ARCTIC
VOL. 63, NO. 4 (DECEMBER 2010) P. 381–390

History of an Under-Ice Subsistence Fishery for Arctic Cisco and Least Cisco in the Colville River, Alaska

LAWRENCE L. MOULTON,[1] BRENT SEAVEY[2] and JERRY PAUSANNA[3]

(*Received 17 February 2009; accepted in revised form 7 April 2010*)

ABSTRACT. Arctic cisco (*Coregonus autumnalis*) and least cisco (*C. sardinella*) are harvested in the Colville River Delta near Nuiqsut, Alaska, after ice forms in the fall. Arctic cisco targeted by the fall fishery derive from spawning stocks in the Mackenzie River of Canada. Young-of-the-year fish are recruited into the Colville region during August or September, aided by westerly coastal currents generated by predominantly easterly winds. In contrast, anadromous least cisco, harvested as the primary by-catch in the fishery, spawn and winter entirely in the Colville delta and lower river. This study reports on fishery monitoring for the 20-year period 1985–2004. During this period, effort in the subsistence fishery showed an increasing trend. Arctic cisco, the target species, averaged over 65% of the annual observed catch, and least cisco averaged 22%. From 1985 to 2002**,** total harvest of arctic cisco for the combined subsistence and commercial fisheries averaged 38 600 fish (15 958 kg) per year, ranging from a low of 5859 fish (2799 kg) in 2001 to 78 254 fish (31 340 kg) in 1993. During the same period, catches of least cisco averaged 18 600 fish (5819 kg), ranging from a low of 6606 fish (2014 kg) in 2001 to 33 410 fish (11 319 kg) in 1985. The subsistence fishery caught 56% of the total arctic cisco harvest and 42% of the least cisco harvest (in numbers of fish). In the six years for which estimates of both harvest and population level were available, total estimated annual harvest of arctic cisco within the Colville River Delta averaged 8.9% of the available fish, with yearly estimates ranging from 5.4% to 12.9%. For least cisco, the average annual removal rate was 6.8% (range: 2.9% to 13.8%).

Key words: arctic cisco, least cisco, subsistence, under-ice fishery, Colville River, Beaufort Sea, Alaska, harvest rates, age structure

RÉSUMÉ. Le cisco arctique (*Coregonus autumnalis*) et le cisco sardinelle (*C. sardinella*) sont pêchés dans le delta de la rivière Colville près de Nuiqsut, en Alaska, après la formation de la glace à l'automne. Les ciscos arctiques qui font l'objet de cette pêche d'automne proviennent de la fraie du fleuve Mackenzie au Canada. Les jeunes poissons de l'année sont recrutés dans la région de Colville en août ou en septembre, et sont aidés par les courants côtiers d'ouest générés par les vents principalement de l'est. Pour leur part, les ciscos sardinelles anadromes, qui sont récoltés en tant que prise fortuite principale de la pêche, fraient et hivernent entièrement dans le détroit Colville et la rivière inférieure. La présente étude fait état d'un projet de surveillance des pêches échelonné sur une période de 20 ans, soit de 1985 à 2004. Au cours de cette période, la pêche de subsistance a affiché une tendance à la hausse. Le cisco arctique, soit l'espèce ciblée, représentait en moyenne plus de 65 % de la prise annuelle observée, tandis que le cisco sardinelle représentait 22 % en moyenne. De 1985 à 2002**,** la récolte totale de cisco arctique pour l'ensemble de la pêche de subsistance et de la pêche commerciale a atteint, en moyenne, 38 600 poissons (15 958 kg) par année, allant du faible nombre de 5 859 poissons (2 799 kg) en 2001 à 78 254 poissons (31 340 kg) en 1993. Au cours de cette même période, les prises de ciscos sardinelles ont atteint, en moyenne, 18 600 poissons (5 819 kg), allant du faible nombre de 6 606 poissons (2 014 kg) en 2001 à 33 410 poissons (11 319 kg) en 1985. La pêche de subsistance a permis de récolter 56 % de tous les ciscos arctiques capturés et 42 % des ciscos sardinelles (pour ce qui est du nombre de poissons). Dans le cas des six années pour lesquelles il existe des estimations du taux de capture et de population, la capture annuelle totale estimée de ciscos arctiques dans le delta de la rivière Colville a atteint, en moyenne, 8,9 % des poissons disponibles, et les estimations annuelles s'échelonnaient entre 5,4 % à 12,9 %. Dans le cas du cisco sardinelle, le taux moyen annuel de prise s'élevait à 6,8 % (avec une étendue de 2,9 % à 13,8 %).

Mots clés : cisco arctique, cisco sardinelle, subsistance, pêche sous la glace, rivière Colville, mer de Beaufort, Alaska, taux de capture, structure par âge

Traduit pour la revue *Arctic* par Nicole Giguère.

[1] MJM Research LLC, 1012 Shoreland Drive, Lopez Island, Washington 98261, USA; lmoulton@rockisland.com
[2] 9532 Liberty Circle, Anchorage, Alaska 99515-1427, USA
[3] 364 Pausanna Street, Nuiqsut, Alaska 99789, USA

INTRODUCTION

Arctic cisco (*Coregonus autumnalis*), a highly prized food source in Alaskan Inupiat communities, is harvested near Kaktovik in late summer and in the Colville River Delta near Nuiqsut after ice forms during fall. In addition to this subsistence fishery, a commercial fishery operated in the Colville River Delta from the early 1950s until recent years. Prior to 1985, there was little information on the subsistence harvests of anadromous fishes, although detailed information existed on the commercial fishery (Craig and Haldorson, 1981; Gallaway et al., 1983; George and Kovalsky, 1986; George and Nageak, 1986; Moulton et al., 1986a; Craig, 1987). Local people expressed concern that oilfield developments would affect their traditional subsistence fishery for arctic cisco. The fishery assessment reported here was initiated in 1985 when the North Slope Borough, the local government for Alaska's Arctic Coastal Plain region, requested that information be collected to assess fisheries in the Colville River that were considered to be most at risk.

