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The Effect of New Breaching in a Prudhoe Bay Causeway on the Coastal Distribution of Humpback Whitefish

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ABSTRACT. West Dock is a solid-gravel petroleum production causeway 4.3 km long that was constructed along the Beaufort Sea coast near Prudhoe Bay, Alaska, in the late 1970s. In the winter of 1995–96, a breach 200 m wide was constructed 1 km from the base of the causeway. Fish monitoring studies conducted during the summers of 1996 and 1997 indicated that the catch of adult (≥ 200 mm fork length) humpback whitefish (*Coregonus pidschian*) had increased significantly east of West Dock relative to levels observed in the 11 previous years. Data suggest that humpback whitefish dispersing eastward along the coast from their overwintering grounds in the Colville River had been blocked from moving east of West Dock and that construction of the breach has allowed these fish to extend their summer foraging range farther to the east.

Key Words: Arctic, causeways, *Coregonus pidschian*, humpback whitefish, impacts, oil production

RÉSUMÉ. West Dock est un pont-jetée de 4,3 km de long, construit avec du gravier, en structure pleine. Il a été édifié le long du rivage de la mer de Beaufort, près de Prudhoe Bay en Alaska, à la fin des années 70, en vue de la production pétrolière. Durant l'hiver de 1995-1996, une brèche de 200 m a été ouverte à 1 km du point d'attache du pont-jetée. Des travaux de surveillance du poisson menés durant les étés de 1996 et 1997 ont révélé que les prises de cisco à bosse (*Coregonus pidschian*) adulte (≥ 200 mm de longueur à la fourche) avaient augmenté de façon notable à l'est de West Dock par rapport aux niveaux relevés au cours des 11 années précédentes. Les données suggèrent que le cisco à bosse, qui longe la côte en direction de l'est depuis son aire d'hivernage dans la rivière Colville, avait la route bloquée pour aller à l'est de West Dock et que la construction de la brèche lui avait permis d'étendre plus à l'est son aire estivale d'alimentation.

Mots clés: Arctique, ponts-jetées, *Coregonus pidschian,* cisco à bosse, retombées, production pétrolière

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INTRODUCTION

Summer fish monitoring programs have been conducted in the Prudhoe Bay area of Alaska since the late 1970s in response to oil and gas development along the Beaufort Sea coast (e.g., Craig and Haldorson, 1981; Gallaway et al., 1983; Griffiths et al., 1983; Moulton et al., 1986; Cannon et al., 1987; Fechhelm et al., 1989; Schmidt et al., 1989; Glass et al., 1990; Gallaway et al., 1991; Hachmeister et al., 1991; Reub et al., 1991; Robertson, 1991; Griffiths et al., 1992; Gallaway et al., 1997; Griffiths et al., 1998; Fechhelm et al., 1999). Studies were designed to monitor the health and status of local amphidromous fish stocks that are important to Native subsistence and commercial fisheries and to a limited recreational fishery (U.S. Army Corps of Engineers, 1980, 1984). Four dominant species that fit these criteria have been the general focus of scientific study: arctic cisco (*Coregonus autumnalis*), least cisco (*C. sardinella*), broad whitefish (*C. nasus*), and Dolly Varden (*Salvelinus malma*).

One issue associated with oil development has been the construction of solid-fill gravel causeways along the Beaufort Sea coast. These structures are used as platforms for recovering offshore petroleum reserves and extracting the seawater that is injected into subsurface oil reservoirs. Amphidromous fishes spend the winter in North Slope river systems but disperse out into brackish nearshore coastal waters to feed during the ice-free Arctic summer (Craig, 1989). The concern is that causeways might disrupt these feeding migrations along the coast, either by physically blocking fish or by altering hydrographic conditions so that nearshore waters become more marine (i.e., colder and more saline) than normal (U.S. Army Corps of Engineers, 1980, 1984). While most studies of causeway effects have been directed at the four species named above, data have also been collected over the years for a number of "incidental" species. One of these is the humpback whitefish (*C. pidschian*).

