AN ASSESSMENT OF THE BEAUFORT SEA STOCK OF ARCTIC CISCO (COREGONUS AUTUMNALIS) BASED UPON THE DERISO MODEL APPLIED TO THE CATCH AND EFFORT DATA FROM THE HELMERICKS' COMMERCIAL FISHERY

by

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ABSTRACT

Prompted by an apparent decline in the numbers of Arctic cisco which occurred between 1976 and 1979, we undertook the task of performing a stock assessment analyzing commercial fishery data using the Deriso (1980) model. The model estimates the various survival and recruitment parameters that result in the best fit of a predicted sequence of catch-effort data with the observed pattern. This analysis was performed to determine whether the apparent declines resulted from a normally occurring population cycle or from other factors such as overfishing and offshore oil and gas development.

The results of the analysis showed that the observed fluctuations in population levels could be explained if Arctic cisco are characterized by a strong density-dependent stock-recruitment function and if a large proportion of spawners are not vulnerable to the fishery. There is some evidence to support this hypothesis. Few running-ripe or spawned-out Arctic cisco are taken in the commercial fishery. The Mackenzie River (N.W.T.) system appears to be the main spawning area of this species for the North Slope of Alaska and Canada.

However, given the short period of record, the observed and simulated patterns of abundance could have resulted from a few "bad" ice years (years in which the ice does not move off the mainland shore for most of the summer—e.g. 1974-1975). The results of a few more years of catch and effort data from the fishery should enable us to distinguish between the *two* hypotheses. In the interim, additional work describing the functional responses of Arctic fishes to environmental factors as a basis for attempting population level assessments is needed.

INTRODUCTION

The Arctic cisco, *Coregonus autumnal is*, is both one of the most abundant and valued of the anadromous fishes occurring along the North Slope of Alaska. As a subsistence fish, it is considered to be "much fatter, larger, and more tasty" than other commonly-occurring whitefish (Flossie Hopson, Environmental Protection and Conservation Office, North Slope Borough, 1980, pers. comm.). In Alaska, Arctic cisco are at present the target of seasonal subsistence fisheries at Nuiqsut in the Colville Delta and at Griffin Point east of Barter Island, Alaska. The former is a fall/winter fishery, whereas the Griffin Point fishery operates during summer. A commercial fishery (permitted to take a maximum of 50,000 Arctic cisco) also operates in the Colville River Delta in fall and early winter. In the Mackenzie River valley in Canada the Arctic cisco also represents an important component of the domestic fishery (Hatfield et al. 1972).

The Arctic cisco ranges from northern Europe and Siberia to western Arctic North America. In the latter region, it is distributed along the Arctic coast from about Point Barrow, Alaska to Bathurst Inlet, Northwest Territories, Canada (Fig. 1, Morrow 1980). The population is apparently centered in brackish waters around the Mackenzie (Canada) and Colville (Alaska) River Deltas, habitats which are used for overwintering following summer feeding dispersals into the nearshore Beaufort Sea. In the Mackenzie River system, Arctic cisco range as much as 1600 km above the delta (Laird River) during late summer-fall spawning runs (0'Neill et al. 1981). This run is similar to those which have been reported for Arctic cisco in Siberia, where the fish migrate over 1500 km from the sea to spawning areas in the upper parts of the Yenisei. River (Nikolsky and Resbetnikov 1970). Following spawning, adult Arctic cisco undertake post-spawning migrations to brackish-water delta regions where they overwinter with other segments of the population (Wynne-Edwards 1952, Nikolsky and Reshetnikov 1970, Craig and Mann 1974, O-Neil et al. 1981).

In conjunction with oil and gas development numerous fish studies have been conducted in western Arctic North America since the mid-1970"s. Some of these studies (e.g. Bendock 1977, Doxey 1977, Craig and Haldorson 1981) have emphasized summer tagging programs, with the recapture effort supplemented by fall--winter tag returns and catch data obtained from the Colville River commercial fishery. Craig and Haldorson (1981) used these data as the basis for population estimates which suggested that an 86% decline in the numbers of Arctic cisco overwintering in the Colville River Delta occurred between 1976 and 1979. This observation was supported by the commercial catch data which, during 1979, dropped to only 25% of its average during previous years. The 1980 commercial catch and population estimates were also low, similar to 1979 levels.

The timing of the apparent Arctic cisco decline corresponded with not only the first major offshore oil and gas development of consequence, but also with the establishment of the village of Nuiqsut at the head of the delta (see Fig. 2) in 1973. The latter event undoubtable increased the local demand for and take of fish, including Arctic cisco. Craig and Haldorson (1981) using an estimated Nuiqsut population of 157 persons, determined the annual village requirement for fish could be as much as 68,874 pounds. The increase in the take of fish from the Colville River Delta raised the question of overfishing as a major factor contributing to the observed decline.

The offshore development in question was the construction in 1975 of the 1.3-km long, solid-fill causeway just west of Prudhoe Bay which *was* extended offshore by an additional 1.5 km in 1976, and further extended by 1125 m in 1981. Given that causeways might directly impede fish migrations or indirectly affect anadromous fish by altering longshore currents and local temperature and salinity regimes, there was some concern that, if the decline in abundance of Arctic cisco was real, it might in someway have been related to this structure. In any case, it was clearly evident that a great deal more information about the population dynamics and biology of Arctic cisco was needed before any interpretive judgments could be made with regards to the apparent decline.