Arctic cisco targeted by the fall fishery derive from spawning stocks in the Mackenzie River of Canada, with young-of-the-year fish recruiting into the Colville region during August or September, as described by Gallaway et al. (1983, 1989), and Fechhelm et al. (2007). Recruitment of age 0 arctic cisco into the Colville River region was aided by westerly coastal currents generated by predominantly easterly winds in the Beaufort Sea region. Strength of recruitment has been correlated to the percentage of easterly winds from June to September (Fechhelm and Fissel, 1988; Fechhelm et al., 2007). During the study period, summer winds from the east averaging 5 km/h or more resulted in a large increase in the catch per unit effort (CPUE) of young-of-the-year fish sometime in August. Conversely, in years when summer winds from the east averaged less than 5 km/h, or in years of net west winds, there was no dramatic increase in CPUE (Fechhelm et al., 2007). Since arctic cisco return to the Mackenzie River to spawn when they mature (at age 7 or 8), they were available to the fishery for only two or three years prior to maturity. In contrast, anadromous least cisco (*C. sardinella*), harvested as the primary by-catch in the fishery, were from local stocks that spawn and winter entirely in the Colville delta and lower river. While least cisco is not a preferred species, these fish were often retained when arctic cisco was in low abundance; otherwise, they were donated to others or used as dog food.

Initially, the goals of this fishery assessment were to describe the fishery and evaluate harvest levels of both cisco species relative to the fish populations. When it became apparent that the study would extend to multiple years, the goals changed to developing time series to measure trends in effort and catch rate in order to evaluate changes in both fishery effort and harvested populations. The period in which these trends were measured (1985 to 2004) was characterized by rapid climate change (Hinzman et al., 2005; Martin et al., 2009) as well as rapid industrial development (NRC, 2003); thus, data from this time period may be useful when attempting to analyze changes in the fishery or fish populations. Objectives of the study were to 1) document trends in effort, catch rate, and harvest for the fall cisco fishery in the Colville River Delta, 2) obtain length and age information on cisco populations being harvested, and 3) evaluate harvest levels relative to population abundance to assist harvest management.

METHODS

The study area included the Colville River from the Itkillik River downstream to Harrison Bay (Fig. 1). The study area was stratified into four traditional fishing areas: 1) the Outer Colville River Delta, 2) the Upper Nigliq Channel near Nuiqsut, 3) the Nanuk area of the Nigliq Channel, and 4) the Nigliq Delta (Fig. 1). Fishing typically began in early October and often continued into early December, at which time it was hampered by low daylight and thick ice. Fishery monitoring was initiated soon after the first nets were deployed and continued until late November. Nets were initially set near town while river ice was too thin to allow access with snow machines; effort spread away from town after ice thickened to the point at which safe travel was possible.

Subsistence catches were sampled daily for species composition, number of fish caught, and fork length to the nearest millimeter. All fish were examined for tags, fin clips, and dye marks applied by other fish studies in the region. Set duration, net length, net depth, and mesh size data were also recorded so that CPUE could be calculated. Effort was calculated in net days by using the start and end dates for each net. Effort data were adjusted for net length and set duration by standardizing net length to 18 m and set duration to 24 hr, leading to a net-day defined as effort per 15 m of net over a 24 hr period (Gulland, 1968). Nets in the subsistence fishery varied in length, with 18 and 24 m nets averaging 70% of the lengths used each year (range: 47% to 87%), and most nets were 1.8 m deep.

Within the main sampling areas, catch rates (CPUE) were estimated by obtaining catch and effort data according to mesh size in each fishing area during the season. For each mesh size in each fishing area, the total observed catch was divided by the total observed effort to provide a CPUE estimate. Catch rates for each mesh size by area were then multiplied by the total effort estimated for each mesh size/area combination, and estimated catches were summed to provide an estimate of total catch. In the subsistence fishery, 76 mm mesh nets were preferred, being used on average in 60% of the total annual effort over the 20 years of monitoring (range: 48% to 81%). Catch rate indices used for comparisons among areas and years and evaluation of changes in length distributions were based on 76 mm mesh.

Salinity was monitored in conjunction with the fishery because arctic cisco was commonly associated with salinities in the range of 15 to 25 ppt (parts per thousand). Salinity was measured every other day at standard locations in

