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The Arctic Cisco (*Coregonus autumnalis*) Subsistence and Commercial Fisheries, Colville River, Alaska: A Conceptual Model

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ABSTRACT. The arctic cisco (*Coregonus autumnalis*), known regionally by its Inupiat name *qaaqtaq*, is the principal target of fall subsistence and commercial fisheries that operate in the Colville River along the Alaskan Beaufort Sea. Our conceptual model of the fisheries is based on more than two decades of continuous scientific study conducted in conjunction with oil industry growth on the North Slope. It expands upon an existing body of published literature to discuss additional factors that affect fishery yields. Long-term data indicate that arctic cisco spawn in Canada's Mackenzie River system. Young-of-the-year are transported westward into Alaska by wind-driven coastal currents. Arctic cisco successfully recruit to Alaska's Colville River when summer winds blow from the east with an average speed greater than 5 km/h. The successful recruitment of these young arctic cisco to central Alaska is a prerequisite for the eventual entry of harvestable five- to eight-year-old fish into the region's subsistence and commercial fisheries. Recruitment into the fisheries also requires that fish survive in central Alaska for the five to six years it takes for them to grow to a harvestable size. Once these fish are recruited into the fisheries, annual harvests are strongly dependent on salinity conditions within the fishing grounds. Although fishing mortality occurs, the loss of older fish from the region is attributed largely to the emigration of sexually mature fish back to Canada.

Key words: Alaska, arctic cisco, Colville River, *Coregonus autumnalis*, fishery, fyke nets, Inupiat, North Slope, subsistence, transport

RÉSUMÉ. Le cisco arctique (*Coregonus autumnalis*), connu régionalement sous le nom de *qaaqtaq* en inupiat, est la principale cible des pêcheries commerciales et de la subsistance d'automne de Colville River, le long de la partie alaskienne de la mer de Beaufort. Notre modèle conceptuel des pêcheries repose sur une étude scientifique réalisée sans arrêt pendant plus de deux décennies à la lumière de l'essor connu par l'industrie du pétrole sur la côte Nord. Il s'appuie également sur de la documentation publiée et englobe d'autres facteurs qui ont une incidence sur le rendement des pêcheries. Les données de longue date laissent entendre que le cisco arctique fraie dans la partie canadienne du réseau du fleuve Mackenzie. Les jeunes de l'année sont transportés vers l'Ouest, en Alaska, par les courants de dérive du littoral. Le cisco arctique réussit à se recruter dans la région alaskienne de Colville River lorsque les vents d'été soufflent de l'est à une vitesse moyenne de 5 km/h. Le recrutement réussi de ces jeunes ciscos arctiques vers le centre de l'Alaska est un préalable pour l'entrée éventuelle des poissons pêchables de cinq à huit ans en vue de la subsistance de la région et de la pêche commerciale. Le recrutement implique également que les poissons doivent survivre dans le centre de l'Alaska pendant les cinq à six années qu'il leur faut pour atteindre une taille se prêtant à la pêche. Une fois que ces poissons sont recrutés dans les pêcheries, les récoltes annuelles dépendent beaucoup des conditions de salinité présentes aux pêcheries. Malgré le taux de mortalité par pêche, la perte de poissons plus âgés dans la région est grandement attribuable à l'émigration au Canada de poissons prêts à se reproduire.

Mots clés : Alaska, cisco arctique, Colville River, *Coregonus autumnalis*, pêcherie, verveux à ailes, Inupiat, côte Nord, subsistance, transport

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INTRODUCTION

The arctic cisco (*Coregonus autumnalis*), known regionally by its Inupiat name *qaaqtaq*, is one of the most abundant and widely distributed coregonids found in Alaskan Beaufort Sea coastal waters during summer (Craig, 1984). Arctic cisco 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, emergent young (age-0) are flushed from spawning areas downstream into ice-free coastal waters (Fig. 1). Some young-of-the-year (YOY) are transported westward into Alaska by wind-driven coastal currents (Gallaway et al., 1983; Fechhelm and Fissel, 1988; Moulton, 1989; Fechhelm and Griffiths, 1990; Schmidt et al., 1991; Colonell and Gallaway, 1997).

