

Passage of Large Fish Around a Causeway in Prudhoe Bay, Alaska

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ABSTRACT. Fish movements around a 2.8 km solid-fill causeway in Prudhoe Bay, Alaska, were examined by tagging anadromous least and arctic cisco (>220 mm) on each side of the causeway in summer and comparing the recapture ratios when the fish were later caught in the Colville Delta commercial fishery 80 km to the west. There was no significant difference in proportions of recaptures among fish (species combined) that did and did not have to swim around the causeway. Thus, available data indicate that the net movements of large least cisco, and probably arctic cisco, were unaffected by this man-made coastal feature.

Key words: least cisco, *Coregonus sardinella*, arctic cisco, *Coregonus autumnalis*, movements, Beaufort Sea

INTRODUCTION

Pursuit of oil and gas in coastal waters of the Beaufort Sea will involve some alteration of coastline features in areas of active development. In particular, long solid-fill causeways (jetties) projecting into the sea are viewed as serving a variety of functions, from docks to drilling platforms. One such structure, the ARCO (Atlantic Richfield Company) causeway at Prudhoe Bay, already exists. Fish passage around causeways is a topic of current concern because of the nature of fish migrations in these waters (OCSEAP, 1978).

When anadromous char, ciscoes and whitefish (which are important in local subsistence and commercial fisheries) enter the sea in summer, they disperse along the coastline rather than moving offshore. Many migrate immediately adjacent to shore, often within 100 m of the shoreline in shallow waters only 1 m deep (Craig and Haldorson, 1981). Their nearshore distribution is associated with a band of relatively warm and brackish water which flows along the coast with prevailing westward currents. The width of this band of water usually is 1-4 km depending on coastal features such as barrier islands and freshwater plumes of the larger North Slope rivers.

Causeways might affect anadromous fish and their movements directly or indirectly: (1) the structures might impede fish migrations, or (2) the structures might alter the longshore flow of brackish water, thereby affecting the suitability of nearshore habitats for use by anadromous fish. Indeed, local temperature and salinity regimes in Prudhoe Bay have been altered by the ARCO causeway (Bendock, 1977; Mungall *et al.*, 1978).

While data from fish tagging studies show that some fish are able to swim around the existing ARCO causeway (Doxey, 1977; Bendock, 1977; Craig and Haldorson, 1981), few tagged fish were recaptured in these studies, as might be expected in this thinly-populated region. For example, Doxey's (1977) study shows only that a maximum of 5.7% of the 4962 tagged fish actually swam around the ARCO causeway, leaving one to ponder the fate of the other 94.3% of the sample. To overcome this problem, the pre-

sent study takes advantage of a convenient mark-and-recapture situation based on the distribution, migratory patterns and commercial harvest of two abundant anadromous fishes, least cisco (*Coregonus sardinella*) and arctic cisco (*C. autumnalis*). The freshwater sources and overwintering areas of these fish, and the location of a small commercial fishery for these fish in the Colville River, are all rivers to the west of Prudhoe Bay. Thus, ciscoes which disperse eastward along the coastline during the summer (and encounter the ARCO causeway) will return to these western streams in the fall. Prior to their return, we tagged ciscoes on both sides of the causeway. In the fall we compared the proportions of tagged fish from each side of the causeway which were caught in the commercial fishery. Thus, one group of fish had to swim around the ARCO causeway while the other group did not.

STUDY AREA

Studies were conducted in Prudhoe Bay near the ARCO causeway which is also known as the "West Dock" (Fig. 1). The bay is relatively small (6 x 10 km) and shallow (maximum 2.4 m). During the ice-free season (late June to late September), waters in the bay are brackish and generally turbid. A 1.3 km causeway was built in 1975, extended to 2.8 km in 1976, and extended again another 1.1 km in 1981 after completion of our study (USACE, 1980). This structure deflects westward-flowing brackish water seaward, which is replaced by a wedge of more marine water on the lee (west) side of the causeway; consequently, water temperatures tend to be 2.4°C cooler and salinities 10 ppt higher on the lee side. During the period 25 July-24 August 1977, conditions on the east side averaged 7.8°C (SD = 2.2, range 4-11°C) and 17.2 ppt (SD = 5.6, range 5-31 ppt) while on the west side conditions were 5.1°C (SD = 2.2, range 2-9°C) and 27.5 ppt (SD = 3.9, range 19-32 ppt) (combined data from Bendock, 1977 and Mungall *et al.*, 1978 when measurements were taken on both sides of the causeway). These trends were also observed in the present study. On 11 days when measurements were taken on both sides of the causeway, temperatures averaged 0.6°C

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cooler and salinities 6.1 ppt higher on the west side, but average turbidity values were similar on both sides (15.6 NTU vs. 15.4 NTU).

