FINAL REPORT
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Nearshore Beaufort Sea Fish Monitoring in the Prudhoe Bay Region, 2003

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by

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EXECUTIVE SUMMARY

During summer 2003, LGL Alaska Research Associates, Inc. (LGL) conducted a fish monitoring study in the coastal waters of the Beaufort Sea near Prudhoe Bay, Alaska. The study's objective was to collect biological and physical data necessary for monitoring the distribution, abundance and health of regional anadromous and amphidromous fish stocks that are important to the Native subsistence fishery at Nuiqsut and the commercial fishery that operates in the lower Colville River. This study is a continuation of a series of annual fish monitoring surveys that have been conducted by BP Exploration (Alaska), Inc. (BP) in the Prudhoe Bay area for 21 of the past 23 years. The following are the major findings of the 2003 study.

Arctic Cisco

- There was no recruitment of young-of-the-year Arctic cisco into the Prudhoe Bay region in 2003. Results are consistent with the absence of sustained east winds during summer that are needed to transport fry westward along the coast from spawning grounds in Canada. Winds for the months of July and August must typically blow from the east with and average speed of 5 km/h or better for recruitment to occur. There also appeared to be no periods of strong easterly winds in the month of September that could have facilitated a late recruitment. This is the third consecutive summer of poor recruitment. The absence of the 2001-2003 year classes should adversely affect yields in the Colville River subsistence and commercial fisheries beginning in 2006-2007 and lasting through 2009-2010.

- The 2003 catch of Arctic cisco age-3 and older was the highest ever reported in Prudhoe Bay for the 1985-2003 period of record. This age-3+ group appears to be dominated by three particularly strong year classes—1997, 1998, and 1999. Provided these year classes remain healthy, they should support strong commercial and subsistence harvests over the next few years.

- The growth of Arctic cisco has decreased dramatically over the past two summers. In 2003, age 3-6 fish were significantly smaller for their age than has previously been reported. Further, Arctic cisco failed to gain weight during the 2003 feeding season. Decreased growth and the absence of weight gain may be related to the unusual predominance of west winds in 2003. Arctic cisco feed primarily on marine invertebrates. West winds prevent sub-surface marine water, and the marine invertebrate fauna that inhabit it, from moving onshore. Because nearshore consumers quickly deplete food resources, the continuous immigration and transport of marine invertebrates into the nearshore zone is necessary to provide adequate levels of prey. West winds may have disrupted this process resulting in lower prey levels and poor feeding.

- Results of the 2003 study indicate that while three exceptionally strong years classes (1997, 1998, and 1999) are overwintering in the Colville River, which should otherwise provide substantial support to commercial and subsistence fisheries over the next few years, those fish may not be finding enough prey in coastal waters to support their own growth or the accumulation of fat reserves needed to survive the winter. How these factors may affect the health of these three year classes over the next few years is uncertain.

Least Cisco

- Catches of both small and large least cisco were the highest recorded in the Prudhoe Bay area for the 1985-2003 period of record. High catches may reflect an expansion in the Colville River least cisco population or enhanced eastward transport to the Prudhoe Bay region caused by the excessive west winds (easterly currents) that characterized the month of July.

- The wind-transport model predicted the arrival date of small fish at Prudhoe Bay within 24 hours of the actual arrival, again validating the hypothesis that the migration of juvenile least cisco from the Colville River to Prudhoe Bay is largely attributable to a wind-driven transport process.

- Based upon three seasons of study, we have been unable to find evidence that least cisco are gaining weight during summer. At this point, we do not know whether the apparent absence of weight gain is real or an artifact of our analysis. This is only the third year in which least cisco have been the subject of aging analysis and data may still be insufficient to identify broader patterns. There is also evidence that least cisco found in coastal waters of Prudhoe Bay may be a mixture of anadromous and freshwater forms. This would confound growth, aging, and condition analyses. On the other hand, there is compelling evidence that Arctic cisco have failed to grow or put on weight in recent years, which suggests that the phenomenon in least cisco may be real. At this point, the issue remains unsettled.

Broad Whitefish

- The 2003 catch rates of broad whitefish age-2 and age-3+ were the highest ever recorded in the 1985-2003 period of record. CPUE for age-3 fish was the fourth highest for this group. Collectively data suggest that the Sagavanirktok River broad whitefish stock is robust and healthy.

- Simulation models indicated that the growth of age-1 and age-2 broad whitefish during summer 2003 was in line with expectations. The fact that juvenile broad whitefish appear to have grown normally over the past two summers while Arctic cisco growth has been below normal (see above) is not unreasonable. Whereas Arctic cisco feed primarily on invertebrates of marine origin, broad whitefish rely more heavily on Chironomids (midge fly larvae) that are washed down river into the delta flats. If the west winds that dominated in the month of the July did prevent marine invertebrates from moving onshore and replenishing depleted prey stocks, the phenomenon would not have affected the supply of freshwater invertebrates.

Dolly Varden

- The catch rates of all size classes of Dolly Varden were well within historic ranges for Prudhoe Bay fish surveys.

- The summer growth of Dolly Varden smolts was the lowest for the 1985-2003 period of record. Estimated growth for 2003 extends a trend of decreasing summer growth that has been apparent since 1989. The reasons for this decrease in growth rate are unknown.

Humpback Whitefish

- The catch of humpback whitefish east of West Dock continued to remain elevated relative to the initial sharp rise that first occurred in the summer of 1996. Data are consistent with the hypothesis that the construction of the West Dock breach in the winter of 1995-1996 has allowed this species to extend its coastal distribution farther to the east.

- Catch rates in 2003 were the highest in the 1985-2003 period of record. This may reflect an expansion in the Colville River population, or enhanced dispersal eastward in conjunction with the heavy west winds (easterly flowing currents) that characterized the 2003 season.

- Most humpback whitefish were adults. The absence of small fish again suggests that the Prudhoe Bay area is well beyond the summer dispersal range of juvenile fish from the Colville River.

- Unlike previous years, humpback whitefish were taken in large numbers well into late August. The unusually low salinities that were prevalent through late July may have delayed triggering their westward return migration back to the Colville River.

Arctic Flounder and Rainbow Smelt

- The sharp increase in the abundance of the marine Arctic flounder and the anadromous rainbow smelt that first began in 1990 continued through 2003. Catch rates of both species remain higher than the rates reported in the 1980s. The phenomenon may be associated with major climatic regime shifts that were reported to have occurred in 1989 for the North Pacific and Bering Sea.

Meteorology/Climate

- The summer of 2003 was the second consecutive year in which average winds blew from the west. Net summer winds typically blow out of the east. The unusual west winds that have characterized 2002 and 2003 may reflect broader climatic shifts that have been documented for the North Pacific and Bering Sea in recent years. There is circumstantial evidence that the documented regime shift of 1989 coincided with major increases in the abundance of the marine species Arctic flounder and rainbow smelt, and a change in the summer growth patterns of Dolly Varden smolts. West winds have resulted in no recruitment of young-of-the-year from Canada to Alaska, which has negative connotations for commercial and subsistence fisheries. Wind-driven circulation patterns may also be having negative impacts on Arctic cisco summer feeding success. The long-term impact that global climate shifts may have on Beaufort Sea fishery resources is uncertain at this time.

***Key words**:* Amphidromous fish, anadromous fish, Arctic cisco, Arctic flounder, Beaufort Sea, broad whitefish, causeways, Dolly Varden, humpback whitefish, least cisco, marine biology, monitoring, oceanography, Prudhoe Bay, rainbow smelt

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INTRODUCTION

Study Objectives

During summer, 2003, LGL Alaska Research Associates, Inc. (LGL) conducted a fish monitoring study in the coastal waters of the Beaufort Sea near Prudhoe Bay, Alaska. The study's objective was to collect biological and physical data necessary for monitoring the distribution, abundance and health of regional anadromous and amphidromous fish stocks that are important to the subsistence and commercial fisheries in the lower Colville River. The program represents the latest in a series of studies designed to assess the effects of oil and gas development on regional fish populations and fisheries. These studies include the West Dock studies of 1981–1983 (Griffiths and Gallaway 1982; Critchlow 1983; Biosonics 1984), the Lisburne Development studies of 1983–1984 (Woodward-Clyde Consultants 1983; Moulton et al. 1986), and the Endicott Development studies of 1982, 1985-1998 (Griffiths et al. 1983; Cannon et al. 1987b; Glass et al. 1990; LGL 1990, 1991, 1992, 1993, 1994a, 1994b, 1999a, 1999b; Reub et al. 1991; Griffiths et al. 1995, 1996, 1997; Fechhelm et al. 2001, 2003).Summer fish monitoring programs have historically focused on four species that are important to subsistence and commercial fisheries, and to a limited recreational fishery (U.S. Army Corps of Engineers 1980, 1984). They are Arctic cisco (*Coregonus autumnalis*), least cisco (*C. sardinella*), broad whitefish (*C. nasus*), and Dolly Varden (*Salvelinus malma*). These four indicator species continued to be the primary focus of the 2003 Beaufort Sea fish monitoring study.

Business Rationale

This study was completed for BP Exploration (Alaska) Inc. in compliance with the North Slope Borough Ordinance 19.40.120(f), which requires fish monitoring of the Endicott Development. It also represents a continuing commitment by BP begun over two decades ago to monitor, understand, and if necessary, mitigate for environmental effects related to its developments. To our knowledge, information compiled over the past 25 years from these fish monitoring programs represents the largest, most comprehensive, most continuous biological database on Arctic fishes ever collected in the world. The health and status of fisheries in the central Alaskan Beaufort Sea is continuously assessed against a long-term historical record dating back to the late 1970s. Baseline information on fish that inhabit the nearshore Beaufort Sea waters of the Prudhoe Bay region are also used to assess the potential environmental effects of other nearshore and inland developments. Most importantly, these data are used to forecast the strength of future Arctic cisco recruitment into the Colville River subsistence and commercial fisheries.

STUDY AREA

The 2003 study consisted of an array of four fyke nets positioned along the coast from the western base of West Dock to the eastern side of the Endicott Causeway (Figure 1). The four sites were chosen for specific reasons. Station 220 is located at the western base of West Dock where it captures fish moving into the Prudhoe Bay region from the Colville River and areas west. Data from this site have historically helped determine whether migrating fish were being blocked by West Dock and, in recent years, the effectiveness of the new West Dock breach. From 1981 to 2002 (excluding 1999 and 2000 when no fish studies were conducted), Station 220 was sampled in 19 of 20 summers. Station 218, located in western Prudhoe Bay proper, was sampled in all 20 years of study from 1981 to 1998 and from 2001 to 2002. The site provides information on fish movement along the western side of the bay and consistently catches large numbers of anadromous, amphidromous and marine species. Station 230 is located along the mainland segment of the Endicott Causeway. In terms of catch, this site has historically been one of the most productive,

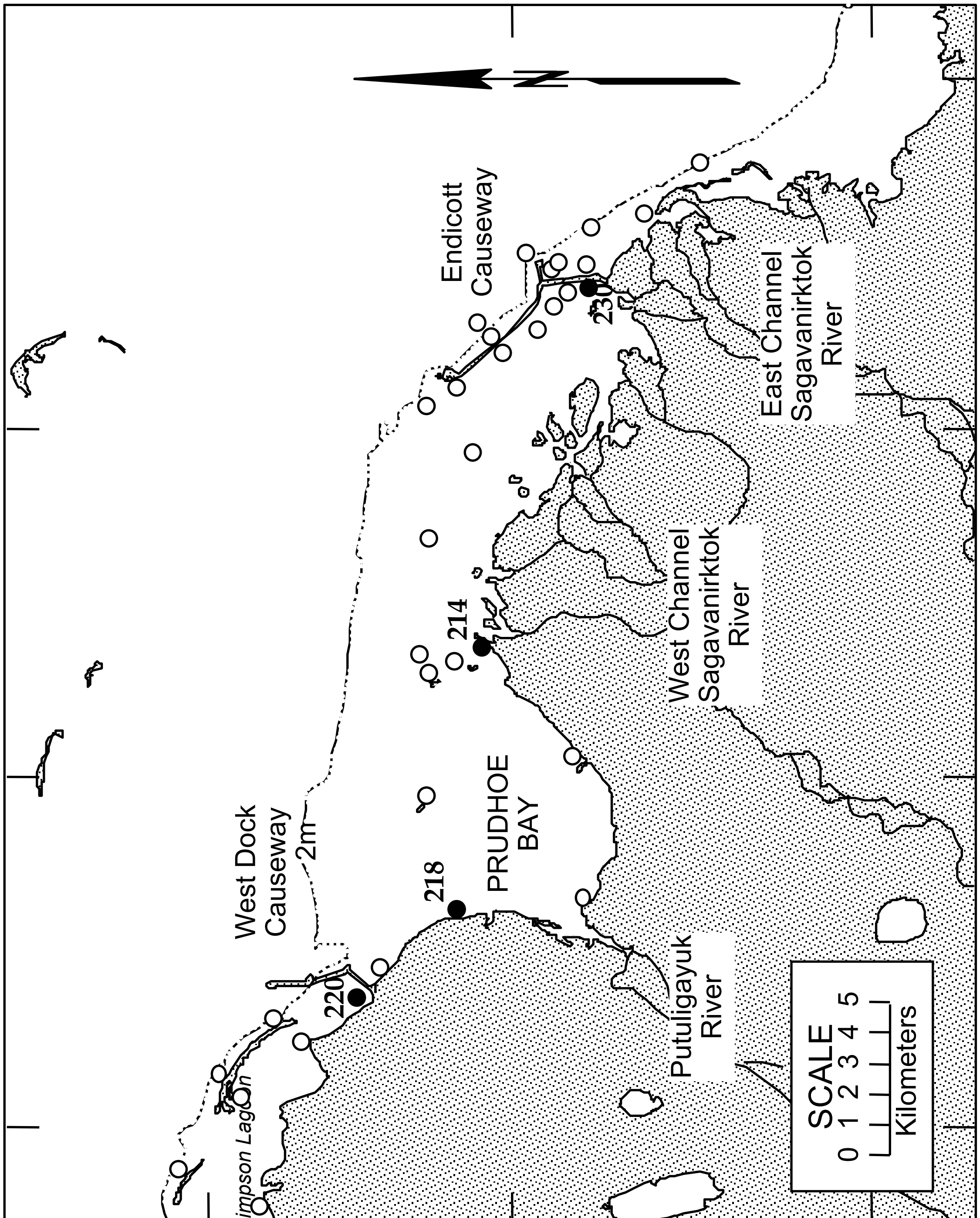


Figure 1. Sites sampled by fyke net in the summers 1985-1998 and 2001-2003. Sites sampled in 2003 are denoted by solid symbols.

particularly for juvenile Arctic cisco and broad whitefish that forage in the delta during summer.

The fourth site sampled in 2003 was Station 214 located at the tip of Heald Point in the western Sagavanirktok Delta (see Figure 1). Prior to 2002, Station 231, located on the other side of the mainland section of the Endicott Causeway from Net 230, was the fourth site sampled. This site had to be abandoned in 2002 because of inadequate water depth. Over the years, siltation has caused shoals to accumulate along the entire eastern face of the causeway's mainland segment. Even during periods of high water depths at this site are too shallow to properly operate a fyke net. Station 214 was chosen as its replacement. Station 214 was one of the original baseline stations sampled in 1982 (Griffiths et al. 1983), and was sampled from 1985-1995 following construction of the Endicott Causeway. It was not sampled after 1995 when the scope of the studies was reduced to focus on events in the interior delta. Station 214 is a productive site and data collected there have been an integral part of the Beaufort Sea fish database.

METHODS

Fyke Net Sampling

Fyke nets were used to collect fish during the 2003 study. Nets consisted of paired stainless-steel frames measuring 1.7 m (5.6 ft.) by 1.8 m (6.0 ft), each supporting a cod end trap made of 1.27-cm stretched-mesh netting (Figure 2). The two separate traps shared a single 60-m (200-ft) lead constructed of 2.5-cm knotless nylon mesh net. A single 15-m (50-ft) wing emanated from each of the traps. The entire device was set perpendicular to the shoreline as depicted in Figure 2. Once set, the nets fished continuously, weather and ice conditions permitting.

Fish were removed daily from each cod end trap and placed in floating holding pens where they were held while being processed. All specimens were enumerated and identified to species when possible. Arctic cisco, broad whitefish, least cisco, and Dolly Varden were measured to the nearest mm fork length (FL) at all locations. Fish to be measured were first anesthetized using a 1:4 solution of clove oil and ethanol (Anderson et al. 1997) to minimize scale loss and stress during handling. Approximately 2 ml of clove oil/ethanol solution diluted into 10 L of water (i.e., clove oil concentration of 40 ppm) was sufficient to sedate fish within 2–3 minutes. Once length data were taken, anesthetized fish were placed in a holding pen and allowed to recover before being released.

In cases where large numbers of any one of the four primary species were captured, a subsample of 50 fish was measured. Each of these species has historically been segregated into specific size cohorts for the purposes of subsampling (Cannon et al. 1987b; Glass et al. 1990; LGL 1990, 1991, 1992, 1993, 1994a, 1994b, 1999a, 1999b; Reub et al. 1991; and Griffiths et al. 1995, 1996, 1997; Fechhelm et al. 2001). We maintained this protocol and the following size groupings were used for subsampling: Arctic cisco and broad whitefish <120 mm, 120-250 mm, >250 mm; Dolly Varden <350 mm and =350 mm; and least cisco <180 mm and =180 mm.

Counts of dead fish for all species were recorded at each net by species and size group as a measure of net mortality.

Laboratory Analyses

Specimens of Arctic cisco and least cisco were collected both early and late in the summer for life history analysis (i.e., age, length, weight, gender, sexual maturity, spawning condition). The criterion for selecting the fish was based on length, using eight 50-mm size intervals from 51 to 400 mm (e.g., 51-100 mm, 101-150 mm, etc.). When numbers permitted, 20 individuals were collected from each size interval during each of the two sampling periods.

All fish collected for life history data were processed on the day of capture. Each specimen was weighed in the laboratory to the nearest 0.1 g using an Ohaus Triple Beam Balance (Model 720) and measured to the nearest mm (fork length). Specimens were dissected to determine sex and state of maturity, including ovary weight for mature females. Egg diameters (to the nearest 0.1 mm) were measured for sexually mature females. Otoliths were removed from

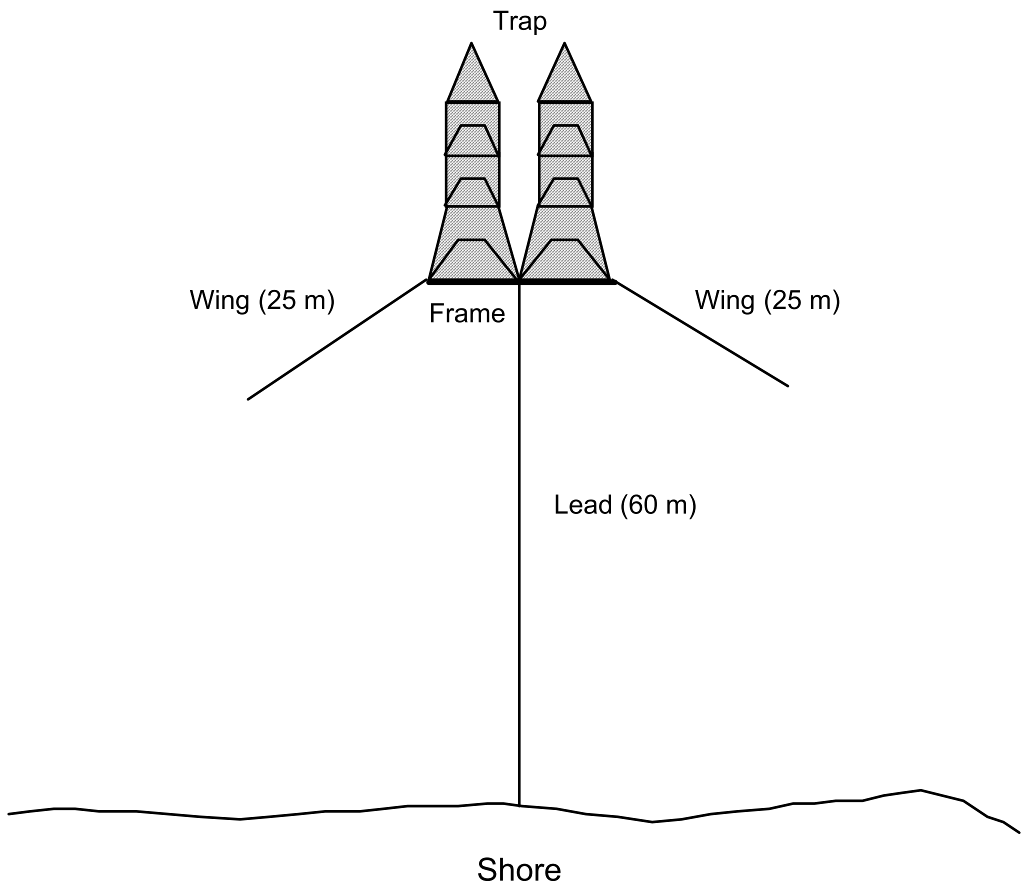


Figure 2. Diagrammatic representation of a double cod end fyke net and its orientation along the shore.

all specimens for aging. The state of maturity was determined using the following criteria that are a modification of the Nikolski classification of maturity described by Lagler (1978). The criteria had been refined during the 1985–1996 monitoring studies to deal specifically with arctic anadromous and amphidromous fish in the central Alaskan Beaufort Sea. The criteria are:

1. Immature – the gonads were very small and underdeveloped, often too small to determine the sex of the fish.
2. Mature Non-spawner – the gonads were small but males and females were easily distinguished; ovaries contained small but visible orange-colored eggs; fish would not spawn in the year of capture.
3. Mature Pre-spawner – gonads large, well developed or developing for spawning the year of capture; eggs >1.0 mm by mid-summer, ovaries occupied a large portion of the body cavity and were immediately visible when the body cavity was opened; testes pale, irregularly swollen; reproductive products were not extruded when light pressure was applied to the abdomen.
4. Mature Spawner – reproductive products were extruded when light pressure was applied to the abdomen.
5. Spent – gonads deflated, residual eggs or milt may have been present, genital aperture inflamed.

Otoliths removed from all sacrificed fish were later examined under a dissecting microscope to determine the age of the fish. Otoliths from small fish were cleared by soaking them in a 50% glycerin and water solution for two days, after which they were examined. Dark annuli or rings representing reduced growth during winter were counted, beginning with the smallest annulus surrounding the light-colored center. The size and clarity of annulus patterns in age 0 and 1 otoliths were useful when evaluating otoliths from older fish. Generally, young fish showed new growth by early July, and by late summer, they had developed a band of light-colored new growth. Fish showed relatively smaller additions of new material to their otoliths with increasing age. All otoliths, except those from age-0 and age-1 fish, were aged using the cross-sectional burn technique (Chilton and Beamish 1982). In this approach, the otolith is broken in half, scorched over an open flame, and examined in cross section. The tightly spaced light and dark rings on the cross section of the otoliths are more distinct using this technique.

Hydrography

Salinity/temperature/depth (STD) profiles were recorded daily at the cod end of each fyke net. Temperature and salinity measurements were taken at 0.5-m (1.6-ft) depth increments with a YSI Temperature-Salinity meter. During the course of the summer, YSI meters were intermittently checked against salinity standards and temperatures measured by an ERTCO standard in-glass mercury thermometer (FC 63903). Meters that deviated by more than 1°C or 2 ppt from the standards were removed from service.

Meteorology

Hourly wind data were collected at the Deadhorse Airport, Deadhorse, Alaska by the National Weather Service. These data were later retrieved from the Arctic Climatic Data Center of the National Weather Service, Asheville, NC.

Data Management

Physical and biological data were recorded on waterproof coding forms in the field. Data sheets were checked for accuracy and consistency at the end of each day and corrections made if necessary. At the end of each day, data were entered into EXCEL computer files and verified after entry by two crew members. Data files were later screened for errors using several computer programs designed to detect spurious data. Questionable data that could not be reasonably resolved were flagged and not included in any of the subsequent analyses.

Data Analysis

Catch-per-unit-effort (CPUE) for individual fish species or size cohorts within species is expressed as the number of fish collected per fyke net per 24 h of fishing effort (fish/net/24 h). The total catch from each cod end was divided by the proportion of the day that the cod end fished, thereby yielding the number of fish caught per day by side of net. The total CPUE for each two-sided fyke net was calculated by summing the CPUE of the two cod ends. Unmeasured fish were prorated into respective size cohorts (discussed separately for each species below) before the standardization by effort occurred.

Standardization of Data

Fishery surveys in the 1980s were often conducted from mid June through mid to late September, while in the 1990s studies were generally of shorter duration, running from late June through the end of August. CPUE from studies of the 1980s were therefore affected by events very early and very late in the season while studies of the 1990s were not. For the purposes of intra-year comparison of catch rates, only data from the common time frame of 1 July–31 August are used. All historic surveys were sampled during this period. Catch rates for all species and groups from the 2002 study are reported for the full sampling effort (29 June–29 August), but when compared visually or statistically to other years only data from 1 July–29 August are used.

Historic Data Access

Although summer fish monitoring programs have been conducted in the Prudhoe Bay area in 1981–1998, and 2001-2002, our access to actual computer data files begins with 1985 and so in most instances historic data records presented in this report cover the period 1985–2002. There are a few cases in which data are presented for the years 1981–1984; the most notable instance is hydrographic measurements collected at fyke nets locations. In the event that data from 1981-1984 are referenced, the specific report from which those data originated are cited.

Explanation of Graphics

A graphic format is used in this report that requires some explanation. Figure 3 shows the length-at-date data for Arctic cisco collected in the Prudhoe Bay region during the summers of 1985–1993. Each panel within the figure consists of a matrix (i.e., a grid of columns and rows that are actually a reduced EXCEL spreadsheet). Each column represents one of a series of consecutive sampling dates with the series generally running from late June to early September for years prior to 1990 and from late June through the end of August for years after 1989. Rows represent fish length in 1-mm increments. There are major demarcations at 100, 200, 300, and 400 mm. Within each grid cell is entered the number of fish collected on a particular day at that particular size (length). For example, 11 fish measuring 71 mm in length were collected on 19 August 1985. These numbers are not actually distinguishable in this version of the figure and appears as dots instead. The darker areas in the figure represent fish in all size classes and therefore reflect greater catches than areas with fewer numbers. When these data are pieced together, they provide both short- and long-term length profiles of the Arctic cisco population in the Prudhoe Bay region. The black diagonal swaths or “clouds” in the top half of each panel (i.e., fish <200 mm) represent the presence of distinct age cohorts. The graphic clearly shows how an age cohort grows in size each year and its contribution to the overall population. Note that the vertical line separating consecutive years represents the 9-10 months of winter when fish do not grow (all growth occurs in the summer). At the start of a summer, fish are approximately the same size as they were at the end of the previous summer (the diagonal swathes form a smooth transition from year to year). Also, note the sudden appearance of fish 50–90 mm in length during August in many years. These are newly recruited age-0 fish arriving at Prudhoe Bay from Canada. Despite some overlap, these age cohorts can be identified and subsequently tracked in following years. This graphic format is presented for several species in this report.

Statistical Analysis

For comparative analyses of catch data among or between years or groups of nets, CPUE ($\log_e$ transformed CPUE + 1) determined over the course of a single season for a single net was considered the basic

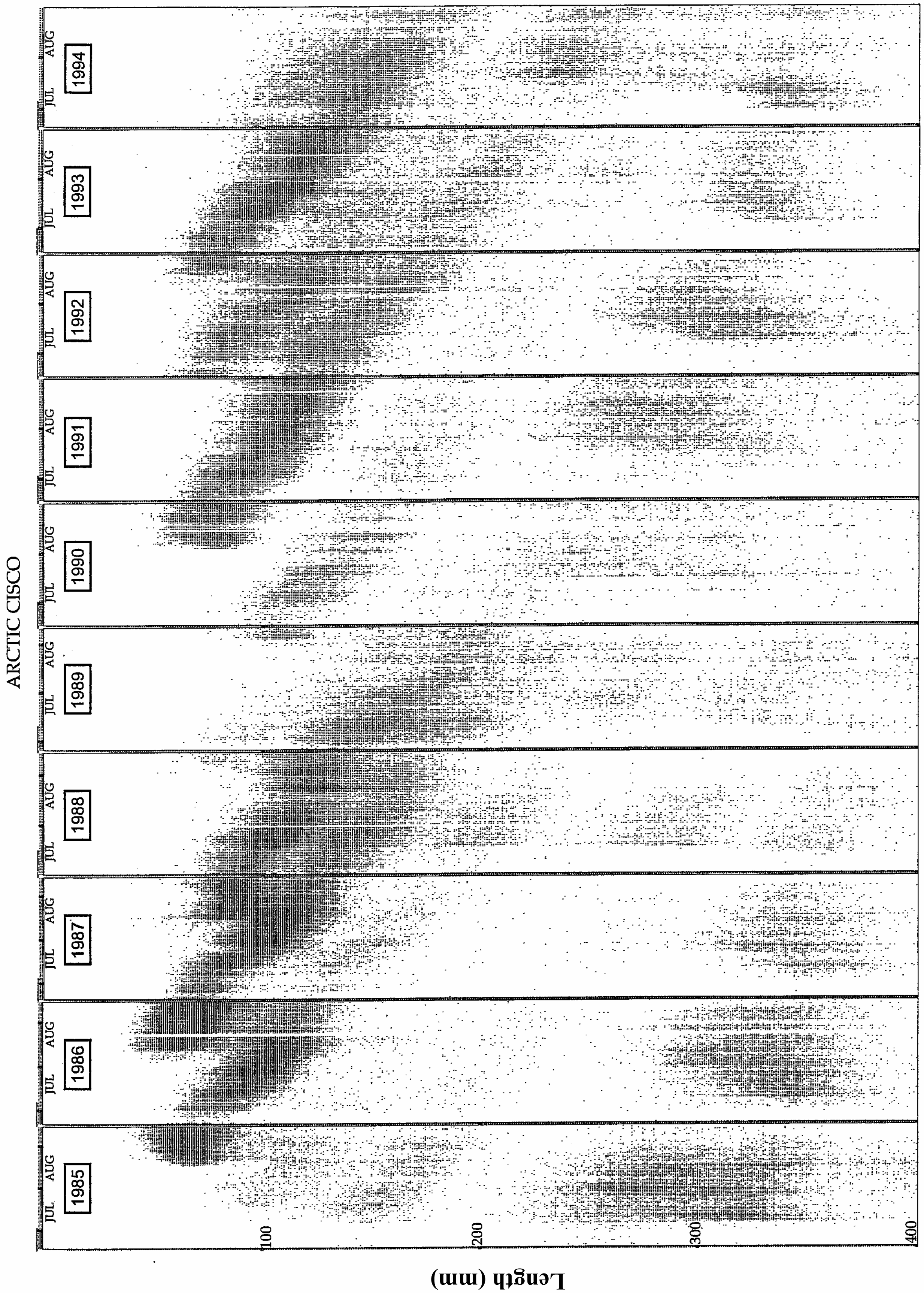


Figure 3. Length distribution by date and year for Arctic cisco. See Explanation of Graphics in Methods Section.

experimental unit. Ten fyke nets in operation during a summer yielded n = 10 measurements of CPUE for the particular species and size group in question. For most size groups and species, the underlying statistical distributions of these inter-year $\log_e$-transformed data sets are normally distributed (Lilliefors test, $P > 0.05$; Wilkinson [1989]). In these cases, statistical analyses of $\log_e$-transformed CPUE data uses parametric (i.e., *t*-test, ANOVA, Tukey HSD) tests. The use of non-parametric statistical tests will be noted when appropriate.

The use of multiple statistical tests inflates the overall probability of committing a type-1 error; i.e., of incorrectly rejecting a null hypothesis within the entire group of tests. To correct for multiple test probabilities we used the sequential Bonferroni adjustment (Holm, 1979; Rice 1989) to establish a tabular level of statistical probability. In the sequential Bonferroni, the initial probability (P) of significance at the $\alpha = 0.05$ level is

$$P_1 = \mathrm{a/k} \qquad (1)$$

where k is the number of statistical tests. The results of all tests are ordered by their P-value from lowest to highest If the test that yields the lowest P is less than a/k it is considered significant. P_2 is then calculated as

$$P_2 = \mathrm{a/k\text{-}1} \qquad (2)$$

and used to test for significance of the test with the second lowest P. If that value is less then a/k-1 the result is considered significant. This process is iteratively applied to all P-values proceeding from lowest to highest until the next test in the progression exceeds P_i. It and all other remaining tests with higher P values are considered non-significant at the table-wide a level of 0.05. The advantage of the sequential Bonferroni is that it has greater statistical power than the standard Bonferroni method (e.g., a/k for all tests). The results of all statistical tests are presented in terms of their inherent P-value and in terms of Bonferroni tabular levels of statistical probability

Outlying Data

The general weight-to-length relationship in fishes is logarithmic and for a group of individuals it is common to express this relationship in linear terms by regressing $\log_e$-transformed values of weight against length:

$$\log_e(W_i) = \log(a) + b \log_e(L_i) + e_i \qquad (3)$$

where W_i is weight in grams, L_i is length in mm, a and b are regression parameters, and e_i is the error term (Ricker 1975). $\log_e$-transformation also normalizes data and corrects for unequal error variances such that data meet the assumptions of linear regression analysis (Neter et al. 1989). Resultant linear models can then be compared to determine if there is a difference in the weight-to-length relationships among different populations or if there are temporal changes in condition within a population (e.g., Analysis of Covariance [ANCOVA]). Outliers, data points that are inordinately different from the main body of data, can reduce the power of statistical tests by increasing the standard error of the parameter estimates (Neter et al. 1989). Outlying data are a reality of non-automated field surveys and can result from simple recording, transcription, or data entry errors. To adjust for this problem, $\log_e$-transformed data sets were first screened for outlying *x*- and *y*-observations by the methods described by Neter et al. (1989). Outlying *x*-observations in the regression analysis were identified by leverage values greater than $2p/n$, where p is the number of parameter estimates (in this case $p = 2$) and n is the number of observations. Outlying *y*-observations were identified by studentized deleted residuals =1.96 SD ($\alpha = 0.05$) from the *t*-distribution. Outliers were then deleted from the data set.

Some argue that outliers may convey significant information. Our position is that, overall, outliers can do more to obscure significant information, trends and relationships. This is particularly true given the human component of fishery surveys. In the following text, the number of deleted outliers is identified in every case.

Terminology

The following are brief descriptions of the four principal life history patterns exhibited by fishes of the Beaufort Sea (Table 1).

Anadromous Fishes – Anadromous fishes are hatched and initially reared in freshwater river systems before migrating to sea where they spend most of their lives before returning to their natal streams as adults to spawn (e.g., salmon). Arctic cisco are considered anadromous because, although they overwinter in major river systems, non-spawners are believed to remain in brackish water deltas and do not move far upriver into strictly freshwater habitats.

Amphidromous Fishes – Amphidromous fishes cycle annually between freshwater and coastal marine environments. They spawn and overwinter in rivers and streams but migrate out into coastal waters for several months each summer to feed. The advantage of amphidromy is that it enables fish to take advantage of the more plentiful food resources that are present in Arctic coastal waters during summer.

Freshwater Fishes – Freshwater species largely remain within river, stream, and lake systems year round, although they may venture out during summer into coastal areas where waters are brackish.

Marine Fishes – Marine fishes spend their entire lives at sea, although some species may migrate into nearshore coastal waters during summer.

RESULTS AND DISCUSSION

Meteorology

Wind data collected by the National Weather Service (NWS) at the Deadhorse Airport are recorded in terms of compass bearing and speed. The NWS typically records a meteorological observation at 53 minutes past the hour, 24 hours a day. During periods of inclement weather, additional meteorological observations, at times 5-6 within a 60 minute period, may be recorded. In all cases, the wind database obtained from the Arctic Climatic Data Center of the NWS, Asheville, NC, was culled so that there was only a single observation per hour. This was the observation at xx:53 minutes or the closest there about (the observer may be off by several minutes). All other observations were deleted. For example from 0100 h on 1 July through 2400 h on 31 August, there are 1488 hourly observations (24 per day x 31 days per month x 2 months) in the modified database. Culling the non-standard data prevents weighing average wind conditions in favor of unequal sampling effort.

NWS wind data in polar coordinates (x, Ø) were converted to linear coordinates (x, y) with the ordinate (x) representing the east/west wind component and the abscissa (y) representing the north/south wind component. The east/west wind component is the principal force that drives many of the physical features (Mangarella et al. 1982; Savoie and Wilson 1983, 1986; Niedoroda and Colonell 1990a, 1990b) and biological systems (Fechhelm and Griffiths 1990; Fechhelm et al. 1994; Griffiths et al. 1992) of the nearshore Beaufort Sea and has been a key diagnostic parameter for interpreting data collected during fish monitoring surveys (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987; Glass et al. 1990; LGL 1990, 1991, 1992, 1993, 1994a, 1994b, 1999a, 1999b; Reub et al. 1991; Griffiths et al. 1995, 1996, 1997 and Fechhelm et al. 2001).

Wind conditions during July-August 2003 differed substantially from those the previous two and a half decades. Whereas the predominant wind direction along the Beaufort Sea coast has historically been from the northeast, net winds in 2003 blew out of the northwest with an average easterly speed of 2.2 km/h (Figure 4). From 1976-2003, net westerly winds have occurred only in 1981 and 2002. The west winds that have characterized 2002 and 2003 may reflect broader climatic shifts that have been documented throughout the Arctic in recent years (Carmack and Macdonald 2002).

Coastal wind patterns for the sampling season consisted of oscillating periods of east and west winds with events lasting from 3 to 10 days (Figure 5). West winds dominated the summer through 8 August. The remainder of August was characterized by the usual northeast winds.

Table 1. Life-history classification for the fish species collected during the 2003 monitoring program.