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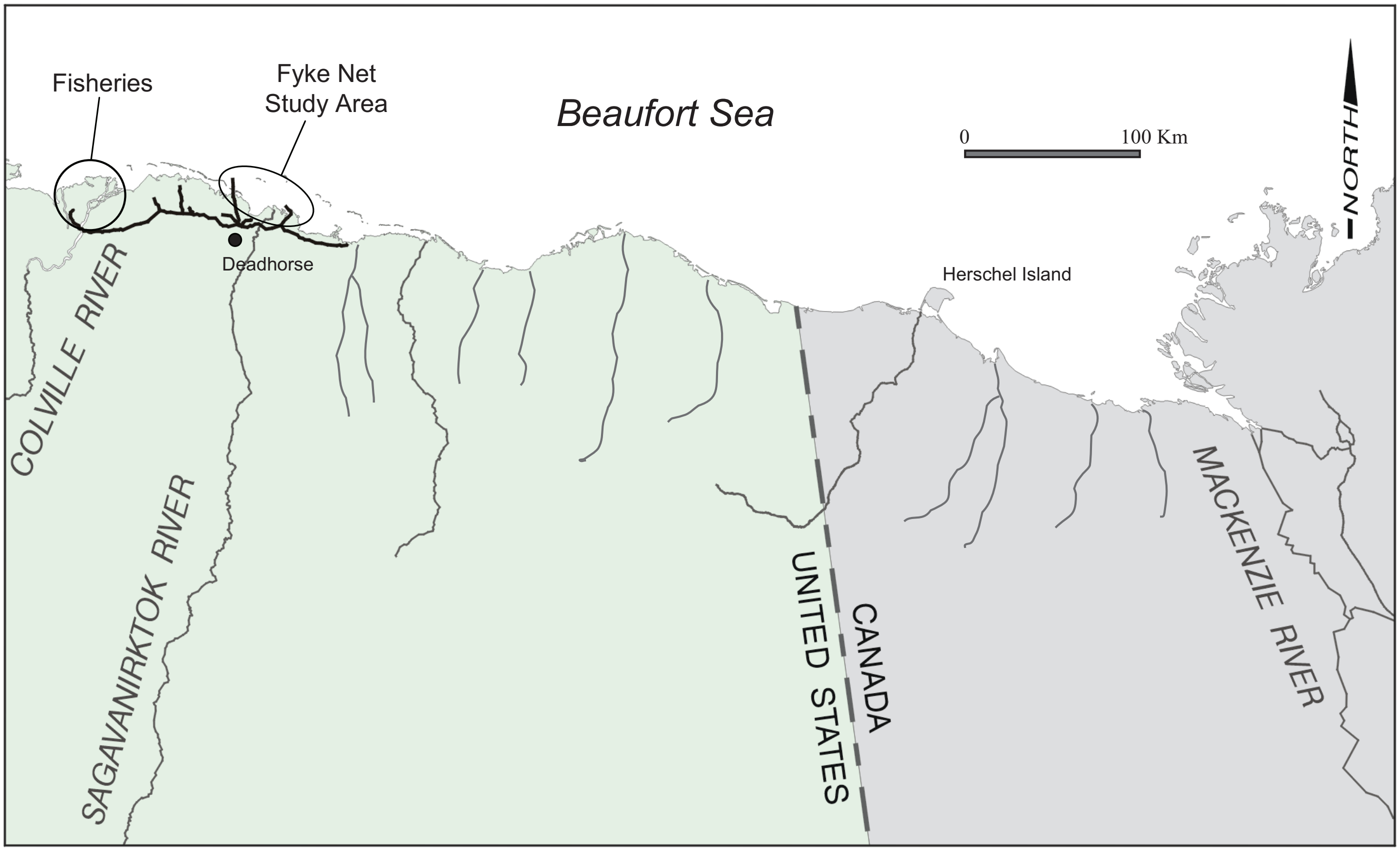

FIG. 1. Map of the Beaufort Sea coast of Alaska and Yukon, showing the Mackenzie River where arctic cisco spawn, the summer fyke net sampling area, and the location of the Colville River fisheries.

In summers characterized by strong and persistent east winds, enhanced westward transport can carry fish to Alaska's Colville River, where they take up residence over the winter. Arctic cisco remain in the Colville River until the onset of sexual maturity, beginning at about age seven, at which point they are believed to migrate back to the Mackenzie River to spawn (Gallaway et al., 1983).

The arctic cisco is an important traditional food for Inupiat communities of the Alaskan Arctic Coastal Plain. It is the principal species targeted in the fall subsistence fishery that operates out of the village of Nuiqsut on the lower Colville River delta, as well as the primary species targeted by the small, family-run Helmericks commercial fishery located in the outer Colville River delta. Collectively, the subsistence and commercial fisheries can harvest up to 80 000 adult fish each fall, using gill nets strung under the ice (Moulton and Seavey, 2005).

Because of its importance to the Native communities of the Coastal Plain, the Alaska arctic cisco population has been intensely studied since the first oil and gas developments were established on the North Slope in the late 1970s. Annual summer and fall fishery monitoring studies have been ongoing for over two decades in the Prudhoe Bay region of Alaska and in the lower reaches of the Colville River. This paper provides a conceptual model of the Colville River fall fisheries based upon data compiled from these studies. We identify those aspects in the life-history dynamics of the Alaskan arctic cisco population that are currently well understood and can be rigorously monitored on an annual basis to assess future trends in fishery harvests. Also identified are key components that continue to confound efforts at forecasting future fishery yields with greater precision.

METHODS

Field Sampling

From 1981 to 1998 and from 2001 to 2005, fish surveys were conducted during the open-water season (late June through mid September) in and around the area of Prudhoe Bay, Alaska (see Fig. 1). Fyke nets—live-capture devices that fish continuously 24 hours per day—were deployed in arrays along the coast. The nets were emptied each day, and the captured fish were identified, counted, measured (fork length), and released. Catch data are expressed in terms of catch-per-unit-effort (CPUE = fish/net/24 hr of fishing effort).