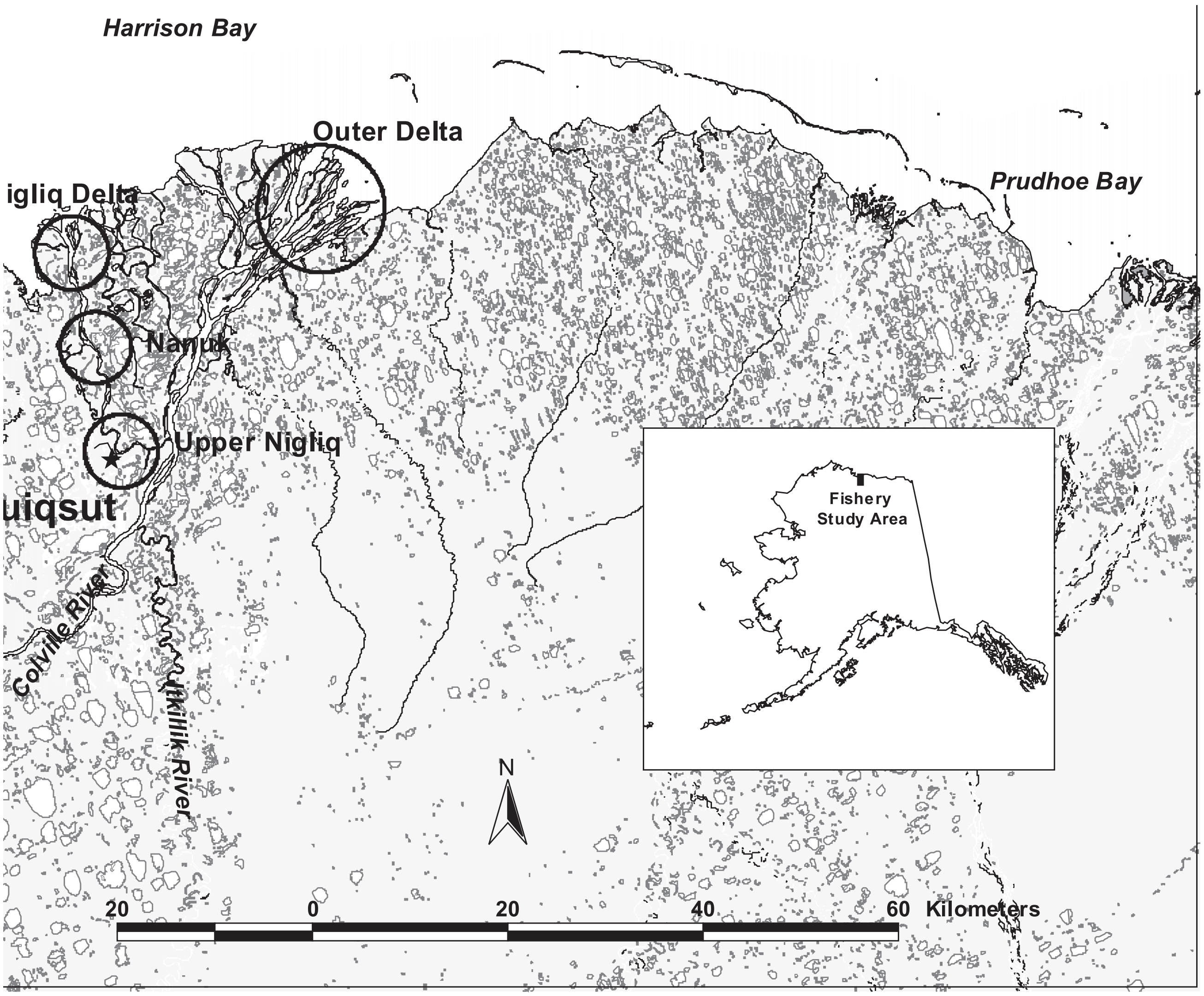

FIG. 1. Colville River Delta region of Alaska, showing locations of major fishing areas in relation to Harrison Bay and Prudhoe Bay.

the three fishing areas on the Nigliq Channel. Salinity was measured as a vertical profile of the water column at 0.5 m increments.

Otoliths obtained from both arctic cisco and least cisco caught in 76 mm mesh were read using the break-and-burn technique (Chilton and Beamish, 1982). Otoliths were broken across the transverse axis, held over a flame until the edge discolored, and placed in isopropyl alcohol to be viewed with a dissecting microscope at 30 power. Annuli appeared as narrow, dark rings between the wider, lighter annual growth bands. The age data were used to partition the catch rate in the fishery by year class and to evaluate relative year-class strength.

Length frequency, length/weight relationships, sex ratio, and estimated catches by mesh size for arctic cisco and least cisco were used to estimate the annual harvested biomass. Length/weight relationships and length frequency data were used to estimate the mean weight of a harvested fish by mesh size for each year; then the total estimated harvest for that mesh size was multiplied by the mean weight. A composite length frequency was generated for mesh sizes in which length frequencies were not determined on an annual basis. Length-weight estimates for least cisco were partitioned by sex because both spent and non-spawning females were caught in the fishery. Analysis of covariance indicated that spent female and male least ciscoes had statistically similar length-weight relationships, while ripe females had significantly higher weight per length ($p < 0.001$). Male and female arctic ciscoes, all of which were immature fish, had statistically identical length-weight relationships.

Records of catch and effort were obtained for the Colville delta commercial fishery between 1967 and 2002 (early years summarized in Gallaway et al., 1983, 1989). Nets used in the commercial fishery were 46 m long with 76 mm mesh; CPUE was standardized to catch per 18 m of net to allow comparison with subsistence catch rates.

Between 1980 and 1993, release and subsequent recapture of anchor-tagged arctic ciscoes and least ciscoes during studies of coastal fishes in Harrison Bay and near Prudhoe Bay allowed an estimate of the total number of fish available to fisheries in the Colville delta (Griffiths and Gallaway, 1982; Critchlow, 1983; Griffiths et al., 1983; Moulton et al., 1986a, b; Envirosphere Company, 1987; LGL Alaska Research Associates, Inc. 1990, 1992a, b, 1994a, b). The method for estimating population size was a modified Petersen population estimate used by Craig and Haldorson (1981) and Moulton and Field (1994) for Colville River arctic and least cisco and was based on analysis techniques described in Ricker (1975:78). An adjustment was made to the total number of tags released because fish that were tagged were captured by fyke net, while recoveries were by gill net. Gill net meshes were highly selective for a particular size range, so that many of the fish tagged during summer could not be captured during the fall fishery. The predominate gill net mesh used in this fishery, 76 mm stretched mesh, selected fish in the range of 300 to 340 mm fork length. Assuming that all released tagged fish were vulnerable to the fishery would lead to a substantial error in population estimates. Therefore the number of tagged fish released was adjusted to the number of tags vulnerable to gill nets, as described in Ricker (1975:93–95).

In using the Petersen method we assumed that 1) tagged fish suffered the same natural mortality as untagged fish, 2) tagged fish were as vulnerable to fishing as untagged fish, 3) tagged fish did not lose their tags, 4) tagged fish became randomly mixed with untagged fish, 5) all tags were recognized and reported on recovery, and 6) there was only a negligible amount of recruitment to the harvestable population during the time the recoveries were being made.

The additional tagging mortality and tag loss rates (assumptions 1 and 3) were not known for the cisco populations in question, but were thought to be low. The studies from which tag release data were obtained did not estimate either tagging mortality or tag loss, so estimates for these parameters are not available. No correction for these sources of error was made in the calculations for lack of information on appropriate rates. Tags in the Colville River least cisco population persisted for more than 10 years and demonstrated a low decay rate over time (Moulton and Field, 1994). These observations suggested that the errors introduced by not correcting for tag loss and tagging mortality were likely to be small compared to errors arising from other assumptions of the method. If tag loss or tagging mortality or both were significant, the population estimate would decrease by a corresponding amount. For example, a tag loss or tagging mortality of 10% would reduce the population estimate by about 10%. Population estimates as given (with no correction for tag loss or tagging mortality) were thus maximum estimates.

Assumptions 2, 4, and 6 did not appear to be significant sources of error in the Colville delta situation. There was no evidence that anchor-tagged fish were more or less vulnerable to the gill nets used in the fishery. Distribution of tag returns from throughout the delta demonstrated that tagged fish were reasonably mixed with untagged fish. Since the fish had ceased growing prior to returning to the wintering area where the fishery was conducted, recruitment to the harvestable population while the fishery was in progress was probably negligible.

The assumption that all tags were recognized was likely to have been a greater source of error early in the tagging period than in later years. In early years, relatively few tags were applied and catches were high, so the probability of missing a tag was likely higher. In addition, the existence of tags in the catch was a new phenomenon. A missed tag would induce a greater error when few tags were applied than when larger numbers of tags were being returned.

Data on arctic cisco abundance in the Prudhoe Bay region were obtained from fyke nets set to monitor fish populations in that region. Coastal fish monitoring near Prudhoe Bay has been conducted annually since 1981, except in 1999 and 2000, and the resulting data provide a time series of fish abundance in the region (Fechhelm et al., 2007). At the end of each field season, arctic cisco length and abundance data from the fyke net surveys were obtained to compare with information obtained from the fishery.