Type	Common Name	Scientific name	Inupiat Name
Anadromous Species	Arctic cisco	*Coregonus autumnalis*	Qaataq
	Bering cisco	*Coregonus laurettae*	Tiipuq
	Rainbow smelt	*Osmerus mordax*	Ilhaugniq
	Chum salmon	*Oncorhynchus keta*	Iqalugruaq
	Pink Salmon	*Oncorhynchus gorbuscha*	Amaqtuuq
Amphidromous Species*	Broad whitefish	*Coregonus nasus*	Aanaakliq
	Least cisco	*Coregonus sardinella*	Iqalusaaq
	Humpback whitefish	*Coregonus pidschian*	Piquktuuq
	Dolly varden	*Salvelinus malma*	Iqalukpik
Freshwater Species	Arctic grayling	*Thymallus arcticus*	Sulukpaugaq
	Round whitefish	*Prosopium cylindraceum*	Savigunnaq
	Ninespine stickleback	*Pungitius pungitius*	Kaklalisauraq
	Threespine stickleback	*Gasterosteus aculatus*	
Marine Species	Fourhorn Sculpin	*Myoxocephalus quadricornis*	Kanayuq
	Arctic flounder	*liopsetta glacialis*	Puyyagiaq
	Arctic cod	*Boregogadus saida*	Iqalugaq
	Saffrom cod	*Eleginus gracilis*	Uugaq
	Capelin	*Mallotus villosus*	Panmigriq
	Pacific herring	*Clupea harengus*	Uqsruqtuuq
	Kelp Snailfish	*Liparis tunicatus*	

* Have some components of their populations that remain in freshwater year round

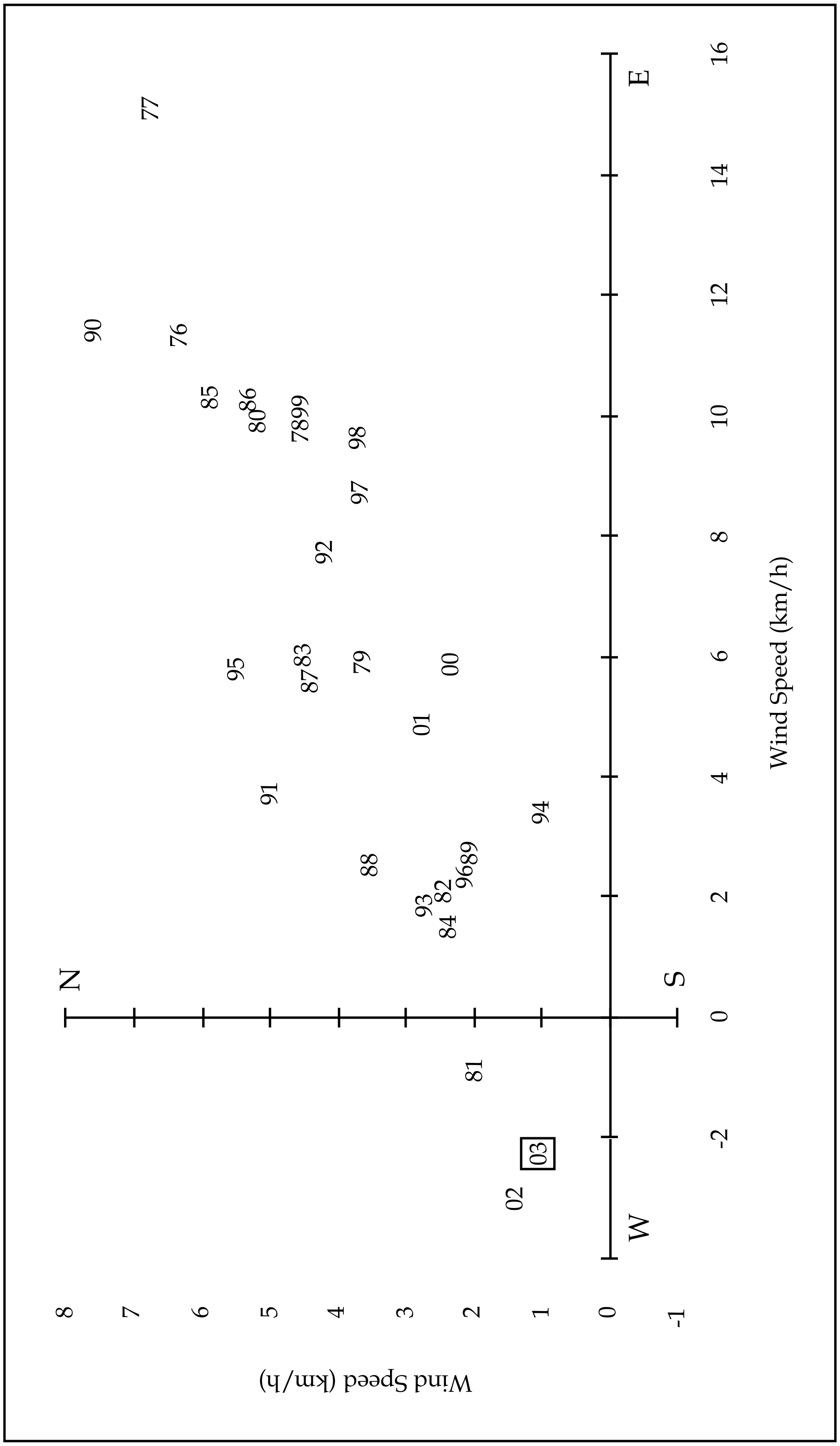


Figure 4. Mean hourly winds speed by year from 1976 to 2003 for the period 1 July-31 August. Data are expressed in rectangular coordinates with the ordinate (*x*) representing the east/west wind component and the abscissa (*y*) representing the north/south component. Data for summer 2003 are highlighted. Data were collected at the Deadhorse Airport, Deadhorse, Alaska, by the National Weather Service. The icon for 1999 (9.7 km/h) is displaced slightly to the left by the 1978 icon.

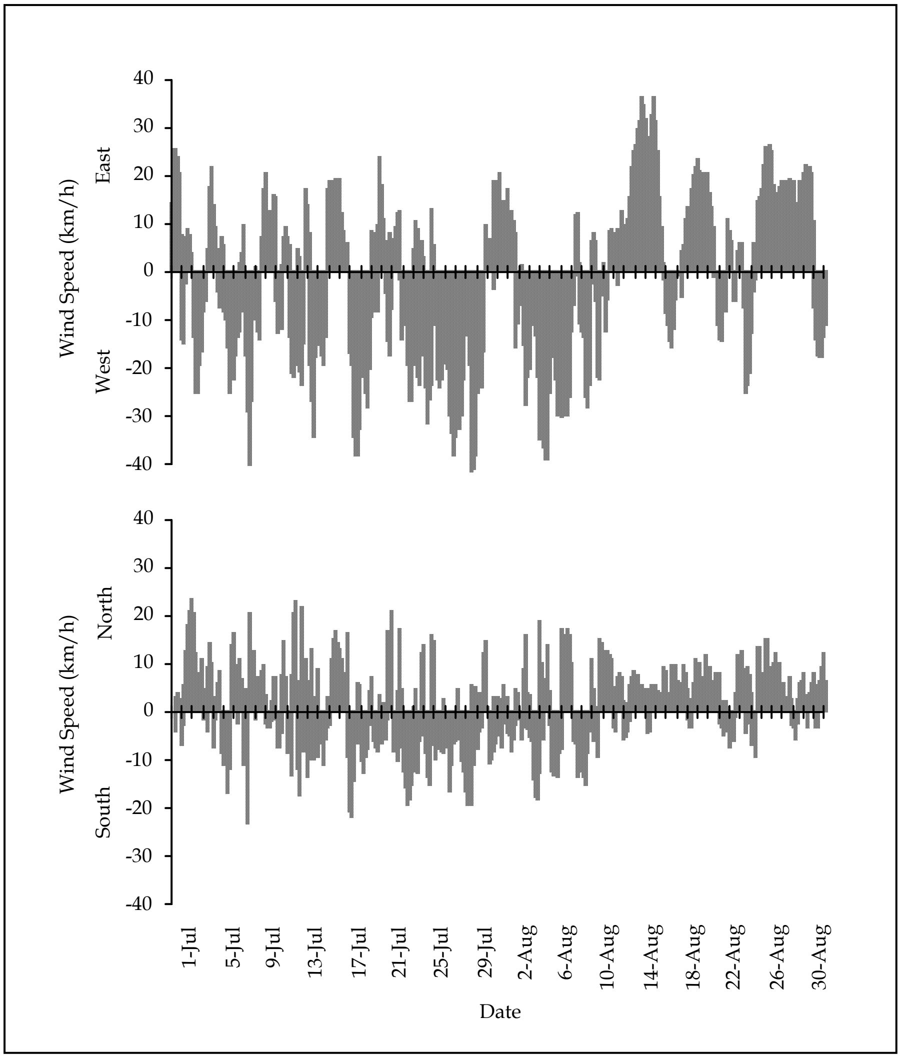


Figure 5. Hourly east/west (top panel) and north/south (bottom panel) wind speeds recorded at the Deadhorse Airport, Deadhorse, Alaska, by the National Weather Service for 2003.

Hydrography

Background. Summer hydrographic patterns along the Beaufort Sea coast are well documented (Mangarella et al. 1982; Savoie and Wilson 1983, 1986; Hachmeister et al. 1987; Niedoroda and Colonell 1989, 1990a, 1990b). In early summer, river runoff and the melting of sea ice creates brackish conditions (low to moderate salinities) in nearshore areas, particularly near the mouths of rivers. Warm river discharge and heating by solar radiation elevates nearshore water temperatures. As the summer progresses, this nearshore coastal band of warm, brackish water begins to deteriorate as it mixes with the vast sink of cold, arctic marine water. By late summer, rapidly decreasing daylight, decreased river discharge, and the mixing with ocean water all contribute to the dissipation of the warm, brackish nearshore band. Nearshore waters remain cold and saline until the September freeze and the onset of winter.

Within this general seasonal pattern, localized hydrography can be affected by bathymetric, topographic, and meteorological conditions. Nearshore coastal currents along the Beaufort Sea coast are governed primarily by winds. East winds generate westerly flowing surface currents that are deflected offshore in response to Coriolis forces (Niedoroda and Colonell 1990a, 1990b). The offshore deflection of surface waters causes a depression in sea level (negative storm surge), which is partially compensated for by an onshore movement of underlying marine water sometimes referred to as the “marine wedge.” Conversely, west winds cause surface currents to flow eastward with a resultant onshore Coriolis deflection. The onshore transport of surface waters is balanced by a seaward movement of the marine wedge, resulting in regional down welling along the coast. In general, west winds keep warm, brackish water nearshore and colder marine water offshore, whereas east winds have the opposite effect causing warm, brackish surface water to flow offshore and cold marine bottom water to flow onshore. This wind-driven interplay between both water masses is modified locally by the presence of rivers and protected barrier-island lagoons.

Summer 2003. In general, hydrographic patterns were fairly typical for the nearshore Beaufort Sea during summer. Low salinities characterized early summer, with water becoming more saline as the season progressed (Figure 6). Except for a week-long period in early August and another near the end of the month, the Sagavanirktok River discharge kept salinities low at Station 230. In typical fashion, salinities in the delta (Nets 214 and 230) generally remained lower than those at Nets 218 and 200 located closer to West Dock and away from the direct influence of the Sagavanirktok River plume. Water temperatures fluctuated in July and reached seasonal highs of 12-13°C on 21-23 July. Thereafter they declined rapidly and remained below 8°C for the remainder of the summer.

From a historic perspective, the strong west winds in July helped to keep nearshore salinities quite low. Salinity at Stations 218 and 220, those out of the direct influence of the Sag plume, usually increase rapidly in early July (Figure 7). In 2003, salinity at Station 220 remained at or below 5 ppt until 27 July. After a rapid increase, salinities still tended to remain below 20-22 ppt for the remainder of the summer. Salinity at Station 218 rose gradually throughout July ending at levels of 10 to 12 ppt. There was a big dip in salinity in mid-August in conjunction with east winds and the westward deflection of the Sag plume into the Station 218 area. The low July salinities are discussed in subsequent sections as they relate to seasonal fish catch.

Station 218. Hydrographic data have been collected at Station 218 located on the western shore of Prudhoe Bay in 18 of the past 21 years, far more than any other location in the region. Data from this site have been used to analyze long-term patterns in water temperature and salinity at Prudhoe Bay. Prior to 1988, only surface water hydrography was measured in conjunction with the daily fyke net sampling. After 1988, hydrography was measured at the surface and at every subsequent 0.5-m-depth increment down to the bottom (i.e., 0.5 m, 1.0 m, etc.). Because of the shallow depths (typically about 0.5 m), there was little stratification at the Station 218 net site: paired

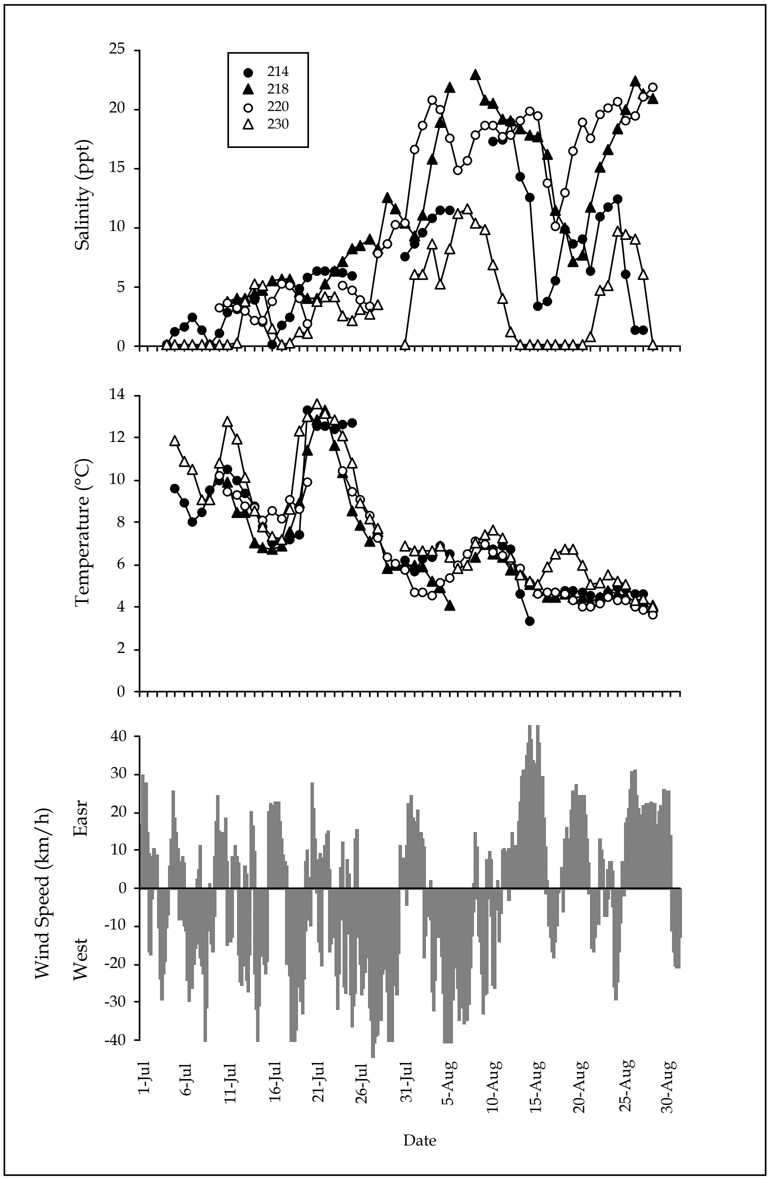


Figure 6. Smoothed (3-point average) daily depth-averaged salinity and temperature values by station for 2003 along with daily east/west wind speeds.

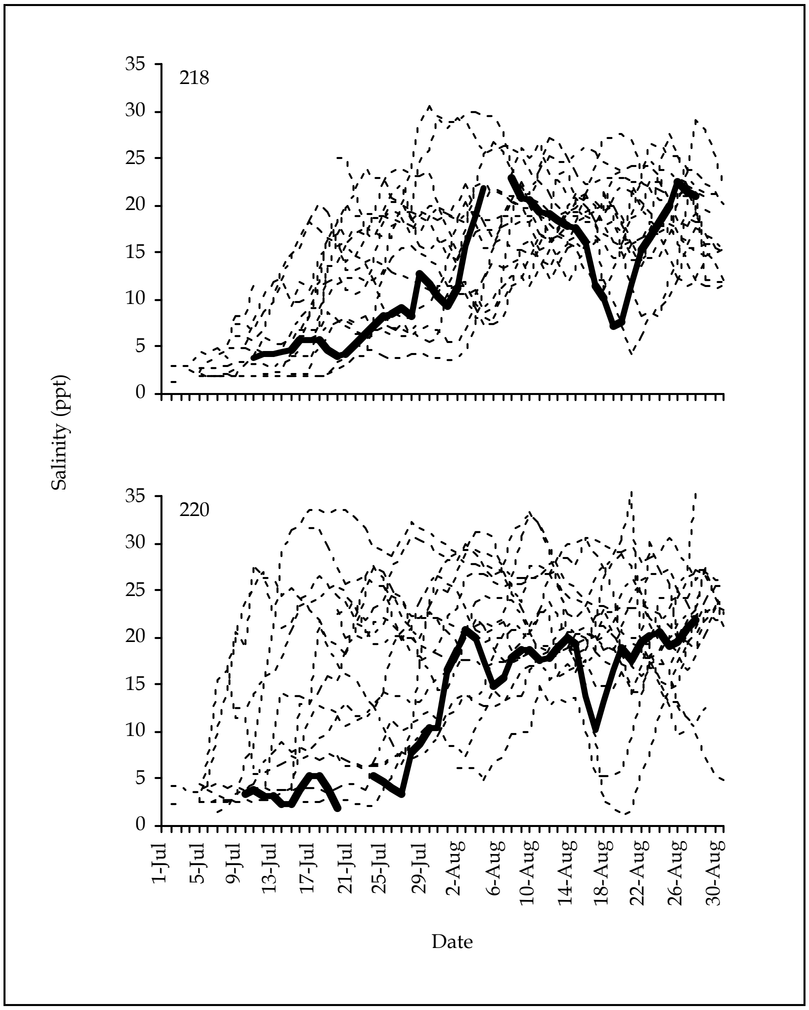


Figure 7. Smoothed (3-point average) daily depth-averaged salinity values (ppt) for stations 218 and 220 for the years 1986-1998 and 2001-2003. Only surface measurements were taken prior to 1986. Bold black line denoted 2003 data. Data indicate that nearshore salinities in 2003 were at the low end of the expected range for the month of July.

comparisons of surface versus bottom water measurements pooled from all years after 1987 indicated no significant difference in temperature (P = 0.06, n = 527; paired t-test) with depth. Surface water temperatures were therefore analyzed for the 21-year period from 1981–2003 (there were no studies in 1999 and 2000) to maintain continuity among years. Hydrographic data for the years 1981-1984 were obtained from the following reports: Griffiths and Gallaway (1982) for 1981, Critchlow (1983) for 1982, Biosonics (1984) for 1983, and Moulton et al. (1986) for 1984.

At Site 218, water temperature in early July can be quite variable from year to year. West Beach is an exposed area of coastline and during periods of east winds drift ice accumulates along the shore. In years of early ice breakup or when winds prevent ice accumulation, July water temperature in western Prudhoe Bay can rise rapidly in response to river discharge and solar heating. In summers when breakup is late or there is heavy ice accumulation, water temperature can remain depressed later into the summer. In general, drift ice is gone from coastal areas of Prudhoe Bay by mid July. The second feature of seasonal water temperatures in Prudhoe Bay is the relatively rapid decline that occurs in the last two weeks of August. Decreased solar heating and river discharge, and continued mixing with offshore marine water, accelerate the dissolution of the nearshore warm-water band. To eliminate the effects of major early and late summer shifts in coastal hydrography that are characteristic of the seasonal cycle, we limited temperature data to measurements taken during mid summer from 20 July–15 August (Fechhelm et al. 2003). This appeared to be the most stable period of the open-water season.

Autocorrelation analysis of hydrographic data from the Prudhoe Bay studies indicates that concurrent daily observations are not independent of each other but that they are after two days (Fechhelm et al. 2001). To circumvent the problem of non-independence, only hydrographic measurements taken every other day within each year were used in the analysis.

A least squares regression of water temperature against year (years indexed as 1 to 23) yielded a significant (P <0.006) positive linear relationship over the 23 years from 1981 to 2003 (Figure 8). The regression was not significant at adjusted Bonferroni tabular levels of statistical probability. The adjusted R^2 = 0.029 indicated that the linear model explained only about 4% of the variance in water temperature; however, this is not surprising given the considerable variation that occurs both within years and among years. A least squares regression of salinity against year also yielded a significant (P < 0.008) positive linear relationship, however the regression also was not significant at adjusted Bonferroni tabular levels of statistical probability. Again, the model explained only about 3% of the variance. The regression analysis initially identified seven data points as outliers. Each data point was examined in the context of the specific year in which it occurred. In all cases, the data point seemed reasonable for water quality conditions in the specific year. For example, the highest temperature reported for 1981 (11.5°C; see Figure 8) was identified as an outlier for the full regression analysis but did not seem unreasonable relative to the distribution of temperature measurements reported for 1981. Outliers, therefore, were not removed from the regression analysis.

Whether the subtle increase in temperature and salinity detected at Station 218 reflects a real shift in hydrographic conditions at Prudhoe Bay over the course of two decades, or are merely chance results of a highly variable system, is unknown. Hydrographic surveys have never been the main focus of fish monitoring studies. Data have been collected to provide a broad picture of water quality conditions that are used as a diagnostic to help explain the movement and growth patterns of arctic fishes. The techniques employed for collecting data are far from the sophisticated and rigorous methods that would be employed in a focused hydrographic program. On the other hand, it seems unreasonable to expect any ecological system to remain completely static over the long term and, at minimum, subtle long-term oscillations should be expected.

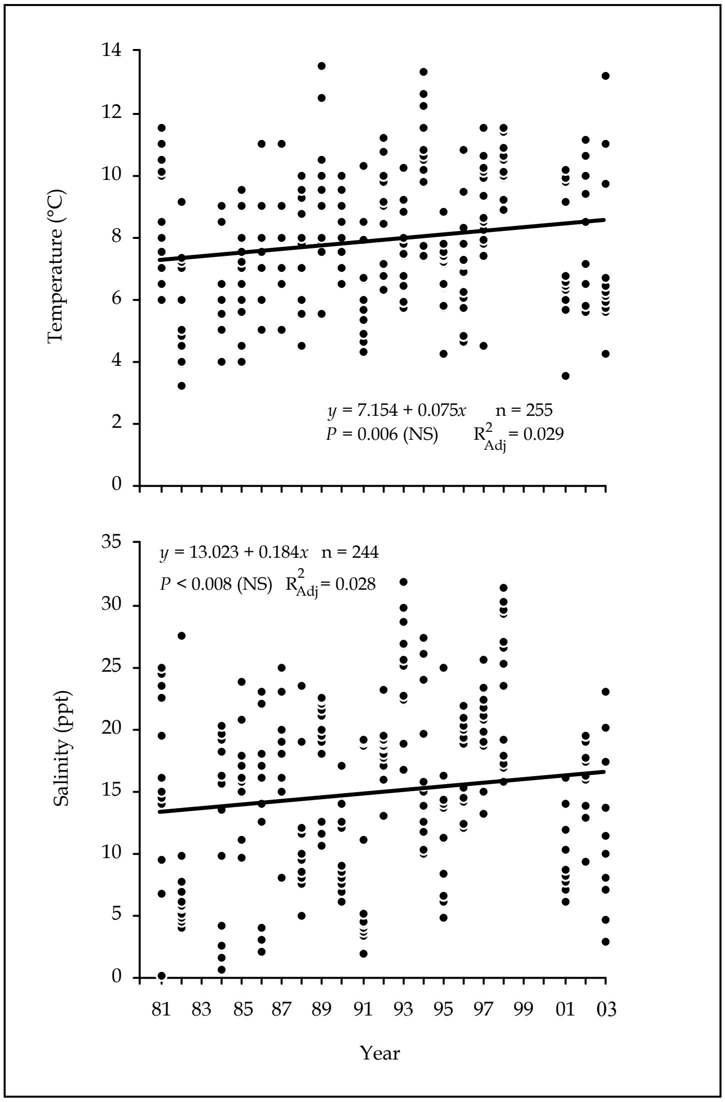


Figure 8. Daily surface temperature and salinity by year for Station 218. Least squares regressions are superimposed. Daily temperature and salinity values are restricted to the common time frame 20 July-15 August of each year (see text). NS indicates non-significance at adjusted Bonferroni tabular levels of statistical probability.

Fishing Effort

A total of 156.4 net-days of fishing effort was expended during the 2003 study (Appendix Table A1). Station 230 was initially set along the Endicott Causeway on 29 June. Ice moved out from the Heald Point area on 4 July and Net 214 was set the following day. Waters in western Prudhoe Bay and around West Dock first became ice-free on 11 July and Nets 218 and 220 were subsequently set on successive days. Fishing had to be halted several times during the summer in conjunction with weather-related events. East wind storms destroyed the entire fyke net at Heald Point Station 214 on 25 July and on 27 July Net 230 went down. Conditions eased on the evening of 31 July and both nets were reset. A second east wind event and resultant strong currents destroyed Net 214 again on 5 July and it was not reset until 10 August.

Species Composition

A total of 114,854 fish representing 20 species, 8 families, and 6 orders were collected during the study (Tables 2 and 3). Three marine species—Arctic cod, fourhorn sculpin, and Arctic flounder—accounted for over half of the total catch.

Fyke Net Fish Mortality

A total of 6,071 mortalities were recorded for 2003; the highest mortalities were for Arctic cod and rainbow smelt (Table 4). Rainbow smelt and Arctic cod typically suffer high mortality in the fyke nets (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987; Glass et al. 1990; LGL 1990, 1991, 1992, 1993, 1994a, 1994b, 1999a, 1999b; Reub et al. 1991; Griffiths et al. 1995, 1996, 1997 and Fechhelm et al. 2001).

Arctic Cisco

Background. Arctic cisco of the Alaskan Beaufort Sea are believed to originate from spawning grounds in the Mackenzie River system of Canada (Gallaway et al. 1983, 1989; Bickham et al. 1989; Morales et al. 1993). In spring, newly hatched young-of-the-year (age-0) fish are flushed down river to ice-free coastal waters adjacent to the Mackenzie Delta. In summers characterized by strong and persistent east winds, large numbers of these fish are transported westward by wind-driven coastal currents (Gallaway et al. 1983; Fechhelm and Fissel 1988; Moulton 1989; Fechhelm and Griffiths 1990; Schmidt et al. 1991; Underwood et al. 1995; Colonell and Gallaway 1997). Once in Alaska, they take up overwintering residence in some of the larger North Slope drainages like the Colville and Sagavanirktok rivers (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987; Glass et al. 1990; LGL 1990, 1991, 1992, 1993, 1994a, 1994b, 1999a, 1999b; Reub et al. 1991; Griffiths et al. 1995, 1996, 1997 and Fechhelm et al. 2001). Although the Sagavanirktok River may provide overwintering habitat for juvenile fish during their first 2–3 years, the Colville River is the only Alaskan drainage large enough to support populations of sub adult and adult Arctic cisco throughout the winter (Schmidt et al. 1989, Adams and Cannon 1987). The Colville River population supports the subsistence fishery at Nuiqsut and the commercial fishery that operates in the lower Colville Delta (Moulton 1994, 1995; Moulton and Field 1988, 1991, 1994; Moulton al. 1992, 1993). Arctic cisco typically enter both fisheries at about age 5 to 6 and are generally caught from ages 5 to 8. Arctic cisco remain in the Colville River until the onset of sexual maturity beginning at about age 7, at which time they are believed to migrate back to the Mackenzie River to spawn (Gallaway et al. 1983).

Based upon the size structure of the Arctic cisco population in Prudhoe Bay (Figure 9), analysis has historically focused on four size cohorts. The three smallest age groups can be delineated by size, and aging analysis (using saggital otoliths) has repeatedly confirmed that these age cohorts represent age-0 (young-of-the-year), age-1, and age-2 fish (LGL 1988, 1989, 1990, 1991, 1992, 1993). Beyond age-2, the length distributions of individual age classes begin to overlap and often cannot be distinguished. This fourth age cohort is therefore designated as age-3+.

Table 2. Fish species collected during the 2003 Beaufort Sea study.

Clupeiformes
- Clupeidae
  - Pacific herring - Clupeia pallasi

Salmoniformes
- Osmeridae
  - Rainbow smelt - Osmerus mordax
  - Capelin - Mallotus villosus
- Salmonidae
  - Arctic cisco - Coregonus autumnalis
  - Broad whitefish - C. nasus
  - Least cisco - C. sardinella
  - Humpback whitefish - C. pidschian
  - Dolly Varden - Salvelinus malma
  - Bering cisco - C. laurettae
  - Round whitefish - Prosopium cylindraceum
  - Chum salmon - Oncorhynchus keta
  - Pink Salmon - O. gorbuscha
  - Arctic grayling - Thymallus arcticus

Gadiformes
- Gadidae
  - Arctic cod - Boreogadus saida
  - Saffron cod - Eleginus navaga

Gasterosteiformes
- Gasterosteidae
  - Ninespine stickleback - Pungitius pungitius
  - Threespine stickleback - Gasterosteus aculeatus

Scorpaeniformes
- Cottidae
  - Fourhorn sculpin - Myxocephalaus quadricornis
- Cyclopteridae
  - Liparis sp. - snailfish

Pleuronectiformes
- Pleuronectidae
  - Arctic flounder - Pleuronectes glacialis

Table 3. Species composition by net for fish collected during the 2003 Beaufort Sea fish monitoring study.

	Station				
Common Name	214	218	220	230	Total
Arctic cod	1,997	28,946	2,526	4,892	38,361
Least cisco	5,011	9,602	7,910	7,041	29,564
Fourhorn sculpin	3,374	4,220	1,351	2,608	11,553
Arctic flounder	4,081	2,756	2,120	1,911	10,868
Broad whitefish	2,315	490	493	3,926	7,224
Arctic cisco	936	1,191	2,305	1,131	5,563
Rainbow smelt	1,427	1,625	678	1,140	4,870
Humpback whitefish	465	914	1,492	557	3,428
Dolly Varden	590	155	102	750	1,597
Round whitefish	84	18	8	825	935
Ninespine stickleback	234	44	15	76	369
Saffron cod	14	148	40	48	250
Pacific herring	18	42	22	9	91
Snailfish	6	20	30	0	56
Threespine stickleback	17	9	8	6	40
Pink salmon	9	6	5	9	29
Capelin	6	14	7	2	29
Arctic grayling	11	1	1	9	22
Chum salmon	2	1	1	0	4
Bering Cisco	0	1	0	0	1
Total	20,597	50,203	19,114	24,940	114,854

Table 4. Fyke net mortalities by species for the 2003 Beaufort Sea study.

Species	Number	Total Catch	Percent of Total Catch
Arctic cod	4,178	38,361	10.9
Rainbow smelt	851	4,870	17.5
Least cisco	361	29,564	1.2
Broad whitefish	332	7,224	4.6
Fourhorn sculpin	174	11,553	1.5
Round whitefish	59	935	6.3
Arctic flounder	36	10,868	0.3
Arctic cisco	30	38,361	0.1
Humpback whitefish	27	3,428	0.8
Dolly Varden	8	3,428	0.2
Ninespine stickleback	6	369	1.6
Pacific herring	5	91	5.5
Saffron cod	4	250	1.6
Total	6,071		

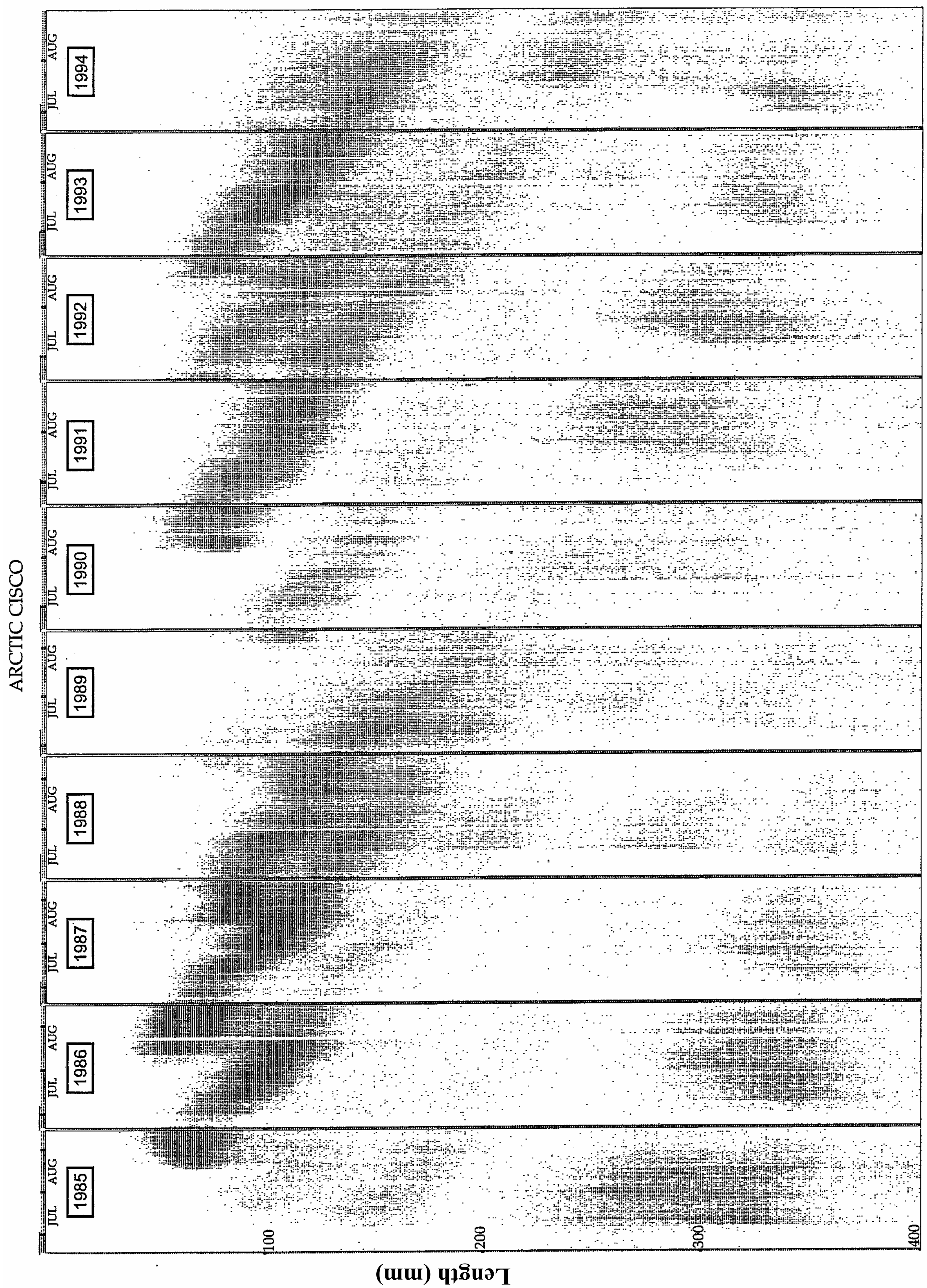


Figure 9. Length distributions by date and year for Arctic cisco. See Explanation of Graphics in Methods Section.

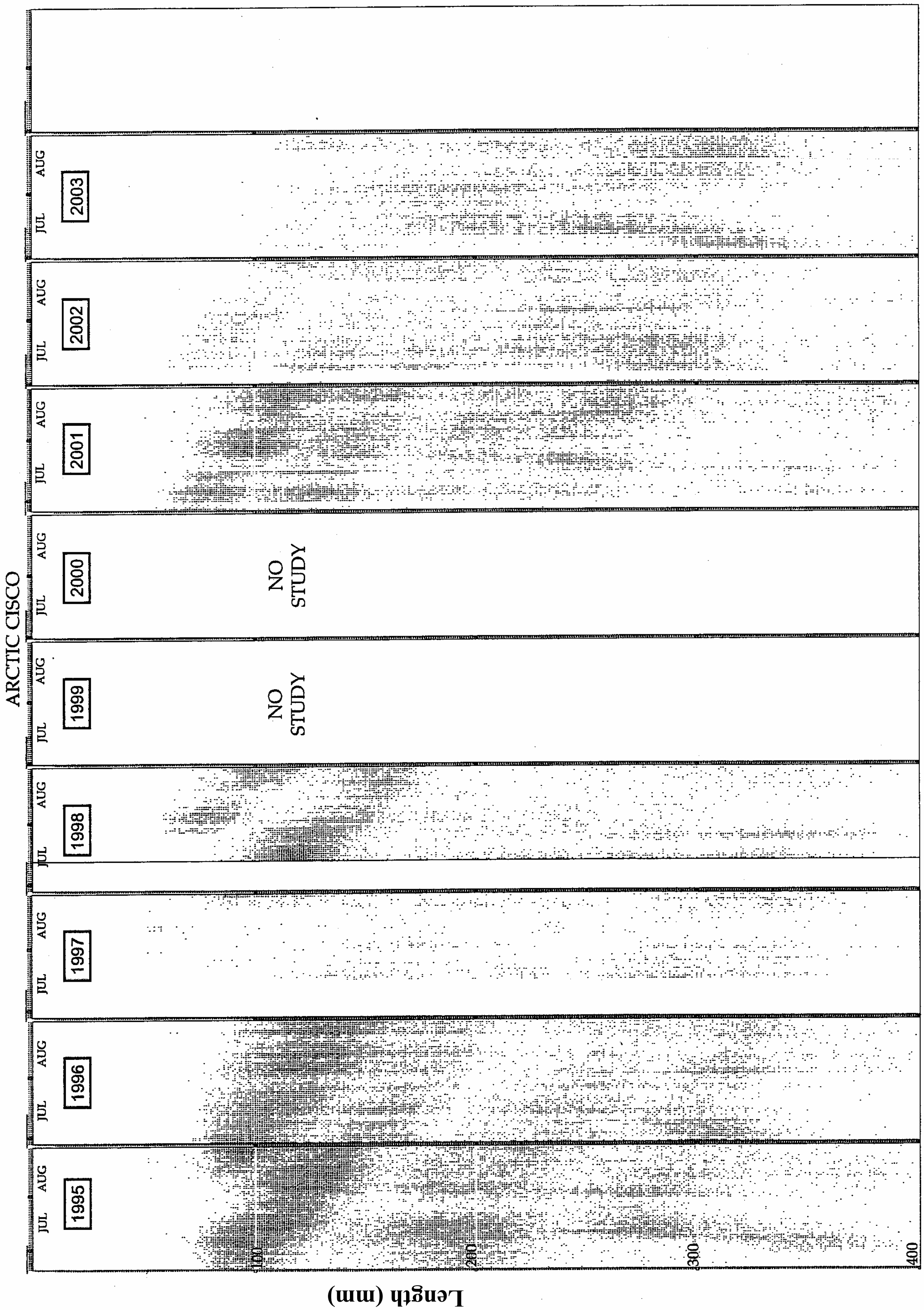


Figure 9. Continued

Figure 10 illustrates the length distribution data for 2003. In 2001 and 2002 there were no major recruitments of Arctic cisco from Canada. This resulted in very few age-1 and age-2 fish in the Prudhoe Bay area during 2003. Because of these low numbers of fish, we were unable to distinguish among the different size cohorts. Based upon historical patterns and the results of the otolith aging analysis, we delineated Arctic cisco into only two cohorts: fish younger than 3 years of age and fish 3 years and older. This delineation is not as clear cut as it has been in the past but is a reasonable estimate based on historic patterns.

Cohort 1 (0-2 years). There was no recruitment of young-of-the-year (YOY), or age-0, fish into the Prudhoe Bay area in 2003. The absence of a recruitment was consistent with the unusually high frequency of west winds that characterized the summer. Sustained east winds are necessary to transport fry westward along the coast from spawning grounds in Canada. Historically, good recruitment requires average easterly winds in excess of 5 km/h throughout July and August (Figure 11). Average winds during the summer of 2003 blew out of the west at 2.2 km/h. The possibility of a late recruitment in September is unlikely. Winds during the first half of September blew primarily from the west: from 1-16 September, hourly west winds averaged 11.9 km/h with prolonged periods in excess of 20 km/h. Winds were mixed for the remainder of the month. It is doubtful that Arctic cisco could have been transported to Prudhoe Bay in large numbers under those conditions.

A total of 283 (1.9 fish/net/24 h) age-1 (2002 year class) and age-2 (2001 year class) Arctic cisco were collected in 2003. In terms of seasonal catch, 2003 (1.9 fish/net/24 h) is among the poorest years within the 1985-2003 period of record (Figure 12). The low catch rate is consistent with the absence of a recruitment in 2001 and 2002 (Fechhelm et al. 2001, 2003). The poor recruitment of three consecutive year classes (2001-2003) will have a negative effect on the Colville River subsistence and commercial fisheries beginning in about 2006-2007 when these fish normally would enter as 5- to 6-year-olds (Moulton 2001). Because the fisheries target Arctic cisco ages five through eight, the weak 2001-2003 year classes will adversely affect the fisheries through 2009-2010.