Each summer, subsamples of fish were collected early and late in the season for dissection and life-history analyses. Subsample selection was based on fish length, using eight 50 mm size intervals from 51 to 400 mm (e.g., 51–100 mm, 101–150 mm, etc.). Numbers permitting, 20 individuals were collected from each size interval among all nets during each of the two sampling periods. Subsampled fish were measured to the nearest millimeter and weighed to the nearest 0.1 g. Sagittal otoliths were excised, stored dry in vials and subsequently aged by counting the cross-sectioned annuli using a 10–70× magnification dissecting scope. Otoliths were aged using the cross-sectional burn technique (Chilton and Beamish, 1982).

Subsistence and Commercial Fisheries Data

Subsistence and commercial fishery yield data from the Nuiqsut village fishery and the Helmericks family fishery were taken from Moulton and Seavey (2005). The under-ice Nuiqsut subsistence fishery, first established in 1985, is active from late September through November of each year. Fishing effort is concentrated at two sites in the lower Colville Delta and at a site near the village of Nuiqsut. Records of catch and fishing effort from 1985 through 2004 are available for the subsistence fishery. The Helmericks family has run an under-ice commercial gill net fishery in the Colville Delta during fall since the early 1960s. Records of catch and fishing effort from 1967 to 2002 are available for the Helmericks fishery. Although arctic cisco taken in the fisheries range in age from three to eleven years, the gill net fisheries are size-selective and primarily take fish five to eight years of age. Each season, subsamples of fish are collected from each fishery to assess the age (otolith analysis), length/weight relationship, and length frequencies of arctic cisco taken in the annual harvests. The aging data can be used to identify the catch rates of individual year classes, both annually and cumulatively, as they move through the fishery.

Meteorological Data

Hourly wind data were collected by the National Weather Service (NWS) at the Deadhorse Airport, Deadhorse, Alaska. The NWS typically records a meteorological observation at 53 minutes past the hour, 24 hours a day. During periods of inclement weather, additional observations may be recorded within a 60-minute period. The NWS wind database was culled to a single observation per hour: the observation at 53 minutes past the hour or the one closest to that time (the observer may be off by several minutes). All other observations were deleted. Culling the non-standard data prevents weighting average wind conditions in favor of unequal sampling effort.

The east/west wind component is the principal force that drives many of the oceanographic (Niedoroda and Colonell, 1990) and biological systems (Fechhelm and Griffiths, 1990; Fechhelm et al., 1992; Griffiths et al., 1992) of the nearshore Beaufort Sea. Accordingly, NWS wind data are expressed in linear coordinates (x, y) with the x-axis representing the east/west wind component and the y-axis representing the north/south wind component.

RESULTS AND DISCUSSION

Length Frequency Distribution

Length-frequency distributions for arctic cisco for the years 1985–94 are depicted in Figure 2. These data are representative; length-frequency distributions are available for all study years. 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 or year classes. Their diagonal orientation reflects seasonal growth within summers. The sudden appearance of fish 50–90 mm in length during August in many years represents the arrival of age-0 fish in the area (denoted by arrows). These cohorts can be tracked as age-1 fish the following summer and as age-2 fish the summer after that. The distinct presence of age-0, age-1, and age-2 cohorts has repeatedly been confirmed via otolith aging analysis. Beyond age 2, the clear distinction between age classes often dissipates. Because age-0, age-1, and age-2 cohorts can be isolated, CPUE for each of these age groups can be calculated directly from the catch data.

Because individual age cohorts cannot be distinguished for fish age 3 and older from length-frequency distribution, CPUE was calculated from the fyke net data for the age-3+ cohort as a whole. Within this group, estimates of CPUE for individual year classes were determined using age-length keys and techniques described by Ricker (1975) and DeVries and Frie (1996). Essentially, the proportionate age distribution as determined from the otolith data is extrapolated to the entire age-3+ fyke net catch and expressed as CPUE for individual age classes. This enables catch rates to be estimated for any individual year class during the summer.

Winds, Recruitment, and Fishery Yield

When the summer catch rates of YOY arctic cisco were compared with east/west winds recorded for July–August of each year, a consistent pattern became evident (Fig. 3). In years characterized by summer winds averaging 5 km/h or more blowing from the east, there was a dramatic increase in the CPUE of YOY fish sometime in August. In years when summer winds from the east averaged less than 5 km/h, or years of net west winds, there was no dramatic increase in CPUE. Catch rates of age-0 fish in years when east winds averaged 5 km/h or more in summer were significantly higher ($p = 1.0$ E-9, t-test; Ostle and Mensing, 1975) than catch rates in years with weak east to west summer winds. This pattern is consistent with the original Gallaway et al. (1983) hypothesis that arctic cisco fry are transported westward from the Mackenzie River to Alaska by wind-driven coastal currents, as well as with numerous other works in the published literature (Gallaway et al., 1983; Fechhelm and Fissel, 1988; Moulton, 1989; Fechhelm and Griffiths, 1990; Schmidt et al., 1991; Colonell and Gallaway, 1997).