Detailed summaries of annual fishery data from 1985 to 2004 were included in annual reports, ending with Moulton and Seavey (2005).

RESULTS

Salinity Distribution

Wind direction during fall fishing within the Colville River Delta had the opposite effect of summer winds that influence arctic cisco young-of-the-year recruitment into the coastal region. During east winds in the fall, the water level in the river dropped, and channels freshened. When wind reversed and came from the west, water levels rose and saline water moved into the delta, bringing in arctic cisco and displacing least cisco, humpback whitefish, (*C. pidschian*) and broad whitefish (*C. nasus*). Mean salinity varied substantially from year to year; in addition, there was spatial variation, with salinity highest in the downstream fishing area and decreasing upstream (Fig. 2). In some years, notably 1988, 1995, and 2002, water in the upper fishing area remained fresh through the fishing season.

Distribution of Fishing Effort

Effort in the subsistence fishery showed an increasing, but not significant ($p = 0.08$), trend over the period of record. During the first 10 years of monitoring, from 1985 to 1994, effort averaged 1473 net-days per year (range: 631–1880 net-days), while during the second 10-year period, from 1995 to 2004, effort averaged 1811 net-days (range: 1377–2525 net-days). In the Nigliq Channel, subsistence effort gradually shifted downstream during the 20-year

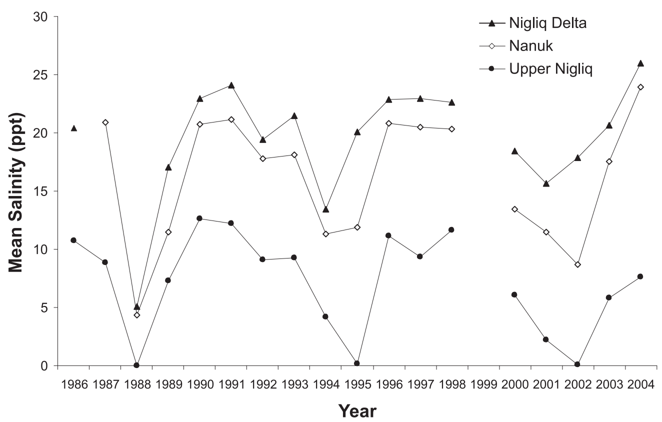

FIG. 2. Mean salinity during the fall fishery at major fishing areas in the Nigliq Channel, Colville River Delta, Alaska, 1986–2004.

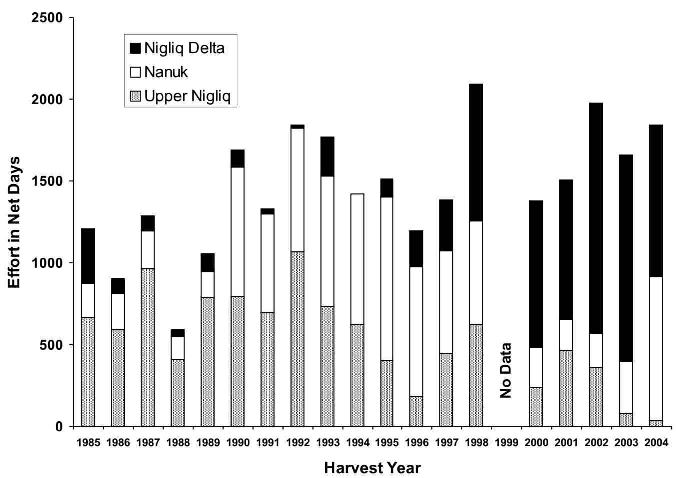

FIG. 3. Subsistence fishing effort in the Nigliq Channel has shifted downstream from 1985 to 2004 (by fishing area, all meshes combined).

period (Fig. 3). From 1985 to 1989, from 65% to 74% of the effort within the channel was expended in the Upper Nigliq area. In 1993, effort in the Nanuk area exceeded that in the Upper Nigliq area. And in 2004, more than 76% of the Nigliq Channel effort was in the Nigliq Delta area. After 1997, the Nigliq Delta had the highest effort of the three Nigliq Channel areas. Predominant meshes were 76 mm stretched mesh (which accounted on average for 60% of the annual effort) and 89 mm mesh (26% of annual effort). The remaining effort involved mostly 64 and 83 mm mesh, with a scattering of others used on a trial basis.

In contrast to the subsistence fishery, the commercial fishery had a decline in effort during the survey period. Commercial effort averaged 1847 net-days per year from 1967 to 1991 (range: 378–3568 net-days), but changing markets led to reduced effort after 1991, averaging 498 net-days from 1992 to 2002 (range: 233–920 net-days). Commercial effort employed primarily 76 mm mesh (86% of annual effort), followed by 83 mm (13%).

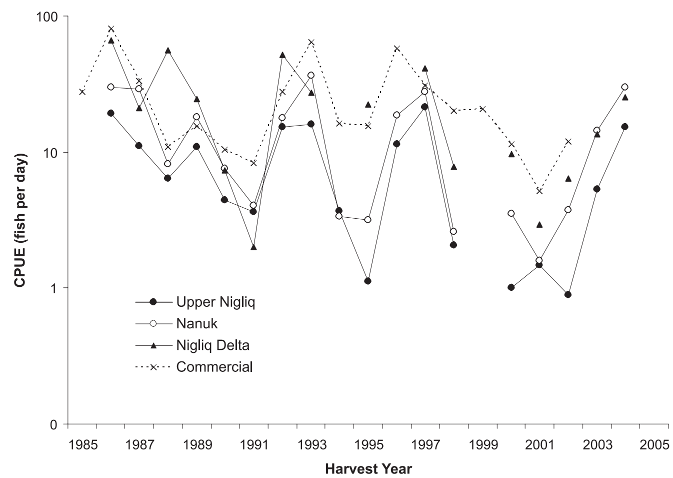

FIG. 4. Catch rate of arctic cisco at fishing areas in the Colville River Delta, Alaska, 1985–2004 (CPUE = fish per 18 m net-day in 76 mm mesh).

Catch Composition and Harvest Levels

Catch rates in the arctic cisco fishery have cycled with apparent changes in population abundance (Fig. 4). All three subsistence harvest areas along the Nigliq Channel and the commercial fishery generally responded similarly on an annual basis. Within the Nigliq Channel, catch rates were highest in the Nigliq Delta, averaging 24.0 fish per day from 1986 to 2004 and decreased progressively upstream, averaging 14.4 fish per day in the Nanuk area and 8.4 in the Upper Nigliq area. Arctic cisco mean catch rates in the Nigliq Channel tested with linear regression were significantly correlated ($p = 0.0005$) with commercial catch rates from the Outer Delta fishing area.