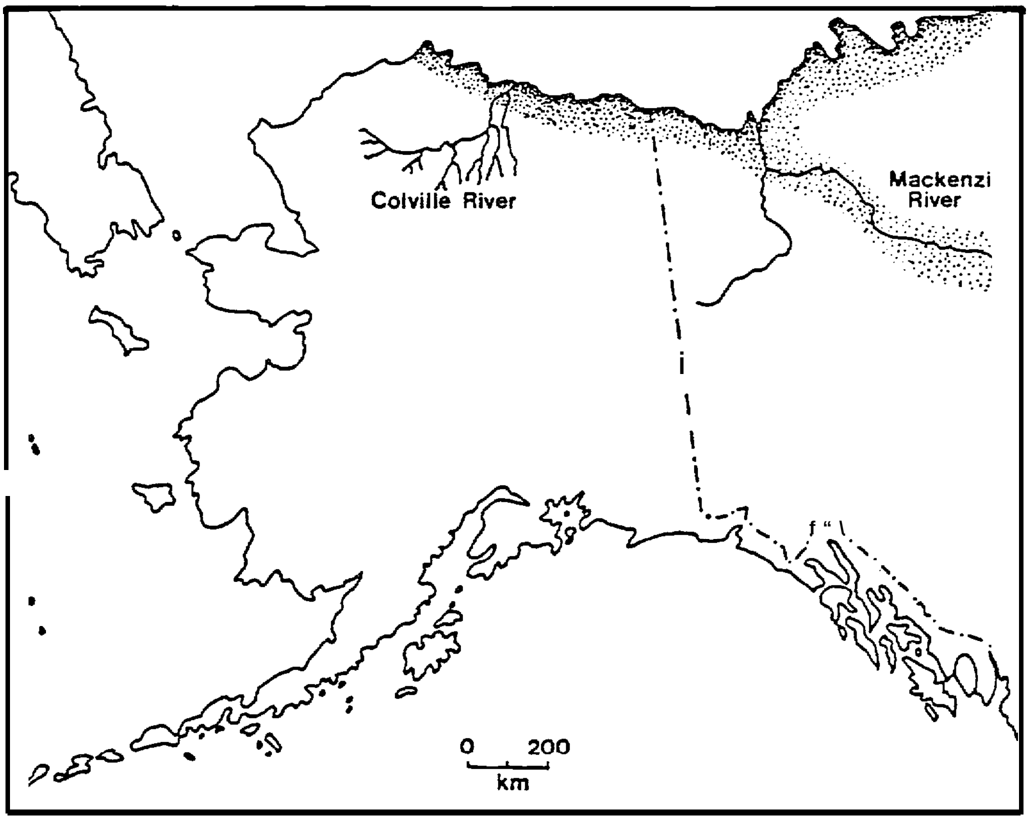

Fig. 1. The distribution (stippled area) of the Arctic cisco (*Coregonus autumnalis*) in Alaska and Canada (after Morrow 1980) .

Deriso (1980) provided a major breakthrough in population dynamics methodology. His contribution was the derivation of a model incorporating features such as time lags, growth, mortality and recruitment (all of which can be related to biological processes) whose parameters could be estimated from a time series of catch/effort (CPUE) data. Prior to Deriso's efforts, such dynamic pool models could be constructed, but required *a* time series of accurate age composition data (which are seldom available) as opposed to simple catch-effort data. Given this tool, and the availability of a time series of catch/effort data from the Colville Delta commercial fishery dating from 1967, we undertook the task of describing the apparent population dynamics of the Arctic cisco. Whereas the main purpose was to contribute to the understanding of the biology of this species, another goal was to evaluate whether the observed decline could best be explained by population attributes> overfishing or impacts resulting from environmental conditions.

THE DERISO MODEL

The Deriso model, simply stated, says that next years" biomass will be the survivors of the years stock, corrected for weight growth, plus new recruits. When numbers are modeled instead of biomass, the Deriso model can be simplified to:

$$C_{t+1} = \ell(1-qE_t+m)C_t+\ell^2 m(\ell-qE_{t-1})C_{t-1}+q(1-m)$$
$$+q(1-m)R\{(1-qE_{t-1-k})C_{t+1-k}/_q\}$$

where the variables are:

C_t = CPUE during year t

Et = effort during year t

R(.) = recruitment function with R(s) = $Se^{\alpha\beta s}$ (Ricker curve)

and the parameters are:

ℓ = annual natural survival

q = matchability coefficient

α, β = Ricker recruitment parameters

$1-m$ = fraction of spawners vulnerable to fishery (allows for incomplete recruitment)

k = lag time between birth and recruitment ($k+1$=age at recruitment)

We modeled numbers instead of biomass because number of fish caught (not biomass) was recorded by the fishery.

Parameters were estimated using Walters (1981) Applesoft Basic computer program written for a 48k Apple 11 plus micro-computer with DOS and a single disc drive. In this program, the approach is to use quasi-linearization and non-linear Newton's methods to estimate the set of survival and recruitment parameters that will make a predicted sequence of catch/effort agree best with the observed sequence (see Deriso 1980 and Walters 1981).

THE FISHERY

The Helmericks' commercial fishery in the Colville Delta has been operated during fall and early winter in essentially the same fashion every year since 1967. Fishing is conducted in the Main (Kupigruak) and East channels of the river adjacent to Anachilik Island (Fig. 2). When the ice becomes thick enough to walk on, holes are drilled and gill nets are set in a continuous series along the deep bottoms of the channels. The nets are typically 2x50 m, having either 7.6 (3 in) or 10.2 (4 in) cm stretched mesh. The smaller mesh is used in both channels, but the larger mesh is used exclusively in the Main Channel where humpback whitefish (a species larger than the ciscoes) occur more commonly. Effort with the small mesh nets has comprised over 98% of the total soak time expended by the fishery over the 1967-81 period.

Fishing usually begins about the first of October and is terminated towards the end of November. The nets are typically picked every day with the exception of Sundays. The catch is recorded by date and usually by location. Effort records are maintained by date and location. The nets