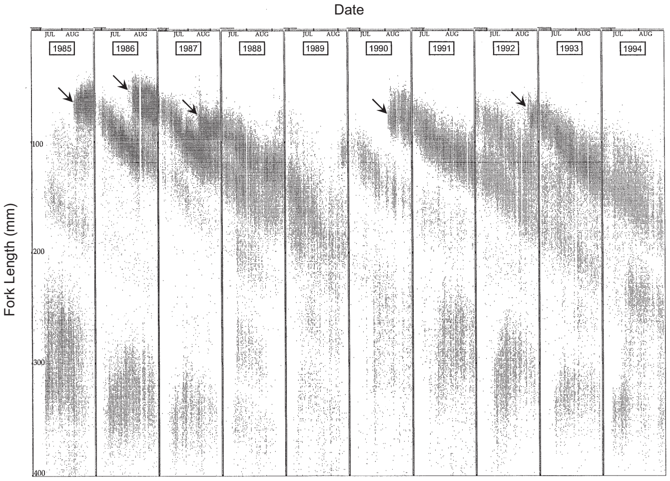

FIG. 2. Length-frequency distributions for arctic cisco collected from 1985 to 1994. Each panel within the figure consists of a matrix (i.e., a grid of columns and rows that are actually a reduced spreadsheet). Each column within a panel represents one of a series of consecutive sampling dates for that year. Rows represent fish length in 1 mm increments, with 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 that particular year. The vertical line separating consecutive years represents the nine to ten months of winter when fish do not grow. Arrows denote the appearance of YOY arctic cisco in some summers. Source: latest compilation from Fechhelm et al. (2006).

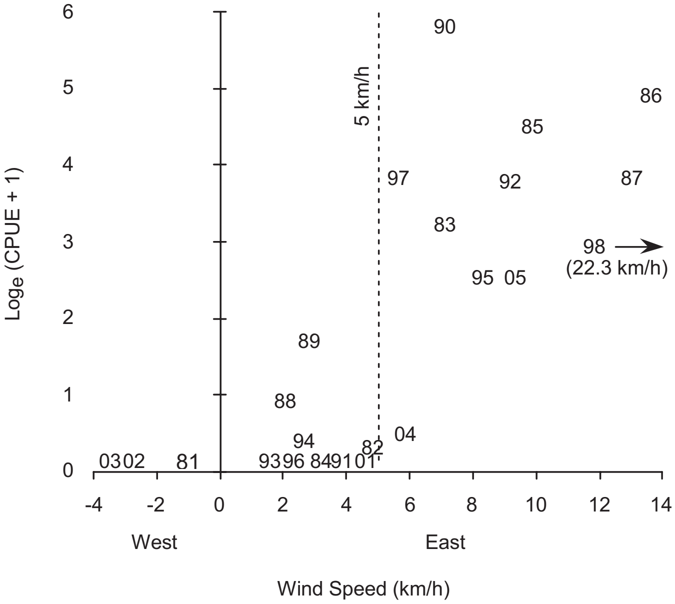

FIG. 3. Log$_e$ (CPUE [fish/net/24 h] + 1) of age-0 arctic cisco against resultant winds recorded at Deadhorse Airport for the years 1982–98 and 2001–05. The horizontal axis denotes the mean value of the east/west wind component based upon hourly observations calculated from 1 July through the date when fish arrive at Prudhoe Bay or, in cases when there was no arrival, through the last date of the sampling. Numbers represent years, and each data point indicates the wind direction in that year. CPUE was calculated beginning on the day age-0 fish were first caught. CPUE = 0 when no fish were caught (i.e., 1981, 1982, 1984, 1991, 1993, 1996, 2001, 2002, and 2003). Note: the "82" icon is raised off the CPUE = 0 line only to allow for visibility of the "01" icon (there was no catch in 1982). Source: latest compilation from Fechhelm et al. (2006).

Another consistent pattern that became evident over the years was that if a year class had no recruitment of YOY into central Alaska during their initial year, that year class continued to be poorly represented in following years as age-1 and older fish. The permanent absence of poorly recruited year classes in central Alaska is evident from commercial and subsistence harvest data.

During the 18 years for which full harvest records and wind data are available, no year class hatched during a summer in which average July–August winds fell below the 5 km/h (blowing from the east) threshold ever contributed substantially to either the commercial or the subsistence fishery (Fig. 4). The strongest contributions to fishery yields came from year classes hatched in strong east-wind years. The cumulative yield (CPUE in the fishery) for year classes hatched in summers with strong east winds is significantly higher for both the commercial fishery (p = 1.7 E-3, t-test; Ostle and Mensing, 1975) and the subsistence fishery (p = 3.5 E-6, t-test; Ostle and Mensing, 1975) than the cumulative CPUE associated with summers of weaker east winds or west winds.