Arctic cisco, the target species, averaged over 65% of the annual observed catch (range: 35–96%). Least cisco accounted for an average 22% of the observed catch (range: 3.8–51%), and humpback whitefish was the third most abundant species, averaging 6.4% (range: 0–28%). In 1990, Bering cisco (*C. laurettae*) were abundant, comprising almost 22% of the observed harvest; however, aside from the one year, they were rarely caught. Broad whitefish (2.9%) were often present early in the fishing season, while rainbow smelt (0.2%) moved into the fishing area later in the season when salinity increased. Fourhorn sculpin were abundant at all times, but were not retained and the catch was not quantified.

Total harvest of arctic cisco for both fisheries combined averaged 38 600 fish (15 958 kg) from 1985 to 2002 (the last year for which commercial fishery figures are available). The harvests ranged from a low of 5859 fish (2799 kg) in 2001 to 78 254 fish (31 340 kg) in 1993 (Table 1). During the same period, catches of least cisco averaged 18 600 fish (5819 kg), with a low of 6606 fish (2014 kg) in 2001 to 33 410 fish (11 319 kg) in 1985. The subsistence fishery caught 56% of the total arctic cisco harvest in numbers of fish, and 42% of the least cisco harvest. The sex ratio of the arctic cisco

TABLE 1. Estimated numbers and biomass of harvested arctic cisco and least cisco by year for subsistence and commercial fisheries in the Colville River Delta, 1985–2004.

	Subsistence Harvest				Commercial Harvest			
	Arctic Cisco		Least Cisco		Arctic Cisco		Least Cisco	
Year[1]	Catch (in fish)	Biomass (kg)	Catch (in fish)	Biomass (kg)	Catch (in fish)	Biomass (kg)	Catch (in fish)	Biomass (kg)
1985	46 681	19 478	15 814	5298	23 678	10 146	17 596	6021
1986	33 522	14 414	6804	2176	29 456	12 640	9000	2959
1987	20 926	9800	6178	2020	27 494	12 945	11 939	4117
1988	6098	2951	2321	793	10 480	5264	23 040	8121
1989	12 892	6497	6036	1844	24 802	12 697	19 640	7006
1990	11 224	4407	9100	2584	21 105	8634	17 049	5513
1991	8269	2852	3193	754	23 698	8695	7744	1838
1992	45 402	15 700	2658	777	22 754	8391	7284	2513
1993	46 944	18 615	7599	2093	31 310	12 725	6037	1795
1994	10 956	4502	8669	2455	8958	4037	10 176	3153
1995	8574	3463	8573	2487	14 311	5353	8633	2658
1996	41 205	15 387	15 854	4645	21 817	8124	7796	2375
1997	33 274	14 487	10 002	2979	16 990	7186	10 754	3228
1998	13 559	5435	19 323	5487	8752	3501	11 822	3443
2000	9956	4851	1973	641	2619	1218	5758	1873
2001	3935	1886	3630	1089	1924	913	2976	925
2002	7533	2669	5422	1555	3935	1424	5503	1710
2003	23 369	9986	7748	2327	–	–	–	–
2004	40 605	15 325	15 228	5556	–	–	–	–

[1] 2000–04 subsistence harvest represents only the Nigliq Channel harvest.

harvest was 58 males to 42 females, while the least cisco harvest was 90% females (60% non-spawning females).

Population estimates for harvestable arctic cisco (240–380 mm fork length), generated from tag and release studies in the region, fluctuated substantially from 1980 to 1993 (Table 2). Linear regression tests indicated that these population estimates were significantly correlated with commercial catch rates ($p = 0.01$) during the same years. Conversely, population estimates for harvestable least cisco during the same time period showed no relationship to catch rates in the fishery ($p = 0.29$) when tested with linear regression.

Total estimated harvest of arctic cisco within the Colville delta averaged 8.9% of the available fish for six years in which estimates of both harvest and population level were available, with estimates ranging from 5.4% to 12.9% (Table 3). For least cisco, the average removal rate was 6.8%, and the range from 2.9% to 13.8%.

Year Class Abundance

Ages of arctic cisco taken in 76 mm mesh were obtained from 1985 to 2004 (Fig. 5). Age data were used to partition catch rate in the Nuiqsut Channel fishery by year class in order to evaluate relative year class strength. The cumulative catch rate for a year class was used as an index to year class productivity. The analysis demonstrated that 1986 had a high catch rate because two abundant year classes (1979 and 1980) reached a harvestable size in the same year. In subsequent years, the abundance of these year classes decreased, and they were replaced by later year classes. The 1987 year class, which dominated the fishery from 1992 to 1994, was essentially gone by 1996. The cumulative harvest of this year class surpassed any other single year class in abundance. The 1990 year class contributed the second-highest cumulative harvest and was responsible for high catch rates in 1996 and 1997. Year classes between 1990 and 1997 had low abundance, which was responsible for low catch rates until the 1997 year class recruited in 2003.

Least cisco were sampled every other year for age structure because of their slow growth rate and the relative stability of the population, with over 85% of harvested least cisco between ages 8 and 15. The distribution of ages in least cisco did not show a change in year-class dominance. The mean age of harvested fish has shown a continuing upward shift from 1978 to the present. In 1978, mean age was 9.6 years (Craig and Haldorson, 1981), but by 1995, mean age was 12.5 years. In subsequent years, mean age remained more than 11 years.

Predictability in Arctic Cisco Harvest Rates

To provide a pre-season estimate of catch rates, we regressed the catch rate of 260–300 mm arctic cisco from fyke nets set in the Prudhoe Bay coastal region during the summer prior to entering the fishery against the catch in 76 mm mesh gill nets used in the commercial fishery within the Colville delta in the following year. The theory was that after an additional summer of growth, this group would grow into the 300–340 mm size range that was highly vulnerable to 76 mm mesh gill nets. The correlation between fyke net catches of 260–300 mm arctic cisco and the next year's catch of 300–340 mm fish was statistically significant ($p = 0.02$).

The harvest rate for 300–340 mm arctic cisco was predicted for seven years between 1994 and 2002 using the relationship between commercial gill net catch rates and

TABLE 2. Summary of Petersen population estimates for 1980–93.