A small commercial fishery operates on the Colville Delta, 80 km west of Prudhoe Bay. This fishery harvested approximately 31 000 least cisco and 15 000 arctic cisco during October-December 1980.

METHODS

During the period 19 July to 9 August 1980, fish were caught on each side of the ARCO causeway by seine (91.4 m) and fyke net. The fyke net was set perpendicular to the shoreline with the lead net attached to shore. Fyke net dimensions were as follows: lead net 66.7 x 1.2 m, wing net 15.2 x 1.2 m, trap mouth 1.2 x 1.8 m, and trap length 3.7 m.

Initially, sample locations were near the base of the causeway, but on 26 July the east net was repositioned in search of higher catches of large fish to tag. Fish tagged on the west side of the causeway were captured between the causeway base and Point McIntyre; fish tagged on the east side were captured near either the causeway base or the old dock on the east side of Prudhoe Bay (Fig. 1).

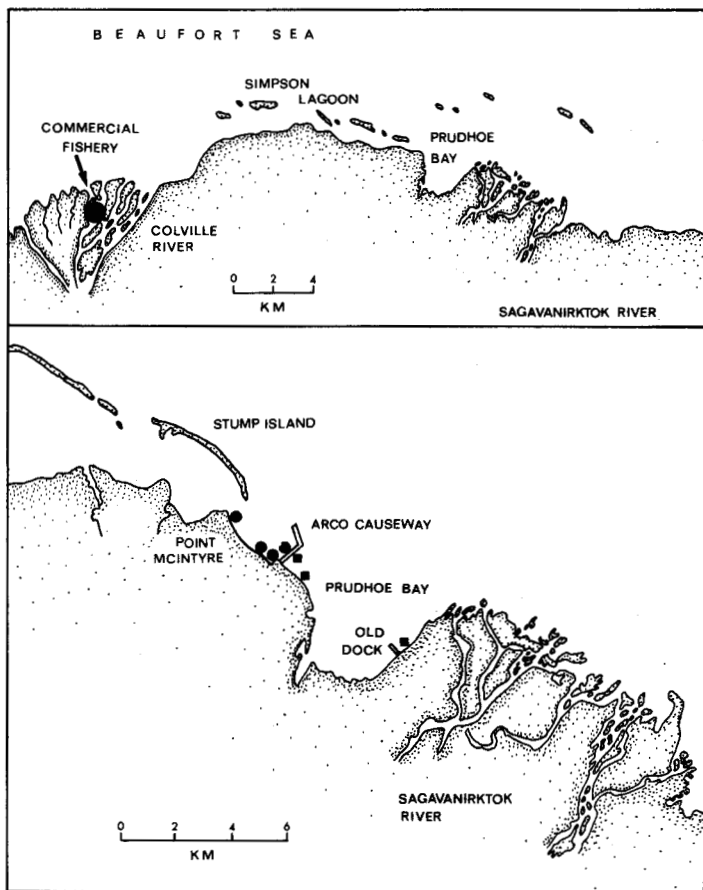


FIG. 1. The study area showing (a) fish tagging sites (Prudhoe Bay) and recapture sites (commercial fishery in Colville Delta), and (b) tagging sites on east side (squares) and west side (circles) of the ARCO causeway.

Large anadromous fish (>220 mm) were measured and tagged with numbered and color-coded Floy anchor tags. Most (94%) of the 1385 fish tagged were least and arctic cisco ($n = 1067$ and 229 , respectively). A few arctic char, *Salvelinus alpinus*, ($n = 65$) were tagged but this species is not taken in the fall commercial fishery in the Colville Delta. Eight humpback whitefish (*Coregonus clupeaformis*) and 16 broad whitefish (*C. nasus*) were also tagged but not recaptured.