The pattern of poorly recruited year classes remaining weakly represented in the Alaskan population probably reflects an absence of overwintering grounds in eastern Alaska. The Mackenzie River in Canada and the Colville River in Alaska are the two largest Beaufort Sea drainages, and both systems provide overwintering habitat for large numbers of fish species, including arctic cisco (Craig, 1984, 1989). The Sagavanirktok River is the third largest North Slope drainage; however, the amount of overwintering area in the river and delta is limited by the shallowness of the river's main channels and delta. Schmidt et al. (1989) reported that the Colville River had about 220 km of main channel deepwater habitat that could be suitable for overwintering, compared to only 1.3 km in the Sagavanirktok River. None of the streams and rivers between the Sagavanirktok and Mackenzie rivers provide useful areas of overwintering habitat for arctic cisco (Craig, 1984). It is this paucity of overwintering habitat that probably places YOY arctic cisco at risk. Most fish that cannot reach the overwintering haven of the Colville River (and possibly the marginal habitat provided by the Sagavanirktok River) before freeze-up likely perish. Some consider winter mortality associated with the absence of adequate habitat to be one of the major factors limiting North Slope diadromous and freshwater fish populations, and particularly the survival of their young fish (Craig, 1989).

Conceptual Model

The wind-governed recruitment of YOY arctic cisco into Alaska is the fundamental or threshold component affecting yields in the Colville River subsistence fishery (Fig. 5). In summers characterized by weak east to west winds, few YOY fish are recruited into Alaska. There will be no representatives of that year class to support the future Alaskan fisheries. However, in summers characterized by strong east winds, large numbers of YOY are recruited into the Alaskan region and establish a year-class pool that has the potential for contributing to future harvests.

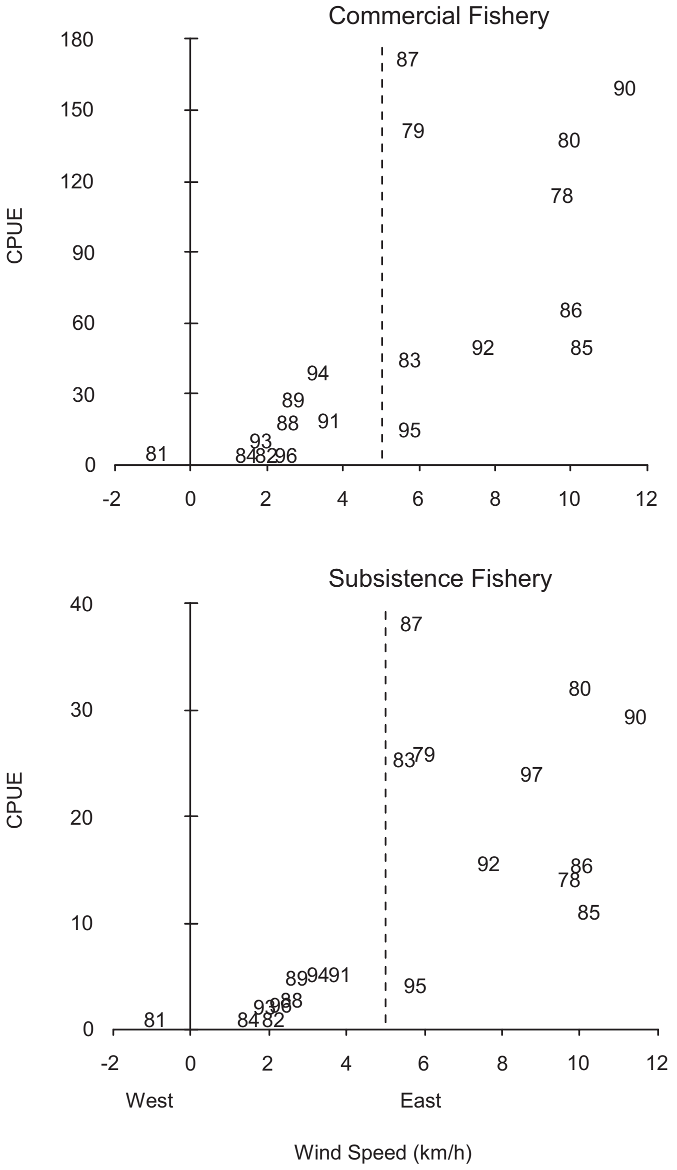

FIG. 4. Cumulative CPUE (fish/48 m of gill net/day) of arctic cisco harvested in the commercial and subsistence fisheries by year class plotted against the average hourly east/west wind speed for the period 1 July–31 August for the year in which they were hatched (transported). Numbers represent years, and each data point indicates the wind direction in that year. There is no commercial fishery entry for the 1997 year class for lack of 2003 and 2004 harvest data. Data source: Moulton and Seavey (2005).

In order to realize that potential, the year class must remain relatively strong and robust during the ensuing five years that it takes to grow to a size that renders its fish susceptible to the size-selective gillnet fisheries.

