.5	6	3.8 - 548.7	101.8
4.5 - 4.9				27	1.1 - 987.5	83.9	6	0 - 71.4	31.0
5.0 - 5.4				17	1.0 - 398.7	81.6	1		8.9
5.5 - 5.9				8	0.6 - 161.4	29.2	1		17.5
6.0 - 6.4				6	4.1 - 119.5	28.2	2	20.1 - 40.8	30.5
6.5 - 6.9				3	3.4 - 55.0	23.3			
7.0 - 7.4				0					
7.5 - 7.9				1		48.7			
8.0 - 8.4				1		2.9			
8.5 - 8.9				0					
9.0 - 9.4				1		0			
9.5 - 9.9				0					
10.0 - 10.4				0					
10.4 - 10.9				0					
11.0 - 11.4				1		0			

Table D-3. Abundance ($N/10^4 m^2$) of adult walleye pollock captured in May 1976 and young walleye pollock captured in May and in June 1976. Given are sample size (*N*), mean and range for fish densities at isotherms from -1.5°C to 4.4°C. Data were unavailable where rows are blank.

Temperature °C	Adult in June			Young in May			Young in June		
	N	Range	Mean	*N*	Range	Mean	*N*	Range	Mean
-1.5 - -1.1	5	0 - 7.6	1.5	1		34.2	5	3.4 - 28.6	10.0
-1.0 - -0.6	2	0 - 6.4	3.2	1		19.6	2	7.5 - 11.3	9.4
-0.5 - -0.1	1			1		189.3	1		134.8
0 - 0.4	0			3	12.6 - 142.4	57.1	0		
0.5 - 0.9	12	33.9 - 489.6	164.8	1		98.7	12	4.0 - 685.4	99.5
1.0 - 1.4	1		197.4	0			1		116.9
1.5 - 1.9	11	48.3 - 947.4	233.0	1		65.9	11	0 1205.4	129.7
2.0 - 2.4	0			2	2.2 - 17.4	9.8	0		
2.5 - 2.9	1		335.0	1		4.7	1		428.0
3.0 - 3.4	6	22.1 - 304.6	150.7	10	0 - 36.4	7.0	6	0 - 15.1	6.3
3.5 - 3.9	1		87.1	3	0 - 9.0	4.6	1		3.7
4.0 - 4.4	1		27.7				1		47.2

Table D-4. Abundance ($N/10^4 m^2$) of young walleye pollock captured in the feeding season (March-September) 1976, 1979, and 1977 & 1980. Given are sample size (*N*), mean and range for fish densities at isotherms ranging from -1.5°C to 11.4°C. Data were unavailable where rows are blank.

Temperature °C	1976			1979			1977 & 1980		
	N	Range	Mean	*N*	Range	Mean	*N*	Range	Mean
-1.5 - -1.1	6	3.4 - 34.2	14.0						
-1.0 - -0.6	3	7.5 - 19.6	12.8						
-0.5 - -0.1	2	134.8 - 189.3	162.1						
0 - 0.4	3	12.6 - 142.4	57.1				1		0.8
0.5 - 0.9	13	4.0 - 685.4	99.4				0		
1.0 - 1.4	2	10.9 - 116.9	63.9				7	0 - 7.0	1.6
1.5 - 1.9	14	0 - 1205.4	130.0				9	0 - 154.7	18.0
2.0 - 2.4	6	2.2 - 317.4	75.3				18	0 - 321.1	30.5
2.5 - 2.9	5	0.5 - 428.0	98.5				8	0 - 823.6	108.4
3.0 - 3.4	22	0 - 240.8	24.3	8	23.9 - 225.0	70.9	22	0 - 1656.3	111.0
3.5 - 4.0	8	0 - 719.2	100.3	62	0 - 2588.6	231.2	23	0 - 79.7	9.6
4.1 - 4.4	2	0 - 47.2	23.6	80	0 - 5055.2	161.6	10	0 - 792.6	80.1
4.5 - 4.9	0			31	0 - 1672.7	108.1	7	0 - 5216.0	748.6
5.0 - 5.4	0			18	0 - 2252.6	182.5	1		0.3
5.5 - 5.9	1		0	8	0 - 77.2	21.0	1		36.5
6.0 - 6.4				6	5.7 - 845.3	339.0	2	0 - 13.8	6.9
6.5 - 6.9				3	23.2 - 496.8	182.7	1		11.4
7.0 - 7.4				0					
7.5 - 7.9				1		38.9			
8.0 - 8.4				1		0.3			
8.5 - 8.9				0					
9.0 - 9.4				1		0.9			
9.5 - 9.9				0					
10.0 - 10.4				0					
10.5 - 10.9				0					
11.0 - 11.4				1		6.1			