To compare sizes of fish tagged with those recaptured in the commercial fishery, 100 least cisco and 100 arctic cisco from the 1980 fishery were measured.

Water temperature and salinity were recorded at fyke net stations using a YSI-33 salinity/conductivity meter. The meter has an accuracy of $\pm 0.6^\circ\text{C}$ and ± 1.1 ppt. Turbidity (in nephelometric turbidity units) was measured with a DRT-15 Turbidimeter manufactured by H.F. Instruments.

RESULTS

Size Correction for Tagged Fish

Prior to calculating recapture ratios, an adjustment was made for fish that were either too large or too small to be vulnerable to the commercial fishery in the Colville Delta. Figure 2 compares size compositions of least and arctic cisco in the commercial fishery with sizes of these species tagged on the east and west sides of the causeway. An adjustment was made when sizes of some tagged fish fell outside the size frequency of the commercial catch (from Ricker, 1975). For each size interval where this occurred, the difference in percent composition was calculated, and the sum of these differences equalled the total adjustment. The number of tagged fish was then reduced by this percentage to estimate the number of tagged fish susceptible to the fishery. From each species, this adjustment was calculated separately for catches on the east and west sides of the causeway, since the fish from the two sides differed in size composition, especially in the case of arctic cisco (it is not known whether this size difference reflects the sampling location or an effect of the causeway). Correction factors ranged from 25.0-49.9% of the fish originally tagged, leaving totals of 742 tagged least cisco and 135 tagged arctic cisco susceptible to the fishery (Table 1).

Fish Passage Around the Causeway

The immediate response of fish upon encountering the ARCO causeway is not known, but tagging data indicate that the net movements of large ciscoes (species combined) were not affected by the existing causeway. Although recaptures were, as in previous studies, infrequent (4.8% of the 877 least and arctic ciscoes susceptible to the commercial fishery were recaptured), proportions of 'east' and 'west' ciscoes caught in the fishery were nearly equal (4.9% vs 4.7%). A statistical comparison using a *chi-square*

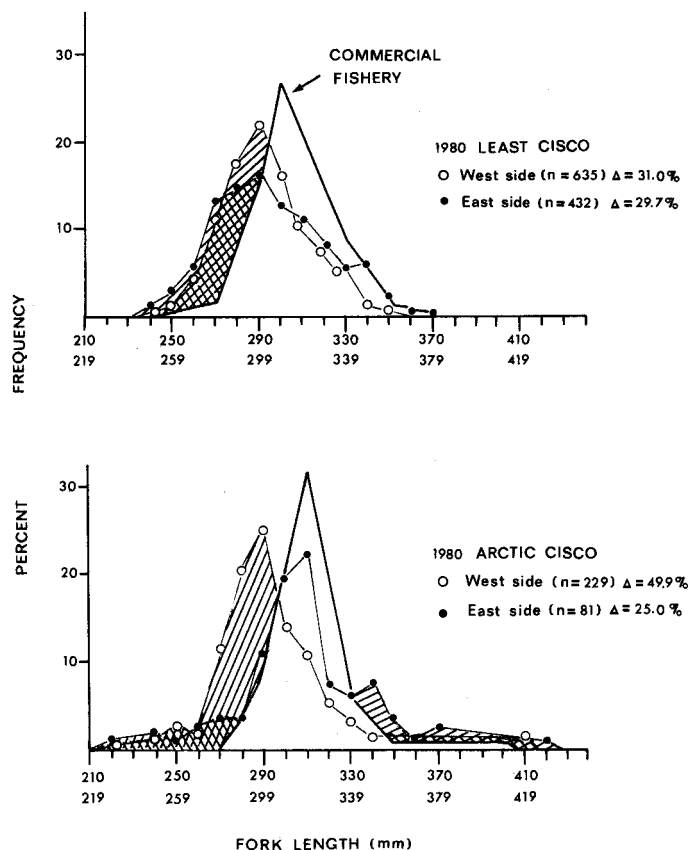


FIG. 2. Comparison of size frequencies of least and arctic cisco tagged on east and west sides of the ARCO causeway in Prudhoe Bay with size frequencies caught in the Colville Delta commercial fishery in 1980 (solid line). The percentage of tagged fish which were too large or small to be caught in the commercial fishery is indicated by symbol.