Age 3+. A total of 5,280 age-3+ Arctic cisco were collected in 2003 for an overall seasonal catch rate of 34.8 fish/net/24 h. Most of the fish from this group were caught during the first three weeks of July. CPUE in 2003 was the highest ever recorded over the 1985-2003 period of record (see Figure 12). The implications of this high catch are discussed below in the Age Analysis section.

Age Analysis. Age data were analyzed using age-length keys (Ricker 1975; DeVries and Frie 1996). Age frequency tables are constructed to estimate the number of fish from individual age classes within a population based on a subsample of that population. The approach requires sampling approximately equal numbers of fish from consecutive and equal size intervals that are then aged. Data for the early summer collection period, that lasted from 2-13 July 2003, are presented in Table 5 to illustrate the technique. Of 159 fish collected in the size interval 151-200 mm, 19 were aged by otolith analysis. Of these, 3 (16%) were age-2, 15 (79%) were age-3, and 1 (5%) was age 4. This proportion is extrapolated to the interval catch to yield 25 three-year-olds, 126 four-year-olds, and 8 five-year-olds. The process was repeated for all size groups and then numbers were summed across the entire catch. In this collection period, it is estimated that of 4,438 fish caught, 25 would be age-2, 189 would be age-3, etc. Under the assumption that the catch is representative of the age-3+ population, 1% would be age-2, 4% would be age-3 and so on.

Because age-1 and age-2 cohorts can be isolated and CPUE calculated directly, only individuals from 50-mm size intervals that encompassed the age-3+ cohort were analyzed. This typically began with the 151-200 mm interval in early summer and the 201-250 mm interval in late summer (by late summer most age-3+ fish have grown to greater than 200 mm). It is important to note that total catch for each interval was for the entire 12-day sampling period and not merely the time it took to fill the category. The 20 fish for some size intervals were caught in a single day while

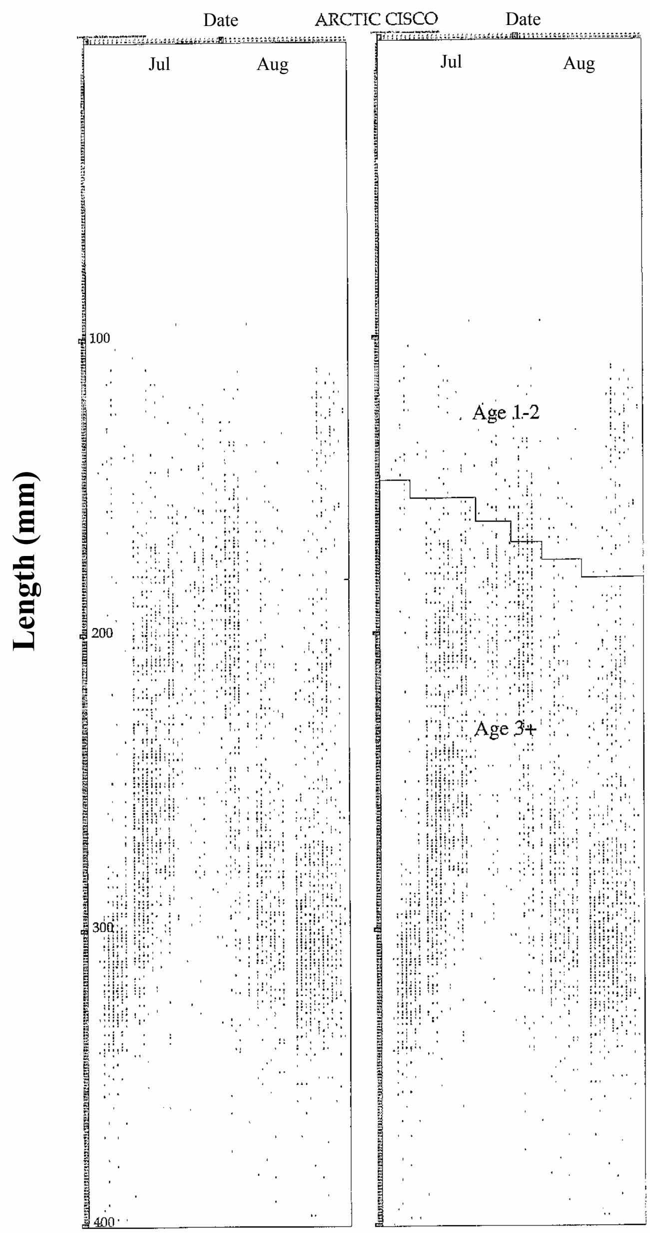


Figure 10. Length distribution by date and year for Arctic cisco. (See Explanation of Graphics in Methods Section). The right-hand panel depicts the breakdown between fish 2-3 year old and fish 3-years-old and older. Age 2 and 3 fish could not be distinguished as individual cohorts and are therefore grouped.

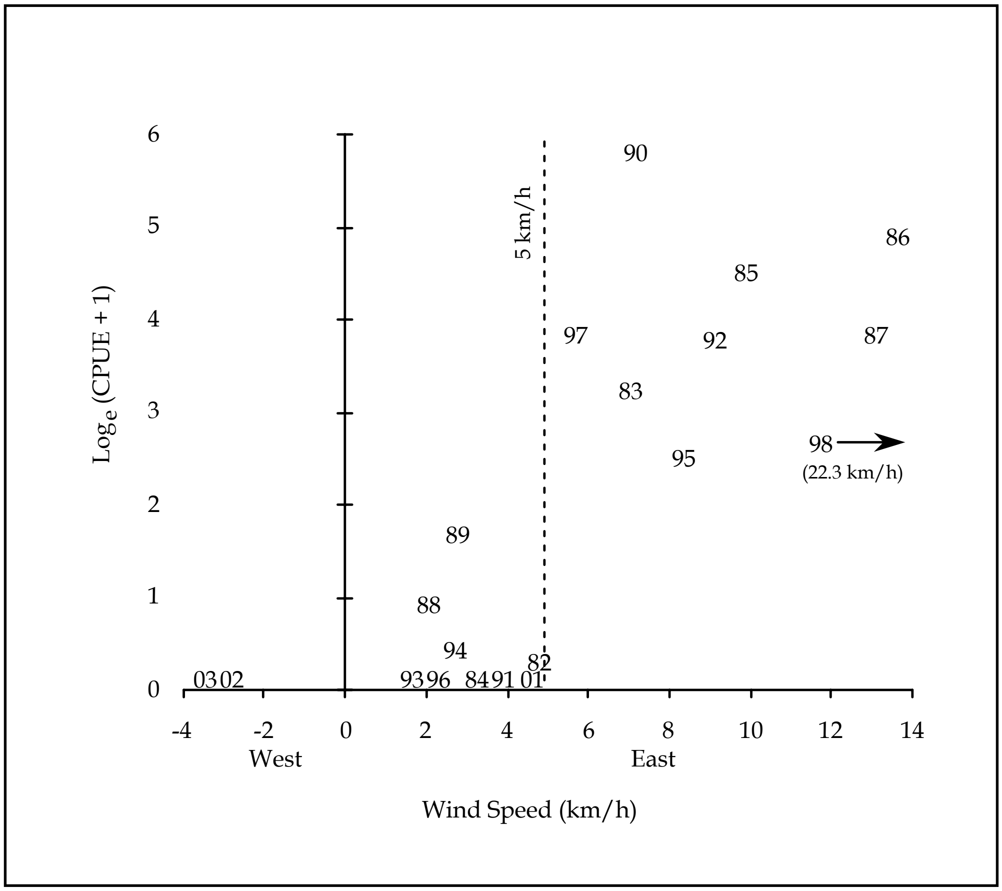


Figure 11. Log$_e$ (CPUE+1) of age-0 Arctic cisco against resultant winds from the Deadhorse Airport for the years 1982-1998 and 2001-2003. The horizontal axis denotes the mean value of the east/west wind component based upon hourly observations calculated from 1 July through the date of arrival of fish at Prudhoe Bay or, in cases when there was no arrival, through the end of the sampling period. CPUE was calculated beginning on the day age-0 fish were first caught. CPUE = 0 when no fish were caught (i.e., 1982, 1984, 1991, 1993, 1996, 2001, 2002, 2003. Note: the "82" icon is raised off the CPUE = 0 line to allow for visibility of the "01" icon (there was no catch in 1982).

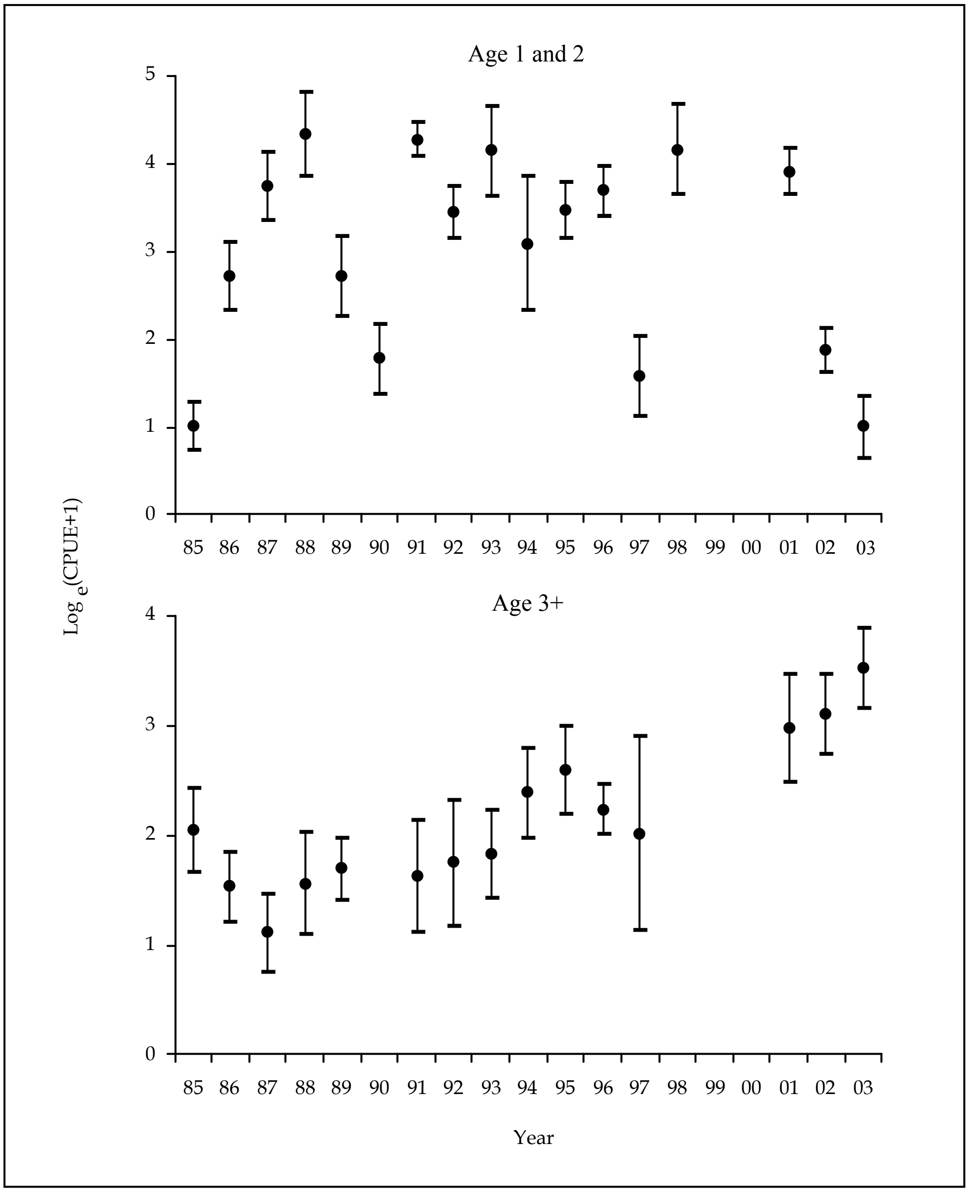


Figure 12. Log$_e$ (CPUE+1) ± 95% CI for age-1 and age-2 combined, and age-3+ Arctic cisco by year.

Table 5. Age-frequency table based upon stratified sampling used to estimate age class strength within the age-3+ Arctic cisco cohort for the early 2-13 July, 2003, dissection period. Aged fish from within each size interval are extrapolated to the total catch within that size interval for the entire 12-day sampling period, then summed across all size intervals. Estimates are rounded to the nearest whole fish.

Size Interval	Total Catch	Age	No. Fish Aged	Percent Each Age	No. Fish
151-200	159	2	3	0.16	25
		3	15	0.79	126
		4	1	0.05	8
201-250	1332	3	1	0.05	63
		4	15	0.71	951
		5	4	0.19	254
		6	1	0.05	63
251-300	1383	4	3	0.14	198
		5	15	0.71	988
		6	1	0.05	66
		7	1	0.05	66
		9	1	0.05	66
301-350	1484	6	21	0.95	1417
		9	1	0.05	67
351-400	128	6	4	0.31	39
		8	3	0.23	30
		9	6	0.46	11

Age	No. Fish	Percent of Population
2	25	0.01
3	189	0.04
4	1157	0.26
5	1242	0.28
6	1585	0.36
7	66	0.01
8	30	0.01
9	144	0.03
Total	4438	

for other intervals the full compliment of 20 fish was never collected over the 12 days. Total catch must be for the full 12-day period (or whatever the length of the collection period is) so that extrapolated values are weighted by catches over a common time period. Because the underlying assumption is that the distribution of ages within a size interval are a random representation of all fish within that interval, data for size intervals in which less than 20 fish were collected were included in the calculations.

Data for the early and late collection periods were pooled to provide a single estimate of age class abundance for the season. The 2003 data were consistent with standard protocol (Ricker 1975; DeVries and Frie 1996). The number of biases inherent in age-length key data has been widely debated (Kimura 1977; Westrheim and Ricker 1978; Bettoli and Miranda 2001). Those associated with calculations such as mean length at age, variance, mortality rates, or extrapolating results from one year to another are not relevant because that was not the goal of our analysis; the 2003 effort was merely to identify the relative strength of different year classes within a single season. However, even the biases associated with age-frequency estimates are subject to debate (Kitchen 1949; Kimura 1977). Bettoli and Miranda (2001) point out that the common practice of fixed-age subsampling (collecting a fixed number of fish from each length group, as in our case) may bias estimates of when many age classes are within a single length interval. Despite these technical pitfalls, the use of fixed-age subsampling age-frequency keys continues to be a widely used tool in fisheries science (Bettoli and Miranda 2001).

For our analysis, age-frequency distributions determined from keys were assumed to be representative of the Alaskan Arctic cisco population for that summer. The second assumption was that seasonal CPUE was representative of the abundance of all age-3+ year classes combined (this is the standard assumption for all CPUE data). Proportionally allocating the seasonal catch rate of the age-3+ cohort among year classes yielded an estimated catch rate for each year class. For example, if the seasonal catch rate of the age-3+ cohort was 10.0 fish/net/day and 20% of the cohort was estimated to be 5-year-olds, then the catch rate of age-5 fish would be 2.0 fish/net/24 h. This overall approach was applied to all years for which life history (i.e., aging) data were collected in 1988–1996 and 2001-2003.

Figure 13 depicts the results of this age-frequency analysis. Note there is a difference between negligible catch and no catch (total absence of data). With the 1992 year class, for example, abundance estimates for this group from age groups 3 and 4 were based on life history data collected in 1995 (age-3) and 1996 (age-4). There are no estimates for this year class from age 5 to 8 because no dissections were conducted during the summers 1997 to 2000. There are estimates for this year class as 9-, 10- and 11-year-olds based upon the resumption of dissections in the 2001, 2002 and 2003 surveys. In another example, estimates for the 1982 year class covering ages 6–11 were available from the 1988–1993 collections; however, CPUE was negligible in all years. In other words, the graphs within Figure 13 each show how that particular year class survived over the succeeding years (e.g., the 1987 year class was well represented over the years, the 1985 year class less so).

There are a number of consistencies in the patterns depicted in Figure 13. Since 1980 (there are no meaningful age data for year classes prior to 1980), the 1981, 1982, and 1984 year classes have been the most poorly represented in the Colville River commercial fishery. The absence of these year classes in Alaska is consistent with poor recruitment in 1981, 1982, and 1984. Their absence is also evident in low CPUE at ages 5–8, the ages when they are most susceptible to the fishery. Similarly, the 1986, 1987 and 1990 year classes were three of the strongest in the fishery and this reflected the good recruitments for each of these years. Each year class appeared to remain strong into the 5- to 8-year-old range.

The principal feature of the age-frequency analysis for 2003 is the dominance of the 1997, 1998, and 1999 year classes relative to the historic record. These results are consistent with estimates reported for the 2001 and 2002 studies (Fechhelm et al. 2001, 2003). Griffiths et al. (2002) also reported that record catches of age-3+

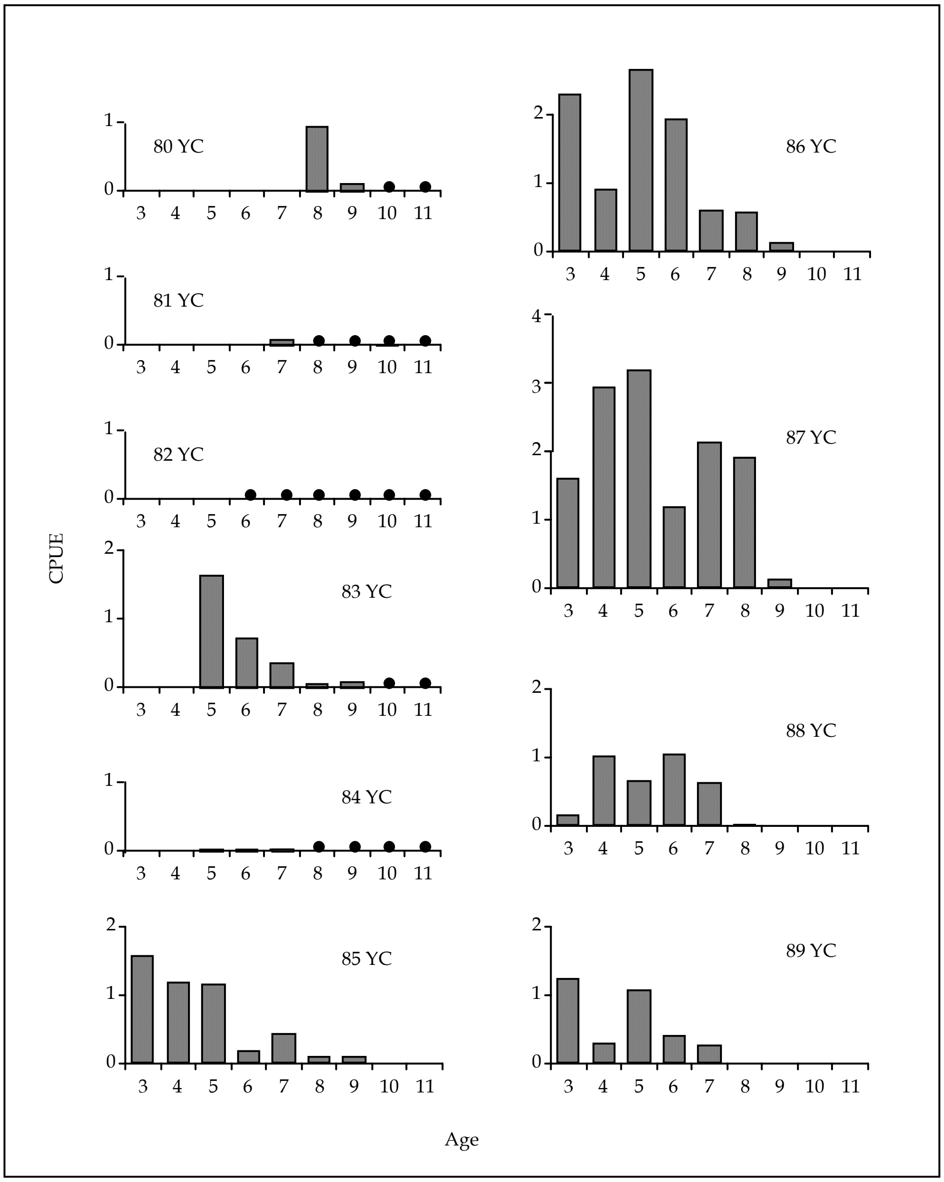


Figure 13. Catch-per-unit-effort (CPUE = fish/net/24 h) for individual year classes (YC) of Arctic cisco by age based upon 1988-1996 and 2001-2003 aging analysis. No histogram means no estimate could be made. Estimates where CPUE is very low to 0 are denoted by the symbol (•). For example, the first panel illustrates how the 1980 year-class was represented in the years 1988-1991; in 1988, the 1980 year-class was age 8 and the catch was approximately 1 fish/net/24 h.

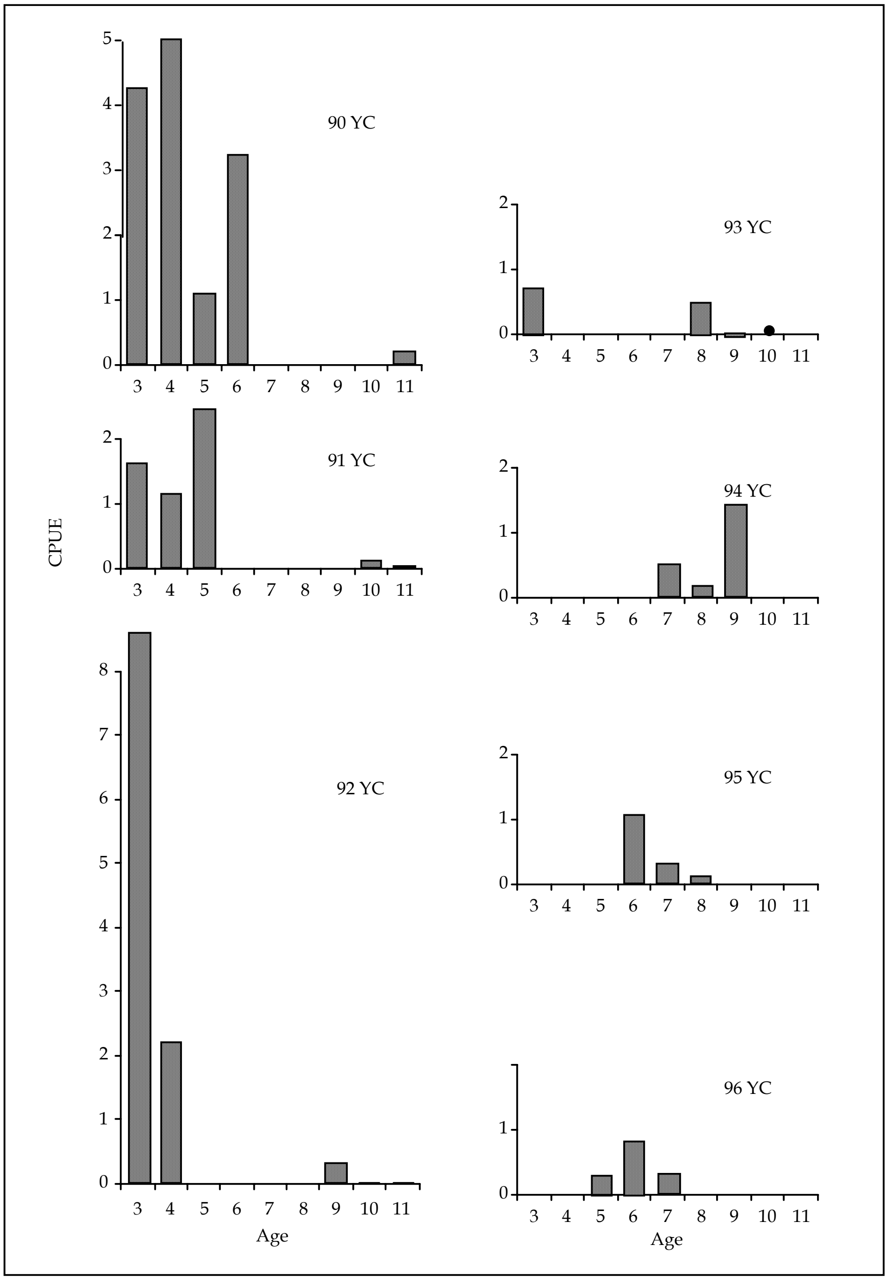


Figure 13. Continued

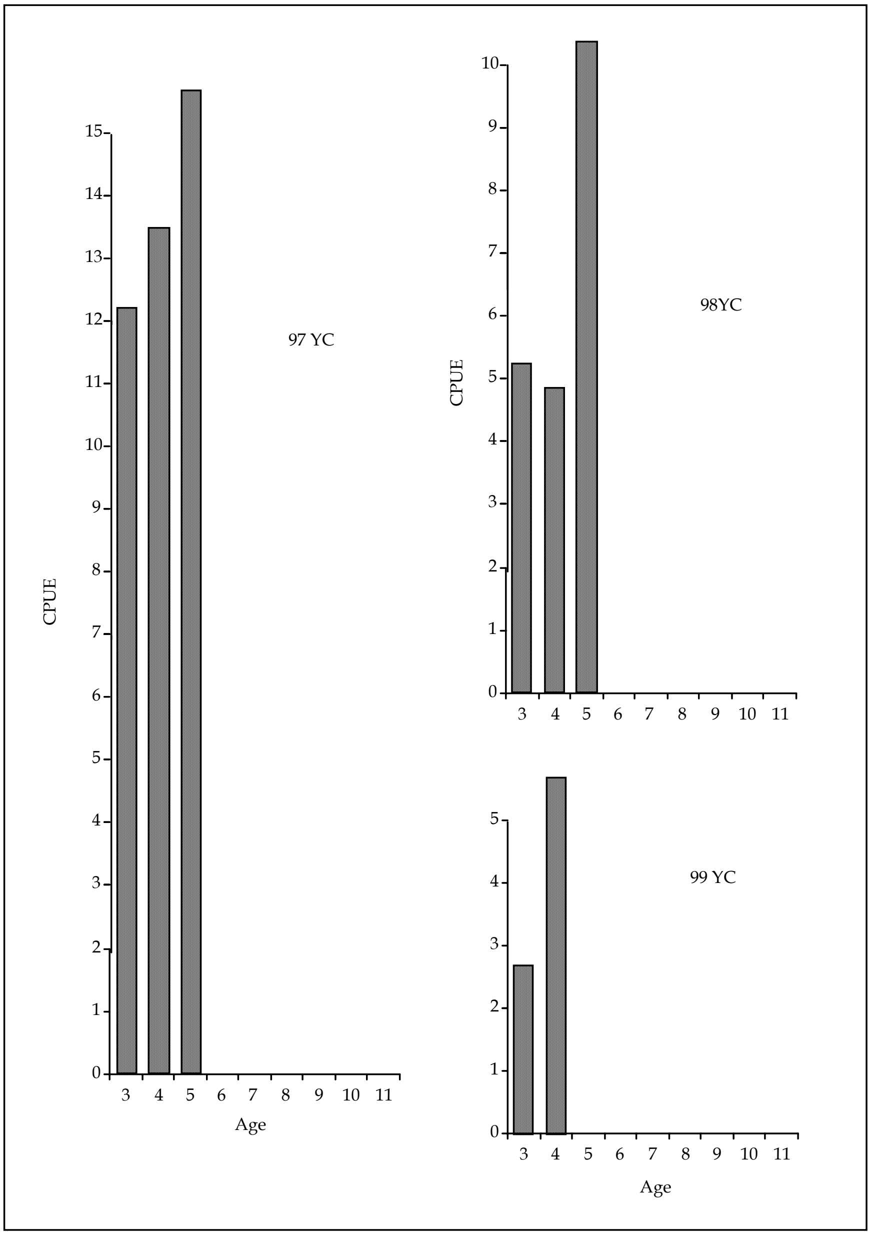


Figure 13. Continued

fish at Point Thomson in 2001 were probably caused by a strong presence of the 1997 year class.

Based upon the 2003 data, we believe that there are three very strong (1997, 1998, and 1999) year classes of Arctic cisco overwintering in the Colville River. Previously, Fechhelm et al. (2001, 2003) predicted that the 1997 year class would enter the Nuiqsut subsistence fishery in the fall of 2002 as 5-year-olds and increase harvests. This did not happen. One suspected reason was that fish may have grown more slowly in recent years and not reached a size that would render them susceptible to the 2002 Nuiqsut gill net fishery. This appears to be the case. Figure 14 illustrates the length at age for Arctic cisco based upon all of the late-summer dissection studies conducted from 1988 through 2003. For example, from 1988 through 1996, age-5 Arctic cisco had annual mean lengths that ranged between about 297 to 316 mm. In 2002 mean length had dropped to 290 mm and by 2003 it was down to 268 mm. Of the six age classes for which there is sufficient data for analysis, four (ages 3-6) have suffered a substantial decrease is size relative to the historic norm. Data imply reduced growth over the past two summers for much of the Arctic cisco population.

Arctic cisco harvests in the Nuiqsut subsistence fishery did increase dramatically in 2003 (L. Moulton, pers. comm., MJM Research) most likely with the entrance of the 1997 year class. Provided the Arctic cisco population remains healthy, the 1997, 1998, and 1999 year classes should keep harvests strong over the next few years.

It is uncertain why the summer growth of Arctic cisco has dropped off so dramatically over the past two years. One possibility is the unusually high frequency of west winds that dominated the summers of 2002 and 2003. Arctic cisco feed primarily on marine invertebrates including mysids, amphipods, and copepods (Cannon et al. 1987a, Knutzen et al. 1990, Knutzen and Jewett 1991). West winds cause surface coastal currents to flow in an easterly direction. This flow is deflected onshore in response to Coriolis forces and results in regional down welling along the coast (Niedoroda and Colonell 1990a, 1990b). The onshore deflection of surface waters causes nearshore water levels to rise (positive storm surge), which is partially compensated for by an offshore movement of underlying marine water (the so called marine wedge). West winds in 2002 and 2003 would have kept marine bottom water, and the marine invertebrate fauna that inhabit it, from moving onshore into coastal shallows. Nearshore consumers can quickly deplete food resources and require substantial and continuous immigration and transport of marine invertebrates into the nearshore zone (Craig et al. 1984). Without a constant replenishment of prey resources, Arctic cisco feeding and growth may have suffered.

Condition. Fish condition is the weight-to-length relationship of an individual fish or group of fishes and is considered a general index of health, fatness, and/or gonadal development (Le Cren 1951). In the Beaufort Sea, summer is the primary feeding season for anadromous and amphidromous fishes and it is a time when individuals achieve most of their yearly growth and accumulate fat and protein reserves (i.e., increase condition) that are needed to survive the arctic winter (Craig 1989). The inability to accumulate sufficient fat reserves in summer could jeopardize winter survival. Accordingly, the condition of key species is measured as part of the Prudhoe Bay fish monitoring surveys in order to measure the success of the feeding season and the potential success of subsequent overwintering.

Techniques for studying condition involve the concepts of the relative condition factor (Le Cren 1951) or relative weight (Wege and Anderson 1978). Both examine the deviation of predicted weight as described by the common weight-length relationship against the actual weight of a fish or group of fishes. A variation of this approach, residual analysis, has been used to study intra- and inter-seasonal changes in the condition of broad whitefish and Arctic cisco in the Prudhoe Bay area (Fechhelm et al. 1995b, 1996). In a linear model, the residual is defined as the difference between the observed value and the fitted value defined by the model (Neter et al. 1989). We use the residual analysis approach described by Fechhelm et al. (1994, 1996) in this report as well as more traditional statistical methods of ANCOVA.

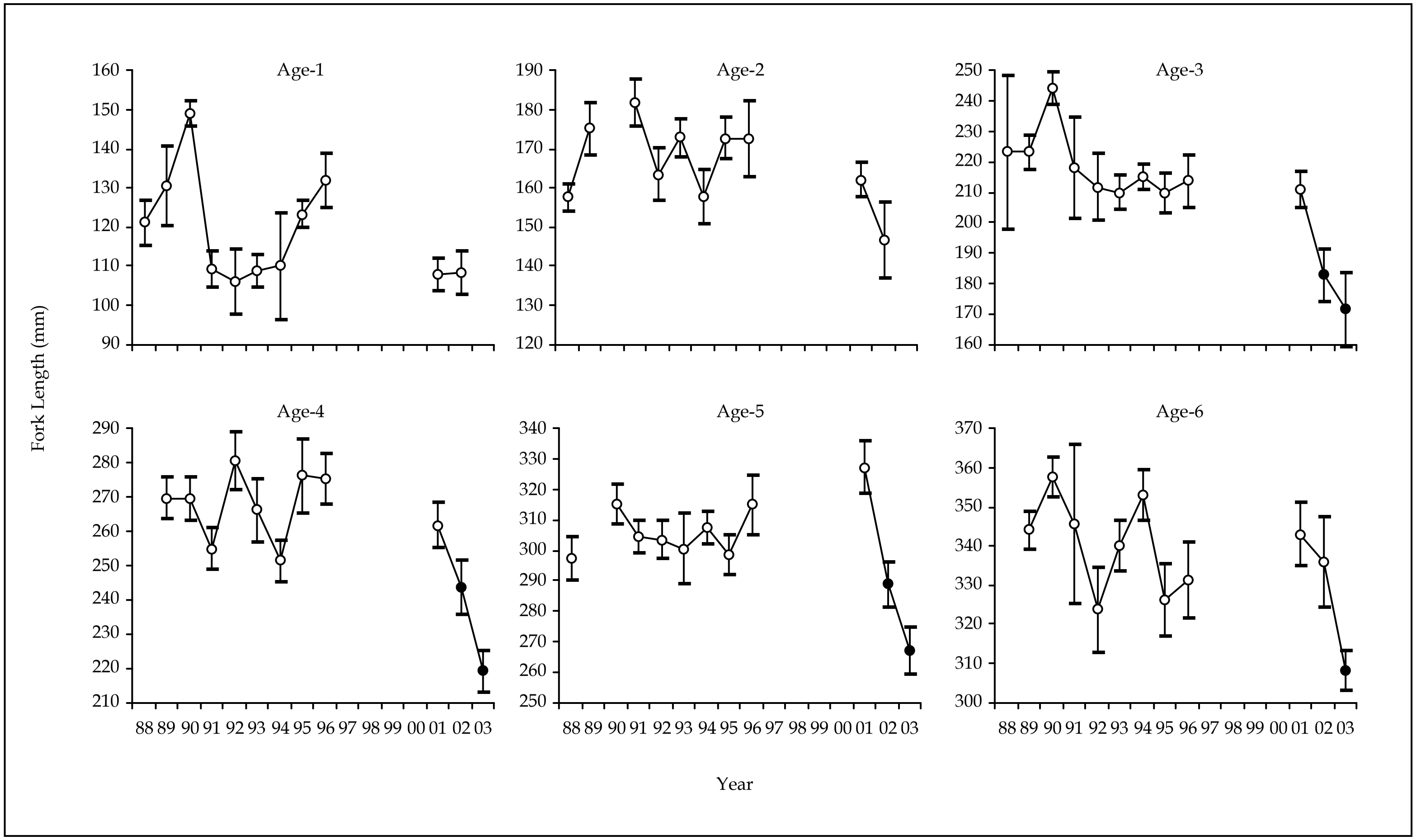


Figure 14. Mean (± 95% CI) length at age for various age classes of Arctic cisco by year. Data are based on otolith aging analysis for fish collected in late summer only. Dark symbols denote if mean length for years 2001, 2002, or 2003 are significantly different from pooled data for the 1988-1996 period of record (ANCOVA; Tukey HSD test). In all noted cases, significant differences are also significant at Bonferroni tabular levels of statistical probability.

Log_e-transformed weight and fork length data from all 2,958 Arctic cisco collected during 1988–1996 and 2001-2003 were fitted with a linear least squares regression model as described in equation (1) (see Methods). Age-0 fish were excluded from the model because they are in transit from spawning grounds in Canada's Mackenzie River system during their initial summer and their weight-length relationship would not reflect environmental conditions in the study area. Sexually mature fish, those with marked and conspicuous gonadal development, also were not included because the focus was on seasonal changes in condition relative to feeding and overwintering strategy, not changes linked to gonadal development. Thirty-two of 2,958 data points (0.01%) also were classified as outliers and deleted as described in the Methods section.

Individual fish were indexed by their residual weight (i.e., observed transformed weight minus predicted transformed weight). Mean (± 95% CI) residual values were then calculated for individual year classes for both early and late summer sampling periods by year (minimum n = 3). Results for 2001-2003 are depicted in Figure 15. The typical pattern is for condition to increase from early to late summer as fish put on weight during the feeding season, then to decrease from late summer to early summer of the following year indicating the loss of weight during winter. When viewed in terms of consecutive summers, a saw-tooth pattern generally develops. Given the inherent variability that can affect weight (e.g., small sample size, time of last feeding, possible regurgitation in the net) there is no set quantitative value that defines "good" condition. Rather, it must be viewed relative to other year classes, temporal patterns of change, and the historic record.

Of the four year classes (1997-2000) for which there were sufficient data to estimate condition change in 2003, two (1998 and 1999) exhibited an increase in condition from early to late summer and two (1997 and 2000) exhibited a decrease (see Figure 15). More traditional Analysis of Covariance (ANCOVA) using PERIOD (i.e., early summer versus late summer) as the second independent variable (Neter et al. 1989) yielded no significant (P = 0.124) PERIOD effect and no significant (P = 0.112) LENGTH by PERIOD interaction, i.e., the slopes of the two regression models were not different. When the model was re-run deleting the interaction effect there was no significant (P = 0.259) PERIOD effect. Results collectively suggest that Arctic cisco did not gain weight during the summer 2003.

Growth. We were unable to model and analyze growth patterns of juvenile Arctic cisco in 2003 using the model of Griffiths et al. (1992) because of insufficient numbers of fish.

Least Cisco

Amphidromous least cisco in the Beaufort Sea are associated with two main population centers. Alaskan populations occur in "tundra" rivers that lie west of and including the Colville River, while Canadian populations are associated with the Mackenzie River watershed (Craig and McCart 1975; Craig 1984; Craig 1989). There are no known spawning populations associated with the Sagavanirktok River or with the "mountain" rivers that lie along the 600 km of coastline between the Mackenzie and Colville rivers. Because of proximity to the two least cisco population centers, it is assumed that most adult, and therefore any juvenile, least cisco found in coastal waters of Prudhoe Bay are from Colville River stocks.