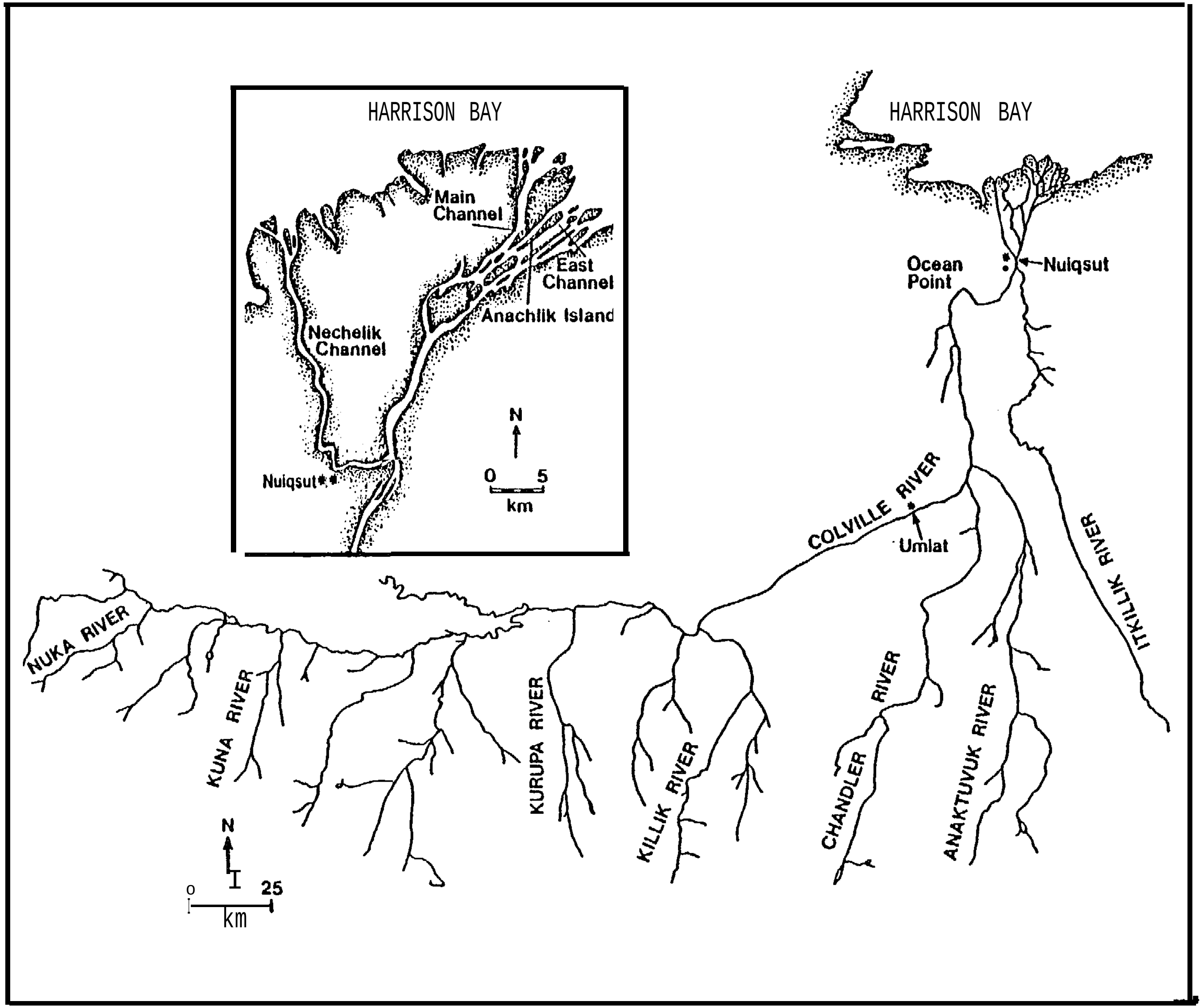

Fig. 2. The Colville River of Alaska with detail of the delta region (insert) showing major fishing sites.

are set and fished over the entire period, although they are occasionally mov ed. The nets are removed as the quota is approached or the catches are considered too low to continue fishing.

With the exceptions of six years, the pattern of daily effort has been reasonably regular in that maximum effort has ranged from about 10 to 25 nets fished/day, and most fishing has been conducted in October and November (Fig. 3). The years 1968, 1971 and 1976 were characterized by unusually high levels of maximum effort (31 to 41 nets fished/day), levels which-were sustained for longer periods in 1968 and 1971 than in 1976. The years 1978-80 differed from all other years for the period of record in that fishing effort was extended well into December. Further, in two ot these years (1978 and 1979), fishing was initiated several days later than usual, this was also the case for the years 1973 and 1981 (Fig. 3).

Because the catch data were sometimes recorded as total catch for a given day or group of days and were not always designated between each of the two fishing sites, we combined the total effort and catch data from each of the two habitats, respectively. Effort in the East Channel has historically been greater than effort in the Main Channel, and the annual patterns of effort for each habitat have been quite similar (Fig. 4b). Arctic cisco are believed by the fishermen to mainly use the shallower East Channel, whereas broad whitefish and least cisco are believed to mostly use the deeper Main Channel.

The annual catch of Arctic cisco taken in the fishery (Fig. 4a) has ranged from a high of 71,575 in 1973 to a low of 9268 in 1979. The catch levels among these years suggest a marked decline as described in the introductory section. During the same years, effort Levels, although variable, suggested an increasing rather than a decreasing trend (Fig. 4 b) Maximum effort for the period of record was expended in the years 1968 and 1971.

Craig and Haldorson (1981) showed that the Arctic cisco taken in the commercial. fisheries are moderately large fish (range 240 to 380 mm in length). However, most of these fish fall within the 280- 340 mm length range (Fig. 5). The age composition of the catch ranges between 3 and 10 years, but fish aged five to eight dominate the catch. Male and female