Release year	Number of tags released	Gear selectivity adjustment factor	Total effective release	In-year examined catch	Population recovered tags	Estimate (No. of fish)	Lower bound	Upper bound
Arctic Cisco								
1980	229	0.397	138	14 753	10	186 551	104 930	317 443
1981	1756	0.649	617	38 176	62	374 311	293 022	477 718
1982	874	0.302	610	15 975	20	465 027	306 113	700 635
1983	0	–	–	18 162	–	–	–	–
1984	5840	0.460	3152	27 677	89	969 612	789 628	1 190 100
1985	11 695	0.455	6375	23 678	147	1020 100	868 848	1 197 495
1986	0	–	–	29 456	–	–	–	–
1987	0	–	–	14 788	–	–	–	–
1988	1077	0.243	815	9022	23	306 920	207 367	451 409
1989	0	–	–	12 145	–	–	–	–
1990	727	0.422	420	11 105	9	467 510	258 035	817 049
1991	2407	0.710	697	9 558	26	247 202	170 682	356 245
1992	3628	0.301	2534	22 754	67	848 441	670 217	1 073 229
1993	1591	0.140	1368	31 310	69	612 365	485 351	772 053
Least Cisco								
1980	1067	0.286	762	30 982	32	716 657	512 127	999 536
1981	6157	0.095	5570	15 504	90	949 150	773 829	1 163 695
1982	3929	0.281	2825	27 085	243	313 759	276 843	355 578
1983	0	–	–	37 909	–	–	–	–
1984	14 126	0.397	8512	13 076	313	354 526	317 470	395 895
1985	9915	0.171	8224	17 596	432	334 259	304 252	367 220
1986	0	–	–	9000	–	–	–	–
1987	0	–	–	11 939	–	–	–	–
1988	867	0.462	467	13 884	34	185 477	133 807	256 341
1989	0	–	–	10 328	–	–	–	–
1990	5895	0.289	4194	11 049	104	441 504	365 011	533 856
1991	10 834	0.399	6507	3632	62	375 292	293 791	478 970
1992	6744	0.359	4321	7284	122	255 989	214 695	305 155
1993	8514	0.405	5064	6037	95	318 583	261 124	388 535

TABLE 3. Annual removal rates of arctic cisco and least cisco for years in which an estimate of harvestable fish is available.

Harvest year	Commercial harvest	Village harvest	Total harvest	Population estimate	Percent harvested
Arctic Cisco					
1985	23 678	46 681	70 359	1 020 100	6.9%
1988	10 470	6098	16 568	306 920	5.4%
1990	21 772	11 224	32 996	467 510	7.1%
1991	23 731	8269	32 000	247 202	12.9%
1992	22 754	45 401	68 155	848 441	8.0%
1993	31 310	46 944	78 254	612 365	12.8%
Least Cisco					
1985	17 383	15 814	33 197	334 259	9.9%
1988	23 196	2320	25 516	185 477	13.8%
1990	17 064	9100	26 164	441 504	5.9%
1991	7743	3193	10 936	375 292	2.9%
1992	7284	2659	9 943	255 989	3.9%
1993	6037	7599	13 636	318 583	4.3%

fyke net catch rates in the previous year (Table 4). There was substantial error surrounding the prediction, which can be attributed to a number of factors, including how well fyke net and gill net catch rates reflected regional fish abundance and changes in fish distribution during the fishing season because of annual variability in salinity within the delta. The correlation between fyke net CPUE and Nigliq Channel subsistence gill net CPUE has considerably more error than that already noted. Thus, with the weak correlations, pre-season estimates using these relationships did not provide reliable harvest predictions. The best way we could make predictions was to examine the summer fyke net CPUE in the prior year and make a judgment about whether the gill net CPUE was likely to increase, decrease, or remain similar to that of the previous year.

DISCUSSION

Trends in Fishing Effort and Harvest

The 20 years of subsistence fishery monitoring in the Colville delta from 1985 to 2004 provided data that have been useful for evaluating trends in harvest effort, fishery

TABLE 4. Actual catch rate of arctic cisco (in fish per day for 15 m of 76 mm mesh) compared to the prediction based on abundance of 260–300 mm fish captured in coastal fyke nets in the previous year.

Year	Predicted CPUE (fish /day)	Actual CPUE (fish /day)	Percent error
1994	15.3	15.0	-2%
1995	35.6	32.2	-30%
1996	59.1	130.0	98%
1997	55.4	50.1	-10%
1998	66.6	20.1	-68%
1999	56.1	26.7	-52%
2002	52.5	12.7	-76%

performance, and population abundance. Increasing effort from the village of Nuiqsut was likely the combined result of greater familiarity with distribution of arctic cisco in the region and an increasing user population. The village, which had been abandoned in the 1940s, was re-established in 1972. The new residents included people from both the Colville region and Barrow. Those with historical roots in the region brought existing knowledge of appropriate harvest strategies, but the newer harvesters needed to learn these strategies in order to become successful fishermen. The monitoring study began as these user groups were becoming more efficient at harvesting existing resources, so some of the changes identified in the fishery were an indication of that learning process. One such change was the gradual downstream shift in fishing effort that occurred as more fishers learned how salinity influences the distribution of arctic cisco.

Arctic cisco harvest rates in both the commercial and subsistence fisheries fluctuated with fish population abundance in the region, which was a direct result of wind-induced recruitment from the Mackenzie River (Fechhelm at al., 2007). These recruitments were measured when the young-of-the-year arrived in the region, and measures of abundance were repeated annually as they grew into harvestable size, reached maturity, and eventually left to return to spawning areas. Knowledge of arctic cisco juvenile recruitment into the region as a whole and information on growth rates prior to recruitment into the fishery allowed some prediction of impending increases or decreases in the arctic cisco catch rate (Fechhelm et al., 2007). Unpredictable variables, such as the distribution of saline water in the delta, as well as possible variations in natural mortality, growth, and maturation rates, make accurate predictions of catch rates unlikely. For example, salinity in the Upper Nigliq fishing area remained low in 1988, 1995, and 2002, and arctic cisco remained downstream, leading to lower-than-expected catch rates in this area (Fig. 4).

Estimates of harvest rate for both arctic cisco and least cisco indicated a low to moderate rate of harvest, averaging less than 10% of the available fish, from 1985 to 1993. Since that period, the commercial harvest has dropped to a negligible level, and most of the subsistence harvest has been from one channel in the western delta. Thus, the exploitation rate has declined in recent years. These harvest rate estimates assumed that the population estimates do not contain substantial error; however, because of the lack of information on tag mortality and tag loss, these harvest estimates were likely low.