The typical catch pattern for least cisco in the Prudhoe Bay area is that few fish are caught in June (Figure 16). A sudden increase in fyke-net CPUE in early July signals the arrival of fish from the Colville River which is located about 80 km to the west (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987; Glass et al. 1990; LGL 1990, 1991, 1992, 1993, 1994a, 1994b, 1999a, 1999b; Reub et al. 1991; Griffiths et al. 1995, 1996, 1997 and Fechhelm et al. 2001). While large least cisco are present in the Prudhoe Bay region every summer, the catch of juvenile fish is variable from year to year. The presence of small fish appears linked to transport by wind-driven

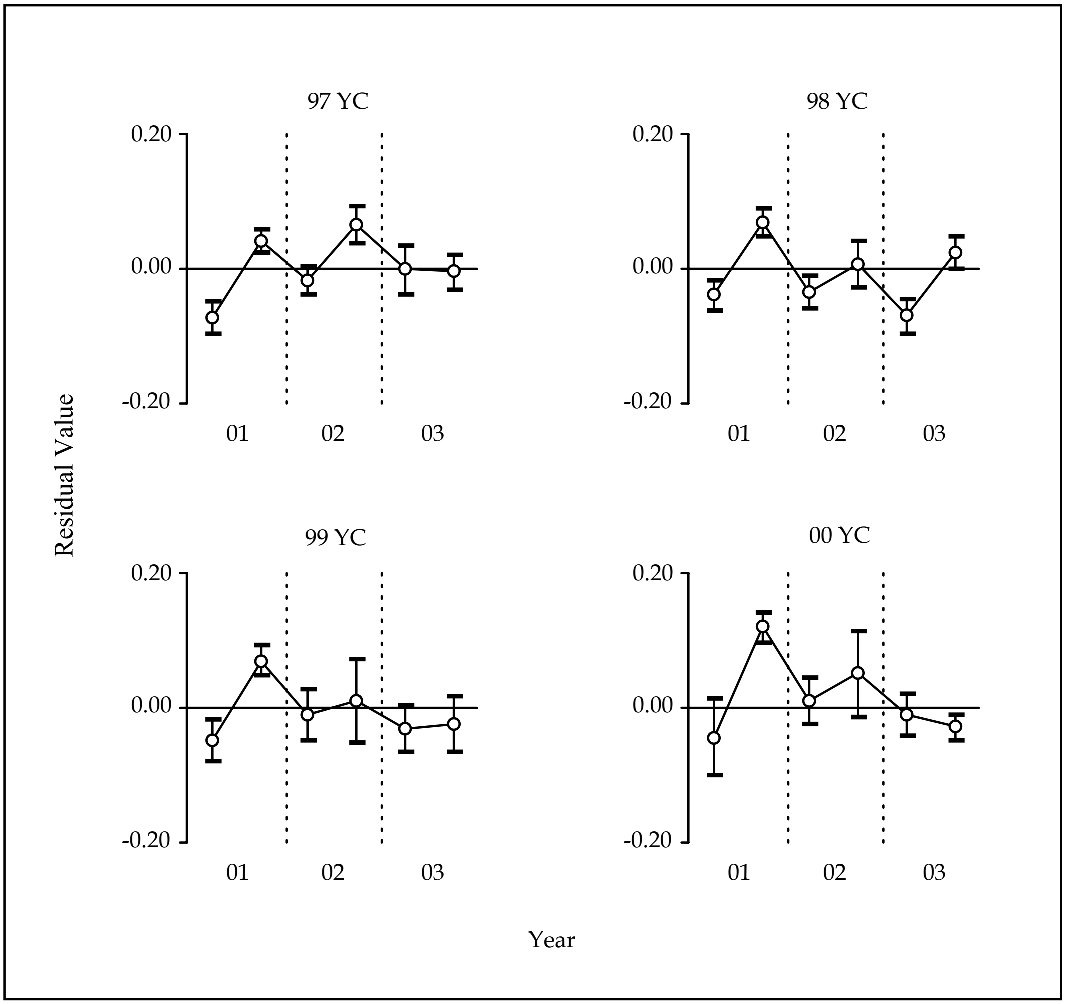


Figure 15. Mean (± 95% CI) residual values for Arctic cisco by year class (YC) and collection year from 2001 to 2003. Each collection year is divided into early and late sampling periods. A minimum N = 3 was required for inclusion of data.

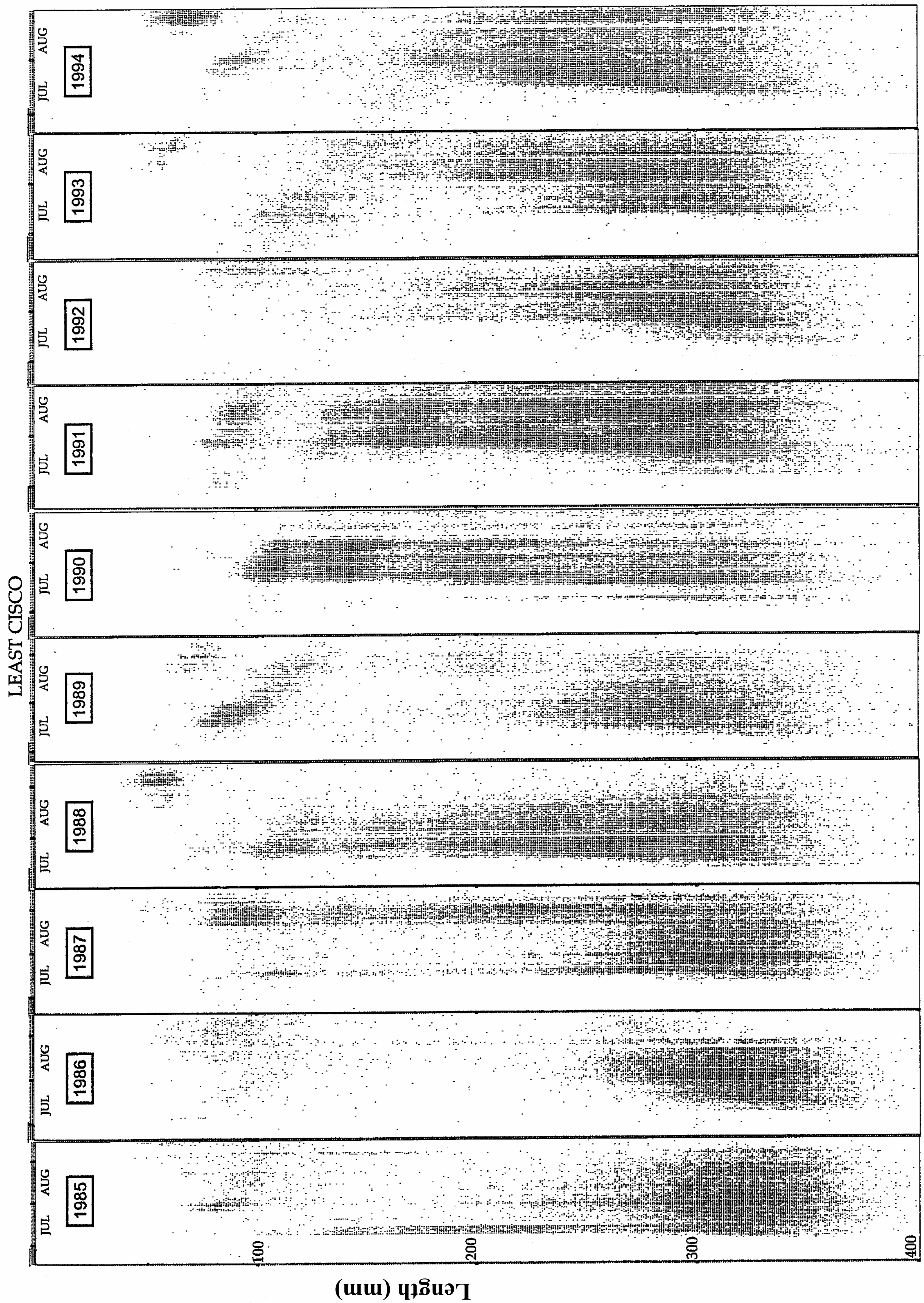


Figure 16. Length distributions by date and year for broad whitefish. See Explanation of Graphics in Methods Section.

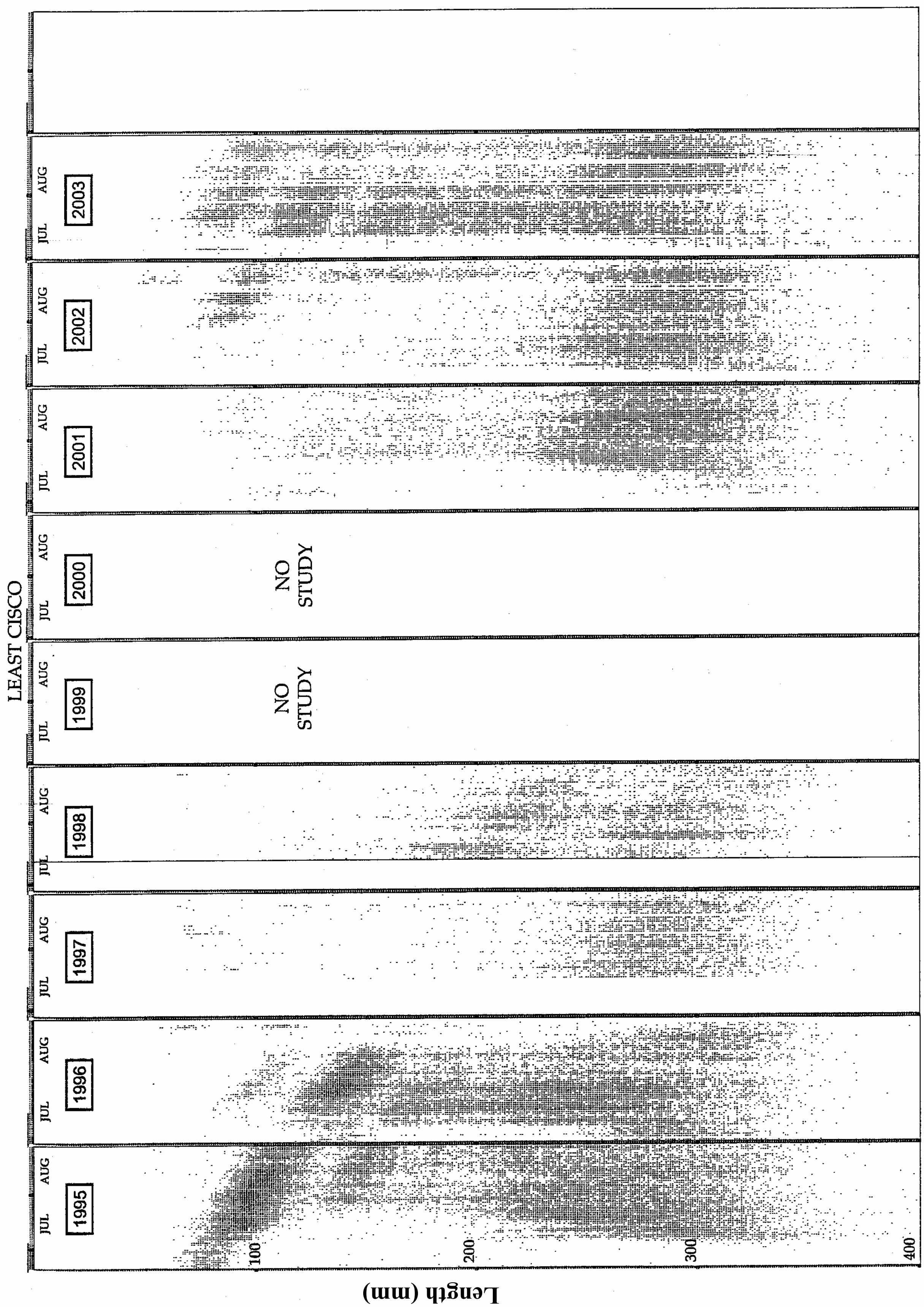


Figure 16. Continued

coastal currents primarily during the month of July (Fechhelm et al. 1994). West winds cause a net easterly flow of coastal waters that transport young fish to the east. Conversely, east winds create westerly flow that impedes eastward dispersal of fish toward Prudhoe Bay. In summers when east winds predominate in July, few juvenile least cisco reach Prudhoe Bay and catches there remain low throughout the summer (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987; Glass et al. 1990; LGL 1990, 1991, 1992, 1993, 1994a, 1994b, 1999a, 1999b; Reub et al. 1991; Griffiths et al. 1995, 1996, 1997 and Fechhelm et al. 2001). In summers characterized by west winds, juveniles arrive at Prudhoe Bay in mid to late July and cause marked increases in CPUE.

Least cisco have historically been segregated in two size groups for analysis: <180 mm and =180 mm (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987; Glass et al. 1990; LGL 1990, 1991, 1992, 1993, 1994a, 1994b, 1999a, 1999b; Reub et al. 1991; Griffiths et al. 1995, 1996, 1997 and Fechhelm et al. 2001). This delineation is arbitrary and does not segregate the population into distinct age classes, as is the case with Arctic cisco and broad whitefish. Juvenile least cisco are often not very abundant in the Prudhoe Bay area during summer, which prevents the identification and tracking of distinct juvenile age classes. Although large least cisco are always abundant in Prudhoe Bay, individual age-class are not evident from the population's length-frequency distribution. This report adheres to the two-cohort distinction to maintain continuity with previous reports.

Cohort 1 (<180 mm). A total of 10,727 small least cisco (70.5 fish/24 h) was collected in the 2003 survey. Juveniles did not arrive in the Prudhoe Bay area in large number until 11 July and the largest catches were between that date and 9 August (Figure 17). CPUE for 2003 was the highest ever recorded in the 1985-2003 period of record (Figure 18). High catches may reflect an expansion in the Colville River least cisco population or enhanced eastward transport to the Prudhoe Bay region caused by the excessive west winds (easterly currents) that characterized the month of July. Using the wind-transport model of Fechhelm et al. (1994) we simulated the movement of juvenile least cisco from the Colville River to Prudhoe Bay for 2003. Model results indicated that fish should have arrived in Prudhoe Bay on 11 July (Figure 19). CPUE increased dramatically on 12 July. Results again appear to validate the hypothesis that the migration of juvenile least cisco from the Colville River to Prudhoe Bay is largely attributable to a wind-driven transport process. The dramatic intra-annual variability in historic catch rates of small least cisco (see Figure 18) are partially attributable to variable wind-driven transport in different years Fechhelm et al. (1994) and partially to West Dock blocking the alongshore migration of small fish (Fechhelm et al. 1989, 1999) prior to instillation of the new breach in the winter of 1995-1996.

Cohort 2 (>180 mm). A total of 18,837 large least cisco (125.2 fish/net/24) was caught in 2003. This is the highest catch rate recorded in the 1985-2003 period of record and continues a 19-year trend of increasing catch of these large fish in the Prudhoe Bay area (see Figure 18). Because there is no indication that the summer eastward dispersal of large least cisco is governed by transport processes, the nearly two-decade increase in CPUE would suggest an increase in population size. However, these data are not supported by comparative increases in commercial and subsistence harvests in the Colville River, which have remained relatively stable over the past 20 years (Moulton et al. 2002).

Condition. In 2003, 242 least cisco were collected for life history analysis. Length and weight data were analyzed (see methods in Arctic Cisco section) in terms of residuals for individual year classes. Of the 7 year classes for which there was sufficient data, 6 gained weight during the course of the summer (Figure 20). More traditional Analysis of Covariance (ANCOVA) using PERIOD (i.e., early summer versus late summer) as the second independent variable (Neter et al. 1989) yielded no significant (P = 0.534) PERIOD effect and no significant (P = 0.719) LENGTH by PERIOD

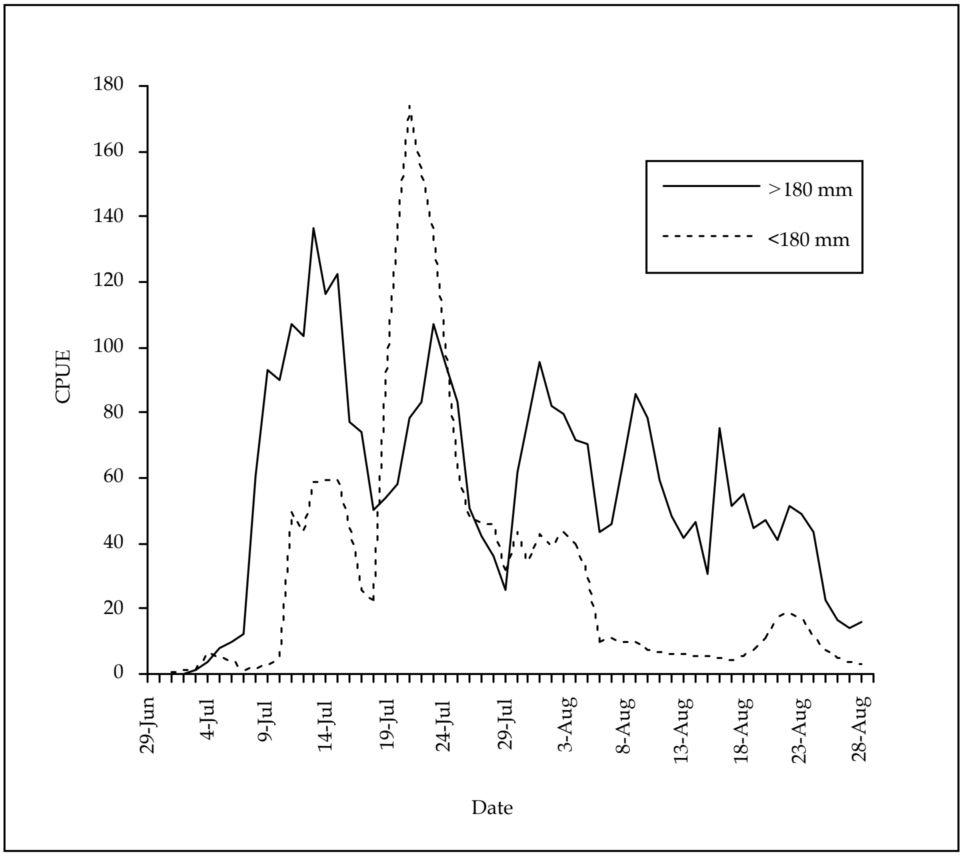


Figure 17. Three-point average of daily catch-per-unit-effort (CPUE = fish/net/24 h) for small and large least cisco by date for 2003.

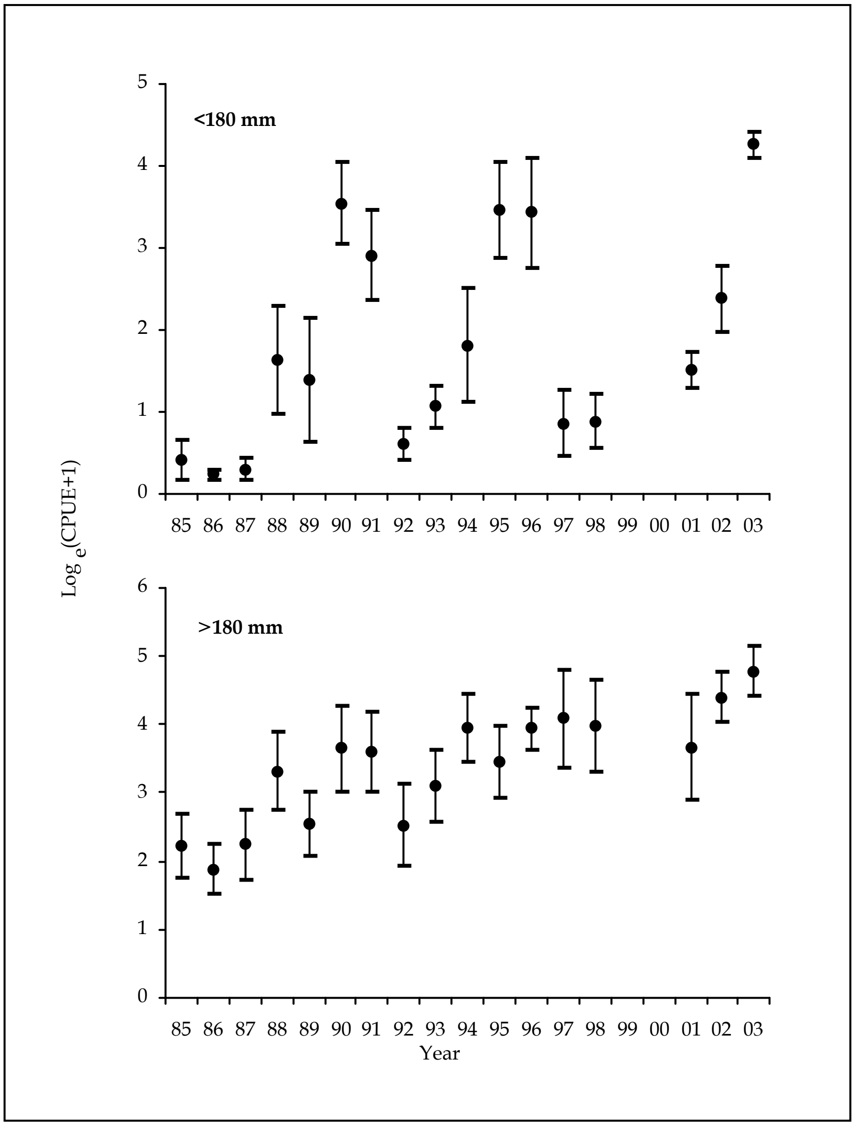


Figure 18. Log$_e$ (CPUE + 1) ±95% CI for small (upper panel) and large (lower panel) least cisco by year.

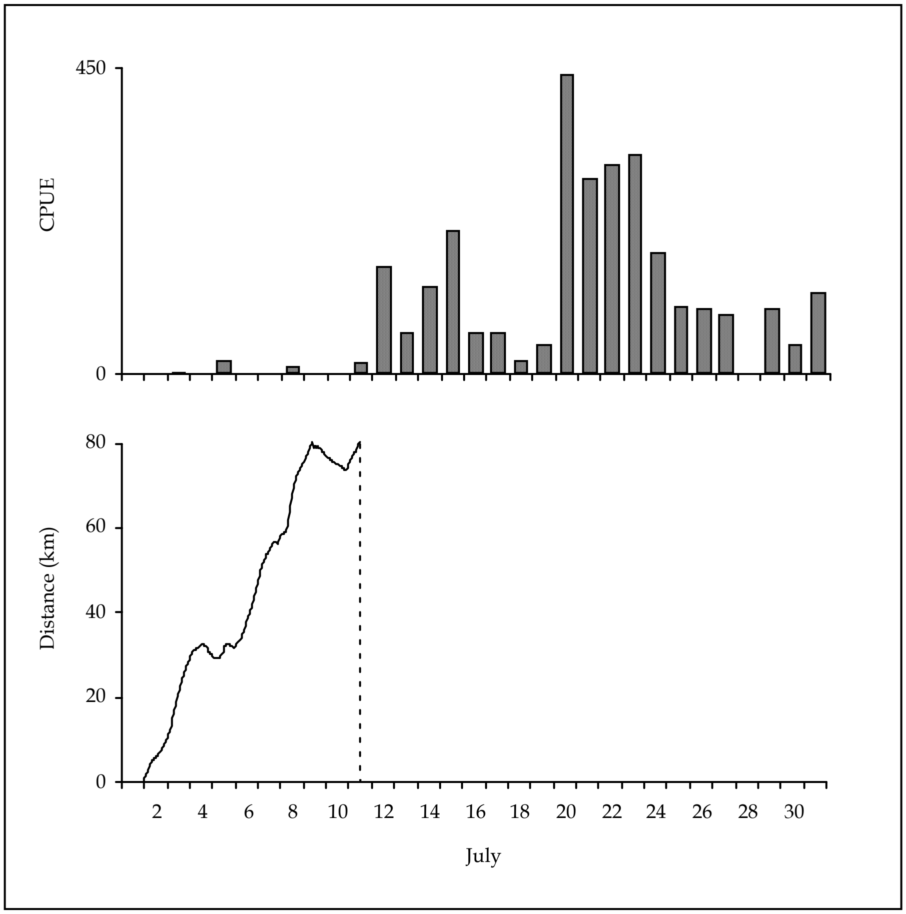


Figure 19. Top Panel: Daily CPUE of small (<180 mm) least cisco for the Prudhoe Bay fyke nets during the month of July. Bottom Panel: Simulated distance traveled by small (<180 mm) least cisco from the Colville River (0 km) to the West Dock Causeway (80 km) for 2003 based on the transport model of Fechhelm et al. (1994). The distance line terminates at the dashed vertical line if the net distance traveled reaches 80 km (i.e., arrival in Prudhoe Bay study area) before 31 July.

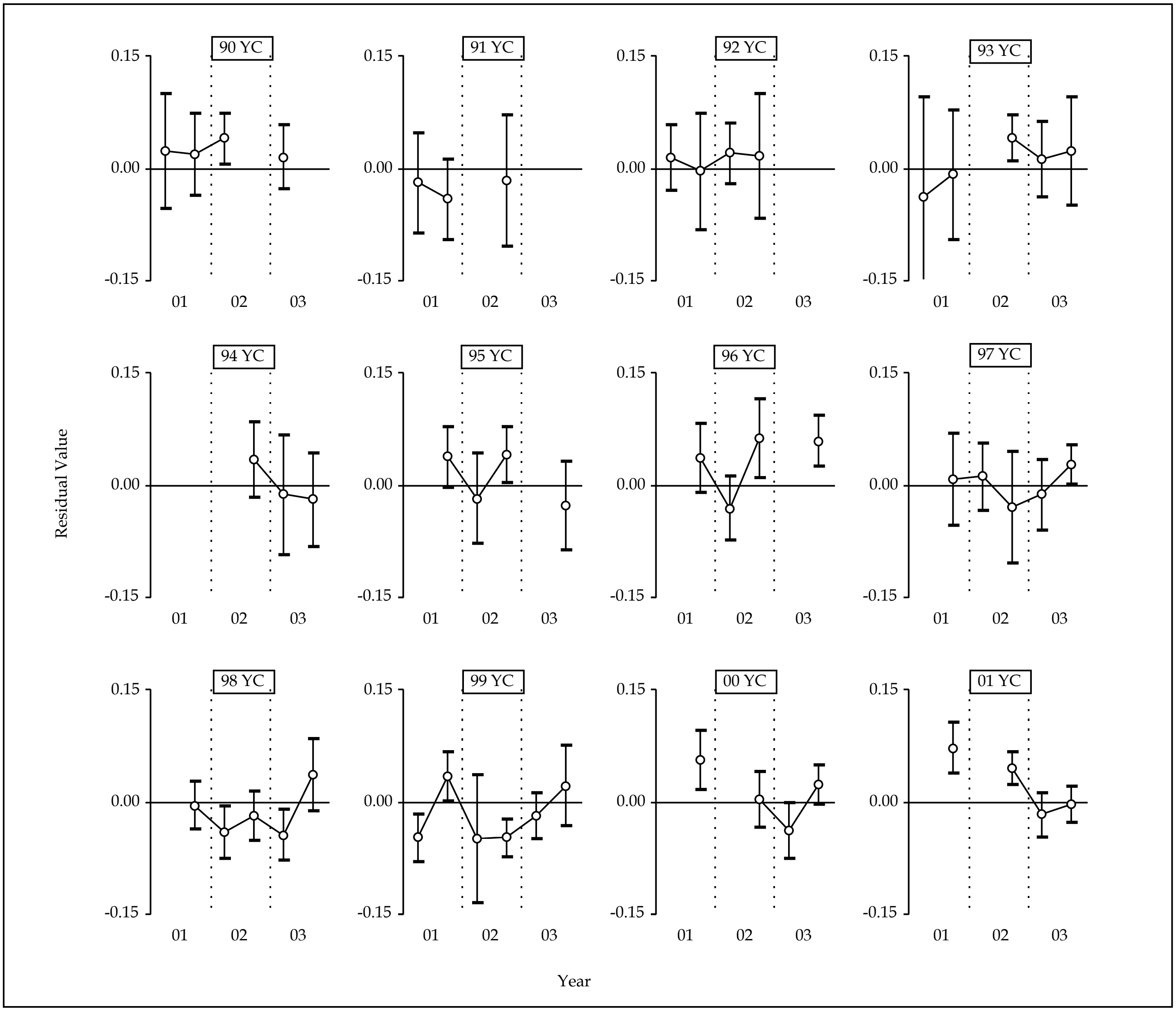


Figure 20. Mean (± 95% CI) residual values for least cisco by year class (YC) and collection year from 2001 to 2003. Each collection year is divided into early and late sampling periods. A minimum of *n* = 3 was required for inclusion of data.

interaction, i.e., the slopes of the two regression models were not different. When the model was re-run deleting the interaction effect there was a significant ($P = 0.002$) PERIOD effect. This result was not significant at adjusted Bonferroni tabular levels of statistical probability.

Based upon three seasons of study, evidence that least cisco are gaining weight over the course of the summer is equivocal. At this point, we do not know whether conflicting evidence of weight gain is real or an artifact of our analysis. This is only the third year in which least cisco have been the subject of aging analysis and data may still be insufficient to identify broader patterns. There is also evidence that least cisco found in coastal waters of Prudhoe Bay may be a mixture of anadromous and freshwater forms (Fechhelm et al. 2003). This would confound growth, aging, and condition analyses. On the other hand, there is more compelling evidence that Arctic cisco have failed to grow or put on weight in recent years, which suggests that the phenomenon in least cisco may be real. At this point, the issue remains unsettled.

Broad Whitefish

There are two main population centers of broad whitefish in the Alaskan/Canadian Beaufort Sea. Alaskan populations are typically associated with "tundra" rivers that lie west of and include the Sagavanirktok River, while Canadian populations are associated with the Mackenzie River (Craig and McCart 1975; Craig 1984; Craig 1989). There are no known spawning populations of broad whitefish in the "mountain" rivers along the 300 km of coastline between the Sagavanirktok River and Canada. Based upon this distribution pattern and the distances involved, it is assumed that most broad whitefish observed in the Prudhoe Bay region are primarily from the Sagavanirktok River and to a lesser extent the Colville River.

Based upon the size structure of the broad whitefish population in Prudhoe Bay (Figure 21), analysis has historically focused on four size cohorts. The three smallest age groups can be delineated by size, and aging analysis (using saggital otoliths) has repeatedly confirmed that these age cohorts represent age 0 (young-of-the-year), age 1, and age 2 fish (LGL 1990, 1991, 1992, 1993, 1994a, 1994b; Griffiths et al. 1996, 1997; Fechhelm et al. 2001). Beyond age 2, the length distributions of individual age classes often begin to overlap and cannot be distinguished. This fourth age cohort is therefore designated as age 3+. Figure 22 depicts the length-at-date data for 2003 including the division of year classes.

Age 0. A total of 82 (0.06 fish/net/24 h) young-of-the-year broad whitefish were collected in 2003, all of which were caught at delta stations 214 and 230. All of the fish were caught in August. This catch pattern is consistent with other years; age-0 broad whitefish typically appear in mid to late summer in small numbers and are limited to the interior areas of the Sagavanirktok Delta where salinity levels are low (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987; Glass et al. 1990; LGL 1990, 1991, 1992, 1993, 1994a, 1994b, 1999a, 1999b; Reub et al. 1991; Griffiths et al. 1995, 1996, 1997 and Fechhelm et al. 2001).

Age 1 and Age 2. A total of 4,293 (27.1 fish/net/24 h) age-1 and 993 (6.1 fish/net/24 h) age-2 broad whitefish were caught in 2003. Nearly 96% of age-1 fish and 87% of age-2 fish were caught at stations 214 and 230 in the Sagavanirktok Delta. The high concentration of juveniles in the delta is typical (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987; Glass et al. 1990; LGL 1990, 1991, 1992, 1993, 1994a, 1994b, 1999a, 1999b; Reub et al. 1991; Griffiths et al. 1995, 1996, 1997 and Fechhelm et al. 2001) and presumably reflects their intolerance of high-salinity conditions that occur elsewhere along the coast. The seasonal catch patterns of both age classes, as well as age-3+ fish, were erratic throughout the summer (Figure 23). Such patterns are normal and presumably reflect movements of fish within the delta and surrounding area in conjunction with storms, shifts in currents, and marine fronts.

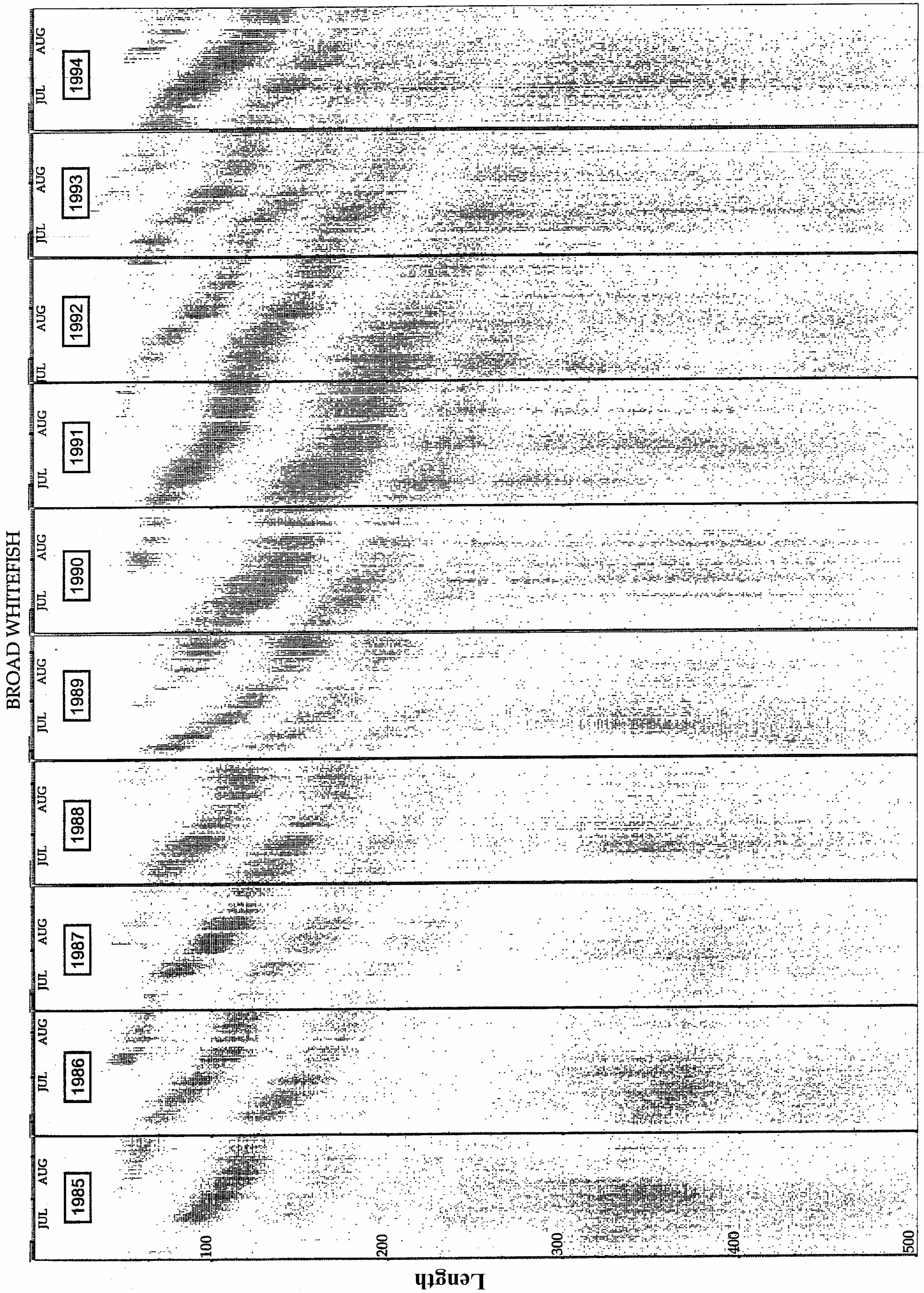
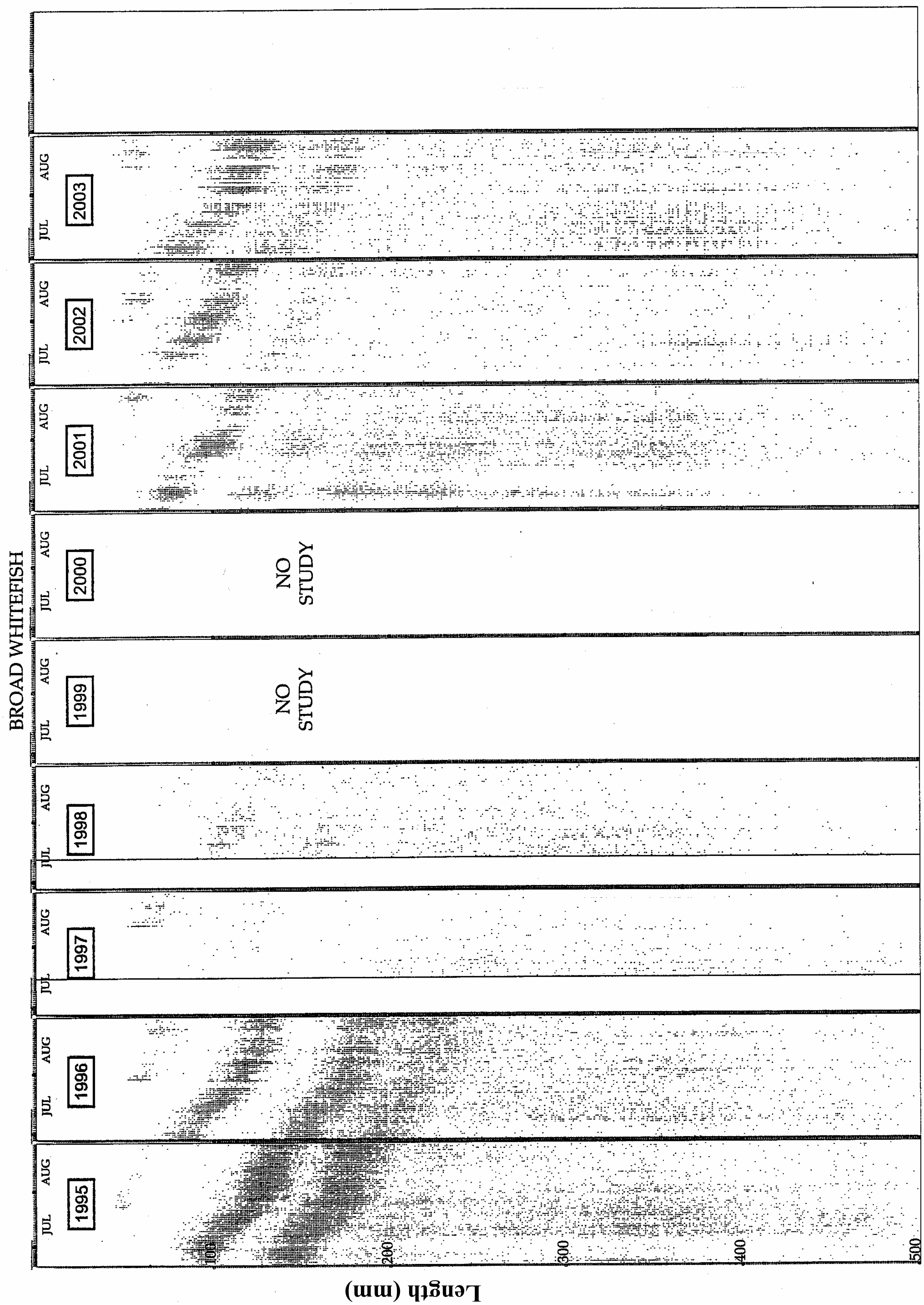


Figure 21. Length distributions by date and year for broad whitefish. See Explanation of Graphics in Methods Section.