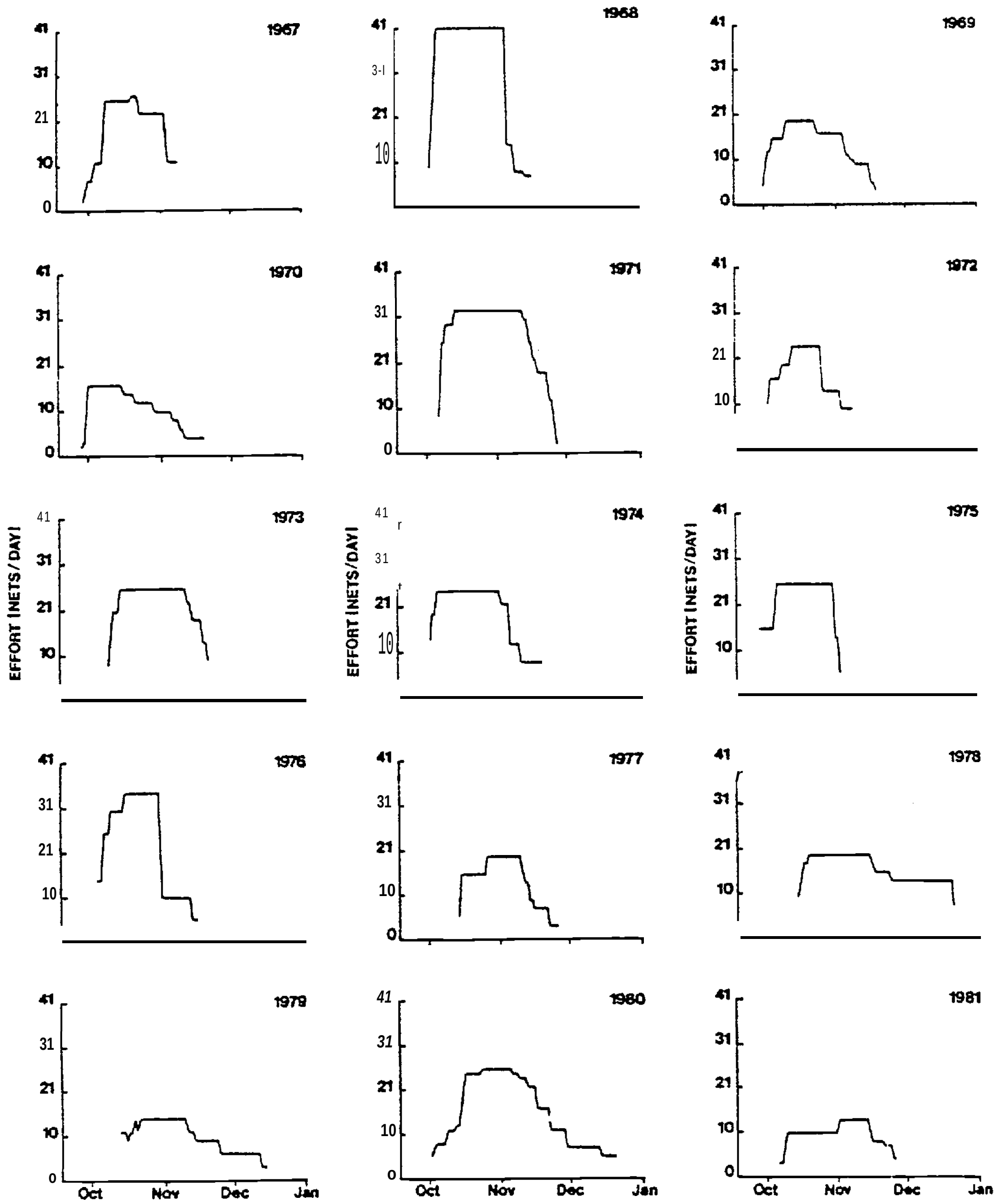

Fig. 3. Patterns of daily commercial fishing effort for the 15-year period of record for the Helmericks' Commercial Fishery.

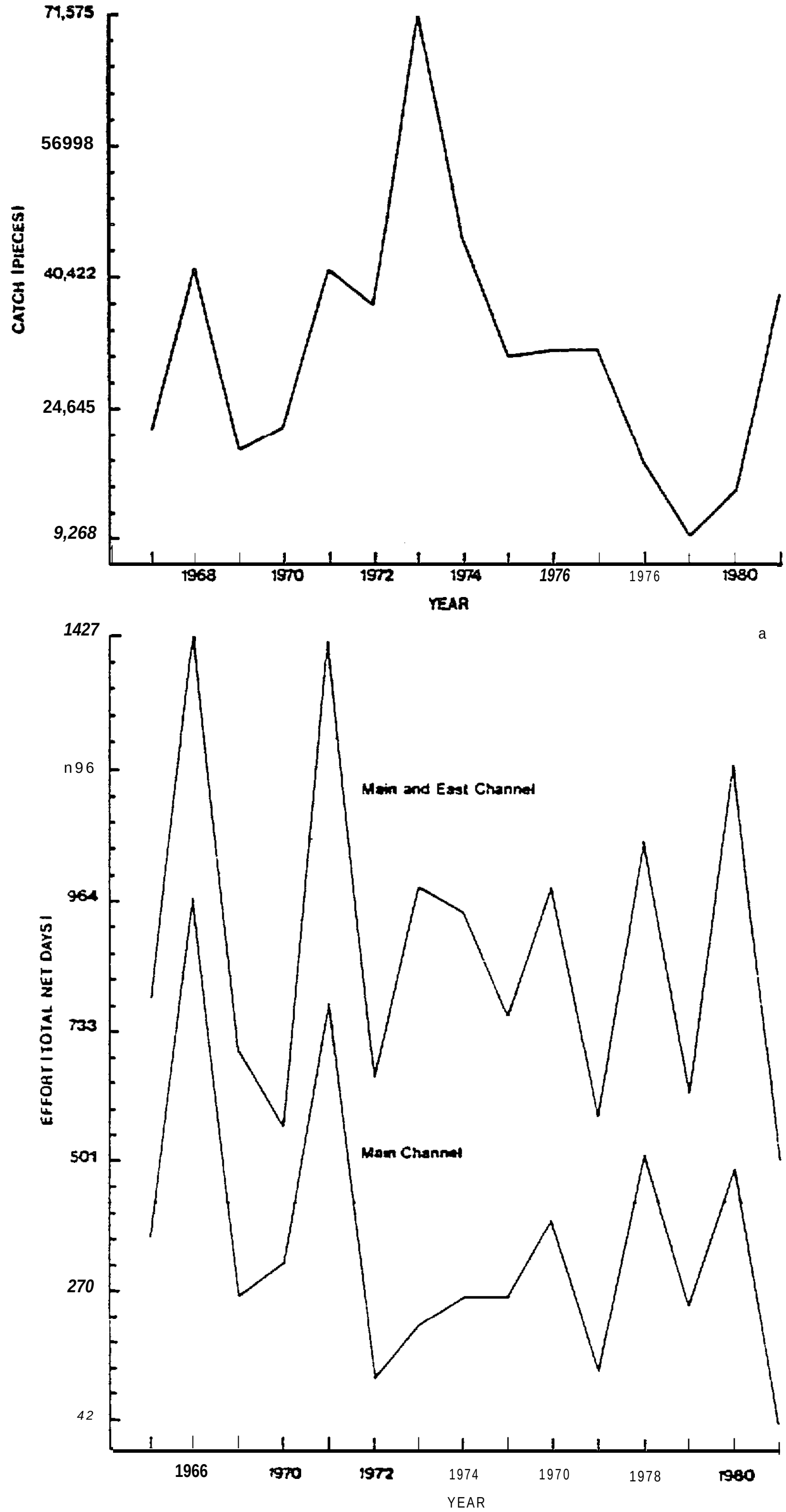

Fig. 4. Patterns of annual catch (A) and fishing effort (B) for the Helmericks' Commercial Fishery, 1967-1981.