one-sample test showed that the difference was highly non-significant:

Tagging Site	All Ciscoes		χ^2	P
	Tagged	Recaptured		
East side	365	17.7	0.026	>0.75
West side	512	24.5		

Recapture ratios were also non-significant when least cisco were examined separately, but analyses for arctic cisco were complicated by small sample sizes and a species identification problem for three of the recaptured 'west' ciscoes (Table 1, footnote). Recapture ratios for arctic cisco were non-significant only if all three of the misidentified ciscoes were arctic ciscoes. If not, then statistical analyses indicate that significantly more of the 'east' arctic ciscoes were recaptured than the 'west' arctic ciscoes. This result is considered spurious since it is difficult to imagine that arctic cisco movements are hindered by not having to swim around the causeway.

TABLE 1. Numbers of least and arctic cisco tagged on east and west sides of the ARCO causeway in Prudhoe Bay and recaptured in the Colville Delta commercial fishery

	Least cisco		Arctic cisco		Ciscoes combined	
	East	West	East	West	East	West
Number tagged	432	635	81	148	513	783
Correction for size	29.7%	31.0%	25.0%	49.9%	—	—
Effective no. tagged	304	438	61	74	365	512
No. recaptured	11	21-24*	7	0-3*	18	24
χ^2 **		0.576		8.942		0.026
		1.318		2.485		
P***		N.S. (>0.25)		<0.005		N.S. (>0.75)
		N.S. (>0.25)		N.S. (>0.10)		

* The identity of three recaptured 'west' ciscoes was inconsistent between tagging and recapture records, so the number of least and arctic cisco recaptures are listed as ranges and χ^2 and P are calculated for low and high numbers of recaptures.

** *chi-square one-sample test.*

*** N.S., not significant.

DISCUSSION

Tagging data indicate that the 2.8 km ARCO causeway did not impede the net movements of large anadromous fish (>220 mm) in Beaufort Sea coastal waters. These results seem reasonable in that the causeway, as it existed in 1980, is somewhat similar in size and shape to naturally occurring barrier islands in the vicinity. Furthermore, anadromous fish are highly mobile — tagging data from other studies (summarized in Craig and Haldorson, 1981) indicate that these fish travel along the coastline at a net rate of 2.9-5.6 km/day (range 0-23 km/day), so a 2.8 km causeway appears easily navigated. At some point, however, it also seems reasonable that longer causeways, or causeways which join offshore barrier islands and create large embayments, might indeed affect the coastal migrations of anadromous species. It should also be noted that movements of small fish have not been examined.

While the causeway does not block migration of large anadromous fish, it has altered the local aquatic environment. As previously mentioned, water temperatures tend to be 2-4°C cooler and salinities 10 ppt higher on the west side compared to the east side (Bendock, 1977; Mungall *et al.*, 1978). Although these differences are well within the range of fluctuations frequently observed in the study area (Craig and Haldorson, 1981), the consistent tendency for local habitats on the west side to be cooler and more marine during the open-water season might affect the fish directly (temperature/salinity preference or avoidance responses) or indirectly (prey abundance and distribution). For example, several studies indicate qualitative or quantitative associations between temperature/salinity patterns and distributions of some fishes in the study area (Bendock, 1977; Moulton *et al.*, 1980; Craig and Haldorson, 1981). In the case of the ARCO causeway in Prudhoe Bay, temperature/salinity changes were relatively small and of a local nature. However, the ARCO causeway was again extended after completion of our study (USACE, 1980) and there is a likelihood of additional causeways in the region. Each structure may alter nearshore temperature/salinity regimes,

and the cumulative effect of these changes may be of significant consequence to anadromous fishes which rely on brackish coastal waters.

ACKNOWLEDGEMENTS

This study was funded by the U.S. Bureau of Land Management through interagency agreement with the U.S. National Oceanic and Atmospheric Administration, as part of the Outer Continental Shelf Environmental Assessment Program. The experimental design of this study emerged during the OCSEAP workshop and was the inspiration of Benny Gallaway. We thank Gunter Weller and Dave Norton (OCSEAP) for their continued interest in our programs; Rob Dillinger, Rodney Netterer and Dave Schmidt for their field assistance; J. Richardson for editorial comments; and Jim Helmericks for providing tag recapture data from the commercial fishery.

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