Climate Change Implications

Fechhelm et al. (2007) postulated that arctic cisco rearing in the Colville delta could drastically decrease if eastern winds were no longer of sufficient intensity and duration to ensure recruitment of young-of-the-year. The present data series (1985–2004) covers the period of warming that focused attention on the subject of climate change (Hinzman et al., 2005) and therefore provides a baseline for evaluation of future changes in abundance and growth. Some evidence suggests that a decline in arctic cisco abundance has begun: catch rates have generally decreased during the period of record, and both peak and low catch rates are lower than in the mid to late 1980s (Fig. 4). Correlations between arctic cisco catch rate and time, however, were not statistically significant. There was insufficient evidence to assign causes for this trend because, as noted by Fechhelm et al. (2007), little information exists on stock status within the Mackenzie River, the source of arctic cisco in the Alaskan Beaufort Sea region. Favorable stock status could override climate changes occurring within the Colville region. In addition, the study covered a period when substantial industrial development accompanied the rapid climate change. Because both climate change and industrial development were occurring simultaneously, it may be difficult, if not impossible, to attribute changes in fish populations to a single cause. Long-term measures of 1) adult arctic cisco abundance in the Mackenzie region, 2) wind intensity and duration along the Beaufort Sea coast, and 3) continued monitoring of arctic cisco recruitment into the Alaskan Beaufort region would assist analysis of future population changes.

ACKNOWLEDGEMENTS

The study was initiated by ARCO Alaska and continued by its successor company, ConocoPhillips Alaska. BP Exploration (Alaska) funded the project from 1988 to 1996 under the Endicott Monitoring Program. Project managers included Robert Newell, Mike Joyce, Chris Herlugson, Ray Jakubzak, Bill Wilson, Caryn Rea, and Sally Rothwell. The study was initiated at the request of the City of Nuiqsut and continued with encouragement from the North Slope Borough Department of Wildlife Management. Numerous residents of Nuiqsut participated in the study over the years, most notably the active fishers who allowed access to their daily catches. Field assistants included Eli Nukapigak, Bryan Nukapigak, Sam Kunaknana, Robert Lampe, Clarence Ahnupkana, Jeff Long, Walter Oyagak, Willie Sielak, Joe Bolt, Matt Kopec, Kirk Waggoner, and Marcus Ahmakak. James Helmericks provided documentation of the commercial fishery.

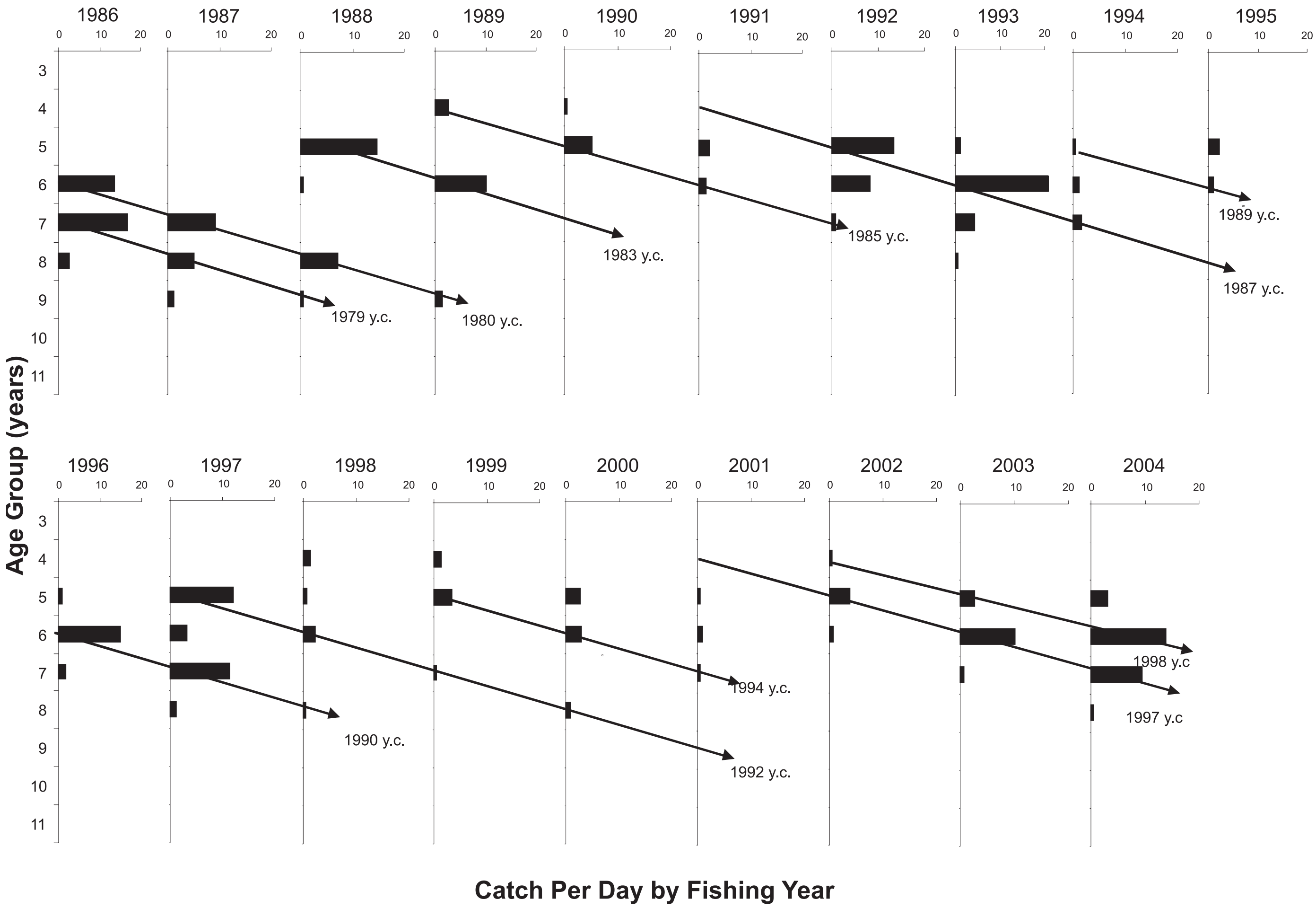

FIG. 5. Age distribution of arctic cisco caught in the Nigliq Channel fishery, 1986–2004, scaled to CPUE (from fish caught in 76 mm mesh nets). Arrows indicate progression of year classes through the fishery.

REFERENCES

Chilton, D.E., and Beamish, R.J. 1982. Age determination methods for fishes studied by the Groundfish Program at the Pacific Biological Station. Canadian Special Publication of Fisheries and Aquatic Sciences 60. 102 p.