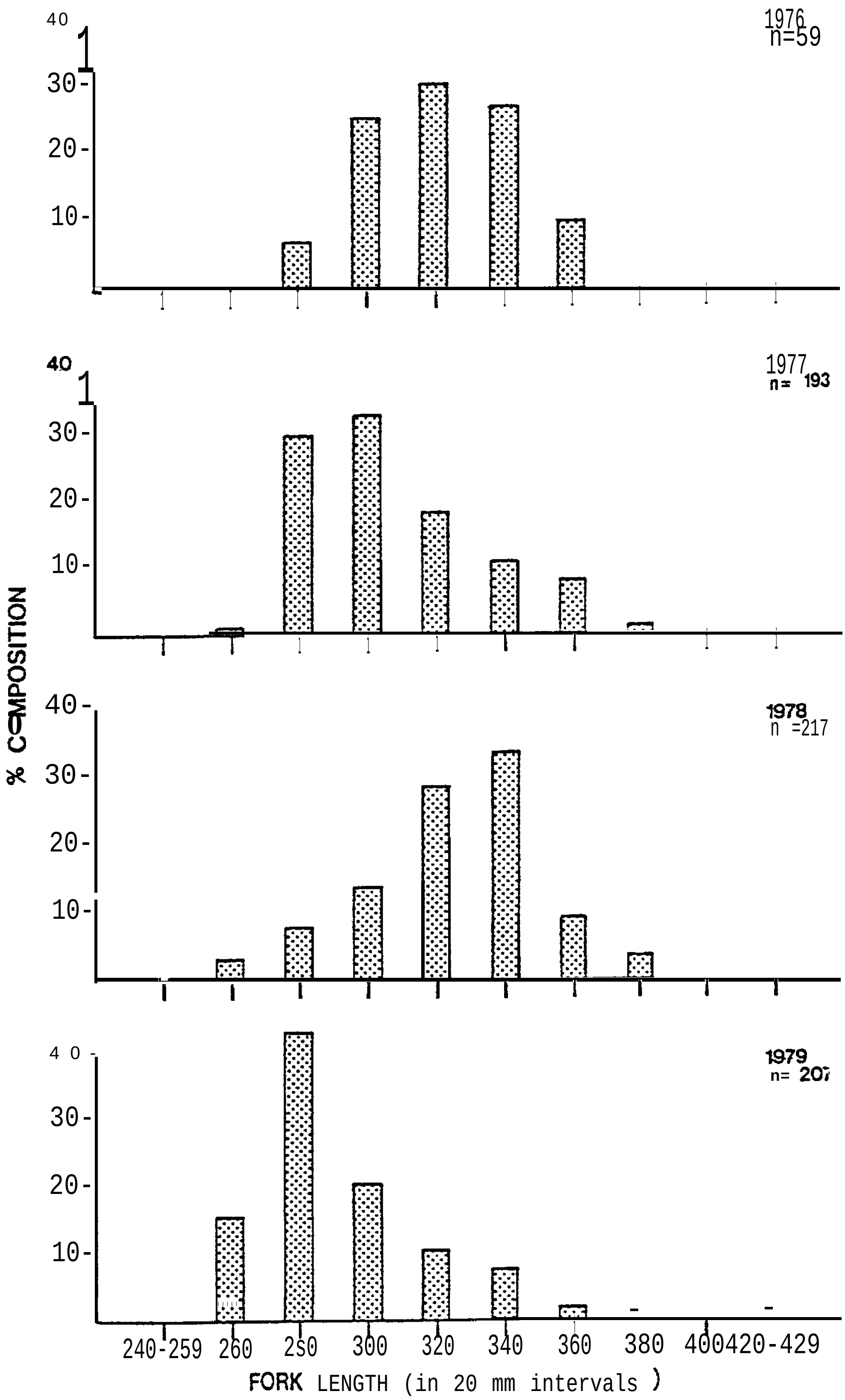

Fig. 5. Size distribution of Arctic cisco taken in the Helmericks' Commercial Fishery, 1976-1979 (after Craig and Haldorson 1981).

Arctic cisco first attain sexual maturity at ages seven and eight, respectively (Craig and Haldorson 1981). From Fig. 5, dominant age/size groups can be seen to move through the fishery in a pulsed fashion.

Based upon Craig and Haldorson's (1981) examination of about 200 specimens taken each year from the commercial catch during 1977-79, sexually mature fish comprised some 49 to 57 percent of the catch. During 1976, only 12% of the catch was estimated to have been sexually mature, but the sample consisted of only 59 fish. However, no fish in spawning condition or spawned-out fish were found in any of the samples examined by Craig and Haldorson (1981), which was surprising considering that the spawning period immediately preceeds and/or overlaps the fishing season. When requested in 1979 to supply any spawned-out fish, the fisherman provided only nine fish out of the entire catch, of which only one spawned-out male and two "possibly" spawned-out females were confirmed by Craig and Haldorson (1981). The autumn commercial fishery in the Colville Delta harvests essentially a non-spawning segment of the Arctic cisco population.

RESULTS AND DISCUSSION

Peak population levels of catchable Arctic cisco according to CPUE data occurred in 1973 and 1981, with a lessor peak occurring in 1977 (Fig. 6). The Deriso Model provided a very good fit of *the* historical record (Fig. 6), with the best fit obtained using the parameter estimates of k=5; $\ell=0.37$; $q=0.33$; $\alpha=4.8$, $\beta=5.5\times10^{-5}$; and $m=0.64$. The model did not reflect a minor peak in 1977, nor was this peak suggested by independent population estimates calculated from mark-recapture data available from other studies (Craig and Haldorson 1981, Griffiths and Gallaway 1982) covering the period 1976 through 1981 (see Fig. 6). With the exception of 1977, each of the three population estimators (CPUE, MODEL, MARK-RECAPTURE) reflected a similar trend in population levels for the years held in common.