Over the years, some notable collapses of strongly recruited year classes have been observed. The 1985 year class was one of the strongest cohorts ever recruited into Alaska (see Fig. 3), but summer CPUE for this group decreased from 21.1 fish/net/24 h in 1986 (second summer) to 1.3 fish/net/24 h in 1987 (third summer), a decline of 90%. Catch rates for the strongly recruited 1995 year class dropped by nearly 97% between its second (34.9 fish/net/24 h) and third (1.0 fish/net/24 h) summers. Catches never recovered over the following years, and neither of these “strongly recruited” year classes ever contributed substantially to the commercial and subsistence fisheries (see Fig. 4). The reasons for these collapses are unknown but could be related to poor summer feeding coupled with excessively harsh winters. The ongoing summer fyke net surveys allow year-class strength to be monitored annually during the first five years of residency. The findings enable adjustments to be made to harvest expectations.

Successful foraging during the summer feeding season can not only affect the survival of year classes, but also govern the age at which individual cohorts enter and remain within the fishery. Summer growth for juveniles is strongly correlated with coastal water temperature (Griffiths et al., 1992). Provided that ample food is available, the warmer the water temperature, the faster fish grow. A succession of warm summers could cause fish to enter the size-selective gill net fisheries at an early age. Conversely, colder summers could delay their entry. Food availability and temperature may not only determine how rapidly arctic cisco grow through the fishery but also affect the onset of sexual maturity and the resultant emigration back to Canada.

If a year class of arctic cisco remains robust, and the fish eventually grow to a size that renders them susceptible to the gillnet fisheries, environmental factors come into play that can affect their vulnerability. Arctic cisco are considered to be truly anadromous and appear to be more tolerant of salt water than most coregonids (Scott and Crossman, 1973; Morrow, 1980). They move into freshwater only to spawn, and then move back down toward the sea again. In contrast, most other coregonids of the Alaskan Beaufort Sea are amphidromous: they cycle annually between coastal marine waters in summer and freshwater habitats in winter (Craig, 1989). The arctic cisco’s affinity for saline water appears to affect its distribution on the Colville River fishing grounds. During the fall, arctic cisco move into Colville River channels as salinity increases after ice formation (Moulton and Seavey, 2004). Periodic west winds transport high-salinity water upriver, and fish appear to move upriver in association with the saline front. In years when salinity on the river fishing grounds does not increase to at least 20 ppt, subsistence yields are lower than expected (Moulton and Seavey, 2004).

Thus, even strongly recruited year classes that have remained healthy and robust over the years may not increase fishery yields if salinity conditions prevent the fish from moving into the primary fishing grounds. Conversely, moderate-strength year classes might substantially increase the harvest if the right salinity conditions prevail. During the four years (ages 5–8) in which arctic cisco are susceptible to the fishery, their contribution to yield may fluctuate from year to year, largely because of vagaries of meteorological and oceanographic conditions. Although there is no way to anticipate the physical conditions that will characterize the lower Colville River and delta in any given year, hydrographic monitoring is conducted in