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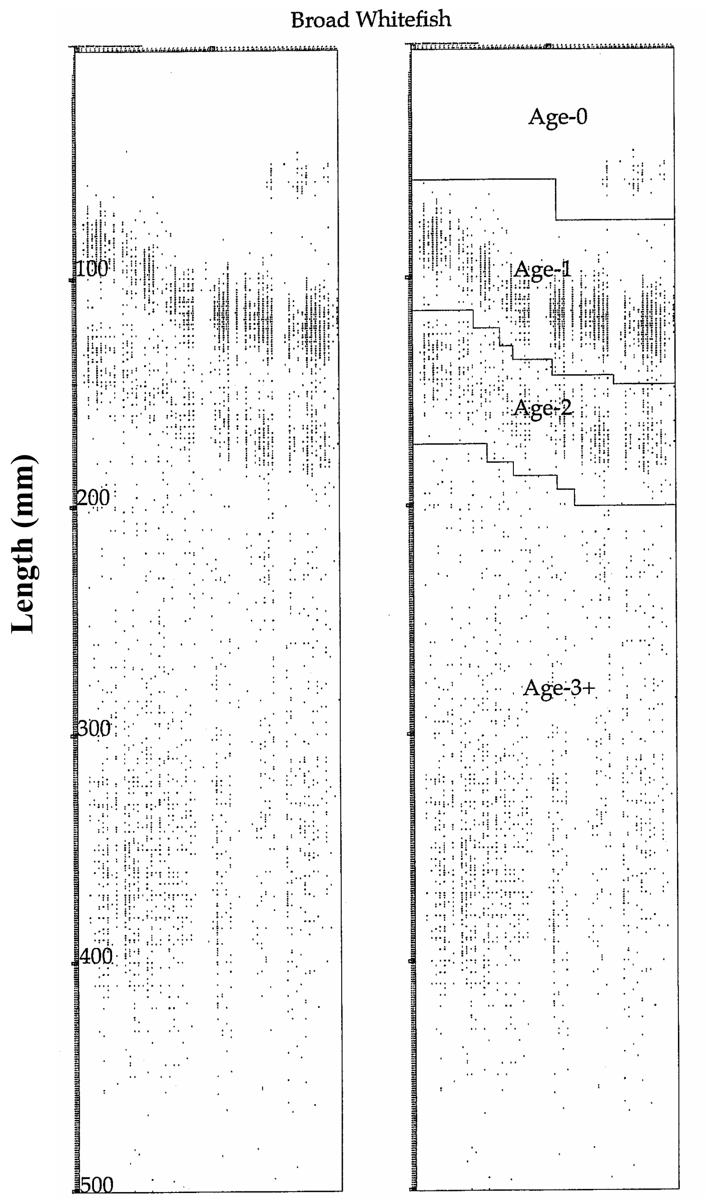

Figure 22. Length distribution for broad whitefish collected in 2003. Second panel denotes cohort delineations. See Explanation of Graphics in Methods Section.

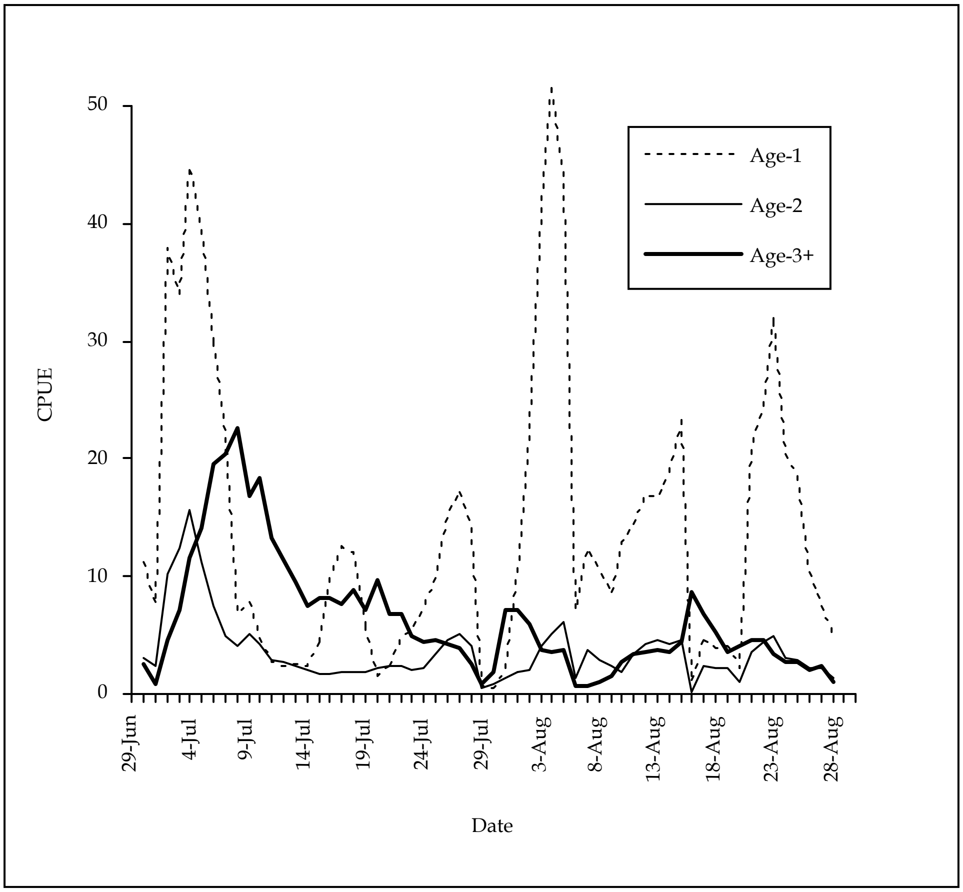

Figure 23. Three-point average of daily catch-per-unit-effort (CPUE = fish/net/24 h) for broad whitefish by date for 2003.

Seasonal CPUE for age-1 broad whitefish was the highest ever recorded in the 1985-2003 period of record (Figure 24). CPUE for age-2 fish was the fourth highest. Population estimates[1] based upon mark-recapture data for small fish (120–250 mm) have ranged from a low of 25,800 individuals in 1985 to highs of 431,046–547,349 fish in 1990 and 404,434–428,499 fish in 1995 (Griffiths et al. 1997). The high population estimates for 1990 were consistent with a high catch of the 1989 year class as yearlings (age-1 fish in 1990; see Figure 24). The 1993 and 1994 year classes also appeared strong: CPUE for age-1 fish were the second and third highest on record in 1994 and 1995, and catch rates for age-2 fish in 1995 and 1996 were the highest on record. The combined data for 2003 suggests the population to be reproductively strong.

Age 3+. A total of 1,857 (12.5 fish/net/24 h) age-3+ broad whitefish were collected in 2003 and represents the highest catch of this group in nearly two decades and a sharp rebound for catch rates recorded in summer 2002 (see Figure 24). Gallaway et al. (1997) has hypothesized that the dramatic oscillation in the size of the Sagavanirktok River broad whitefish population may reflect density-dependent processes associated with the limited overwintering area available to the fish. Excessive numbers of adults crowd out small fish from overwintering areas, thereby depressing the overall population. Periodically, as older fish naturally die off, overwintering area becomes available for small fish, increasing their survival and resulting in population expansion. Eventually, another cohort of adults takes over and the year class cycle begins anew. The population may also be affected by variations in the severity of individual winters, with milder winters providing more overwintering space (less ice cover) and greater survival.

[1] Mark-recapture studies were conducted in 1982-1984 and 1988-1996. Population estimates are given in ranges because three estimation techniques were used: Bayesian, Schumacher-Eschmeyer, and Schnabel. Only Schnabel estimates are available for 1982 and 1983.

Growth. Growth models were developed for age-1 and age-2 broad whitefish (Fechhelm et al. 1992, 1995a). They used water temperature measurements (depth averaged) taken daily at four locations (stations 204, 206, 212, and 214; see Figure 1) ranging across the delta from Heald Point in the west to Point Brower in the east. Because these sites are no longer sampled, we used temperature measurements from stations 214 and 230 as indicators of delta water temperature and applied them to the model.

Starting fork length (T_1) for the model is determined by applying a least squares linear regression to the first 10 days of actual length data, then assigning the intercept (β_0) as the start length. The growth models are expressed as

$$L_{i+1} = L_i + (0.44 + 0.164T_i) \qquad (5)$$

for age-1 fish and

$$L_{i+1} = L_i + (0.236 + 0.771T_i) \qquad (6)$$

for age-2 fish, where L_i is the mean cohort length in mm on day i, T_i is mean depth averaged temperature on day i, and L_{i+1} is the predicted mean cohort length for the following day $i + 1$. The starting fork length (T_1) for the model is determined by applying a least squares linear regression to the first 15 days of actual length data (either age group), then assigning the intercept (β_0) as the start length. The predicted length T_2 then forms the basis of the next day's prediction. The equation is applied iteratively to generate a time series of predicted cohort lengths for the entire summer.

Applications of the model reasonably mimicked the growth of both year classes through the summer (Figure 25). There was no major divergence between observed and predicted results as was the case in 1990 when actual growth declined below predicted growth for both year classes in conjunction with a large immigration of least cisco into the Prudhoe Bay area (Fechhelm et al. 1995a). There was evidence that reduced growth may have been linked to competition that overtaxed the trophic carrying capacity of the

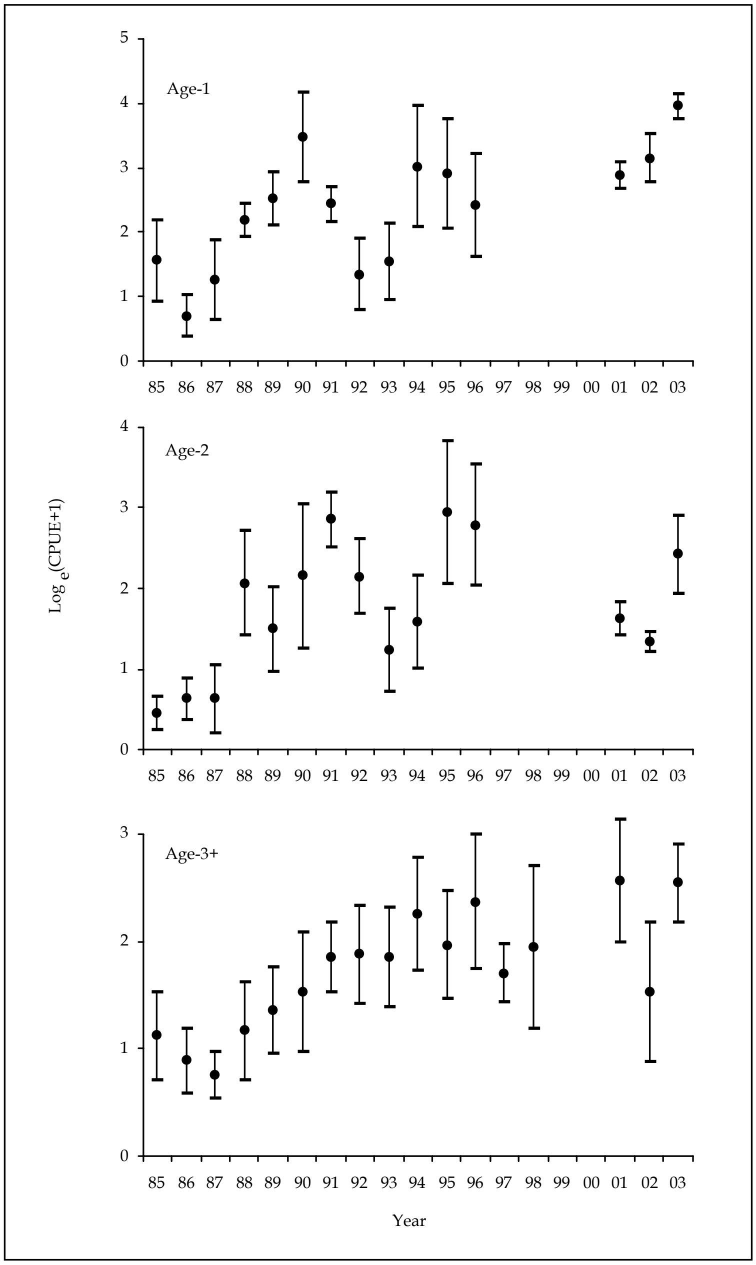

Figure 24. Log$_e$ (CPUE +1) ±95% CI for age-1, age-2, and age-3 broad whitefish by year. Data for age-2 and age-3 fish are only for stations located in the delta of the Sagavanirktok River (see Fig. 1). No delta stations were sampled in 1997 and 1998. There were no studies in 1999 and 2000.

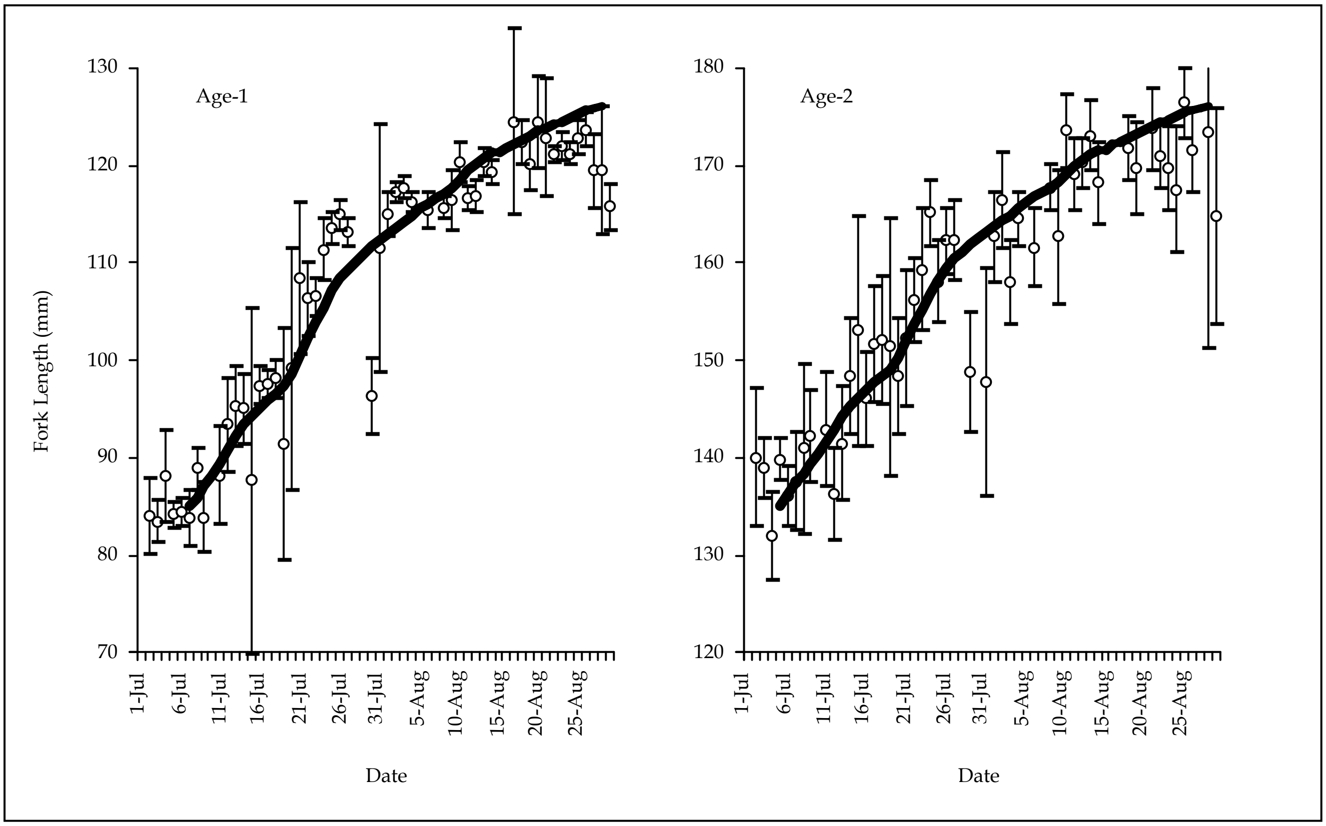

Figure 25. Mean daily fork length (±2 95% CI) of age-1 and age-2 broad whitefish collected during the 2003 study. Superimposed lines on the graphs are predicted daily mean fork lengths based upon the water temperature models of Fechhelm et al. (1992, 1995b). Model results are based on water temperatures measured at stations 214 and 230 (see text).

Sagavanirktok Delta. There were no unusual trends for summer 2003.

The fact that juvenile broad whitefish appear to have grown normally over the past two summers while Arctic cisco growth has apparently been below normal (see Arctic Cisco above) is not unreasonable. Whereas Arctic cisco feed primarily on invertebrates of marine origin (e.g., mysids, copepods, amphipods), broad whitefish rely more heavily on Chironomids (midge fly larvae) that are washed down river into the delta flats (Cannon et al. 1987a, Knutzen et al. 1990, Knutzen and Jewett 1991). If the west winds that dominated in the month of the July did prevent marine invertebrates from moving onshore and replenishing depleted prey stocks, the phenomenon would not have affected the supply of freshwater invertebrates.

Dolly Varden

The northern form of the amphidromous Dolly Varden spawns in many of the larger river systems of the Alaskan/Canadian Beaufort Sea (Craig 1984; Everett and Wilmot 1987). The presence of perennial springs appears to be a prerequisite for spawning in these arctic rivers most likely because they provide fish with unfrozen habitat throughout the winter (Craig 1984). Juveniles remain within their natal streams for several years prior to their first seaward migration to food-rich coastal waters (Craig 1977a, 1977b, 1989). After smolting, Dolly Varden generally exhibit an amphidromous life history strategy wherein they disperse out into coastal waters to feed each summer, then return upriver to overwinter (Craig 1989). There is also a component of the population that consists of non-amphidromous males that remain within their natal rivers for their entire life (Craig 1977a, 1977b, 1989). Amphidromous Dolly Varden migrate considerable distances along the coast during the summer, and although spawners are believed to maintain fidelity to their natal streams, non-spawners may overwinter in non-natal drainages (Glova and McCart 1974; Craig 1977a; DeCicco 1985, 1992).

Dolly Varden have historically been segregated in two size groups for analysis: <350 mm and =350 mm (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987; Glass et al. 1990; LGL 1990, 1991, 1992, 1993, 1994a, 1994b, 1999a, 1999b; Reub et al. 1991; Griffiths et al. 1995, 1996, 1997 and Fechhelm et al. 2001). This delineation is arbitrary and does not segregate the population into distinct age classes, as is the case with Arctic cisco and broad whitefish. This report adheres to the two-cohort distinction for some analyses to maintain continuity with previous reports. Another characteristic of the Dolly Varden population is the presence of a distinct size group that represents smolts emerging into coastal waters for their first summer. In Figure 26, the smolt cohort appears as a dark diagonal swath beginning at 150-200 mm in early summer and growing to 200-270 mm by the end of summer, and typically with a period of low abundance in mid summer. This cohort is the subject of a separate discussion.

Cohort 1 (<350 mm) and Cohort 2 (=350 mm). A total of 1,158 cohort 1 (7.5 fish/net/24 h) and 439 cohort 2 (3.4 fish/net/24 h) fish were caught in 2003. The highest catches for both groups (>25 fish/net/24 h) occurred early in the summer. High catch early in the summer is typical for Dolly Varden and presumably reflects the out migration of fish from the Sagavanirktok River. Low catch in mid summer is also typical for this species and reflects fish vacating the Prudhoe Bay area on their summer feeding dispersal to other areas of the Beaufort Sea. Seasonal CPUE for both size classes was well within the range of historic variability for the Prudhoe Bay area (Figure 27).

Smolts. The smolt cohort was isolated from the rest of the Dolly Varden population after Fechhelm et al. (1997). The length-frequency profile for the Dolly Varden population was compiled on a weekly basis (Figure 28). The smolt cohort was then isolated by inspection for that week (i.e., visually truncating the mode or “bell curve”). Those data were again truncated by excluding all lengths outside of the mean ± 1.96 SD. The process was repeated for each week. The overall truncated data set was then used to estimate the mean daily cohort length throughout the summer.

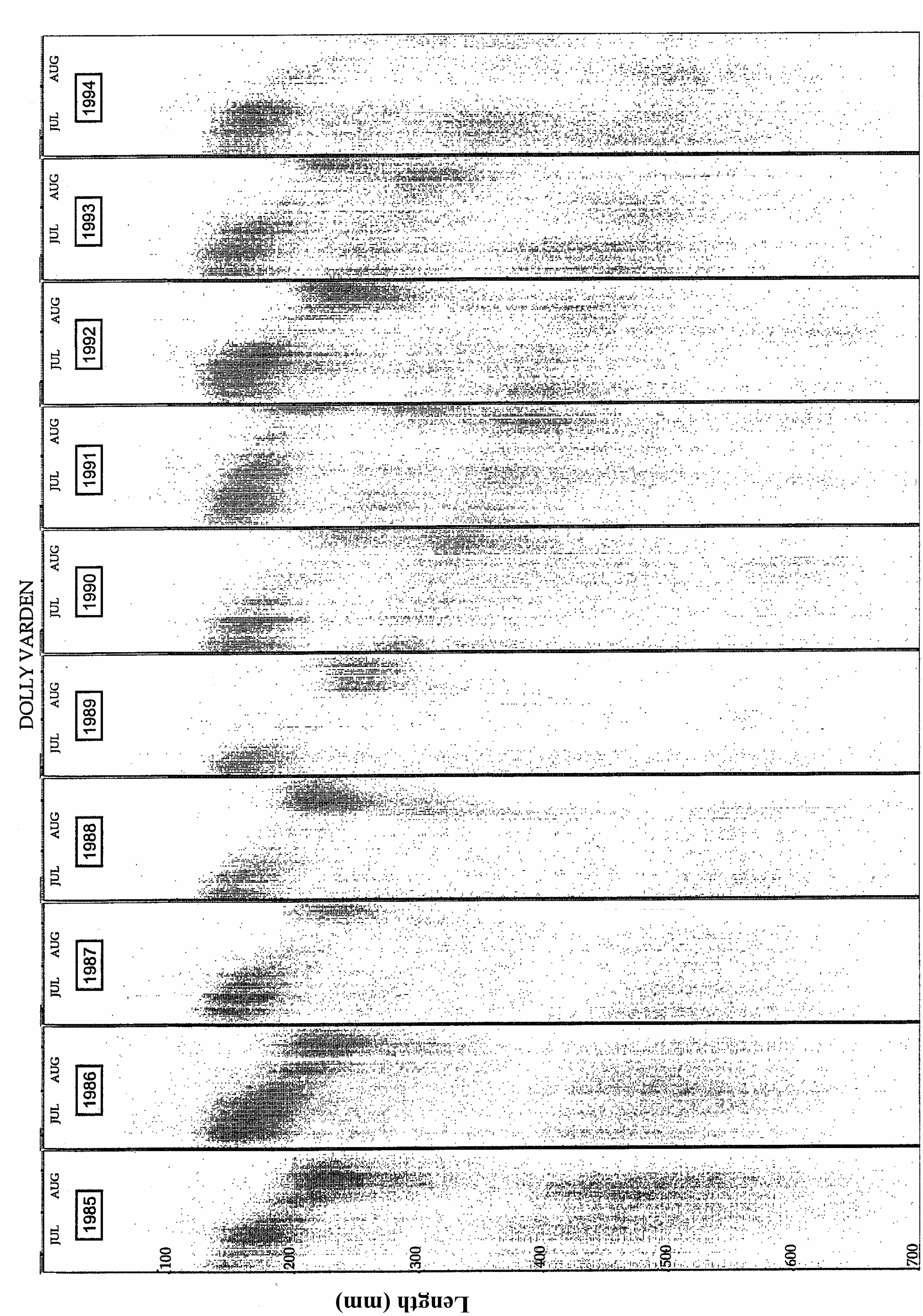

Figure 26. Length distributions by date and year for Dolly Varden. See Explanation of Graphics in Methods Section.

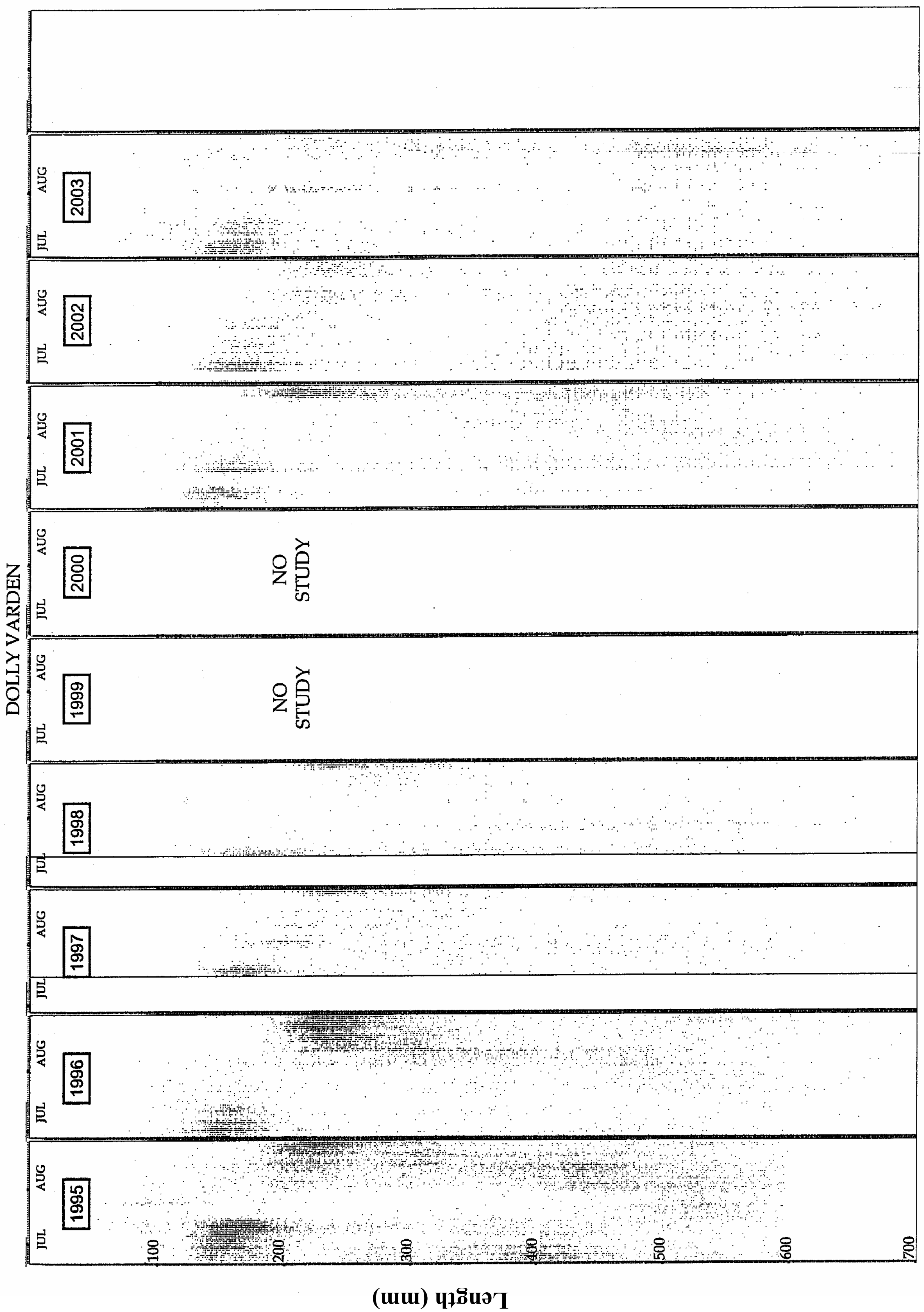

Figure 26. Continued.

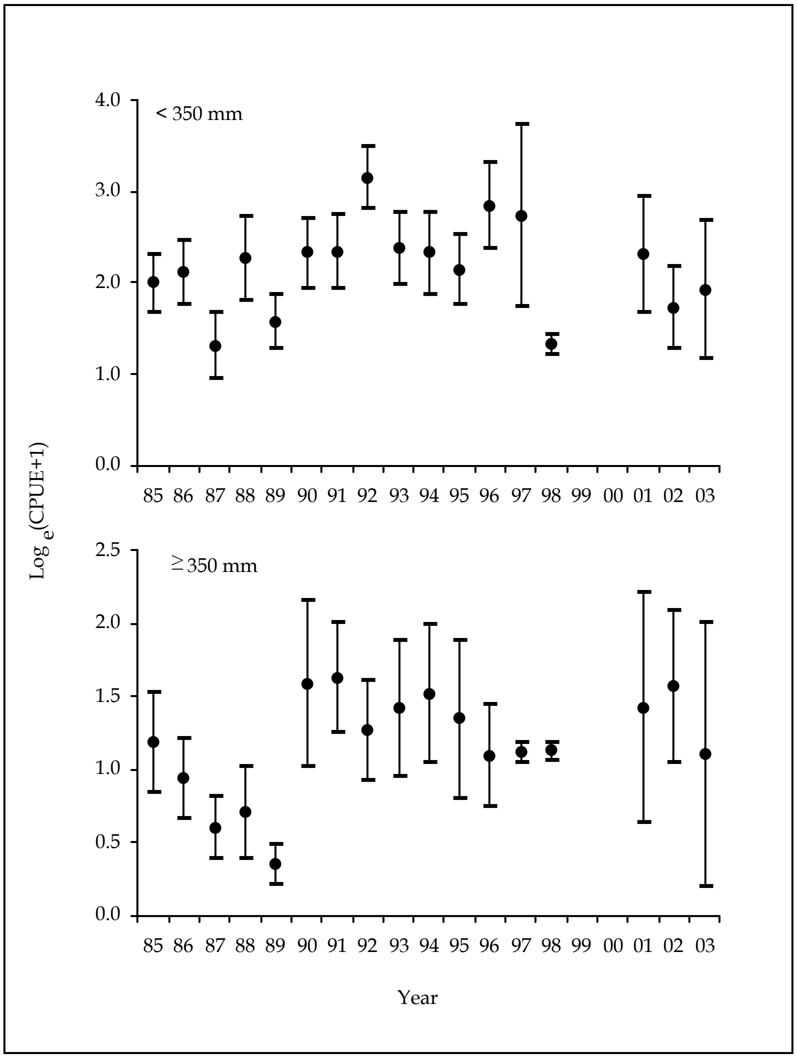

Figure 27. Log_e (CPUE+1) ± 95% CI for small and large Dolly Varden by year.

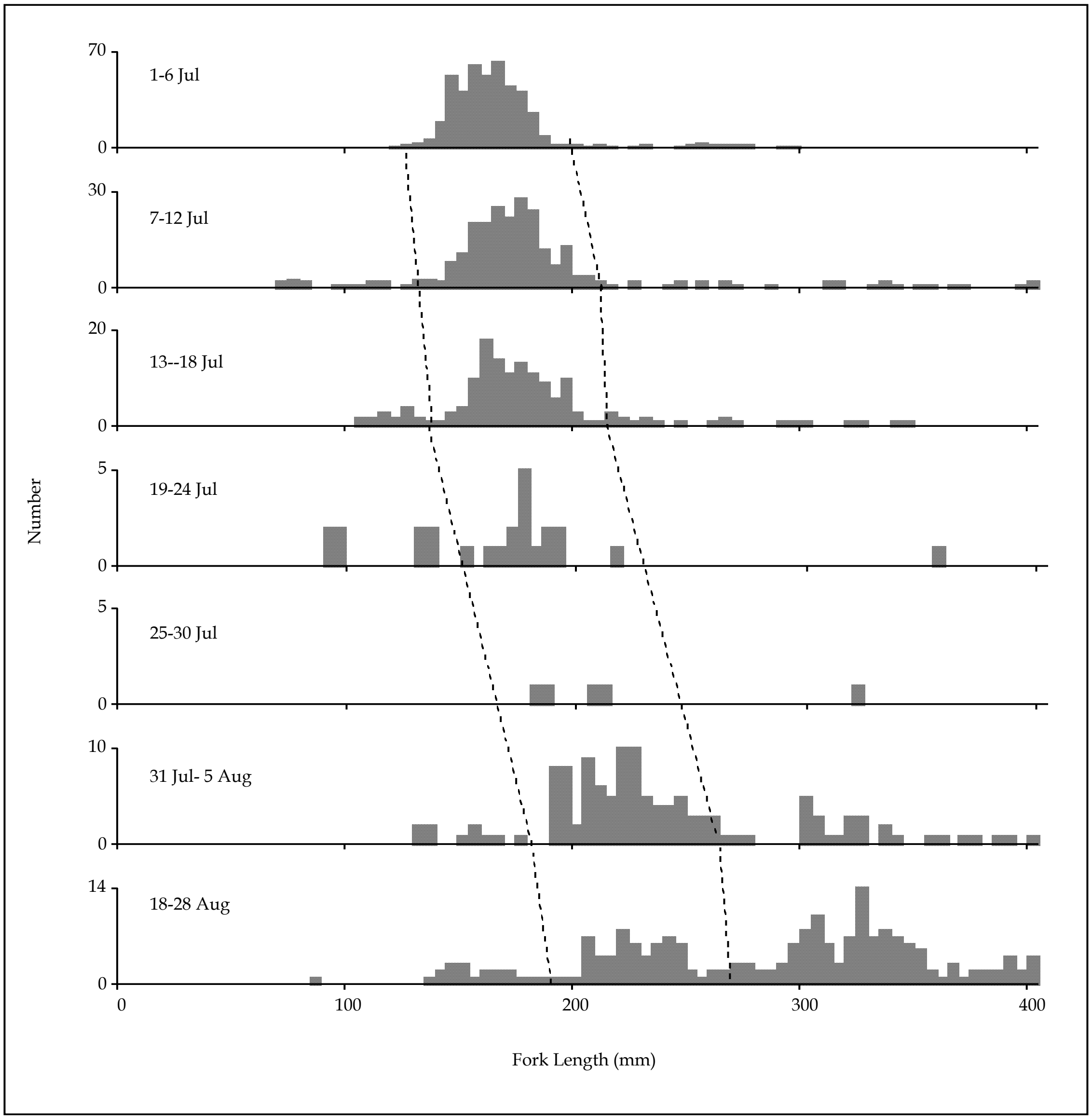

Figure 28. Weekly length-frequency distributions for Dolly Varden for 2003. Dashed lines delineate the approximate bounds of the smolt cohort (see text).

The mean length-at-date pattern of the smolt cohort appeared curvilinear and monotonically increasing (top panel; Figure 29). A nonlinear logistic regression function (Neter et al. 1989) was used to initially fit the data (i.e., mean daily cohort length against date) using the equation:

$$Y_i = b_2 + b_3((\exp(b_0 + b_1 X_i))/(1 + \exp(b_0 + b_1 X_i))) \quad (7)$$

where X_i is mean daily cohort length, b_0 and b_1 are the curve parameters, b_2 is the estimated start length parameter, and b_3 is the parameter that estimates the total change in daily mean length ($b_2 + b_3$ = asymptotic length estimate) through the season. Parameter values were estimated using the Quasi-Newton method (Wilkinson 1989). This approach uses estimates of first and second derivatives to minimize the model's loss function via iteration.

The logistic regression model provided a good fit of the data (Figure 29, top panel; $R^2 = 0.97$). The trend in mean length over time was sigmoidal which is typical for Dolly Varden smolts in the Prudhoe Bay region (see bottom panel; Figure 29). This pattern is probably caused by a combination of growth, migration, and the mixing of stocks (Fechhelm et al. 1997). Total estimated growth over the summer was 72.6 mm (b_3), which is the lowest for the 1985-2002 period of record (Figure 30). Estimated growth for 2003 extends a trend of decreasing growth in Dolly Varden smolts that has been apparent since 1989. The reasons for this decrease in growth rate are unknown, however, the key date of 1990 is about the time major climatic regime shifts were reported for the North Pacific and Bering Sea (Hare and Mantua 2000, Minobe 2002).

Humpback Whitefish

Background. The humpback whitefish has a discontinuous distribution in the river systems of the Beaufort Sea: eastern populations are associated with the Mackenzie River, Canada, while western populations are found in the Colville River, Alaska, and numerous rivers further to the west (Craig 1984). There are no known populations inhabiting the rivers between the Colville River and the U.S.-Canadian border, a distance of some 380 km (Craig 1984).

Humpback whitefish were not originally classified as a key indicator species for studying the effects of Beaufort Sea oil development on arctic fishes (U.S. Army Corps of Engineers 1980, 1984). Although humpback whitefish had been collected regularly during fish monitoring programs at Prudhoe Bay, their numbers were too low for them to be considered a "secondary" species of interest (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987; Glass et al. 1990; LGL 1990, 1991, 1992, 1993, 1994a, 1994b, 1999a, 1999b; Reub et al. 1991; Griffiths et al. 1995, 1996, 1997 and Fechhelm et al. 2001). However, there has been recent speculation that prior to 1996, the eastward summer dispersal of western humpback whitefish along the Beaufort Sea coast had been blocked by the West Dock causeway (Fechhelm 1999). In the winter of 1995-1996, a 200-m-wide breach was constructed near the base of West Dock. During the following two summers, the catch rates of humpback whitefish increased significantly east of the causeway relative to what had been reported in any previous year of study. It was hypothesized that West Dock had prevented western humpbacks from dispersing eastward along the coast but that the new breach now provides a migratory passageway that enables these fish to extend their distribution farther to the east (Fechhelm 1999). Because of these findings, LGL fish monitoring reports now provide a full species account for humpback whitefish. Results of the 1998, 2001, and 2002 Prudhoe Bay studies (Fechhelm et al. 2001, 2003) indicated that humpback whitefish catch in the Prudhoe Bay area, including stations east of West Dock, has remained substantially higher then pre-breach years.

The 2003 Study. A total of 3,428 humpback whitefish (22.2 fish/net/24 h) were collected during the 2003 Prudhoe Bay study. This represents the highest catch rate of this species in the Prudhoe Bay region over the entire 1985-2003 period of record (Figure 31). Again, the high catch rate throughout the study area, particularly at nets located east of West Dock, relative

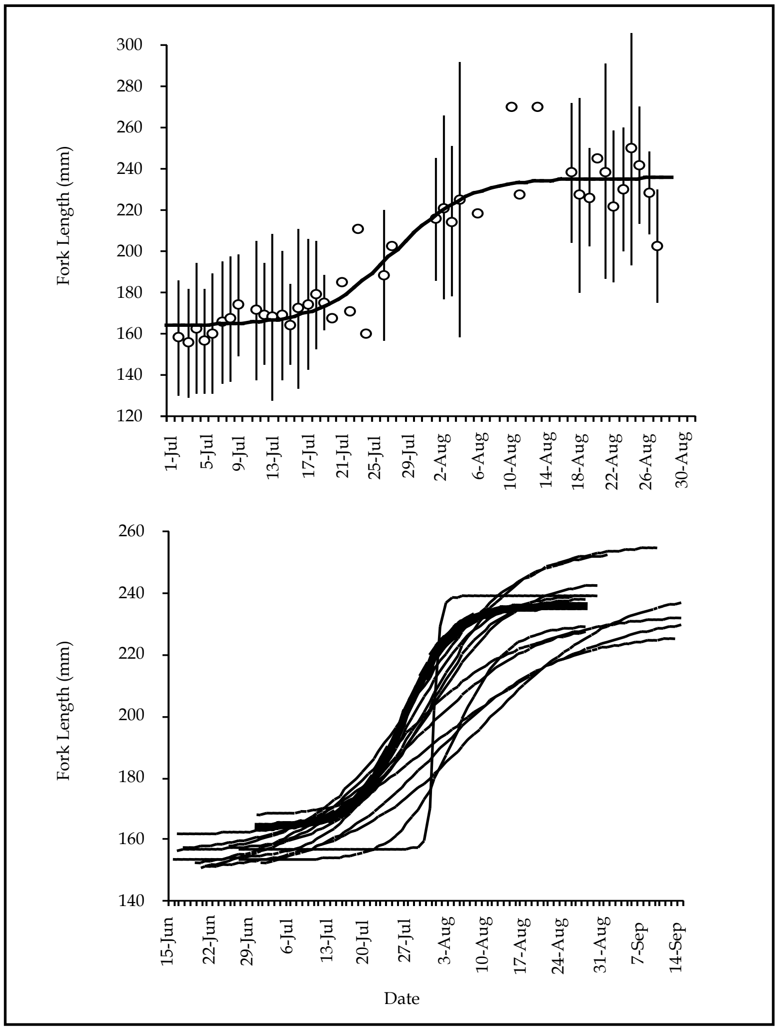

Figure 29. Top panel: mean (±2 SE) fork length of the Dolly Varden smolt cohort by date for 2003 with the logistic regression function model superimposed. Bottom panel: logistic regression function models for 1985-1990, 1992-1993, 1995-1996, and 2001-2003. Results for 2003 are highlighted as the bold line. There were insufficient data in 1991, 1992, 1997, and 1998 to generate meanful model fits. No studies were conducted in 1999 and 2000. R-squared values for all models were ≥ 0.95.