The model was very sensitive *to* the five-year lag period between events, as well as to the m value of 0.64 which indicates an exceptionally high unmatchable proportion of spawners. These data suggest that the bulk of the catch should consist of fish of ages five to seven , and spawners

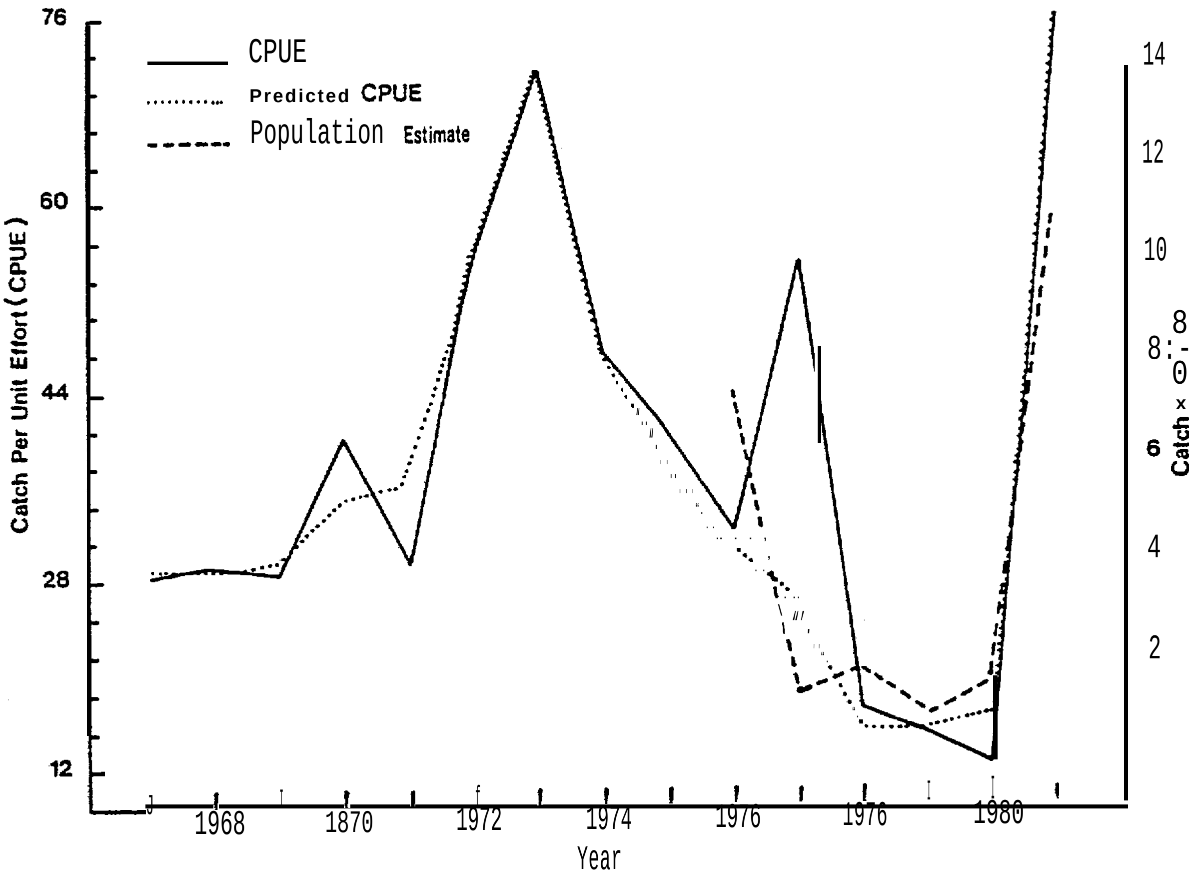

Fig. 6. Population trends of Arctic cisco (Coregonus autumnalis) based upon CPUE, model, and mark-recapture data from the Helmericks' Commercial Fishery, 1967-1981.

should comprise a small proportion of the catch as compared to mature non-spawners. Both of these implications from the biological model agree well with the observed age and maturity composition of the actual catch from the fishery, suggesting model validity. However, the question of why spawners are largely non-vulnerable to the fishery remains unanswered.

One of the explanations is that the Arctic cisco overwintering in the Colville River, for the most part, leave this system in the spring and summer period of the year following the attainment of sexual maturity. We believe that these sexually mature fish travel to the Mackenzie River to spawn; i.e. we suggest that there are not two stocks of Arctic cisco--one associated with the Mackenzie and the other with the Colville River—as has been previously postulated (e.g. Craig and Mann 1974), but rather only one which is reproductively associated with the Mackenzie system.

Spawning migrations and early life histories of Arctic cisco are reasonably well-documented for the Mackenzie River system. Spawners leave nearshore, brackish waters and enter the Mackenzie System during late June through late July, and undertake spawning migrations to some of the larger tributaries (e.g. Peel, Arctic Red, Great Bear, Mountain and Laird Rivers). The spawning runs in these tributaries occur at different times depending upon the distance up the Mackenzie the fish must move. Hatfield et al. (1972) reported sexually mature Arctic cisco in the Artic Red River (near the Mackenzie Delta) from late June to the end of August, and at the Great Bear River (approximately mid-way up the Mackenzie River) from early August to late September. O'Neal et al. (1981) reported that Arctic cisco spawners first appeared at the mouth of the Liard River (furthest upstream Arctic cisco river reported) by mid-August in 1979, peak numbers occurred in September and the run was completed by mid-October.

During the spawning run in the Mackenzie River, Arctic cisco apparently cease feeding, and eggs increase in diameter from a range of 0.6- to 1.3-mm characteristic of mature, green females in nearshore, brackish-marine habitats (Griffiths et al. 1975, Griffiths et al. 1977, Craig and Haldorson 1981) to mean sizes of 2.03 mm (SD=0.08, range 1.9 to 2.1 mm) for green females and 2.13 mm (SD=0.10, range 2.0 to 2.3 mm) for ripe females (Gary Ash, RL and L Consultants, Vancouver, British Columbia, pers. comm. 1981).

" After spawning in the fall, Arctic cisco in greatly emaciated condition (Nikolsky 1961, Hatfield et al. 1972) then undertake a distinct post-spawning migration back down the Mackenzie River. Autumn surveys have shown that large numbers of spawned-out fish occur in the West Channel of the Mackenzie River Delta during; early October (Wynne-Edwards 1952; Hatfield et al. 1972).

Arctic cisco eggs hatch the following spring and the young-of-the-year are carried down the Mackenzie River to the delta during spring break-up, where they are already foraging in the shallow lakes of the deltaby early June (Hatfield et al. 1972, McLeod et al. 1979, O'Neal et al. 1981, Taylor et al. 1982). Taylor et al. (1982) reported that between 80-90% of all Arctic cisco found in the lakes they sampled *were* young-of-the-year (Age=0) and that most Arctic cisco had left the lakes by mid-September. Some young-of-the-year are undoubtable carried into nearshore, marine habitats during the spring freshet and perhaps during other times of the year.