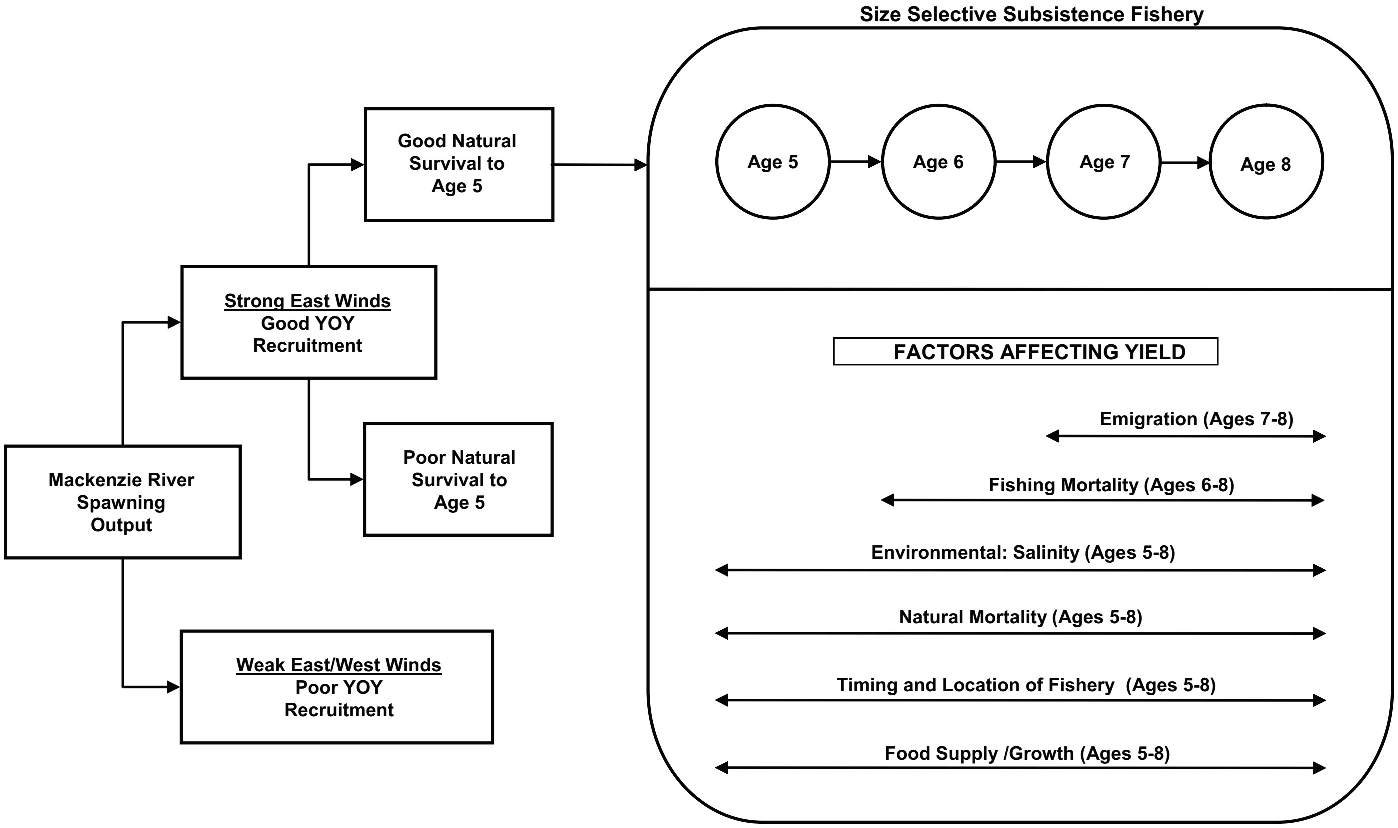

FIG. 5. Conceptual model of the fall arctic cisco fisheries in the Colville River.

conjunction with the fall subsistence fishery to provide a posteriori information that might explain deviations from expected harvest levels.

Similarly, the timing and location of the fishery would influence annual yields. The Colville River subsistence fishery targets three general locations: the upper delta, the mid delta, and the outer delta (Moulton and Seavey, 2005). In general, salinities increase as one moves downstream, so catches would be expected to increase in conjunction with the more saline waters. On average, from 1986 through 2004, catch-per-unit-effort in the subsistence fishery has been highest in the outer delta and lowest at the most upstream location (Moulton and Seavey, 2005). The higher yields in the outer delta have resulted in a gradual downstream shift in fishing effort over the years.

To this point, many of the major factors that affect the strength of the central Alaskan arctic cisco population and the fall fisheries are reasonably well understood and regularly monitored: strong versus weak wind-driven recruitment of YOY, good versus poor natural survival to age five, physical conditions on the fishing grounds themselves, and the spatial distribution of fishing effort. However, other factors also affect fishery yields. One is the extent to which the fisheries themselves affect stock strength. The 1997 and 1998 year classes were strongly recruited into Alaska, and both have remained strong and robust over the years (Fechhelm et al., 2005). These two year-classes have had a profound affect on fishery harvests since 2003. The 1997 year class is reported to have entered the Colville River subsistence fishery in 2003, as six-year-olds, and caused a sharp rise in yields that had been depressed since 1998 (Moulton and Seavey, 2004). In the fall of 2004, the subsistence harvest increased to its third highest level in the 20-year existence of the fishery, a yield that was largely attributed to the entry of the 1998 year class (Moulton and Seavey, 2005).

While the 1997 and 1998 year classes have substantially increased subsistence harvests, their stock strengths have also undergone notable changes. In summer of 2003, the estimated CPUE for six-year-olds (1997 year class) from the Prudhoe Bay coastal monitoring studies was an unprecedented 15.7 fish/net/24 hr (Fig. 6). That fall, the year class entered the fall subsistence fishery, causing a substantial increase in the harvest over previous years (Moulton and Seavey, 2004). The following summer, CPUE for the 1997 year class declined nearly 94%, to just 0.8 fish/net/24 hr. A similar, if less dramatic, decrease in CPUE occurred with the 1998 year class. In 2004, fyke net CPUE for six-year-old fish (1998 year class) was estimated at 5.9 fish/net/24 hr. In the fall of 2004, the subsistence harvest increased to its third-highest level in the 20-year existence of the fishery, and much of the harvest was attributed to the entry of the 1998 year class (Moulton and Seavey, 2005). By the following summer, fyke-net CPUE had declined to 2.6 fish/net/24 hr, a decline of 56% relative to the previous summer. The sharp decline in the summer catch rates of