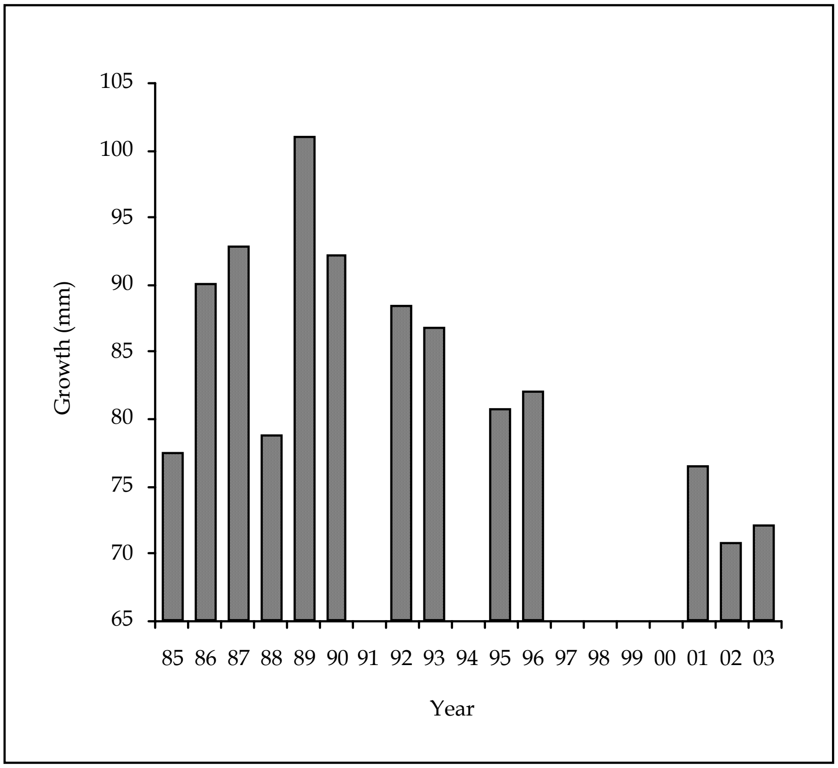

Figure 30. Model parameter values B_3 (total change in mean smolt cohort length for the summer) as determined by the logistic regression model for each year. R-squared values for all models were ≥ 0.95.

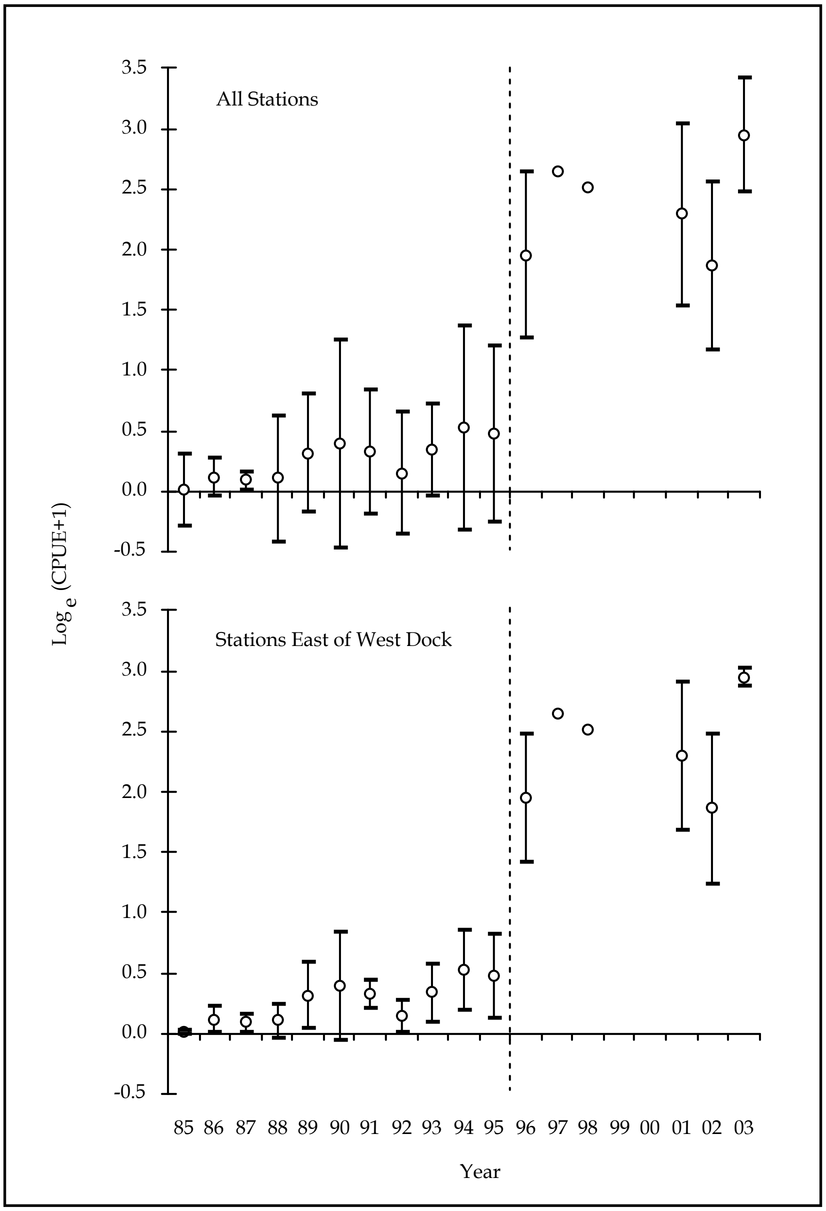

Figure 31. Log$_e$ catch-per-unit-effort (±95% CI) for humpback whitefish collected at all stations (top) and at stations east of West Dock by year. Vertical dashed line denotes the instillation of the West Dock breach during the winter of 1995-1996.

to the historic record are consistent with the hypothesis that the West Dock breach now provides a migratory passageway that enables these fish to extend their distribution farther to the east. Prior to installation, relatively few fish were taken in nets east of West Dock. The reason for the high catches in 2003 relative to other post-breach years is uncertain. It may reflect an expansion in the Colville River population, or enhanced dispersal eastward in conjunction with the heavy west winds (easterly flowing currents) that characterized the 2003 season.

Most humpback whitefish were adults greater than 300 mm, although the length-frequency distribution was skewed to the left indicating the presence of a few juveniles (Figure 32). The size distribution was similar to that reported in previous summers (Fechhelm et al. 2001, 2003). The absence of small fish suggests that the Prudhoe Bay area is well beyond the summer dispersal range of juvenile humpback whitefish from the Colville River.

Another unique aspect of the 2003 study was the period of residency in the study area. Historically, humpback whitefish catches decline to nominal levels by about 4 August, presumably signifying that fish have emigrated from the area and returned westward toward their overwintering grounds in the Colville River (Figure 33). In 2003, humpback whitefish catch remained elevated into late August, with some of the highest catches of the summer occurring around 8-9 and 16 August. The reason for the extended residency time in Prudhoe Bay is uncertain. Humpback whitefish are believed to be intolerant of high salinities and it is possible that the unusually low salinities that were prevalent through late July may have delayed triggering their westward migration back to the Colville River.

Secondary Species

Of the 14 remaining fish species (excluding Arctic cod), three comprised nearly 80% of the total catch for the 2003 season: Arctic flounder, rainbow smelt, and fourhorn sculpin.

Arctic Flounder and Rainbow Smelt. The Arctic flounder is a bottom-dwelling, circumpolar, marine species typically found in shallow coastal waters during summer when it commonly enters low-salinity habitats (Morrow 1980). They are not found far offshore (Morrow 1980). This species is common and widely distributed along the Beaufort Sea coast, and has been taken in small to moderate numbers in virtually every coastal fishery survey conducted in Alaska and Canada. The rainbow smelt is an anadromous species found throughout the Beaufort Sea. Unlike other anadromous and amphidromous species, which spawn in the fall and early winter, rainbow smelt spawn in the spring (McPhail and Lindsey 1970; Scott and Crossman 1973). There is speculation that most spawning in the Beaufort Sea is limited to the Mackenzie and Colville Rivers. Both are large enough to provide open-water, under-ice channels for the spring spawning migration. If so, the greatest year round concentrations of rainbow smelt are likely to be in the vicinity of those two drainages, since rainbow smelt are not believed to migrate far from their natal streams (Morrow 1980).

A total of 10,868 (66.1 fish/net/24 h) Arctic flounder and 4,870 (32.7 fish/net/24 h) rainbow smelt were collected during the 2003 study. These two species are discussed together because the abundance of both rose dramatically in 1990 from levels reported the previous decade (Griffiths et al. 1998). Over the past 12 seasons (1990-1998, 2001-2003) CPUE for Arctic flounder has consistently remained higher than levels reported in the 1980s (Figure 34). A step increase in smelt CPUE also occurred in 1990. Seasonal CPUE remained elevated through the early 1990s but then began to slowly decline to near 1980 levels by the end of the decade. Catch rates for 2001-2003 were again at record highs.

Based upon anecdotal accounts by field technicians, there were unprecedented numbers of "half-dollar" size flounder collected in 1990. This would suggest a major spawning event. During their four-year fyke net study along the ANWR coast, Underwood et al. (1995) also reported that Arctic flounder catch was higher in 1990 and 1991 compared to 1988 and 1989. In many locations, larger flounder were more abundant in 1988 and 1989 but smaller flounder became proportionately more abundant in

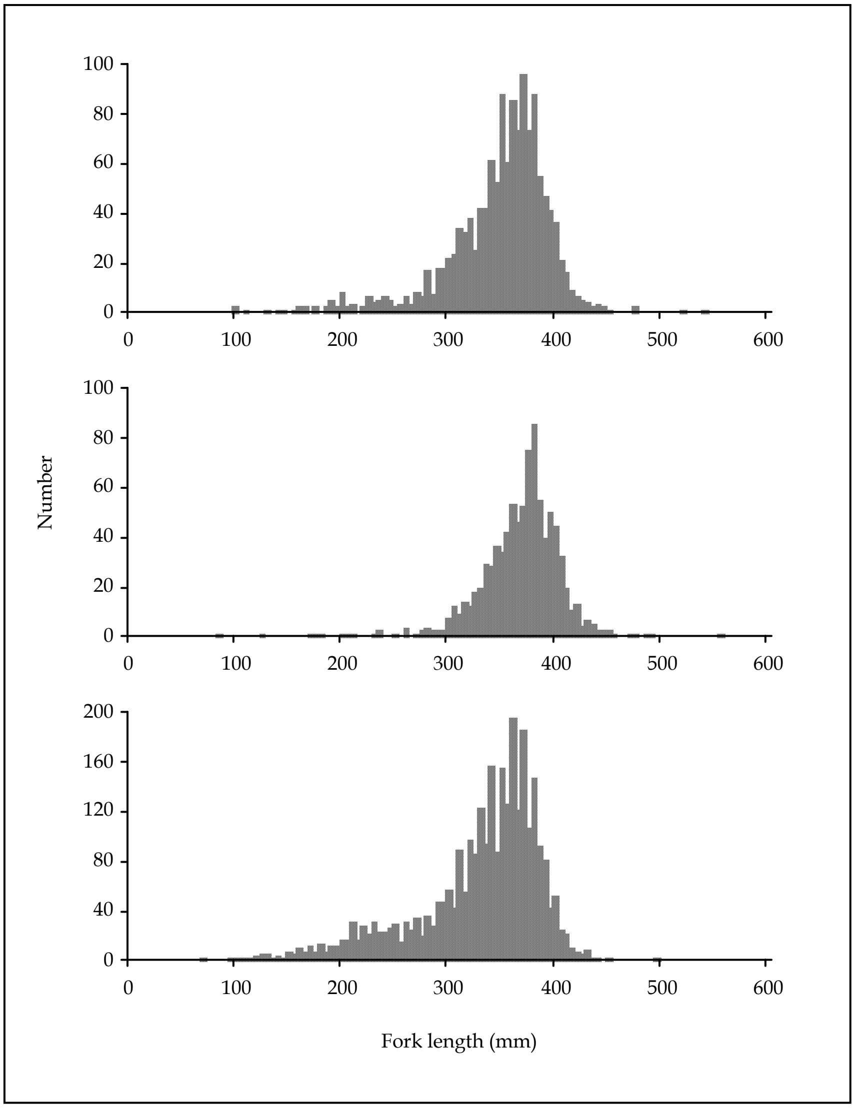

Figure 32. Length-frequency distributions for humpback whitefish collected in 2001-2003.

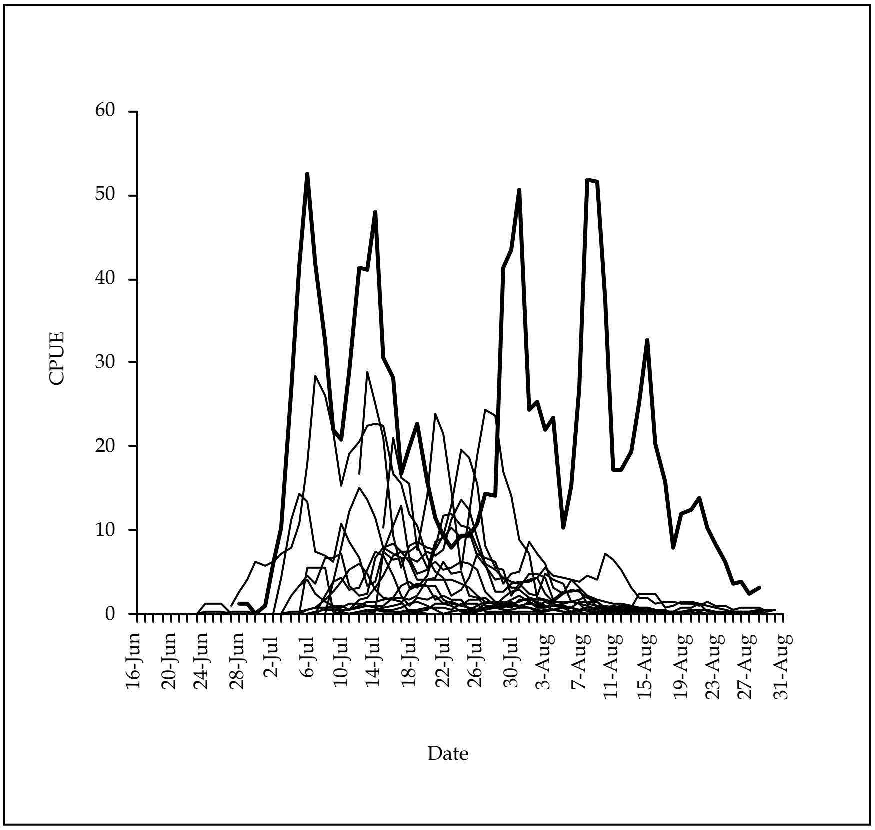

Figure 33. Three-point moving average of CPUE (catch-per-unit-effort = fish/net/24 h) of humpback whitefish by date for the years 1985-2003.

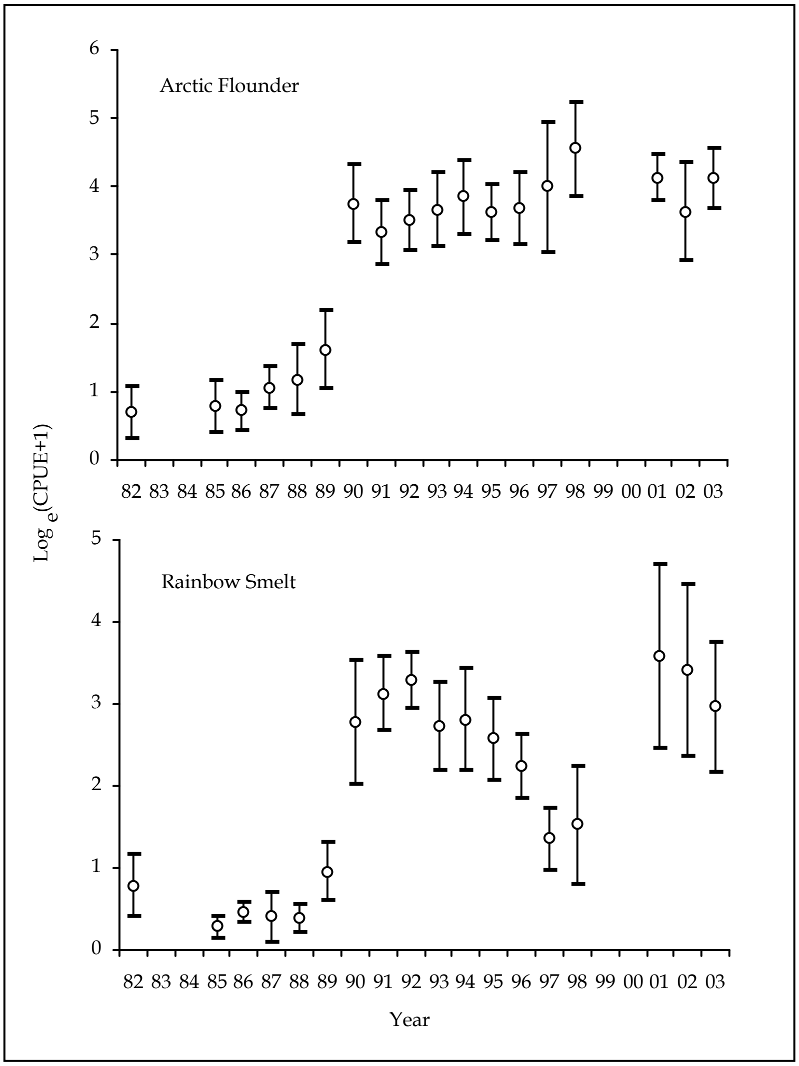

Figure 34. Catch-per-unit-effort (CPUE = fish/net/24h) ±95% CI for Arctic flounder and rainbow smelt.

1990 and 1991. There was no clear increase in the CPUE of rainbow smelt at the ANWR sampling sites from 1988–1989 to 1990–1991 (Underwood et al. 1995).

The similarity in the events reported for Prudhoe Bay and ANWR beginning in the summer of 1990 suggests a region-wide event along the Beaufort Sea coast. The phenomenon may be associated with major climatic regime shifts that were reported to have occurred in 1989 for the North Pacific and Bering Sea (Hare and Mantua 2000, Minobe 2002).

Fourhorn Sculpin. The fourhorn sculpin is a demersal species that has a circumpolar nearshore distribution in brackish and moderately saline waters (Scott and Crossman 1973; Morrow 1980). This species migrates onshore into brackish coastal habitats during summer to feed, and may travel considerable distances up rivers. It has been reported as far as 144 km upstream in the Meade River, Alaska, and 192 km up the Mackenzie River (Morrow 1980). Fourhorn sculpin live primarily near the coast and do not undergo any extensive migrations (Andriyashev 1954). They are most common in shallow waters and rarely descend deeper than 15–20 m (Andriyashev 1954).

A total of 11,553 (73.9 fish/net/24 h) fourhorn sculpin was caught in 2003. This catch rate is well within historic levels.

Arctic Cod. The Arctic cod is a marine species that has a circumpolar distribution and is ubiquitous in waters of the Beaufort Sea. In nearshore waters, Arctic cod abundance is typically low early in the season but increases throughout the season as salinity increases (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987; Glass et al. 1990; LGL 1990, 1991, 1992, 1993, 1994a, 1994b, 1999a, 1999b; Reub et al. 1991; Griffiths et al. 1995, 1996, 1997 and Fechhelm et al. 2001). Moulton and Tarbox (1987) found that cod were associated with highly productive transition layers that separate cold marine bottom water and warm brackish surface water, and that the onshore movement of such layers could be an important factor influencing the species composition in coastal aggregations of fish.

A total of 38,368 (245.3 fish/net/24 h) were caught in 2003. This species is typically the most abundant collected in the Prudhoe Bay area and fluctuations in catch among years can be quite substantial. Catches for 2003 were well within historic levels. Arctic cod are often observed in large age-segregated schools (Bain and Sekarak 1978; Welch et al. 1993; Hop et al. 1997) and the movement of these large schools into coastal areas can be dramatic (Craig and Haldorson 1981). Hop et al. (1997) point out that occurrence of Arctic cod schools in any particular area is both unpredictable and ephemeral.

CONCLUSIONS

The summer of 2003 was the second consecutive year in which average winds blew out of the west. Winds for July-August typically blow from the east. Because of the west winds there was no recruitment of young-of-the-year Arctic cisco into the Prudhoe Bay region from Canada. There also appeared to be no periods of strong easterly winds in the month of September that could have facilitated a late recruitment. The catch of age-1 and age-2 Arctic cisco was among the poorest within the 1985-2003 period of record. The low catch rate is consistent with the absence of a recruitment in both 2001 and 2002. The absence of the 2001-2003 year classes should adversely affect yields in the Colville River subsistence and commercial fisheries beginning in 2006-2007 and lasting through 2009-2010.

The 2003 catch of Arctic cisco age-3 and older was the highest ever reported in Prudhoe Bay for the 1985-2003 period of record. This age-3+ group appears to be dominated by three particularly strong years classes—1997, 1998, and 1999. Provided these year classes remain healthy, they should support strong commercial and subsistence harvests over the next few years.

The growth of Arctic cisco has decreased dramatically over the past two summers. In 2003, age 3-6 fish were significantly smaller for their age than has previously been reported. Further, Arctic cisco failed to gain weight during the 2003 feeding season. Decreased growth and the absence of weight gain may be related to the unusual predominance of west winds in 2003. Arctic cisco feed primarily on marine invertebrates.

West winds prevent sub-surface marine water, and the marine invertebrate fauna that inhabit it, from moving onshore. Because nearshore consumers quickly deplete food resources, the continuous immigration and transport of marine invertebrates into the nearshore zone is necessary to provide adequate levels of prey. West winds may have disrupted this process resulting in lower prey levels and poor feeding.

Catches of both small and large least cisco were the highest recorded in the Prudhoe Bay area for the 1985-2003 period of record. High catches may reflect an expansion in the Colville River least cisco population or enhanced eastward transport to the Prudhoe Bay region caused by the excessive west winds (easterly currents) that characterized the month of July. The wind-transport model predicted the arrival date of small fish at Prudhoe Bay within 24 hours of the actual arrival, again validating the hypothesis that the migration of juvenile least cisco from the Colville River to Prudhoe Bay is largely attributable to a wind-driven transport process.

Based upon three seasons of study, we have been unable to find evidence that least cisco are gaining weight during summer. At this point, we do not know whether the apparent absence of weight gain is real or an artifact of our analysis. This is only the third year in which least cisco have been the subject of aging analysis and data may still be insufficient to identify broader patterns. There is also evidence that least cisco found in coastal waters of Prudhoe Bay may be a mixture of anadromous and freshwater forms. This would confound growth, aging, and condition analyses. On the other hand, there is compelling evidence that Arctic cisco have failed to grow or put on weight in recent years, which suggests that the phenomenon in least cisco may be real. At this point, the issue remains unsettled.

The 2003 catch rates of broad whitefish age-2 and age-3 and older were the highest ever recorded in the 1985-2003 period of record. CPUE for age-3 fish was the fourth highest for this group. Collectively data suggest that the Sagavanirktok River broad whitefish stock is robust and healthy. Simulation models indicated that the growth of age-1 and age-2 broad whitefish during summer 2003 was in line with expectations. The fact that juvenile broad whitefish appear to have grown normally over the past two summers while Arctic cisco growth has been below normal (see above) is not unreasonable. Whereas Arctic cisco feed primarily on invertebrates of marine origin, broad whitefish rely more heavily on Chironomids (midge fly larvae) that are washed down river into the delta flats. If the west winds that dominated in the month of July did prevent marine invertebrates from moving onshore and replenishing depleted prey stocks, the phenomenon would not have affected the supply of freshwater invertebrates.

The catch rates of all size classes of Dolly Varden were well within historic ranges for Prudhoe Bay fish surveys. The summer growth of Dolly Varden smolts was the lowest for the 1985-2003 period of record. Estimated growth for 2003 extends a trend of decreasing summer growth that has been apparent since 1989. The reasons for this decrease in growth rate are unknown.

The catch of humpback whitefish east of West Dock continued to remain elevated relative to the initial sharp rise that first occurred in the summer of 1996. Data are consistent with the hypothesis that the construction of the West Dock breach in the winter of 1995-1996 has allowed this species to extend its coastal distribution farther to the east. Catch rate in 2003 were the highest in the 1985-2003 period of record. This may reflect an expansion in the Colville River population, or enhanced dispersal eastward in conjunction with the heavy west winds (easterly flowing currents) that characterized the 2003 season. Most humpback whitefish were adults. The absence of small fish again suggests that the Prudhoe Bay area is well beyond the summer dispersal range of juvenile fish from the Colville River. Unlike previous years, humpback whitefish were taken in large numbers well into late August. The unusually low salinities that were prevalent through late July may have delayed triggering their westward return migration back to the Colville River.

The sharp increase in the abundance of the marine Arctic flounder and the anadromous rainbow smelt that first began in 1990 continued through 2003. Catch rates of both species remain higher than the rates reported in the 1980s. The phenomenon may be associated with major climatic regime shifts that were reported to have occurred in 1989 for the North Pacific and Bering Sea.

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REFERENCES

Adams, A.B., and T.C. Cannon. 1987. Overwintering study. Vol. 7, Part V *in* Endicott Environmental Monitoring Program, Final Reports, 1985. Report by Envirosphere Co. for Alaska District, U.S. Army Corps of Engineers, Anchorage, Alaska. 33 p.

Anderson, W.G., R.S. McKinley, and M. Colavecchia. 1997. The use of clove oil as an anesthetic for rainbow trout and its effects on swimming performance. North Amercian Journal of Fisheries Management 17:301-307.

Andriyashev, A.P. 1954. Fishes of the northern seas of the U.S.S.R. Keys to the fauna of the U.S.S.R. Zoological Institute of the U.S.S.R. Academy of Sciences No. 53. Translated from Russian by Israel Program for Scientific Translations 1964. 617 p.

Bain, H. and A.D. Sekerak. 1978. Aspects of biology of Arctic cod, *Boreogadus saida*, in the central Canadian Arctic. Report by LGL Limited for Polar Gas Project. 104 p.

Bendock, T., and J. Burr. 1984. Inventory and cataloguing of Arctic area waters. Pages 1-46 *in* L.M. Weidlich, editor. Federal Aid in Fish Restoration and Anadromous Fish Studies, Volume 25. Alaska Department of Fish and Game, Juneau, Alaska.

Bettoli, P.W., and L.E. Miranda. 2001. Cautionary note about estimating mean length at age with subsampled data. North American Journal of Fisheries Management 21:425-428.

Bickham, J.W., S.M. Carr, B.G. Hanks, D.W. Burton, and B.J. Gallaway. 1989. Genetic analysis of population variation in the Arctic cisco (*Coregonus autumnalis*) using electrophoretic, flow cytometric, and mito-chondrial DNA restriction analyses. Biological Papers of the University of Alaska 24: 112-122.

Biosonics, Inc. 1984. Prudhoe Bay Waterflood project fish monitoring program, 1983. Report for U.S. Army Corps of Engineers, Alaska District, Anchorage, Alaska.

Bond, W.A. and R.N. Erickson. 1987. Fishery data from Phillips Bay, Yukon, 1985. Canadian Data Report of Fisheries and Aquatic Sciences 635. 39 p.

Bond, W.A., and R.N. Erickson. 1993. Fisheries investigations in coastal waters of Liverpool Bay, Northwest Territories. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2204. 51 p.

Cannon, T.C., M.S. Brancato, and S.C. Jewett. 1987a. Fish food habits. Pages 1-63 *in* Endicott Environmental Monitoring Program, Final Reports, 1985. Vol. 7. Report by Envirosphere Co. for the U.S. Army Corps of Engineers, Anchorage, Alaska.

Cannon, T.C., B.A. Adams, D. Glass, and T. Nelson. 1987b. Fish distribution and abundance. Pages 1-38 *in* Endicott Environmental Monitoring Program, Final Reports, 1985. Vol. 6. Report by Envirosphere Co. for Alaska District, U.S. Army Corps of Engineers, Anchorage, Alaska. 38 p + Append.

Carmack, E.C and R.W Macdonald. 2002. Oceanography of the Canadian Shelf of the Beaufort Sea: a setting for marine life. Arctic 55, Supplement 1:29-45.

Chilton, D.E., and R.J. Beamish. 1982. Age determination methods for fishes studied by the Groundfish Program at the Pacific Biological Station. Canadian Journal of Fisheries and Aquatic Sciences Special Publication 60.

Cohen, D.M. 1954. Age and growth studies on two species of whitefishes from Point Barrow, Alaska. Stanford Ichthyological Bulletin 4:168-187.

Colonell, J.M., and B.J. Gallaway 1997. Wind-driven transport and dispersion of age-0 Arctic cisco along the Beaufort Sea coast. American Fisheries Society Symposium 19:90-103.

Craig, P.C. 1977a. Ecological studies of amphidromous and resident populations of Arctic char in the Canning River drainage and adjacent coastal waters of the Beaufort Sea, Alaska. Arctic Gas Biological Report Series 41. 116 p.

Craig, P.C. 1977b. Fisheries research in the Shaviovik Drainage, Alaska, with emphasis on Arctic char in the Kavik River. Arctic Gas Biological Report Series 41. 28 p.

Craig, P.C. 1984. Fish use of coastal waters of the Beaufort Sea: a review. Transactions of the American Fisheries Society 113:265-282.

Craig, P.C. 1989. An introduction to amphidromous fishes in the Alaskan Arctic. Biological Papers of the University of Alaska 24:27-54.

Craig, P.C., and L. Haldorson. 1981. Beaufort Sea barrier island-lagoon ecological process studies: Final report, Simpson Lagoon (Part 4, Fish). Pages 384-678 *in* Environmental Assessment of the Alaskan Continental Shelf, Final Reports of Principal Investigators. Vol. 7. BLM/NOAA OCSEAP, Boulder, CO.

Craig, P.C., and P. McCart. 1975. Classification of stream types in Beaufort Sea drainages between Prudhoe Bay, Alaska and the Mackenzie Delta, N.W.T. Arctic and Alpine Research 7:183-198.

Craig, P.C., W.B. Griffiths, S.R. Johnson, and D.M. Schell. 1984. Trophic dynamics in an arctic lagoon. Pages 347-380 in P.W Barnes, D.M. Schell, and E. Reimnitz. The Alaskan Beaufort Sea: Ecosystems and Environments. Academic Press, New York.

Critchlow, K.R. 1983. Fish study. Pages 1-327 *in* Prudhoe Bay Waterflood Environmental Monitoring Program 1982. Report by Woodward-Clyde Consultants for Alaska District, U.S. Army Corps of Engineers, Anchorage, Alaska.

DeVries, D.R., and R.V. Frie. 1996. Determination of age and growth. Pages 483-512 in B.R. Murphy and D.W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

DeCicco, A.L. 1985. Inventory and cataloging of sport fish and sport fish waters of western Alaska with emphasis on Arctic char life history. Annual Report, 1984-1985, Alaska Department of Fish Game, Federal Aid in Restoration 26: 41-134.

DeCicco, A.L. 1992. Long-distance movements of anadromous Dolly Varden between Alaska and the U.S.S.R. Arctic 45:120-123.

Everett, R.J., and R.L. Wilmot. 1987. Population genetic structure of Arctic char (*Salvelinus alpinus*) from rivers of the North Slope of Alaska. U.S Dept. Commerce., NOAA, OCSEAP Final Rep. 63:63-121.

Fawcett, M.H., L.L. Moulton, and T.A. Carpenter. 1986. Colville River Fishes: 1985 Biological Report. Chapter 2 in Colville River Fish Study: 1985 Annual Report. Prepared by Entrix, Inc. for ARCO Alaska, Inc., North Slope Borough and the City of Nuiqsut.

Fechhelm, R.G. 1999. The effect of new breaching in a Prudhoe Bay causeway on the coastal distribution of humpback whitefish. Arctic 52:385-393.

Fechhelm, R.G., and D.B. Fissel. 1988. Wind-aided recruitment of Canadian Arctic cisco (*Coregonus autumnalis*) into Alaskan waters. Canadian Journal of Fisheries and Aquatic Sciences 45:906-910.

Fechhelm, R.G., and W.B. Griffiths. 1990. The effect of wind on the recruitment of Canadian Arctic cisco (*Coregonus autumnalis*) into the central Alaskan Beaufort Sea. Canadian Journal of Fisheries and Aquatic Sciences 47:2164-2171.

Fechhelm, R.G., J.S. Baker, W.B. Griffiths, and D.R. Schmidt. 1989. Localized movement patterns of least cisco (*Coregonus sardinella*) and arctic cisco (*C. autumnalis*) in the vicinity of a solid-fill causeway. Biological Papers of the University of Alaska 24: 75-106.

Fechhelm, R.G., R.E. Dillinger, Jr., B.J. Gallaway, and W.B. Griffiths. 1992. Modeling of in situ temperature and growth relationships for yearling broad whitefish in Prudhoe Bay, Alaska. Transactions of the American Fisheries Society 121:1-12.

Fechhelm, R.G., W.B. Griffiths, L.R. Martin, and B.J. Gallaway. 1996. Intra- and inter-seasonal variation in the relative condition and proximate body composition of Arctic ciscoes from the Prudhoe Bay region of Alaska. Transactions of the American Fisheries Society 125:600-612

Fechhelm, R.G., J. Bryan, W.B. Griffiths, and L.R. Martin. 1997. Summer growth patterns of Northern Dolly Varden (*Salvelinus malma)* smolts from the Prudhoe Bay region of Alaska. Canadian Journal of Fisheries and Aquatic Sciences 54:1103-1110.

Fechhelm, R.G., S.H. Haskell, W.J. Wilson, and W.B. Griffiths. 2001. Nearshore Beaufort Sea fish monitoring study in the Prudhoe Bay region, 2001. Report for BP Exploration (Alaska Inc. by LGL Alaska Research Associates, Inc., Anchorage, AK. 86 p + Append.

Fechhelm, R.G., W.B. Griffiths, B.E. Haley, and W.J. Wilson. 2003. Nearshore Beaufort Sea fish monitoring study in the Prudhoe Bay region, 2002. Report for BP Exploration (Alaska Inc. by LGL Alaska Research Associates, Inc., Anchorage, AK. 86 p + Append.

Fechhelm, R.G., J.D. Bryan, W.B. Griffiths, B.J. Gallaway, and W.J. Wilson. 1994. The effects of coastal winds on the summer dispersal of young least cisco (*Coregonus sardinella*) from the Colville River to Prudhoe Bay, Alaska: A simulation model. Canadian Journal of Fisheries and Aquatic Sciences 51:890-899.

Fechhelm, R.G., W.B. Griffiths, J.D. Bryan, B.J. Gallaway, and W.J. Wilson. 1995a. Application of an in situ growth model: inferred instance of interspecific trophic competition between amphidromous fishes of Prudhoe Bay, Alaska. Trans. Amer. Fish. Soc. 124:55-69.

Fechhelm, R.G., W.B. Griffiths, W.J. Wilson, B.J. Gallaway, and J.D. Bryan. 1995b. Intra- and inter-seasonal changes in the relative condition and proximate body composition of broad whitefish from the Prudhoe Bay region of Alaska. Transactions of the American Fisheries Society 124:508-519.

Fechhelm, R.G., L.R. Martin, B.J. Gallaway, W.J. Wilson, and W.B. Griffiths. 1999. Prudhoe Bay causeways and the summer coastal movements of Arctic cisco and least cisco. Arctic 52(2): 139-151.

Fechhelm, R.G., L.R. Martin, B.J. Gallaway, W.J. Wilson, and W.B. Griffiths. 2001. Estimating the hydrographic effects of Prudhoe Bay causeway breaches using the Before-After Control-Impact (BACI) analysis. Arctic 54(2): 162-173.

Gallaway, B.J., W.J. Gazey, and L.L. Moulton. 1989. Population trends for the Arctic cisco (*Coregonus autumnalis*) in the Colville River of Alaska as reflected by the commercial fishery. Biological Papers of the University of Alaska 24:153-165.

Gallaway, B.J., R.G. Fechhelm, W.B. Griffiths, and J.G. Cole. 1997. Population dynamics of broad whitefish in the Prudhoe Bay Region, Alaska. American Fisheries Society Symposium 19:194-207.

Gallaway, B.J., W.B. Griffiths, P.C. Craig, W.J. Gazey, and J.W. Helmericks. 1983. An assessment of the Colville River delta stock of Arctic cisco – migrants from Canada? Biological Papers of the University of Alaska 21:4-23.

Glass, D., C. Whitmus, and M. Prewitt. 1990. Fish distribution and abundance. Vol. 5, Chap. 1, Part IV *in* Endicott Environmental Monitoring Program Final Reports, 1986. Report by Envirosphere Co. for Alaska District, U.S. Army Corps of Engineers, Anchorage, Alaska. 154 p + Append.

Glova, G., and McCart, P. 1974. Life history of Arctic char (*Salvelinus alpinus*) in the Firth River, Yukon Territory. Arctic Gas Biological Report Series 40. 37 p.

Griffiths, W.B., and B.J. Gallaway. 1982. Prudhoe Bay Waterflood fish monitoring program 1981. Report by LGL Alaska Research Associates. for Woodward–Clyde Consultants, Anchorage, Alaska and the U.S. Army Corps of Engineers, Anchorage, Alaska. 143 p.

Griffiths, W.B., B.J. Gallaway, W.G. Gazey, and R.E. Dillinger, Jr. 1992. Growth and condition of Arctic cisco and broad whitefish as indicators of causeway-induced effects in the Prudhoe Bay region, Alaska. Transactions of the American Fisheries Society 121:557-577.

Griffiths, W.B, R.G. Fechhelm, L.R. Martin, W.J. Wilson, and J.M. Colonell. 1995. The 1994 Endicott Development Fish Monitoring Program. Vol. I: Fish and Hydrography Data Report. Report for BP Exploration (Alaska) Inc. and North Slope Borough. 182 p + Append.

Griffiths, W.B, R.G. Fechhelm, L.R. Martin, and W.J. Wilson. 1996. The 1995 Endicott Development Fish Monitoring Program. Vol. I: Fish and Hydrography Data Report. Report for BP Exploration (Alaska) Inc. and North Slope Borough. 180 p + Append.

Griffiths, W.B, R.G. Fechhelm, L.R. Martin, and W.J. Wilson. 1997. The 1996 Endicott Development Fish Monitoring Program. Vol. I: Fish and Hydrography Data Report. Report for BP Exploration (Alaska) Inc. and North Slope Borough. 192 p + Append.