The Craig and Mann (1974) hypothesis of two stocks of Arctic cisco, was based on a moderate amount of evidence from the Mackenzie Drainage (Wynne-Edwards 1952, Hatfield et al. 1972, Stein et al. 1973 and a small amount of evidence from the Colville River area (Alt and Kogl 1973, Kogl and Schell 1974). Overwintering Arctic cisco had been reported from both these areas (separated by over 400 km) and, although fish in spawning condition had not been documented to occur in Alaskan waters, young-of-the-year fish had been reported in the Colville Delta (Kogl and Schell 1974). Since 1974, several fisheries investigations have been conducted but have yielded little, if any, support for the hypothesis of a spawning population of Arctic cisco associated with the Colville River. The strongest evidence against the idea of two stocks is the lack of fish in spawning condition or subsequent spawned-out fish in the fishery at the Colville River Delta. Additionally, spawning runs of Arctic cisco have not been documented for the Colville River despite summer and fall surveys conducted in 1977 and 1978 by Bendock (1979) and in 1978, 1979 and 1980 by LGL Ecological Research Associates, Inc. (McElderry and Craig 1981, Craig and Griffiths 1981). In contrast, these studies have collectively indicated that Arctic cisco likely do not penetrate the Colville River beyond Umiat (about 48 km upstream), are abundant only as far upstream as the Itkillik River (about 175 km, see Fig. 2) and few, if any, of these fish are in spawning condition. Bendock (1979) did report three male Arctic cisco taken from Seabree Creek near Umiat in mid-June 1977 that he believed were in spawning condition.

The time-at-large data for tagged Arctic cisco as compared to similar data for least cisco (Coregonus sardinella) provides additional evidence that older (larger) Arctic cisco may leave the area. Least cisco have been documented to spawn in the Colville River system. Specimens in spawning condition have been collected throughout the lower reaches of the river (Kogl 1972, McElderry and Craig 1981) and spawned-out individuals are commonly taken in the fall fishery (Jim Helmericks, unpublished data). Least cisco overwinter in the Colville River Delta area and disperse into the nearshore, brackish waters of the region for feeding during summer. Through 1980, a total of 202 tagged least cisco had been recaptured, having time-at-large (years elapsed between marking and recapture) ranging from 0 to 5 years with 100, 50, 35, 10, 1 and 6 fish recaptured each year, respectively (LGL, unpublished data). During this same period, 59 Arctic cisco were recaptured, 48 of which were taken during the same year they were marked and 11 after only one year at large. In 1981, 66 tagged Arctic cisco were recaptured. Of these, 64 were marked during 1981, and two had been marked in 1980. These latter fish and two of the others were recaptured in eastern Alaska at Griffin Point near Barter Island. These data suggest that most large Arctic cisco are scarce or absent from the Colville River area within one year of being tagged. We believe that these data support the contention that most Arctic cisco leave the Colville River Delta region when they approach sexual maturity, and likely return to the Mackenzie system for spawning.

For the above spawning scenario to be reasonable requires a dispersal mechanism to account for the presence of young Arctic cisco in Alaska. The prevailing east to west longshore currents along the Beaufort Sea coast represent an adequate dispersal mechanism. These currents generally move parallel to the coast at about 3 to 4% of the speed of the wind and in the same direction as the wind. Summer winds are typically from the northeast, and average about 5 m/see (Mungall 1978). Coastal waters move westward under these conditions at about 15 cm/sec (13 km/day). Under these conditions, a westward drift of small (mean lengths of Age 0 and 1 fish are 7 and 11 cm, respectively) fish in the nearshore would be expected. If the transport was passive, movement from the Mackenzie to the Colville region under average conditions would require about 35 days, but could be as little as seven days under a sustained period of strong wind which is not uncommon.

Arctic cisco overwintering has been associated with brackish-water habitats in deltaic, estuarine regions--habitat provided by both the Colville and Mackenzie rivers, and perhaps other large rivers on the North Slope between these two systems (e.g. Kuparuk, Sagavanirktok, Canning Rivers). Late winter surveys of overwintering habitats in the Sagavanirktok and Kuparuk River deltas (Bendock 1979, Dew 1982) have not yielded any Arctic cisco, but all have been conducted in upstream freshwater habitats as opposed to the seaward parts of these deltas. Donald Schell (University of Alaska, Fairbanks, 1981, pers. comm.) has recently examined early spring-caught Arctic cisco for carbon composition and has determined that these fish consist primarily of carbon derived from recent marine primary production (marine overwintering) in contrast to other species of anadromous fish which, in spring, show a high percentage of carbon derived from "old" terrestrial primary production (peat) characteristic of detrital-based freshwater systems (freshwater overwintering). Whereas the Mackenzie and Colville River Deltas and estuaries may represent particularly good habitat during winter, Arctic cisco likely use other areas as well.

A conceptual model of the postulated life history cycle for Arctic cisco is shown by Fig. 7. In this model, spawning occurs in the Mackenzie River in fall and young-of-the-year use the delta as nursery grounds during their first summer as well as overwinter there but in different habitat. Some young-of-the-year may be carried by the spring freshet into the nearshore region. At Age 1, the small fish move into the nearshore environment' during the summer feeding dispersal along the coast. Some unknown proportion (although variable, longshore flow in the Mackenzie Delta area is generally to the east) are shown to disperse to the west, and at some point are entrained by the strong westward-flowing longshore currents off the Alaskan coast. Upon the approach of freeze-up, the Colville River and perhaps other rivers afford brackish-water