Craig, P.C. 1987. Subsistence fisheries at coastal villages in the Alaskan Arctic, 1970–1986. Alaska OCS Socioeconomic Studies Program, Technical Report 129. Anchorage: Minerals Management Service. 63 p.

Craig, P.C., and Haldorson, L. 1981. Beaufort Sea barrier-island lagoon ecological process studies: Simpson Lagoon. Part 4. In: Environmental assessment of the Alaskan Continental Shelf, No. 7. Boulder, Colorado: Bureau of Land Management/National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Program. 384–678.

Critchlow, K.R. 1983. Prudhoe Bay Waterflood Project fish monitoring program, 1982. Volume 3, Chapter 5. Anchorage, Alaska: Alaska District, U.S. Army Corps of Engineers. 318 p.

Envirosphere Company. 1987. Endicott Environmental Monitoring Program, Final Report, 1985. 7 volumes. Anchorage, Alaska: Alaska District, U.S. Army Corps of Engineers.

Fechhelm, R.G., and Fissel, D.B. 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., Streever, B., and Gallaway, B.J. 2007. The arctic cisco (*Coregonus autumnalis*) subsistence and commercial fisheries, Colville River, Alaska: A conceptual model. Arctic 60:421–429.

Gallaway, B.J., Griffiths, W.B., Craig, P.C., Gazey, W.J., and Helmericks, J.W. 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.

Gallaway, B.J., Gazey, W.J., and Moulton, L.L. 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.

George, J.C., and Kovalsky, R. 1986. Observations on the Kupigruak Channel (Colville River) subsistence fishery. October 1985. Barrow, Alaska: Department of Wildlife Management, North Slope Borough. 60 p.

George, J.C., and Nageak, B.P. 1986. Observations on the Colville River subsistence fishery at Nuiqsut, Alaska. Barrow, Alaska:

Department of Wildlife Management, North Slope Borough. 35 p.

Griffiths, W., and Gallaway, B.J. 1982. Prudhoe Bay Waterflood Project fish monitoring program, 1981. Prepared by LGL Ecological Research Associates for Alaska District, U.S Army Corps of Engineers, Anchorage. Available from LGL Alaska Research Associates, Inc., 1101 East 76th Avenue, Suite B, Anchorage, Alaska 99518. 142 p.

Griffiths, W.B., Schmidt, D.R., Fechhelm, R.G., and Gallaway, B.J. 1983. Fish ecology. In: Britch, B., and Gallaway, B., eds. Environmental summer studies (1982) for the Endicott development, Vol. 3. Prepared by LGL Alaska Research Associates for Sohio Alaska Petroleum Co. Available from LGL Alaska Research Associates, Inc., 1101 East 76th Avenue, Suite B, Anchorage, Alaska 99518. 323 p.

Gulland, J.A. 1968. Appraisal of a fishery. In: Ricker, W.E., ed. Methods for assessment of fish production in fresh waters. Chapter 12 in IBP Handbook No. 3. London: International Biological Programme. 236–245.

Hinzman, L.D., Bettez, N.D., Bolton, W.R., Chapin, F.S., Dyurgerov, M.B., Fastie, C.L., Griffith, B., et al. 2005. Evidence and implications of recent climate change in northern Alaska and other Arctic regions. Climatic Change 72:251–298.

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. Report for BP Exploration (Alaska) Inc. and North Slope Borough. Anchorage: LGL Alaska Research Associates, Inc. 317 p.

———. 1992a. The 1990 Endicott Development Fish Monitoring Program. Vol. II: Analysis of fyke net data. Report for BP Exploration (Alaska) Inc. and North Slope Borough. Anchorage: Alaska Research Associates, Inc. 160 p.

———. 1992b. The 1991 Endicott Development Fish Monitoring Program. Vol. III: Analysis of fyke net data. Report for BP Exploration (Alaska) Inc. and North Slope Borough. Anchorage: Alaska Research Associates, Inc. 189 p. + appendices.

———. 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. Anchorage: Alaska Research Associates, Inc. 195 p. + appendices.

———. 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. Anchorage: Alaska Research Associates, Inc. 217 p.

Martin, P.D., Jenkins, J.L., Adams, F.J., Jorgenson, M.T., Matz, A.C., Payer, D.C., Reynolds, P.E., Tidwell, A.C., and Zelenak, J.R. 2009. Wildlife response to environmental Arctic change: Predicting future habitats of Arctic Alaska. Report of the Wildlife Response to Environmental Arctic Change (WildREACH): Predicting Future Habitats of Arctic Alaska Workshop, 17–18 November 2008. Fairbanks, Alaska: U.S. Fish and Wildlife Service. 138 p.

Moulton, L.L., and Field, L.J. 1994. The 1992 Colville River Fishery. The 1992 Endicott Development Fish Monitoring Program. Vol. II. Report by MJM Research to BP Exploration (Alaska) Inc. and North Slope Borough. Available from MJM Research, LLC, 1012 Shoreland Drive, Lopez Island, Washington 98261. 55 p. + appendices.

Moulton, L.L., and Seavey, B.T. 2005. Harvest estimate and associated information for the 2004 Colville River fall fishery. Report by MJM Research to ConocoPhillips Alaska, Inc. Available from MJM Research, LLC, 1012 Shoreland Drive, Lopez Island, Washington 98261. 45 p. + appendices.

Moulton L.L., Field, J., and Brotherton, S. 1986a. Assessment of the Colville River fishery in 1985. Chap. 3 in Colville River Fish Study, Final Report. Report by Entrix Inc. for ARCO Alaska Inc., North Slope Borough, and the City of Nuiqsut. Available from MJM Research, LLC, 1012 Shoreland Drive, Lopez Island, Washington 98261. 83 p.

Moulton, L.L., Gallaway, B.J., Fawcett, M.H., Griffiths, W.B., Critchlow, K.R., Fechhelm, R.G., Schmidt, D.R., and Baker, J.S. 1986b. 1984 Central Beaufort Sea Fish Study, Chapter 3. In: Prudhoe Bay Waterflood Project Environmental Monitoring Program 1984. Prepared by Woodward Clyde Consultants, Entrix and LGL Ecological Research Associates for Alaska District, U.S. Army Corps of Engineers, Anchorage, Alaska. Available from MJM Research, LLC, 1012 Shoreland Drive, Lopez Island, Washington 98261. 343 p.

NRC (National Research Council). 2003. Cumulative environmental effects of oil and gas activities on Alaska's North Slope. Washington, D.C.: The National Academies Press.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 191. Ottawa: Fisheries and Marine Service, Department of the Environment. 382 p.