Griffiths, W.B., R.G. Fechhelm, B.J. Gallaway, L.R. Martin, and W.J. Wilson. 1998. Abundance of selected fish species in relation to temperature and salinity patterns in the Sagavanirktok Delta, Alaska, following construction of the Endicott Causeway. Arctic51: 94-104.

Griffiths, W.B, L.R. Martin, S.P. Haskell, W. J. Wilson, and R.G. Fechhelm. 2002. The 2001 Point Thomson fish study. Report to Exxon Owners Group administered by BP Exploration (Alaska) Inc, Anchorage, Alaska.

Griffiths, W.B., D.R. Schmidt, R.G. Fechhelm, B.J. Gallaway, R.E. Dillinger, Jr., W. Gazey, W.H. Neill and J.S. Baker. 1983. Fish ecology. Vol. 3. *in* B.J. Gallaway and R. Britch, editors. Environmental Summer Studies (1982) for the Endicott Development. Report by LGL Alaska Research Associates, Inc. and Northern Technical Services for Sohio Alaska Petroleum Co., Anchorage, Alaska. 342 p.

Hachmeister, L.E, K.S. Short, G.S. Schrader, K.B. Winnick, and J.W. Johannessen. 1987. Oceanographic monitoring. In: 1985 Final Report for the Endicott Environmental Monitoring Program. Vol. 3. Report for U.S. Army Corps of Engineers, Alaska District, Anchorage, Alaska.

Hare, S.R., and N.J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography 47:103-145.

Holm, S. 1979. A simple sequentially rejective multiple test procedure. Scand. J. Stat. 6:65-70.

Hop, H., H.E. Welch, and R.E. Crawford. 1997. Population structure and feeding ecology of Arctic cod schools in the Canadian high Arctic. American Fisheries Society Symposium 19:68-80.

Kimura, D.K. 1977. Statistical assessment of age-length key. Journal of the Fisheries Research Board of Canada 34:317-324.

Knutzen, J.A., and S.C. Jewett. 1991. Fish food habits (stomachs). Pages 1-29 *in* Endicott Environmental monitoring program, final reports, 1987. Vol. 6. Report by Envirosphere Co. for the U.S. Army Corps of Engineers, Anchorage, Alaska.

Knutzen, J.A., M.S. Brancato, and S.C. Jewett. 1990. Fish food habits (stomachs). Pages 1-75 *in* Endicott environmental monitoring program, Final Reports, 1986. Vol. 7. Report by Envirosphere Co. for the U.S. Army Corps of Engineers, Anchorage, Alaska.

Kitchen, K.S. 1949. Stratified subsampling for determining age distributions. Transactions of the American Fisheries Society 79:205-212.

Lawrence, M.J., G. Lacho, and S. Davies. 1984. A survey of the coastal fisheries of the southern

Beaufort Sea. Canadian Technical Report of Fisheries and Aquatic Sciences 1220. 178 p.

Lagler, K.F. 1978. Capture, sampling and examination of fishes. Chapter 2 *in* T. Bagenal, editor. Methods for Assessment of Fish Production in Fresh Waters. Third edition. Blackwell Scientific Publications. Oxford, England.

Le Cren, E. D. 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). Journal of Animal Ecology 20:201-219.

LGL (see LGL Alaska Research Associates, Inc.)

LGL Alaska Research Associates, Inc. 1990. The 1988 Endicott Development Fish Monitoring Program. Vol. II: Recruitment and Population Studies, Analysis of 1988 Fyke Net Data. Anchorage, Alaska. Report for BP Exploration (Alaska) Inc. and North Slope Borough. 317 p.

LGL Alaska Research Associates, Inc. 1991. The 1989 Endicott Development Fish Monitoring Program. Vol. II: Analysis of Fyke Net Data. Anchorage, Alaska. Report for BP Exploration (Alaska) Inc. and North Slope Borough. 143 p + Append.

LGL Alaska Research Associates, Inc. 1992. The 1990 Endicott Development Fish Monitoring Program. Vol. II: Analysis of Fyke Net Data. Anchorage, Alaska. Report for BP Exploration (Alaska) Inc. and North Slope Borough. 160 p + Append.

LGL Alaska Research Associates, Inc. 1993. The 1991 Endicott Development Fish Monitoring Program. Vol. I: Analysis of Fyke Net Data. Report for BP Exploration (Alaska) Inc. and North Slope Borough. 189 p + Append.

LGL Alaska Research Associates, Inc. 1994a. The 1992 Endicott Development Fish Monitoring Program. Vol. I: Analysis of Fyke Net Data. Report for BP Exploration (Alaska) Inc. and North Slope Borough. 195 p + Append.

LGL Alaska Research Associates, Inc. 1994b. The 1993 Endicott Development Fish Monitoring Program. Vol. I: Fish and Hydrography Data Report. Report for BP Exploration (Alaska) Inc. and North Slope Borough. 217 p + Append.

LGL Alaska Research Associates, Inc. 1999a. The 1997 Endicott Development Fish Monitoring Program. Vol. I: Fish and Hydrography Data Report. Report for BP Exploration (Alaska) Inc. and North Slope Borough. 21 p.

LGL Alaska Research Associates, Inc. 1999b. The 1998 Endicott Development Fish Monitoring Program. Vol. I: Fish and Hydrography Data Report. Report for BP Exploration (Alaska) Inc. and North Slope Borough. 21 p + Append.

Mangarella, P.A., J.R. Harper, and T.G. Weingartner. 1982. Prudhoe Bay Waterflood Project Physical Processes Monitoring , 1981. Appendix A. Report to U.S. Army Corps of Engineers, Alaska District, Anchorage, Alaska.

Mann, G.J. 1974. Life history types of the least cisco (*Coregonus sardinella*, Valenciennes) in the Yukon Territory North Slope and eastern Mackenzie River delta drainages. Chapter 3. *In:* P.J. McCart, editor. Life Histories of Three Species of Freshwater Fishes in Beaufort Sea Drainages, Yukon Territory. Arctic Gas Biological Report Series, Volume 18. Report by Aquatic Environments Limited for Canadian Arctic Gas Study Limited and Alaskan Arctic Gas Study Company. 377 p.

Mann, G. and P. McCart. 1981. Comparison of sympatric dwarf and normal populations of least cisco (*Coregonus sardinella*) inhabiting Trout Lake, Yukon Territory. Canadian Journal of Fisheries and Aquatic Sciences 38:240-244.

McPhail, J.D. and C.C. Lindsey. 1970. The freshwater fishes of northwestern Canada and Alaska. Fisheries Research Board of Canada Bulletin 173. 381 p.

Minobe, S. 2002. Interannual to interdecadal changes in the Bering Sea and concurrent 1998/1999 changes over the North pacific. Progress in Oceanography 55:45-64.

Morrow, J.E. 1980. The freshwater fishes of Alaska. Alaska Northwest Pub. Co., Anchorage, Alaska. 248 p.

Morales, J.C., B.G. Hanks, J.W. Bickham, J.N. Derr, and B.J. Gallaway. 1993. Allozyme analysis of population structure in Arctic cisco (*Coregonus autumnalis*) from the Beaufort Sea. Copeia 1993: 863-867.

Moulton, L.L. 1989. Recruitment of Arctic cisco (*Coregonus autumnalis*) into the Colville Delta, Alaska, 1985. Biological Papers of the University of Alaska 24:107–111.

Moulton, L.L. 1994. The 1993 Endicott Development Fish Monitoring Program. Vol. II: The 1993 Colville River Fishery. Report by MJM Research, Bainbridge Island, WA, for BP Exploration (Alaska) Inc. and North Slope Borough. 60 p + Append.

Moulton, L.L. 1995. The 1994 Endicott Development Fish Monitoring Program. Vol. II: The 1994 Colville River Fishery. Report by MJM Research, Bainbridge Island, WA, for BP Exploration (Alaska) Inc. and North Slope Borough. 58 p + Append.

Moulton, L.L. 2001. Harvest estimate and associated information for the 2000 Colville River fall fishery. Report to Phillips Alaska, Inc. and BP Exploration (Alaska) inc., Anchorage, Alaska.

Moulton, L.L. 2003. Harvest estimate and associated information for the 2002 Colville River fall fishery. Report to Phillips Alaska, Inc. and BP Exploration (Alaska) inc., Anchorage, Alaska.

Moulton, L.L. and K.E. Tarbox. 1987. Analysis of Arctic cod movements in the Beaufort Sea nearshore region, 1978-79. Arctic 40:43-49.

Moulton, L.L., and L.J. Field. 1988. Assessment of the Colville River fall fishery 1985-1987. Report by Environmental Sciences and Engineering Inc. for ARCO Alaska Inc., Anchorage, Alaska, North Slope Borough, Barrow, Alaska, and the City of Nuiqsut, Alaska. 42 p.

Moulton, L.L., and L.J. Field. 1991. The 1989 Colville River Fishery *In*: The 1989 Endicott Development Fish Monitoring Program (Vol. III). Report by MJM Research for BP Exploration (Alaska) Inc. and the North Slope Borough. 79 p.

Moulton, L.L., and L.J. Field. 1994. The 1992 Colville River Fishery *In*: The 1992 Endicott Development Fish Monitoring Program (Vol. II). Report by MJM Research for BP Exploration (Alaska) Inc. and the North Slope Borough. 53 p + Append.

Moulton, L.L., B.J. Gallaway, M.H. Fawcett, W.B. Griffiths, K.R. Critchlow, R.G. Fechhelm, D.R. Schmidt, and J.S. Baker. 1986. 1984 Central Beaufort Sea Fish Study. Waterflood Monitoring Program Fish Study. Report by Entrix, Inc., LGL Ecological Research Associates, Inc., and Woodward-Clyde Consultants for Envirosphere Co. Anchorage, Alaska. 300 p.

Moulton, L.L., L.C. Lestelle and L.J. Field. 1992. The 1990 Colville River Fishery *In:* The 1990 Endicott Development Fish Monitoring Program (Vol. III). Report by MJM Research for BP Exploration (Alaska) Inc. and the North Slope Borough. 49 p + Append.

Moulton, L.L., L.C. Lestelle and L.J. Field. 1993. The 1991 Colville River Fishery *In:* The 1991 Endicott Development Fish Monitoring Program (Vol. III). Report by MJM Research for BP Exploration (Alaska) Inc. and the North Slope Borough. 41 p + Append.

Neter, J., W. Wasserman, and M. H. Kutner. 1989. Applied Linear Regression Models. Irwin, Boston.

Niedoroda, A.W., and J.M. Colonell. 1989. Coastal boundary layer processes in the central Beaufort Sea. *In* C.T. Mitchell, editor. A Synthesis of Environmental Information on Causeways in the Nearshore Beaufort Sea, Alaska. U.S. Minerals Management Service, OCS Study. MMS 89–0038.

Niedoroda, A.W., and J.M. Colonell. 1990a. Beaufort Sea causeways and coastal ocean dynamics. Pages 509-516 *in* S.K. Chakrabartl, H. Magda, C. Aage, and F.G. Neilsen, editors. Proceedings of the Ninth International Conference of Offshore Mechanical and Arctic Engineering, Book No. 10296B. American Society of Mechanical Engineers, New York.

Niedoroda, A.W., and J.M. Colonell. 1990b. Endicott area oceanographic processes. *In* B.J. Gallaway and J.M. Colonell, editors. The 1988 Endicott Development Fish Monitoring Program. Vol. I: Executive Summary and Synthesis. Report by LGL Alaska Research Associates, Inc. and Woodward–Clyde Consultants, Anchorage, Alaska, for BP Exploration (Alaska) Inc. and North Slope Borough.

Philo, L.M., J.C. George, and L.L. Moulton. 1993. The occurrence and description of anadromous fish in Dease Inlet/Admiralty Bay, Alaska area, 1988-1990. Report by Department of Wildlife Management North Slope Borough, Barrow, Alaska. 150 p.

Reub, G.S., Durst, J.D., and Glass, D. 1991. Fish distribution and abundance, Vol. 6 *in* Endicott Environmental Monitoring Program Final Reports, 1986. Report by Envirosphere Co. for Alaska District, U.S. Army Corps of Engineers, Anchorage, Alaska. 147 p + Append.

Rice, W.R. 1989. Analyzing tables of statistical tests. Evolution 43:223-225.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of canada Bulletin 191.

Savoie, M.A., and D.C. Wilson. 1983. Prudhoe Bay Waterflood Project Physical Processes Monitoring Program, 1982. Report to U.S. Army Corps of Engineers, Alaska District, Anchorage, Alaska.

Savoie, M.A., and D.C. Wilson. 1986. Prudhoe Bay Waterflood Project Physical Processes Monitoring Program, 1984. Report to U.S. Army Corps of Engineers, Alaska District, Anchorage, Alaska.

Schmidt, D.R., W.B. Griffiths and L.R. Martin. 1989. Overwintering biology of anadromous fish in the Sagavanirktok River delta, Alaska. Biological Papers of the University of Alaska 24:55-74.

Schmidt, D., W.B. Griffiths, D.K. Beaubien, and C.J. Herlugson. 1991. Movement of young-of-the-year Arctic ciscoes across the Beaufort Sea coast, 1985-1988. American Fisheries Society Symposium 11:132-144.

Scott, W.B., and E.J Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin 184.

Underwood, T.J., J.A. Gorden, M.J. Millard, L.A. Thorpe, and B.M. Osborne. 1995. Characteristics of selected fish populations of Arctic National Wildlife Refuge coastal waters, final report, 1988-1991. U.S. Fish and Wildlife Service, Fairbanks Fishery Research Office, Alaska Fisheries Technical Report Number 28, Fairbanks, Alaska.

U.S. Army Corps of Engineers. 1980. Final environmental impact statement, Prudhoe Bay Oil Field, Waterflood project. U.S. Army Corps of Engineers, Alaska District, Anchorage, Alaska.

U.S. Army Corps of Engineers. 1984. Final environmental impact statement, Prudhoe Bay Oil Field, Endicott Development project. U.S. Army Corps of Engineers, Alaska District, Anchorage, Alaska.

Wege, G. J., and R. O. Anderson. 1978. Relative weight (Wr): a new index of condition for largemouth bass. Pages 79-91 *in* G. D. Novinger and J. G. Dillard, editors. New approaches to the management of small impoundments. American Fisheries Society, North Central Division, Special Publication 5, Bethesda, Maryland.

Welch, H.E., R.E. Crawford, and H. Hop. 1993. Occurrence of Arctic cod (*Boreogadus saida*) schools and their vulnerability to predation in the Canadian high Arctic. Arctic 46:331-339.

Westrheim, S.J., and W.E. Ricker. 1978. Bias in using an age-length key to estimate age-frequency distributions. Journal of the Fisheries Research Board of Canada 35:184-189.

Wilkinson, L. 1989. SYSTAT: The System for Statistics. SYSTAT, Inc., Evanston, Illinois. 638 p.

Wohlschlag, D.E. 1954. Growth peculiarities of the cisco, *Coregonus sardinella* (Valenciennes), in the vicinity of Point Barrow, Alaska. Stanford Ichthyological Bulletin 4:189-209.

Woodward-Clyde Consultants. 1983. Lisburne development area: 1983 environmental studies--final report. Report for ARCO Alaska Inc., Anchorage, Alaska. 722 p.

APPENDIX A.

Physical Data

Table A1. **Water Temperature**

Table A2. **Salinity**

Table A1-1. Temperature (°C) by depth for Station 214, 2003

Date	0.0	0.5	1.0
1-Jul			
2-Jul			
3-Jul			
4-Jul			
5-Jul	10.7	10.6	
6-Jul	8.5	8.5	
7-Jul	7.5	7.5	
8-Jul			
9-Jul	9.5	9.5	
10-Jul			
11-Jul	10.5	10.5	
12-Jul	10.5	10.5	
13-Jul	9.0	9.0	9.0
14-Jul	8.5	8.5	8.5
15-Jul			
16-Jul	7.0	7.0	
17-Jul	7.0	7.0	
18-Jul	7.4		
19-Jul			
20-Jul			
21-Jul	13.3	13.3	
22-Jul	11.8	11.8	11.8
23-Jul	12.6	12.6	12.6
24-Jul	12.7	12.7	12.7
25-Jul			
26-Jul			
27-Jul			
28-Jul			
29-Jul			
30-Jul			
31-Jul			
1-Aug	6.2	6.2	6.1
2-Aug	5.4	5.1	6.5
3-Aug	7.4	7.3	
4-Aug	6.5	6.4	
5-Aug			
6-Aug			
7-Aug			
8-Aug			
9-Aug			
10-Aug			
11-Aug	6.7	6.7	
12-Aug	7.1	7.1	
13-Aug	6.4	6.4	
14-Aug	0.3	0.3	
15-Aug			
16-Aug			
17-Aug	4.7	4.7	
18-Aug	4.7	4.7	
19-Aug	4.9	4.8	
20-Aug	4.8	4.8	
21-Aug	4.4	4.5	
22-Aug	4.3	4.3	4.3
23-Aug	4.7	4.7	4.6
24-Aug	5.3	5.1	4.9
25-Aug			
26-Aug	4.6	4.6	
27-Aug	6.5	5.9	
28-Aug	6.2	5.4	
29-Aug	5.8	5.8	

Table A1-2. Temperature (°C) by depth for Station 218, 2003

Date	0.0	0.5	1.0
1-Jul			
2-Jul			
3-Jul			
4-Jul			
5-Jul			
6-Jul			
7-Jul			
8-Jul			
9-Jul			
10-Jul			
11-Jul			
12-Jul	10	9.9	9.9
13-Jul	7	7	7
14-Jul			
15-Jul			
16-Jul	6.8	6.8	
17-Jul		6.8	6.5
18-Jul	7.2	7.2	7.2
19-Jul	8.9	8.9	8.9
20-Jul	11	10.8	10.2
21-Jul	15.2	15.2	13.3
22-Jul	13.2	13.2	13.2
23-Jul	12.1	12.1	12.1
24-Jul	9.7	9.6	9.6
25-Jul	9.3	9.3	9.3
26-Jul	6.7	6.7	6.7
27-Jul	7.5	7.5	7.6
28-Jul			
29-Jul			
30-Jul	5.9	5.9	5.6
31-Jul	6.1	6.1	6.1
1-Aug	6.1	6.1	6.1
2-Aug	5.7	5.7	
3-Aug	6.2	6	5.2
4-Aug	4.1	4	4.1
5-Aug			
6-Aug			
7-Aug			
8-Aug			
9-Aug	6.4	6.3	6.3
10-Aug	7.6	7.6	7.5
11-Aug	5.7	5.7	5.6
12-Aug	5.9	5.9	
13-Aug	5.6	5.6	5.7
14-Aug	5.3	5.3	5.3
15-Aug	4.2	4.2	
16-Aug			
17-Aug	4.7	4.7	4.7
18-Aug	4.2	4.2	4.2
19-Aug	4.9	4.9	4.9
20-Aug	4.2	4.2	
21-Aug	4	4.4	4.4
22-Aug	4.3	4.3	4.4
23-Aug	5	4.7	4.5
24-Aug	5.1	5.2	5.2
25-Aug	3.9	3.9	3.9
26-Aug	4.5	4.5	4.5
27-Aug	4.3	4.3	
28-Aug	3.8	3.8	
29-Aug			

Table A1-3. Temperature (°C) by depth for Station 220, 2003

Date	0.0	0.5	1.0	1.5
1-Jul				
2-Jul				
3-Jul				
4-Jul				
5-Jul				
6-Jul				
7-Jul				
8-Jul				
9-Jul				
10-Jul				
11-Jul	10.2	10.2	10.2	10.2
12-Jul	8.8	8.7	8.6	8.6
13-Jul	9	9	9	
14-Jul	8.5	8.6	8.6	
15-Jul	8.6	8.6	8.6	
16-Jul	7.2	7.2		
17-Jul	9.9	9.9	9.9	
18-Jul	7.4	7.4	7.4	
19-Jul	9.9	9.9	9.9	9.9
20-Jul				
21-Jul				
22-Jul				
23-Jul				
24-Jul				
25-Jul	10.4	10.4	10.6	10.4
26-Jul	8.4	8.4	8.4	8.4
27-Jul	8.2	8.3	8.3	8.3
28-Jul				
29-Jul	6.2	6.2	6.2	6.2
30-Jul	6.5	6.6	6.5	6.4
31-Jul	6.1	5.3	5.2	
1-Aug	5.2	5.2	3.1	
2-Aug	3.4	3.3	4.8	
3-Aug	5.9	5.9	4.7	
4-Aug	4.9	4.8		
5-Aug	5.9	5.9	5.9	6.2
6-Aug				
7-Aug	7.1	7.1	7.1	
8-Aug	7.3	7.3	6.9	7
9-Aug	6.9	6.6	6.6	
10-Aug	6	6	6	
11-Aug	6.6	6.6	6.5	
12-Aug	5.9	6.1	6.1	
13-Aug	4.8	4.8		
14-Aug	4.5	4.5		
15-Aug				
16-Aug	4.9	4.9	4.7	
17-Aug	4.5	4.5	4.5	
18-Aug	4.6	4.6	4.6	
19-Aug	3.8	3.8	3.6	
20-Aug	3.4	3.6	3.8	
21-Aug	4.7	4.6	4.5	
22-Aug	4.3	4.2	4.2	4.1
23-Aug	4.6	4.6	4.6	4.1
24-Aug	4.3	4.3	4.2	
25-Aug	4	4.1	4.3	
26-Aug	3.6	3.6	3.6	
27-Aug				
28-Aug				
29-Aug				

Table A1-4. Temperature (°C) by depth for Station 230, 2003

Date	0.0	0.5	1.0
1-Jul			
2-Jul			
3-Jul			
4-Jul			
5-Jul			
6-Jul			
7-Jul	10.8	10.9	
8-Jul	12.9	12.9	
9-Jul	9.0	9.0	
10-Jul	9.6	9.6	
11-Jul	8.6	8.6	
12-Jul			
13-Jul	13.0	13.0	
14-Jul	12.5	12.5	12.5
15-Jul	10.3	10.2	
16-Jul	7.7	7.6	
17-Jul	7.9	7.7	
18-Jul	7.9	7.9	
19-Jul	6.4	6.4	
20-Jul		10.8	10.8
21-Jul	15.0	12.8	
22-Jul	14.4	14.2	
23-Jul	13.0	12.3	
24-Jul	12.5	12.5	12.5
25-Jul	13.3	13.3	13.3
26-Jul	10.5	10.5	10.5
27-Jul	8.6	8.7	8.7
28-Jul	7.7	7.7	7.7
29-Jul			
30-Jul			
31-Jul			
1-Aug			
2-Aug	6.8	6.9	
3-Aug	5.4	7.4	
4-Aug	7.4	6.4	
5-Aug	5.8	5.8	5.8
6-Aug	6.5	5.8	
7-Aug	8.0	8.0	7.9
8-Aug	9.3	6.9	
9-Aug	6.6	6.6	7.0
10-Aug	6.8	6.9	
11-Aug	5.5	5.5	
12-Aug	4.2	4.2	
13-Aug	5.9		
14-Aug			
15-Aug			
16-Aug	6.5	6.5	
17-Aug	6.9	6.9	
18-Aug			
19-Aug	5.0	5.2	
20-Aug	5.0	5.0	
21-Aug	6.2	4.4	
22-Aug	6.2	6.2	6.2
23-Aug	4.1	4.3	4.2
24-Aug	4.7	4.8	4.8
25-Aug	4.0	4.0	
26-Aug			
27-Aug			
28-Aug			
29-Aug			

Table A2-1. Salinity (ppt) by depth for Station 214, 2003

Date	0.0	0.5	1.0
1-Jul			
2-Jul			
3-Jul			
4-Jul			
5-Jul	0.1	0.1	
6-Jul	2.3	2.3	
7-Jul	2.6	2.6	
8-Jul			
9-Jul	0.1	0.1	
10-Jul			
11-Jul	2.2	2.2	
12-Jul	3.4	3.4	
13-Jul	3.8	3.8	3.9
14-Jul	3.9	3.9	3.9
15-Jul			
16-Jul	0.2	0.2	
17-Jul	0.1	0.1	
18-Jul	4.9		
19-Jul			
20-Jul			
21-Jul	5.6	6.0	
22-Jul	6.9	6.9	6.9
23-Jul	6.4	6.4	6.4
24-Jul	5.9	5.9	5.9
25-Jul			
26-Jul			
27-Jul			
28-Jul			
29-Jul			
30-Jul			
31-Jul			
1-Aug	4.9	6.4	11.5
2-Aug	8.6	10.9	11.4
3-Aug	11.4	11.4	
4-Aug	11.4	11.5	
5-Aug			
6-Aug			
7-Aug			
8-Aug			
9-Aug			
10-Aug			
11-Aug	17.4	17.1	
12-Aug	17.4	18.0	
13-Aug	21.7	21.7	
14-Aug	3.4	3.4	
15-Aug			
16-Aug			
17-Aug	3.8	3.8	
18-Aug	7.2	7.4	
19-Aug	17.1	19.9	
20-Aug	0.1	0.1	
21-Aug	5.0	11.9	
22-Aug	10.3	10.5	10.5
23-Aug	13.3	14.1	14.3
24-Aug	3.6	11.0	18.2
25-Aug			
26-Aug	1.3	1.3	
27-Aug	13.5	15.1	
28-Aug	13.6	19.9	
29-Aug	13.2	16.1	

Table A2-2. Salinity (ppt) by depth for Station 218, 2003

Date	0.0	0.5	1.0
1-Jul			
2-Jul			
3-Jul			
4-Jul			
5-Jul			
6-Jul			
7-Jul			
8-Jul			
9-Jul			
10-Jul			
11-Jul			
12-Jul	3.8	3.8	3.8
13-Jul	4.4	4.4	4.4
14-Jul			
15-Jul			
16-Jul	4.7	4.7	
17-Jul		6.0	6.9
18-Jul	5.9	5.9	5.9
19-Jul	4.3	4.3	5.1
20-Jul	2.8	3.2	4.4
21-Jul	4.0	4.0	4.6
22-Jul	4.6	4.6	4.6
23-Jul	7.0	7.0	7.0
24-Jul	7.1	7.5	7.5
25-Jul	7.3	7.3	7.3
26-Jul	9.9	9.9	9.9
27-Jul	8.2	8.2	8.2
28-Jul			
29-Jul			
30-Jul	11.4	12.4	14.0
31-Jul	10.5	10.5	10.5
1-Aug	8.0	8.0	8.0
2-Aug	9.5	9.5	
3-Aug	13.7	14.7	19.2
4-Aug	21.8	21.9	21.9
5-Aug			
6-Aug			
7-Aug			
8-Aug			
9-Aug	23.0	23.0	23.0
10-Aug	18.4	18.4	18.6
11-Aug	20.1	20.1	20.2
12-Aug	19.0	19.0	
13-Aug	17.3	17.6	18.9
14-Aug	18.1	18.1	18.1
15-Aug	17.3	17.3	
16-Aug			
17-Aug	14.9	15.0	15.3
18-Aug	7.2	7.3	9.1
19-Aug	7.2	7.2	7.2
20-Aug	6.3	6.3	
21-Aug	6.8	10.3	11.1
22-Aug	19.0	19.1	19.9
23-Aug	11.9	16.0	22.3
24-Aug	13.3	13.7	13.8
25-Aug	24.4	24.6	24.8
26-Aug	21.8	21.8	21.8
27-Aug	20.9	20.9	
28-Aug	18.1	18.1	
29-Aug			

Table A2-3. Salinity (ppt) by depth for Station 220, 2003

Date	0.0	0.5	1.0	1.5
1-Jul				
2-Jul				
3-Jul				
4-Jul				
5-Jul				
6-Jul				
7-Jul				
8-Jul				
9-Jul				
10-Jul				
11-Jul	3.3	3.3	3.3	3.3
12-Jul	4.0	4.0	4.1	4.2
13-Jul	2.2	2.2	2.2	
14-Jul	2.8	2.8	2.8	
15-Jul	1.6	1.6	1.6	
16-Jul	2.3	2.3		
17-Jul	7.4	7.4	7.4	
18-Jul	6.2	6.2	6.2	
19-Jul	1.9	1.9	2.0	2.0
20-Jul				
21-Jul				
22-Jul				
23-Jul				
24-Jul				
25-Jul	5.2	5.2	5.2	5.2
26-Jul	4.2	4.2	4.2	4.2
27-Jul	2.5	2.5	2.5	2.5
28-Jul				
29-Jul	13.3	13.3	13.3	13.3
30-Jul	3.7	3.7	3.9	4.4
31-Jul	11.6	14.1	15.0	
1-Aug	13.7	13.7	22.7	
2-Aug	22.0	22.4	20.2	
3-Aug	19.7	19.7	21.0	
4-Aug	19.7	19.9		
5-Aug	14.5	14.6	14.7	15.8
6-Aug				
7-Aug	16.6	16.6	16.0	
8-Aug	17.6	17.6	20.2	21.9
9-Aug	19.3	20.6	21.1	
10-Aug	16.4	16.4	16.4	
11-Aug	15.9	16.4	16.6	
12-Aug	20.8	20.8	20.8	
13-Aug	19.8	19.8		
14-Aug	19.0	19.0		
15-Aug				
16-Aug	7.6	7.5	10.8	
17-Aug	6.9	6.9	20.8	
18-Aug	17.4	17.5	21.8	
19-Aug	18.6	18.6	19.5	
20-Aug	18.6	19.1	19.3	
21-Aug	14.4	14.4	15.0	
22-Aug	24.1	25.0	25.9	25.9
23-Aug	20.4	20.4	20.9	17.1
24-Aug	15.5	15.7	16.5	
25-Aug	19.1	19.1	23.0	
26-Aug	21.8	21.8	21.8	
27-Aug				
28-Aug				
29-Aug				

Table A2-4. Salinity (ppt) by depth for Station 230, 2003

Date	0.0	0.5	1.0
1-Jul			
2-Jul			
3-Jul			
4-Jul			
5-Jul			
6-Jul			
7-Jul	0.1	0.1	
8-Jul	0.1	0.1	
9-Jul	0.1	0.1	
10-Jul	0.1	0.1	
11-Jul	0.1	0.1	
12-Jul			
13-Jul	0.1	0.1	
14-Jul	0.2	0.2	0.2
15-Jul	0.5	0.5	
16-Jul	10.7	10.8	
17-Jul	3.6	5.2	
18-Jul	0.1	0.1	
19-Jul	0.1	0.1	
20-Jul		0.4	0.4
21-Jul	0.2	3.9	
22-Jul	0.4	1.0	
23-Jul	8.2	9.3	
24-Jul	3.2	3.2	3.2
25-Jul	0.5	0.5	0.5
26-Jul	4.2	4.2	4.2
27-Jul	1.7	1.7	2.1
28-Jul	3.5	3.5	3.5
29-Jul			
30-Jul			
31-Jul			
1-Aug			
2-Aug	0.2	0.2	
3-Aug	11.7	12.2	
4-Aug	2.7	7.8	
5-Aug	11.2	11.2	11.4
6-Aug	4.4	19.4	
7-Aug	8.8	8.8	8.8
8-Aug	1.5	15.9	
9-Aug	2.8	3.2	3.8
10-Aug	0.3	0.5	
11-Aug	0.1	0.1	
12-Aug	0.1	0.1	
13-Aug	0.1		
14-Aug			
15-Aug			
16-Aug	0.1	0.1	
17-Aug	0.1	0.1	
18-Aug			
19-Aug	0.1	0.1	
20-Aug	1.6	1.6	
21-Aug	1.4	23.6	
22-Aug	1.5	1.5	1.5
23-Aug	3.5	16.5	25.3
24-Aug	0.1	17.3	18.4
25-Aug	0.2	0.2	
26-Aug			
27-Aug			
28-Aug			
29-Aug			

APPENDIX B.

Biological Data

Table B1-1. Quantitative effort in days by side of net, 2003.

	214W	214E	218W	218E	220W	220E	230N	230S
29-Jun							0.84	0.83
30-Jun							0.95	0.95
1-Jul								
2-Jul							0.94	0.94
3-Jul							1.02	1.00
4-Jul								0.99
5-Jul	0.82	0.85					1.05	1.04
6-Jul	1.00	1.00					1.00	0.98
7-Jul	1.02	1.03					1.06	1.05
8-Jul							0.98	0.91
9-Jul	0.68	0.69					1.01	1.03
10-Jul								
11-Jul	0.98	1.04			0.96	0.94	0.98	0.96
12-Jul	1.15	1.13	0.82	0.76	0.66	0.69	1.18	1.17
13-Jul	0.98	0.95	0.93	0.92	0.99	1.03	0.97	0.97
14-Jul	1.02	1.05			1.04	0.96	1.05	1.04
15-Jul					1.00	1.01	0.91	0.94
16-Jul	1.01	1.03	0.95	0.94	1.01	1.02	1.04	1.03
17-Jul	0.95	0.96	1.19	1.18	1.18	1.19	0.79	0.79
18-Jul			0.81	0.82	0.80	0.79	1.12	1.11
19-Jul				1.00	1.01	1.01	1.01	1.00
20-Jul			1.01	1.00	1.02	1.01	1.07	1.08
21-Jul	0.92	0.91	1.22	1.21			0.91	0.91
22-Jul	1.03	1.03	0.78	0.79			1.01	0.98
23-Jul	1.02	1.02	1.00	1.00			1.05	1.05
24-Jul	1.02	1.01	0.99	1.00			0.99	1.00
25-Jul			1.01	1.01	1.03	1.01	1.00	1.03
26-Jul			1.00	1.00	1.00	1.00	1.02	1.02
27-Jul			0.99	1.00	0.99	0.99	0.91	0.90
28-Jul								
29-Jul					1.98	1.98		
30-Jul			1.03	1.02	1.04	1.03		
31-Jul			1.00	0.99	1.02	1.03		
1-Aug	1.00	1.00	1.02	0.99	0.97	0.97	0.88	0.87
2-Aug	0.92	0.92	1.01	1.00	1.02	1.03	1.02	1.04
3-Aug	0.95	0.95	1.00	1.00	0.99	0.98	0.98	0.98
4-Aug	0.99	0.99	1.00	1.00	0.99	0.99	1.01	0.98
5-Aug								
6-Aug					1.11	0.99	1.92	1.93
7-Aug						1.36		
8-Aug					2.35	2.36	2.09	2.08
9-Aug			1.10	1.08	0.70	0.70	0.82	0.84
10-Aug			0.86	0.86	0.94	0.94	1.06	1.06
11-Aug	0.88	0.88	0.99	1.00	1.00	1.00	1.15	1.14
12-Aug	1.00	1.00	1.01	1.01	1.00	1.00	0.93	0.94
13-Aug	1.00	1.00	0.99	0.99	0.99	1.00	0.99	0.99
14-Aug	1.00	1.00	0.99	0.99	0.99	1.00	0.97	0.97
15-Aug								
16-Aug								
17-Aug	0.99	0.99	0.93	0.92	1.03	1.01		
18-Aug	0.97	0.97	0.99	1.00	0.98	0.98	0.97	0.97
19-Aug	1.02	1.02	1.01	1.01	1.01	1.01		
20-Aug	0.99	0.98	0.99	0.99	0.99	0.99		
21-Aug	1.01	1.02	1.02	1.01	1.02	1.02		1.00
22-Aug	1.00	0.99	0.99	0.99	1.00	1.00	1.01	1.01
23-Aug	1.00	1.00	1.01	1.00	1.01	1.01	0.99	0.99
24-Aug	1.00	1.01	0.99	1.00	1.00	1.00	1.00	1.00
25-Aug			1.00	1.00	0.98	0.99	0.98	0.98
26-Aug	1.00	0.98	1.00	1.00	1.00	0.98	1.08	1.08
27-Aug			1.02	1.01	1.01	1.02	0.95	1.00
28-Aug			0.99	0.99				
29-Aug								

Table B2-1. Catch-per-unit-effort (fish/24 hr) for Cohort 1 (age-2 and age-3) Arctic cisco collected during the 2003 Beaufort Sea fish monitoring program.

Date	214W	214E	218W	218E	220W	220E	230N	230S
29-Jun							1.2	0.0
30-Jun							0.0	0.0
1-Jul								
2-Jul							0.0	0.0
3-Jul							1.0	0.0
4-Jul								2.0
5-Jul	0.0	2.4					1.9	1.9
6-Jul	5.0	0.0					0.0	5.1
7-Jul	0.0	1.0					0.9	0.0
8-Jul							0.0	0.0
9-Jul	0.0	0.0					0.0	2.0
10-Jul								
11-Jul	0.0	0.0			1.0	3.3	0.0	1.0
12-Jul	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0
13-Jul	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14-Jul	0.0	1.0			1.0	3.1	1.0	0.0
15-Jul					0.0	4.9	0.0	0.0
16-Jul	0.0	0.0	0.0	2.1	0.0	3.0	0.0	1.0
17-Jul	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18-Jul			0.0	0.0	1.3	0.0	0.0	0.0
19-Jul				0.0	1.0	7.9	0.0	0.0
20-Jul			0.0	0.0	0.0	3.2	0.0	0.0
21-Jul	0.0	0.0	0.8	0.0			0.0	0.0
22-Jul	0.0	0.0	0.0	0.0			1.0	0.0
23-Jul	2.0	0.0	0.0	0.0			0.0	0.0
24-Jul	1.0	0.0	0.0	0.0			0.0	0.0
25-Jul			0.0	0.0	0.0	1.0	0.0	0.0
26-Jul			3.0	0.0	0.0	3.0	0.0	0.0
27-Jul			6.0	3.0	0.0	3.0	0.0	0.0
28-Jul								
29-Jul					0.0	0.5		
30-Jul			1.0	2.0	0.0	0.0		
31-Jul			0.0	3.0	1.0	1.0		
1-Aug	2.0	2.0	3.9	12.2	0.0	3.1	0.0	2.3
2-Aug	2.2	2.2	0.0	1.0	0.0	1.9	1.0	0.0
3-Aug	0.0	2.1	3.0	3.0	3.0	7.1	0.0	0.0
4-Aug	1.0	0.0	7.0	7.0	0.0	1.0	2.0	2.0
5-Aug								
6-Aug					2.7	0.0	0.0	0.5
7-Aug						0.0		
8-Aug					0.4	0.0	0.5	1.0
9-Aug			0.9	0.0	0.0	0.0	0.0	0.0
10-Aug			1.2	2.3	1.1	1.1	0.9	0.0
11-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
12-Aug	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0
13-Aug	1.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0
14-Aug	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
15-Aug								
16-Aug								
17-Aug	0.0	0.0	0.0	0.0	0.0	0.0		
18-Aug	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
19-Aug	0.0	0.0	0.0	1.0	0.0	0.0		
20-Aug	1.0	1.0	0.0	1.0	1.0	0.0		
21-Aug	0.0	0.0	2.0	4.0	0.0	1.0		0.0
22-Aug	0.0	0.0	2.0	16.1	0.0	4.0	2.0	2.0
23-Aug	4.0	0.0	1.0	9.0	0.0	3.0	1.0	1.0
24-Aug	1.0	0.0	2.0	4.0	0.0	3.0	2.0	1.0
25-Aug			2.0	7.0	0.0	0.0	0.0	3.1
26-Aug	3.0	2.0	1.0	3.0	0.0	0.0	0.0	0.0
27-Aug			1.0	3.0	0.0	0.0	0.0	0.0
28-Aug			0.0	2.0				
29-Aug								
30-Aug								
31-Aug								

Table B2-2. Catch-per-unit-effort (fish/24 hr) for Cohort 2 (age-3+) Arctic cisco collected during the 2003 Beaufort Sea fish monitoring program.