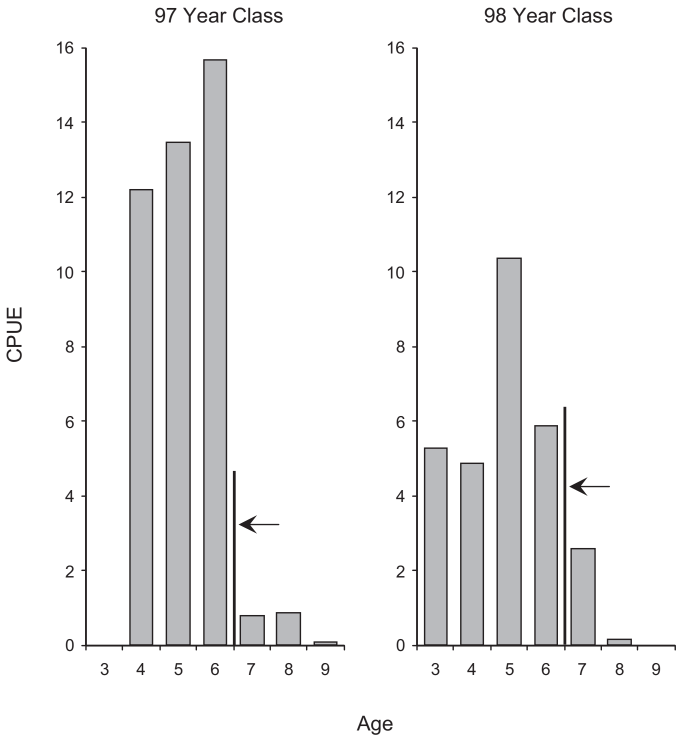

FIG. 6. Estimated catch-per-unit-effort (CPUE = fish/net/24 h) for the 1997 and 1998 year classes. The bold vertical lines denoted by the arrows indicate the fall in which each year class entered the Colville River fisheries. There are no data for the 1997 year class as three-year-olds.

both year classes in the summer following their entry into the fishery suggests that fishing mortality may have been substantial. However, the decline in the strength of the year classes may also be attributable to the emigration of sexually mature fish back to the Mackenzie River.

Arctic cisco reach sexual maturity beginning at about seven years of age (Morrow, 1980) and, upon reaching maturity, are believed to migrate back to the Mackenzie River to spawn (Gallaway et al., 1983). The difficulty is that the age of first maturity and the percentage of sexually mature fish at age reported in the historic literature vary considerably. Kendel et al. (1975) reported that 90% of arctic cisco collected in the coastal waters near Stokes Point, Yukon Territory, Canada, were sexually mature by age seven, and that the earliest age of maturity was age five (75% mature). Bond and Erickson (1987) sampled in the same area and reported age of first maturity at six years; however, only 1 of 58 six-year-old fish was mature (2%), and only 16% of fish were mature by age seven. Craig and Haldorson (1981), sampling in Simpson Lagoon located between the Colville and Sagavanirktok rivers, reported that age of first maturity was seven years, but only 43% of males and 0% of females were mature at this age. Griffiths et al. (1977) reported age of first maturity for male arctic cisco taken near Kaktovik at six years (54%). Age of first maturity for females was seven years, but only 16% of these were mature. Without any consistent estimate of percent maturity at age, there is no way to determine what proportion of seven-year-old arctic cisco might emigrate back to Canada in any given year, and thus no way to estimate to what extent emigration, as opposed to fishing mortality, may have contributed to the marked decline of the 1997 and 1998 year classes (and others) following their entry into the Colville River fisheries.

Emigration is most likely the principal reason for the decline in year-class strength noted above. Moulton and Field (1988) estimated an exploitation rate of around 6% on arctic cisco in 1985, a year of high abundance and high fishing effort. In recent years, both commercial and subsistence fishing efforts have declined substantially in the outer delta region (Moulton and Seavey, 2005). Most fishing is in one small channel in the western delta, while cisco occupying the main river are apparently only lightly fished. It is not likely that present fishing effort can account for the documented decline in abundance from age six to age seven shown in Figure 6.

The final unknown affecting the Alaskan arctic cisco population and the fisheries is the source stock itself. Reproductive success and the size of the recruitment pool are strongly affected by conditions that exist on the spawning grounds in the Mackenzie River. Spawning success is dependent upon spawner density, spawning efficiency, and physical conditions that can affect incubation, embryo development, and hatching success. No Canadian programs currently in place are designed to monitor the annual spawning success of the Mackenzie River arctic cisco populations either directly or indirectly. This metric may not be crucial, however, for understanding the Colville River subsistence fishery. Research over two and a half decades has led to a reasonably good understanding of the fishery and of the mechanisms that affect yield. This has been accomplished without any information concerning spawning success in Canada.

The Fishery and Climate Change

The relationship between summer wind patterns and the presence of individual age classes of arctic cisco in central Alaska has remained remarkably consistent over the 20+ years for which data are available. The strength and persistence of east winds during the year of hatching appear to be critical factors in determining the strength of the arctic cisco population in Alaska. Yet this dependence on meteorological conditions raises the specter of long-term global climate change and the effect it might have on Alaskan arctic cisco populations. Evidence of climatic change in the Arctic continues to mount (Carmack and MacDonald, 2002). Climate models predict a warming trend that could be quite intense at higher latitudes (Walsh and Crane, 1992). Carmack and MacDonald (2002) note that the disproportionate influence of warming on Arctic physical systems will have profound effects on Arctic biota. Physical changes will include increased periods of open water, decreased ice cover, rising sea levels, increased storms, shifting water-mass fronts, and more. For Arctic cisco, a critical element will be the predominance of easterly winds that is so crucial to the recruitment process. In the 1980s and 1990s, there were several instances in which a single severe west-wind storm lasting 3–4 days was sufficient to stop the recruitment of young-of-the-year. If the prevalence of easterly winds is substantially diminished by future climatic shifts, arctic cisco could cease to be a dominant species in the coastal waters and the fisheries of northern Alaska.

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