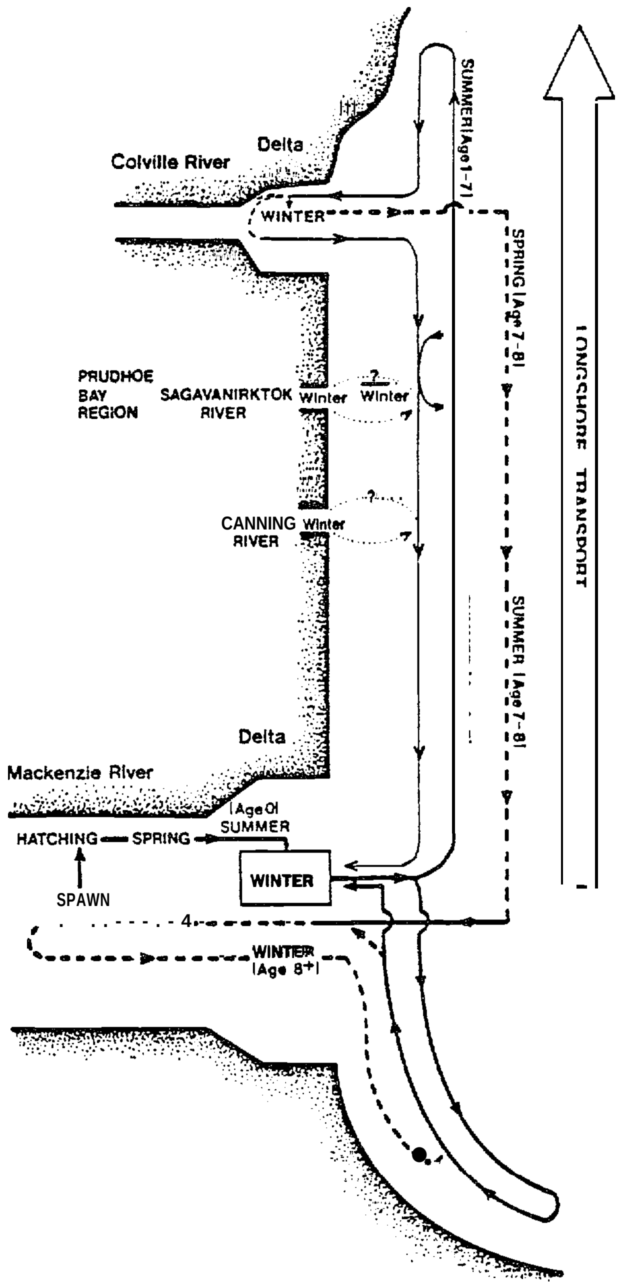

Fig. 7. Conceptual model of Arctic cisco life history cycle in Alaska and Canada.

overwintering habitat in the lower delta areas adjacent to the sea. Arctic cisco which have been transported into Alaska use at least the Colville River and adjacent environs (and perhaps others) until attaining sexual maturity (as well as a size enabling them to contend with the longshore currents) whereupon they seek their natal stream in the Mackenzie River system to spawn. Such a pattern is consistent with the observed seasonal abundance and distributional patterns of Arctic cisco and would account for a high proportion of spawners being non-vulnerable to the fishery.

The a value of 4.8 estimated by the model suggests a strongly density-dependent stock/recruitment relationship which is not unreasonable given the pattern of the catch-effort data. A strongly density-dependent relationship results in an oscillating population level of spawners because the maximum level of recruitment occurs when the spawner population is low and vice versa. Further, the lag time of five years between spawning and recruitment of fish to the fishery agrees well with the known life history of Arctic cisco. However, the value 4.8 for α is unusually high. We believe that *it is* more likely that the oscillations in catch are due more to regional-level environmental effects than to *recruitment* phenomenon. That is, whereas we have the overall dynamics represented correctly, the apparently strong density dependence of recruitment is actually only the result of a few environmentally extreme years. For example, 1974 and 1975 were particularly bad ice years (the pack ice remained along the mainland coast throughout summer) in the Beaufort Sea and were followed by a series of relatively good years (the pack ice was up to 100 km offshore during summer) until 1982. If the environmental conditions of 1974 and 197S affected the transport or survival of Age 1 fish in the nearshore zone during these years, the effects would be seen in the fishery five years later (i.e. during 1979 and 1980). We believe that the question of the stock oscillations being attributable to stock-recruitment relationships versus environmental factors can be resolved given several additional years of data from the fishery. It should be noted that while the model fit is good, and the parameters k and m give us some confidence in the results, the data extends over only 15 years. Given a lag of five years to recruitment means we had only 10 points to fit five parameters.

Given either explanation for the stock oscillations, the fisheries of the Colville Delta probably have little impact on the population levels of catchable Arctic cisco. Mean fishing mortality ($\bar{F}$) was estimated to have been only 0.15. The commercial and subsistence catches will likely continue to fluctuate radically over the years due to either environmental conditions or density of spawners. If the latter case is true, lower densities of spawners would result in higher yields of recruits on a five- to seven-year cycle.

Finally, it is unlikely that the 3-km long causeway near Prudhoe Bay, Alaska has contributed much to the observed oscillations in population levels. Results of tagging studies (Craig and Griffiths 1981, Griffiths and Gallaway 1982) have shown no significant difference in the proportion of large Arctic cisco on the Colville River overwintering grounds between fish which were initially marked during summer on different sides of the causeway. Distributional modeling of small Arctic cisco based upon temperature preference and environmental conditions around the causeway suggest that during conditions of westward transport, small fish would also successfully move around the causeway (Neill et al. 1982). However, the level of understanding of the functional relationship of Arctic fishes to environmental factors is exceedingly low. A great deal more than what is presently known must be learned before one will be able to conclusively relate environmental perturbations resulting from development activities to impacts on fish stocks.

SUMMARY

Application of the Deriso (1980) model to the catch/effort data of the Helmericks' commercial fishery yielded a predicted sequence of CPUE data which closely mimicked the historical record. The model estimates of survival and lag time parameters appeared reasonable in light of what is known or hypothesized about the biology of Arctic cisco, but the parameter associated with recruitment showing a strong density-dependent stock-recruitment relationship appeared suspect due to its magnitude. A few more years' data should enable an assessment of the validity of this parameter estimate versus the alternative hypothesis that the observed population oscillations result from environmental effects.

The conjecture that Arctic cisco in Alaska are representatives of a Canadian stock from the Mackenzie River is proposed and the evidence supporting this concept was described. The principal argument is the lack of evidence of any appreciable spawning of Arctic cisco in Alaska waters despite considerable survey effort which has been conducted to document their spawning in this region. Further, the strategically located and timed commercial fishery does not take ripe or spawned-out fish, and there has been a low relative abundance of spawning-age fish represented in the catch. Finally, tagged fish approaching spawning size disappear after about one year at large, whereas representatives of least cisco (which have been documented to spawn in Alaska) have been taken in catches for up to five years after tagging. Longshore currents which along the Alaskan coast are predominantly from east to west were proposed as a transport mechanism accounting for the westward dispersal of small Arctic cisco into Alaska from western Canada.

The observed decline in Arctic cisco populations which occurred in Alaska during 1976-79 were part of an oscillatory cycle and the downward trend was reversed in 1981 when CPUE levels approached the maximum observed for the 15-year period of record. The oscillations may have been due to either the population dynamics of Arctic cisco or to regional-level environmental effects. Although uncertain, neither the existing 3-km long causeway which has been constructed near Prudhoe Bay, Alaska nor the local fisheries appear to have contributed in a major way to the observed oscillations in population levels.

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