Date	214W	214E	218W	218E	220W	220E	230N	230S
29-Jun							0.0	0.0
30-Jun							2.1	0.0
1-Jul								
2-Jul							0.0	0.0
3-Jul							0.0	5.0
4-Jul								81.2
5-Jul	186.4	22.4					4.8	20.1
6-Jul	72.9	2.0					8.0	91.5
7-Jul	104.2	1.9					15.1	169.1
8-Jul							4.1	73.8
9-Jul	34.0	79.2					3.0	24.4
10-Jul								
11-Jul	44.0	3.8			23.9	188.3	2.0	28.2
12-Jul	3.5	78.1	6.1	9.2	9.0	48.1	0.0	18.8
13-Jul	77.3	34.6	17.3	11.9	20.1	2.9	25.8	93.2
14-Jul	20.6	8.6			55.6	194.2	11.5	48.0
15-Jul					2.0	83.1	7.7	13.8
16-Jul	2.0	2.9	9.5	22.4	8.9	125.8	0.0	2.9
17-Jul	0.0	0.0	18.6	9.3	0.8	21.0	0.0	20.2
18-Jul			3.7	4.9	1.3	31.6	0.0	1.8
19-Jul				4.0	26.9	91.2	17.9	58.8
20-Jul			35.7	10.9	15.6	105.7	3.7	10.2
21-Jul	4.3	1.1	4.9	6.6			1.1	6.6
22-Jul	1.0	4.8	1.3	2.5			3.9	5.1
23-Jul	1.0	2.0	0.0	2.0			0.0	4.8
24-Jul	2.9	1.0	2.0	0.0			3.0	2.0
25-Jul			3.0	2.0	0.0	20.8	0.0	1.9
26-Jul			7.0	2.0	0.0	7.0	3.9	8.8
27-Jul			4.0	10.0	5.1	18.1	0.0	8.8
28-Jul								
29-Jul					2.0	5.1		
30-Jul			8.7	9.8	6.7	1.0		
31-Jul			4.0	6.1	2.9	3.9		
1-Aug	2.0	8.0	12.7	36.5	3.1	27.9	0.0	5.7
2-Aug	7.6	6.5	5.0	16.0	3.9	55.5	1.0	1.0
3-Aug	3.2	3.2	5.0	8.0	4.1	67.0	1.0	4.1
4-Aug	9.1	4.1	18.1	22.1	7.1	14.1	8.9	18.4
5-Aug								
6-Aug					6.3	13.2	16.7	6.7
7-Aug						0.0		
8-Aug					7.2	27.5	5.3	6.3
9-Aug			20.0	35.1	7.1	61.8	1.2	1.2
10-Aug			3.5	16.2	4.3	19.2	5.7	2.8
11-Aug	14.7	3.4	15.1	12.0	1.0	7.0	1.7	11.4
12-Aug	4.0	0.0	3.0	12.9	4.0	18.9	0.0	0.0
13-Aug	2.0	1.0	0.0	19.2	5.0	6.0	0.0	2.0
14-Aug	0.0	5.0	2.0	29.2	3.0	38.1	1.0	1.0
15-Aug								
16-Aug								
17-Aug	10.1	6.1	40.7	82.7	18.5	132.3		
18-Aug	13.5	1.0	17.1	81.8	0.0	36.6	5.1	2.1
19-Aug	1.0	8.8	2.0	10.9	10.9	95.4		
20-Aug	2.0	18.3	0.0	7.1	31.4	166.1		
21-Aug	4.0	0.0	0.0	40.7	9.8	40.4		1.0
22-Aug	6.0	1.0	8.1	8.1	1.0	40.2	1.0	5.0
23-Aug	5.0	5.0	7.9	99.0	3.0	28.8	0.0	1.0
24-Aug	4.0	2.0	3.0	23.9	0.0	42.9	0.0	2.0
25-Aug			21.1	22.1	1.0	10.1	10.2	3.1
26-Aug	4.0	3.1	2.0	22.0	0.0	11.2	1.8	0.0
27-Aug			3.9	30.6	3.9	6.9	2.1	
28-Aug			1.0	6.0				
29-Aug								
30-Aug								
31-Aug								

Table B2-3. Catch-per-unit-effort (fish/24 hr) for Cohort 1 least cisco collected during the 2003 Beaufort Sea fish monitoring program.

Date	214W	214E	218W	218E	220W	220E	230N	230S
29-Jun							0.0	0.0
30-Jun							0.0	0.0
1-Jul								
2-Jul							1.1	0.0
3-Jul							3.9	0.0
4-Jul								0.0
5-Jul	1.2	2.4					1.0	39.3
6-Jul	0.0	0.0					1.0	0.0
7-Jul	2.0	0.0					0.0	0.0
8-Jul							0.0	11.0
9-Jul	1.5	0.0					1.0	1.0
10-Jul								
11-Jul	4.1	2.9			22.9	18.0	4.1	0.0
12-Jul	8.7	0.0	288.2	48.6	158.0	138.5	0.0	0.9
13-Jul	56.0	25.1	81.1	30.3	38.3	3.9	14.5	4.1
14-Jul	113.0	14.3			78.8	82.4	27.7	74.8
15-Jul					14.0	318.7	6.6	85.0
16-Jul	53.4	36.0	6.3	4.3	4.9	59.0	31.3	52.7
17-Jul	55.6	32.4	3.4	1.7	2.5	10.1	17.8	126.5
18-Jul			6.2	7.3	3.8	3.8	19.6	26.0
19-Jul				9.0	19.9	42.6	13.9	26.9
20-Jul			274.5	209.0	230.7	206.8	169.4	236.1
21-Jul	585.7	44.1	110.8	61.2			42.8	25.2
22-Jul	78.8	28.0	180.3	106.8			162.6	372.8
23-Jul	254.9	51.1	95.7	204.9			88.2	277.1
24-Jul	86.9	45.7	102.9	33.1			137.8	130.7
25-Jul			17.8	16.9	18.5	16.8	112.3	115.5
26-Jul			4.0	4.0	25.1	43.1	94.4	120.6
27-Jul			3.0	14.1	51.6	111.8	25.2	63.0
28-Jul								
29-Jul					42.8	54.7		
30-Jul			17.4	29.3	25.0	19.4		
31-Jul			39.1	63.7	106.8	33.1		
1-Aug	41.9	33.2	20.5	43.6	6.2	18.6	6.8	37.9
2-Aug	105.2	30.4	90.3	144.1	2.9	7.8	3.9	25.1
3-Aug	55.0	33.8	68.2	69.7	1.0	19.3	12.3	61.3
4-Aug	61.9	18.2	32.1	32.1	4.1	5.1	45.6	114.5
5-Aug								
6-Aug					6.3	9.1	12.5	21.3
7-Aug						0.0		
8-Aug					1.3	3.8	24.0	18.8
9-Aug			10.0	13.9	5.7	10.1	4.9	14.3
10-Aug			2.3	9.3	5.3	16.0	7.5	6.6
11-Aug	0.0	0.0	2.0	4.0	0.0	0.0	8.7	26.3
12-Aug	21.0	3.0	5.0	6.0	2.0	11.0	2.1	8.5
13-Aug	15.1	0.0	6.0	9.1	5.0	3.0	3.0	3.0
14-Aug	14.0	3.0	2.0	13.1	0.0	4.0	6.2	2.1
15-Aug								
16-Aug								
17-Aug	17.1	3.0	7.5	0.0	1.0	1.0		
18-Aug	11.4	2.1	5.0	5.0	1.0	0.0	1.0	7.3
19-Aug	4.9	2.9	2.0	35.6	1.0	4.0		
20-Aug	2.0	8.1	3.0	32.3	6.1	6.1		
21-Aug	10.9	0.0	3.9	68.4	6.9	8.9		4.0
22-Aug	20.1	6.1	29.4	83.8	3.0	11.1	3.0	41.7
23-Aug	24.0	4.0	13.8	52.0	2.0	15.9	5.0	12.1
24-Aug	13.0	3.0	13.1	25.9	0.0	12.0	10.0	8.0
25-Aug			5.0	21.1	0.0	1.0	5.1	7.2
26-Aug	6.0	1.0	1.0	13.0	1.0	3.1	0.9	6.5
27-Aug			1.0	16.8	0.0	0.0	1.0	
28-Aug			1.0	4.0				
29-Aug								
30-Aug								
31-Aug								

Table B2-4. Catch-per-unit-effort (fish/24 hr) for Cohort 2 least cisco collected during the 2003 Beaufort Sea fish monitoring program.

Date	214W	214E	218W	218E	220W	220E	230N	230S
29-Jun							0.0	0.0
30-Jun							0.0	0.0
1-Jul								
2-Jul							0.0	0.0
3-Jul							0.0	0.0
4-Jul								4.1
5-Jul	11.0	2.4					0.0	5.7
6-Jul	30.0	6.0					6.0	7.1
7-Jul	21.6	0.0					12.3	11.5
8-Jul							1.0	28.6
9-Jul	400.2	115.2					4.9	8.8
10-Jul								
11-Jul	122.8	5.8			175.8	30.7	4.1	28.2
12-Jul	24.4	73.7	436.0	160.1	185.1	220.1	0.0	34.2
13-Jul	213.7	92.2	156.8	89.8	149.5	1.0	14.5	51.8
14-Jul	60.9	23.9			188.0	562.4	40.2	222.6
15-Jul					18.1	158.4	50.4	0.0
16-Jul	154.4	32.1	50.7	54.4	14.8	342.1	46.0	181.5
17-Jul	22.0	10.4	42.2	29.6	12.7	183.0	6.4	131.6
18-Jul			64.2	50.2	23.8	59.4	9.8	105.9
19-Jul				6.0	44.8	15.9	36.7	94.7
20-Jul			82.3	48.8	83.1	99.0	14.0	76.9
21-Jul	22.7	9.9	96.0	153.9			48.3	52.7
22-Jul	33.1	69.6	103.6	249.1			48.3	121.9
23-Jul	99.0	19.6	31.9	194.9			27.5	116.6
24-Jul	185.6	57.6	156.4	113.3			58.3	245.5
25-Jul			36.7	85.3	11.7	37.6	59.2	175.6
26-Jul			17.1	18.1	34.1	82.3	14.7	113.7
27-Jul			7.0	7.0	37.5	88.6	19.8	64.1
28-Jul								
29-Jul					27.2	37.5		
30-Jul			20.3	21.5	25.0	23.3		
31-Jul			47.1	186.1	161.6	66.3		
1-Aug	28.9	25.1	103.6	295.3	16.5	196.6	1.1	18.4
2-Aug	101.9	40.2	121.1	254.2	6.9	197.8	5.9	29.9
3-Aug	20.1	21.1	50.1	130.5	17.3	150.3	94.4	37.8
4-Aug	64.9	10.1	58.2	82.3	15.2	67.7	188.3	140.1
5-Aug								
6-Aug					26.9	132.8	30.2	27.0
7-Aug						0.0		
8-Aug					26.4	90.2	35.0	46.2
9-Aug			75.3	130.3	24.2	252.9	30.3	10.7
10-Aug			16.3	365.8	16.0	127.7	103.8	15.0
11-Aug	47.6	20.5	94.5	109.8	7.0	29.1	13.0	78.8
12-Aug	19.0	14.0	43.6	50.7	0.0	84.6	1.1	40.5
13-Aug	16.1	20.1	14.1	339.3	27.2	46.2	9.1	32.2
14-Aug	6.0	33.1	4.0	129.7	12.1	50.1	3.1	5.1
15-Aug								
16-Aug								
17-Aug	35.2	1.0	125.5	183.9	20.4	84.9		
18-Aug	49.7	13.5	41.3	118.8	1.0	37.6	2.1	0.0
19-Aug	20.6	22.6	5.9	263.1	6.9	61.6		
20-Aug	17.2	20.3	3.0	30.3	37.5	135.7		
21-Aug	16.8	2.9	5.9	75.4	35.4	131.9		3.0
22-Aug	111.3	58.7	35.5	52.5	5.0	80.4	0.0	6.0
23-Aug	182.7	36.8	23.7	241.0	10.9	48.6	12.1	11.1
24-Aug	18.9	24.8	26.1	54.7	2.0	101.9	14.0	14.0
25-Aug			14.1	78.2	2.0	14.1	14.3	10.3
26-Aug	11.0	33.6	7.0	40.0	3.0	4.1	3.7	0.0
27-Aug			4.9	82.0	2.0	4.9	1.0	
28-Aug			3.0	27.2				
29-Aug								
30-Aug								
31-Aug								

Table B2-5. Catch-per-unit-effort (fish/24 hr) for Cohort 1 broad whitefish collected during the 2003 Beaufort Sea fish monitoring program.

Date	214W	214E	218W	218E	220W	220E	230N	230S
29-Jun							0.0	0.0
30-Jun							0.0	0.0
1-Jul								
2-Jul							0.0	0.0
3-Jul							0.0	0.0
4-Jul								0.0
5-Jul	0.0	0.0					0.0	0.0
6-Jul	0.0	0.0					0.0	0.0
7-Jul	0.0	0.0					0.0	0.0
8-Jul							0.0	0.0
9-Jul	0.0	0.0					0.0	0.0
10-Jul								
11-Jul	0.0	0.0			0.0	0.0	0.0	0.0
12-Jul	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
13-Jul	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14-Jul	0.0	0.0			0.0	0.0	0.0	0.0
15-Jul					0.0	0.0	0.0	0.0
16-Jul	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17-Jul	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18-Jul			0.0	0.0	0.0	0.0	0.0	0.0
19-Jul				0.0	0.0	0.0	0.0	0.0
20-Jul			0.0	0.0	0.0	0.0	0.0	0.0
21-Jul	0.0	0.0	0.0	0.0			0.0	0.0
22-Jul	0.0	0.0	0.0	0.0			0.0	0.0
23-Jul	0.0	0.0	0.0	0.0			0.0	0.0
24-Jul	0.0	0.0	0.0	0.0			0.0	0.0
25-Jul			0.0	0.0	0.0	0.0	0.0	0.0
26-Jul			0.0	0.0	0.0	0.0	0.0	0.0
27-Jul			0.0	0.0	0.0	0.0	0.0	0.0
28-Jul								
29-Jul					0.0	0.0		
30-Jul			0.0	0.0	0.0	0.0		
31-Jul			0.0	0.0	0.0	0.0		
1-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5-Aug								
6-Aug					0.0	0.0	0.0	0.0
7-Aug						0.0		
8-Aug					0.0	0.0	0.0	0.0
9-Aug			0.0	0.0	0.0	0.0	0.0	0.0
10-Aug			0.0	0.0	0.0	0.0	0.0	0.0
11-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3
13-Aug	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
14-Aug	12.3	4.0	0.0	0.0	0.0	0.0	2.1	2.1
15-Aug								
16-Aug								
17-Aug	0.0	2.0	0.0	0.0	0.0	0.0		
18-Aug	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
19-Aug	0.0	1.0	0.0	0.0	0.0	0.0		
20-Aug	7.1	7.1	0.0	0.0	0.0	0.0		
21-Aug	8.9	1.0	0.0	0.0	0.0	0.0		0.0
22-Aug	0.0	2.0	0.0	0.0	0.0	0.0	14.1	1.0
23-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24-Aug	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
25-Aug			0.0	0.0	0.0	0.0	0.0	0.0
26-Aug	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.9
27-Aug			0.0	0.0	0.0	0.0	3.1	-0.3
28-Aug			0.0	0.0				
29-Aug								
30-Aug								
31-Aug								

Table B2-6. Catch-per-unit-effort (fish/24 hr) for Cohort 2 broad whitefish collected during the 2003 Beaufort Sea fish monitoring program.

Date	214W	214E	218W	218E	220W	220E	230N	230S
29-Jun							14.2	9.6
30-Jun							15.8	5.3
1-Jul								
2-Jul							8.5	1.1
3-Jul							128.3	14.0
4-Jul								18.3
5-Jul	3.7	34.2					115.6	0.0
6-Jul	12.0	14.0					114.4	43.7
7-Jul	0.0	2.9					11.3	6.7
8-Jul							9.2	5.5
9-Jul	5.9	10.1					4.9	10.7
10-Jul								
11-Jul	5.1	1.9	3.1	1.1			6.1	0.0
12-Jul	0.9	0.0	3.0	5.8	1.2	3.9	3.4	0.9
13-Jul	2.0	5.2	1.0	0.0	0.0	0.0	8.3	0.0
14-Jul	0.0	4.8	1.0	1.0			10.5	3.8
15-Jul			0.0	1.0			2.2	0.0
16-Jul	27.7	8.7	0.0	0.0	0.0	0.0	14.7	3.9
17-Jul	101.8	6.3	0.0	0.0	0.0	0.0	3.8	24.0
18-Jul			0.0	0.0	0.0	0.0	74.1	12.6
19-Jul			0.0	4.0		0.0	0.0	2.0
20-Jul			0.0	4.0	0.0	0.0	1.9	0.0
21-Jul	0.0	3.3			1.6	0.8	4.4	2.2
22-Jul	2.9	1.0			2.6	0.0	7.9	11.3
23-Jul	0.0	1.0			2.0	0.0	4.7	43.0
24-Jul	1.0	3.0			0.0	0.0	12.1	2.0
25-Jul			1.0	1.0	0.0	0.0	39.1	22.3
26-Jul			1.0	2.0	0.0	0.0	53.1	41.2
27-Jul			0.0	2.0	0.0	0.0	64.8	44.2
28-Jul								
29-Jul			0.0	0.5				
30-Jul			1.0	0.0	0.0	2.0		
31-Jul			1.0	0.0	1.0	0.0		
1-Aug	9.0	7.0	0.0	0.0	1.0	1.0	5.7	10.3
2-Aug	98.7	28.3	0.0	0.0	4.0	1.0	17.6	22.2
3-Aug	278.4	31.7	0.0	1.0	1.0	2.0	6.2	12.3
4-Aug	62.9	21.3	1.0	1.0	2.0	3.0	247.4	152.8
5-Aug								
6-Aug			0.0	3.0			26.1	6.7
7-Aug				0.0				
8-Aug			0.0	0.4			35.0	39.9
9-Aug			1.4	0.0	1.8	0.0	25.5	10.7
10-Aug			1.1	2.1	0.0	1.2	12.3	4.7
11-Aug	1.1	1.1	0.0	2.0	1.0	0.0	47.7	143.2
12-Aug	24.9	1.0	1.0	0.0	0.0	0.0	19.3	51.2
13-Aug	71.3	9.0	1.0	1.0	0.0	0.0	27.3	6.0
14-Aug	124.0	13.0	0.0	0.0	4.0	0.0	34.0	11.3
15-Aug								
16-Aug								
17-Aug	0.0	3.0	0.0	0.0	3.2	0.0		
18-Aug	3.1	0.0	0.0	0.0	2.0	2.0	23.7	26.9
19-Aug	13.7	1.0	0.0	0.0	0.0	0.0		
20-Aug	4.0	5.1	0.0	0.0	0.0	1.0		
21-Aug	1.0	0.0	1.0	0.0	2.0	1.0		13.0
22-Aug	112.3	7.1	0.0	1.0	0.0	0.0	226.6	68.0
23-Aug	30.0	11.9	0.0	1.0	4.9	5.0	46.5	30.3
24-Aug	153.2	7.9	0.0	1.0	20.1	5.0	30.1	11.0
25-Aug			0.0	1.0	10.0	2.0	70.1	8.2
26-Aug	40.1	11.2	0.0	0.0	3.0	4.0	10.1	13.8
27-Aug			0.0	0.0	0.0	3.0	16.8	-4.7
28-Aug					0.0	4.0		
29-Aug								
30-Aug								
31-Aug								

Table B2-7. Catch-per-unit-effort (fish/24 hr) for Cohort 3 broad whitefish collected during the 2003 Beaufort Sea fish monitoring program.

Date	214W	214E	218W	218E	220W	220E	230N	230S
29-Jun							4.7	1.2
30-Jun							3.2	3.2
1-Jul								
2-Jul							3.2	0.0
3-Jul							28.5	9.0
4-Jul								21.3
5-Jul	2.4	0.0					29.6	18.2
6-Jul	2.0	2.0					10.0	15.2
7-Jul	1.0	0.0					1.9	6.7
8-Jul							1.0	9.9
9-Jul	1.5	5.8					4.9	7.8
10-Jul								
11-Jul	2.0	1.0			3.1	1.1	10.2	5.2
12-Jul	1.7	0.0	3.7	2.6	3.0	2.9	2.5	0.0
13-Jul	5.1	5.2	0.0	1.1	1.0	0.0	5.2	4.1
14-Jul	2.9	1.0			3.0	1.0	2.9	1.0
15-Jul					0.0	0.0	2.2	0.0
16-Jul	5.9	1.0	0.0	1.1	0.0	0.0	7.4	1.0
17-Jul	4.2	2.1	0.8	0.0	0.0	2.5	2.5	3.8
18-Jul			0.0	0.0	0.0	0.0	6.2	2.7
19-Jul				2.0	2.0	6.0	1.0	0.0
20-Jul			3.0	1.0	0.0	5.9	0.0	1.9
21-Jul	4.3	6.6	2.5	0.8			1.1	0.0
22-Jul	1.0	0.0	1.3	3.8			3.9	5.1
23-Jul	2.9	1.0	2.0	0.0			0.9	3.8
24-Jul	0.0	2.0	0.0	0.0			5.0	3.0
25-Jul			0.0	0.0	1.0	3.0	9.0	6.8
26-Jul			0.0	0.0	2.0	0.0	10.8	17.6
27-Jul			0.0	0.0	1.0	3.0	11.0	15.5
28-Jul								
29-Jul					1.5	1.0		
30-Jul			0.0	0.0	0.0	0.0		
31-Jul			0.0	0.0	3.9	1.9		
1-Aug	9.0	1.0	0.0	2.0	1.0	0.0	1.1	0.0
2-Aug	9.8	2.2	0.0	2.0	0.0	0.0	0.0	2.9
3-Aug	11.3	2.1	0.0	1.0	0.0	0.0	1.0	0.0
4-Aug	6.1	0.0	0.0	0.0	1.0	0.0	39.8	19.6
5-Aug								
6-Aug					0.0	1.0	5.7	0.0
7-Aug						0.0		
8-Aug					0.0	0.0	8.6	18.3
9-Aug			0.0	0.0	0.0	0.0	2.4	1.2
10-Aug			0.0	0.0	0.0	0.0	5.7	0.9
11-Aug	1.1	0.0	0.0	0.0	0.0	0.0	3.5	21.1
12-Aug	2.0	2.0	0.0	0.0	0.0	0.0	9.7	28.8
13-Aug	17.2	1.0	0.0	1.0	1.0	0.0	8.1	3.0
14-Aug	22.9	3.0	0.0	3.0	0.0	0.0	7.2	1.0
15-Aug								
16-Aug								
17-Aug	0.0	0.0	1.1	0.0	0.0	0.0		
18-Aug	13.5	1.0	0.0	0.0	0.0	0.0	7.2	9.3
19-Aug	6.9	2.0	0.0	0.0	0.0	1.0		
20-Aug	0.0	0.0	0.0	0.0	1.0	0.0		
21-Aug	0.0	1.0	0.0	1.0	0.0	0.0		7.0
22-Aug	24.4	1.0	0.0	1.0	0.0	0.0	17.2	21.0
23-Aug	4.0	3.0	1.0	7.0	2.0	1.0	7.1	3.0
24-Aug	14.8	0.0	3.0	4.0	0.0	2.0	2.0	1.0
25-Aug			0.0	0.0	0.0	0.0	6.6	4.1
26-Aug	15.0	1.0	2.0	0.0	0.0	0.0	3.7	2.8
27-Aug			0.0	1.0	0.0	1.0	3.1	-0.9
28-Aug			1.0	2.0				
29-Aug								
30-Aug								
31-Aug								

Table B2-8. Catch-per-unit-effort (fish/24 hr) for Cohort 4 broad whitefish collected during the 2003 Beaufort Sea fish monitoring program.

Date	214W	214E	218W	218E	220W	220E	230N	230S
29-Jun							2.4	4.8
30-Jun							0.0	3.2
1-Jul								
2-Jul							0.0	0.0
3-Jul							3.0	15.0
4-Jul								17.3
5-Jul	18.3	7.1					11.5	8.6
6-Jul	29.0	3.0					16.1	16.3
7-Jul	66.8	8.7					25.5	23.9
8-Jul							8.2	6.6
9-Jul	28.1	38.9					5.9	13.7
10-Jul								
11-Jul	63.5	14.4			2.1	2.1	6.1	8.4
12-Jul	4.4	0.0	12.2	48.6	3.0	17.5	0.0	4.3
13-Jul	10.2	3.1	11.9	14.1	11.5	0.0	6.2	6.2
14-Jul	18.7	3.8			11.1	12.5	8.6	2.9
15-Jul					2.0	8.9	0.0	1.1
16-Jul	29.7	2.9	9.5	3.2	3.0	25.6	1.8	2.0
17-Jul	24.1	7.3	4.2	3.4	5.1	28.5	0.0	1.3
18-Jul			4.9	1.2	1.3	3.8	0.0	3.6
19-Jul				0.0	18.9	5.0	15.9	39.9
20-Jul			4.0	5.0	3.9	8.9	0.9	4.6
21-Jul	18.4	2.2	6.6	17.4			5.5	7.7
22-Jul	5.8	4.8	10.2	5.1			3.0	9.2
23-Jul	15.7	0.0	4.0	4.0			0.0	3.8
24-Jul	9.8	2.0	1.0	2.0			2.0	6.0
25-Jul			5.0	1.0	0.0	0.0	5.0	18.4
26-Jul			7.0	2.0	1.0	4.0	6.9	7.8
27-Jul			1.0	0.0	2.0	2.0	4.4	7.7
28-Jul								
29-Jul					0.5	2.0		
30-Jul			0.0	0.0	1.0	1.0		
31-Jul			1.0	1.0	6.9	5.8		
1-Aug	48.9	4.0	2.0	7.1	4.1	31.0	0.0	0.0
2-Aug	2.2	0.0	4.0	7.0	1.0	15.6	0.0	0.0
3-Aug	4.2	1.1	4.0	1.0	0.0	6.1	0.0	0.0
4-Aug	8.1	3.0	2.0	0.0	3.0	11.1	6.1	7.6
5-Aug								
6-Aug					0.9	0.0	2.6	0.0
7-Aug						0.0		
8-Aug					0.0	0.4	1.0	0.5
9-Aug			1.8	0.9	1.4	4.3	1.2	0.0
10-Aug			0.0	2.3	2.1	5.3	1.9	0.9
11-Aug	13.6	0.0	2.0	4.0	1.0	4.0	0.0	6.5
12-Aug	7.0	4.0	2.0	4.0	1.0	2.0	4.3	7.5
13-Aug	1.0	0.0	1.0	6.1	0.0	2.0	11.1	1.0
14-Aug	5.4	0.0	2.0	13.1	0.0	5.0	5.2	5.1
15-Aug								
16-Aug								
17-Aug	26.2	2.0	4.3	4.4	2.9	11.8		
18-Aug	25.9	1.0	3.0	0.0	0.0	3.0	4.1	5.2
19-Aug	3.9	1.0	1.0	1.0	1.0	4.0		
20-Aug	5.1	3.0	1.0	1.0	3.0	5.1		
21-Aug	4.0	0.0	1.0	19.8	6.9	14.8		1.0
22-Aug	12.7	0.0	3.0	2.0	0.0	2.0	3.9	6.4
23-Aug	5.0	3.0	0.0	15.0	0.0	3.0	1.0	0.0
24-Aug	2.5	1.0	7.0	3.0	1.0	10.0	1.0	0.0
25-Aug			1.0	2.0	0.0	1.0	1.1	0.0
26-Aug	10.0	6.1	0.0	8.0	0.0	2.0	0.9	1.8
27-Aug			0.0	2.0	0.0	2.9	1.0	
28-Aug			0.0	2.0				
29-Aug								
29-Aug								
29-Aug								

Table B2-9. Catch-per-unit-effort (fish/24 hr) for Cohort 1 Dolly Varden collected during the 2003 Beaufort Sea fish monitoring program.

Date	214W	214E	218W	218E	220W	220E	230N	230S
29-Jun							2.4	12.0
30-Jun							10.6	41.3
1-Jul								
2-Jul							9.5	65.2
3-Jul							13.8	65.8
4-Jul								203.0
5-Jul	92.6	42.5					4.8	25.9
6-Jul	4.0	2.0					9.0	23.4
7-Jul	2.0	3.9					7.6	43.0
8-Jul							1.0	45.2
9-Jul	4.4	5.8					2.0	8.8
10-Jul								
11-Jul	9.2	1.9			0.0	4.2	1.0	13.6
12-Jul	0.0	6.2	7.3	22.3	6.0	1.5	0.0	0.9
13-Jul	3.1	3.1	2.2	4.3	0.0	0.0	0.0	3.1
14-Jul	2.0	1.9			1.0	5.2	1.9	11.5
15-Jul					0.0	0.0	3.3	8.5
16-Jul	2.0	3.9	1.1	10.7	0.0	2.0	0.0	1.0
17-Jul	4.2	0.0	9.3	7.6	2.5	5.0	0.0	1.3
18-Jul			1.2	3.7	2.5	2.5	0.0	2.7
19-Jul				0.0	0.0	2.0	0.0	6.0
20-Jul			0.0	0.0	0.0	1.0	0.0	0.9
21-Jul	0.0	0.0	0.0	0.8			0.0	0.0
22-Jul	1.0	0.0	0.0	0.0			0.0	1.0
23-Jul	0.0	1.0	0.0	0.0			0.0	0.0
24-Jul	0.0	0.0	0.0	1.0			1.0	1.0
25-Jul			0.0	0.0	0.0	0.0	0.0	0.0
26-Jul			1.0	3.0	0.0	0.0	0.0	0.0
27-Jul			1.0	0.0	0.0	0.0	0.0	0.0
28-Jul								
29-Jul					0.0	0.0		
30-Jul			0.0	0.0	0.0	0.0		
31-Jul			0.0	0.0	0.0	0.0		
1-Aug	1.0	1.0	4.9	6.1	0.0	5.2	1.1	0.0
2-Aug	0.0	0.0	6.9	12.0	2.0	11.7	1.0	0.0
3-Aug	0.0	0.0	5.0	8.0	4.1	8.1	0.0	0.0
4-Aug	2.0	0.0	4.0	2.0	0.0	0.0	0.0	0.0
5-Aug								
6-Aug					0.0	0.0	0.0	0.5
7-Aug						0.0		
8-Aug					0.0	0.0	0.0	0.0
9-Aug			0.0	0.0	0.0	0.0	0.0	0.0
10-Aug			0.0	1.2	0.0	0.0	0.0	0.0
11-Aug	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13-Aug	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
14-Aug	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15-Aug								
16-Aug								
17-Aug	10.1	0.0	1.1	0.0	0.0	0.0		
18-Aug	9.3	1.0	1.0	0.0	0.0	0.0	0.0	0.0
19-Aug	5.9	0.0	0.0	0.0	0.0	0.0		
20-Aug	6.1	1.0	1.0	0.0	0.0	0.0		
21-Aug	13.8	0.0	0.0	0.0	1.0	3.0		1.0
22-Aug	16.0	1.0	0.0	0.0	0.0	0.0	1.0	4.0
23-Aug	10.0	1.0	0.0	1.0	0.0	0.0	0.0	3.0
24-Aug	6.0	0.0	0.0	0.0	0.0	1.0	1.0	2.0
25-Aug			0.0	1.0	0.0	0.0	3.1	3.1
26-Aug	7.0	1.0	0.0	1.0	0.0	0.0	0.0	4.6
27-Aug			0.0	7.9	0.0	1.0	0.0	-1.2
28-Aug			0.0	2.0				
29-Aug								
30-Aug								
31-Aug								

Table B2-10. Catch-per-unit-effort (fish/24 hr) for Cohort 2 Dolly Varden collected during the 2003 Beaufort Sea fish monitoring program.

Date	214W	214E	218W	218E	220W	220E	230N	230S
29-Jun							0.0	0.0
30-Jun							0.0	0.0
1-Jul								
2-Jul							0.0	2.1
3-Jul							2.0	4.0
4-Jul								6.1
5-Jul	4.9	0.0					1.0	1.0
6-Jul	8.0	0.0					2.0	3.0
7-Jul	7.9	1.0					0.0	3.8
8-Jul							0.0	5.5
9-Jul	0.0	0.0					0.0	2.9
10-Jul								
11-Jul	4.1	0.0			1.0	0.0	0.0	1.0
12-Jul	0.0	3.6	0.0	1.3	0.0	0.0	0.0	0.0
13-Jul	1.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0
14-Jul	1.0	1.0			0.0	0.0	1.9	1.0
15-Jul					0.0	1.0	0.0	0.0
16-Jul	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
17-Jul	2.1	1.0	0.8	1.7	2.5	1.7	0.0	1.3
18-Jul			1.2	0.0	2.5	1.3	0.9	0.9
19-Jul				0.0	1.0	2.0	0.0	0.0
20-Jul			0.0	0.0	0.0	0.0	0.0	1.9
21-Jul	0.0	0.0	0.0	0.0			0.0	0.0
22-Jul	0.0	0.0	0.0	0.0			0.0	1.0
23-Jul	2.0	0.0	0.0	0.0			1.9	0.0
24-Jul	2.0	0.0	0.0	0.0			1.0	1.0
25-Jul			0.0	0.0	0.0	0.0	1.0	0.0
26-Jul			0.0	0.0	0.0	0.0	0.0	2.0
27-Jul			0.0	1.0	0.0	2.0	0.0	0.0
28-Jul								
29-Jul					0.0	0.0		
30-Jul			0.0	0.0	0.0	0.0		
31-Jul			0.0	0.0	1.0	0.0		
1-Aug	6.0	0.0	0.0	1.0	0.0	2.1	0.0	0.0
2-Aug	2.2	0.0	4.0	1.0	2.9	1.9	0.0	0.0
3-Aug	3.2	0.0	0.0	0.0	1.0	1.0	0.0	0.0
4-Aug	3.0	2.0	0.0	0.0	0.0	0.0	1.0	0.0
5-Aug								
6-Aug					0.0	0.0	2.6	0.0
7-Aug						0.0		
8-Aug					0.0	0.0	0.0	0.5
9-Aug			0.0	0.0	0.0	0.0	0.0	1.2
10-Aug			0.0	0.0	0.0	0.0	0.0	1.9
11-Aug	7.9	0.0	0.0	1.0	0.0	0.0	0.9	1.8
12-Aug	2.0	0.0	0.0	2.0	0.0	0.0	1.1	1.1
13-Aug	5.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0
14-Aug	6.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0
15-Aug								
16-Aug								
17-Aug	34.2	0.0	0.0	0.0	1.0	0.0		
18-Aug	18.6	0.0	0.0	0.0	0.0	0.0	0.0	2.1
19-Aug	16.7	0.0	0.0	0.0	0.0	0.0		
20-Aug	39.5	1.0	0.0	0.0	0.0	0.0		
21-Aug	56.4	2.0	0.0	0.0	2.0	1.0		0.0
22-Aug	34.1	0.0	0.0	0.0	0.0	1.0	0.0	1.0
23-Aug	13.0	3.0	0.0	1.0	0.0	0.0	0.0	0.0
24-Aug	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25-Aug			0.0	0.0	0.0	0.0	6.1	1.0
26-Aug	15.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
27-Aug			0.0	0.0	0.0	0.0	0.0	-0.3
28-Aug			0.0	0.0				
29-Aug								
30-Aug								
31-Aug								

Table B2-11. Catch-per-unit-effort (fish/24 hr) for humpback whitefish collected collected during the 2003 Beaufort Sea fish monitoring program.

Date	214W	214E	218W	218E	220W	220E	230S	230N
28-Jun							0.0	2.4
29-Jun							0.0	0.0
30-Jun								
1-Jul							0.0	0.0
2-Jul							1.0	1.0
3-Jul								8.1
4-Jul	8.5	3.5					6.7	6.7
5-Jul	22.0	0.0					5.0	75.2
6-Jul	40.3	0.0					14.2	66.9
7-Jul							2.0	44.1
8-Jul	7.4	13.0					1.0	16.6
9-Jul								
10-Jul	22.5	2.9			16.6	22.2	0.0	11.5
11-Jul	0.9	16.9	7.3	1.3	12.0	20.4	0.0	6.0
12-Jul	74.3	17.8	11.9	14.1	19.2	1.0	15.5	28.0
13-Jul	21.6	3.8			16.2	113.7	2.9	28.8
14-Jul					0.0	26.7	4.4	0.0
15-Jul	4.0	1.0	13.7	7.5	3.0	235.9	0.0	0.0
16-Jul	4.2	1.0	1.7	2.5	0.0	19.3	2.5	7.6
17-Jul			0.0	4.9	2.5	2.5	1.8	13.5
18-Jul				1.0	16.9	9.9	19.9	32.9
19-Jul			20.8	10.0	2.9	19.8	0.0	3.7
20-Jul	3.2	1.1	15.6	28.1			2.2	1.1
21-Jul	3.9	1.0	7.7	7.6			1.0	13.3
22-Jul	2.9	0.0	1.0	8.0			0.9	4.8
23-Jul	1.0	1.0	3.0	11.0			4.0	12.0
24-Jul			0.0	0.0	2.9	9.9	2.0	5.8
25-Jul			4.0	4.0	5.0	12.0	1.0	5.9
26-Jul			6.0	1.0	2.0	9.1	5.5	8.8
27-Jul								
28-Jul					5.0	12.7		
29-Jul			1.9	3.9	7.7	7.8		
30-Jul			22.0	50.6	107.8	10.7		
31-Jul	10.0	3.0	14.7	14.2	4.1	50.7	0.0	0.0
1-Aug	4.3	4.3	7.9	27.0	9.8	73.1	1.0	0.0
2-Aug	1.1	1.1	9.0	17.9	1.0	37.6	1.0	1.0
3-Aug	18.3	5.1	7.0	7.0	6.1	45.5	16.8	0.0
4-Aug								
5-Aug					5.4	28.4	4.2	3.1
6-Aug						0.0		
7-Aug					11.5	33.5	1.9	3.9
8-Aug			26.3	42.5	11.4	81.9	4.9	0.0
9-Aug			11.6	151.6	8.5	49.0	1.9	0.9
10-Aug	17.0	0.0	23.1	26.0	7.0	26.1	0.0	0.0
11-Aug	5.0	1.0	6.9	21.9	2.0	12.9	1.1	2.1
12-Aug	0.0	8.0	2.0	23.2	4.0	15.1	1.0	0.0
13-Aug	1.0	1.0	6.0	53.3	5.0	35.1	0.0	0.0
14-Aug								
15-Aug								
16-Aug	29.2	1.0	16.1	16.3	9.7	25.7		
17-Aug	17.6	0.0	8.1	2.0	0.0	5.1	0.0	0.0
18-Aug	4.9	0.0	1.0	4.9	2.0	7.0		
19-Aug	10.1	3.0	0.0	1.0	2.0	11.1		
20-Aug	11.9	0.0	2.0	16.9	10.8	29.5		0.0
21-Aug	11.0	2.0	7.1	7.1	0.0	4.0	1.0	0.0
22-Aug	4.0	2.0	9.9	29.0	0.0	6.0	2.0	0.0
23-Aug	4.0	4.0	5.0	10.0	1.0	13.0	1.0	0.0
24-Aug			4.0	2.0	0.0	1.0	0.0	0.0
25-Aug	8.0	4.1	0.0	11.0	1.0	3.1	0.0	0.0
26-Aug			0.0	4.0	1.0	0.0	0.0	
27-Aug			1.0	2.0				
28-Aug								
29-Aug								
30-Aug								
31-Aug								