Humpback whitefish have a discontinuous distribution in the river systems of the Beaufort Sea. Eastern populations are associated with the Mackenzie River and several smaller rivers of western arctic Canada (Craig, 1984). Western populations are found in the Colville River, Alaska, and numerous rivers further to the west. There are no known populations inhabiting the rivers between the Colville River and the U.S.-Canadian border, a distance of some

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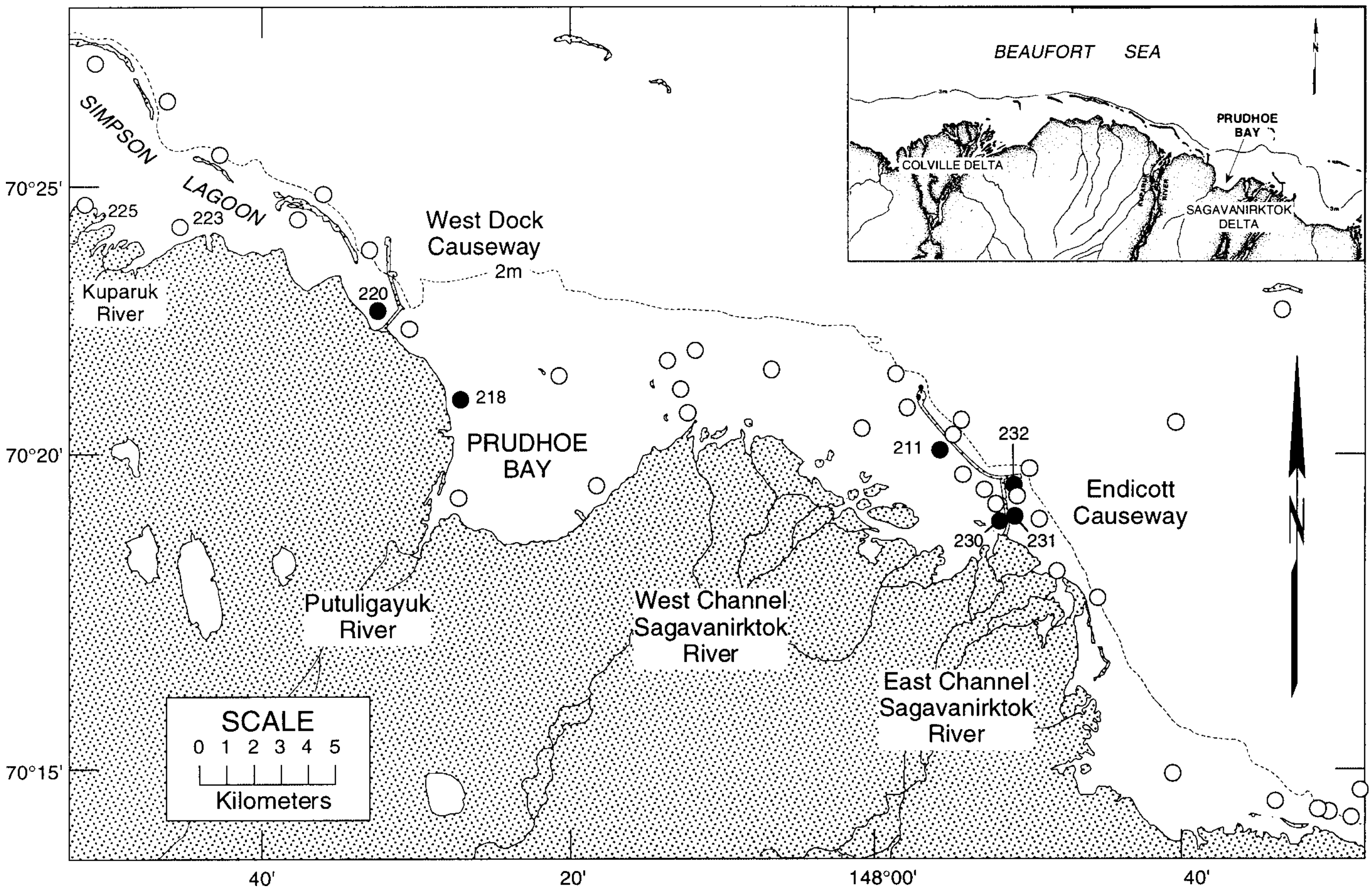

FIG. 1. Map of study area. Circles denote fyke-net sites sampled during the summers 1985–1997. Although not all sites were sampled each year, net arrays did extend along the coast from the Kuparuk River delta in the west to the eastern Sagavanirktok Delta in the east in all years (except 1997), thereby providing reasonable geographic cross-sections of the study area. Solid symbols indicate sites sampled in 1996. Only stations 218 and 220 near West Dock were sampled in 1997. Station numbers are noted for certain sites that are the subject of more detailed discussion within the text.

350 km (Craig, 1984). In the Colville River, humpback whitefish constitute a minor component of the Native subsistence fishery, which operates out of the village of Nuiqsut (George and Kovalsky, 1986; George and Nageak, 1986; Moulton, 1996).

During the winter of 1995–96, a breach 200 m wide was constructed near the base of one of Prudhoe Bay's major causeways: West Dock. The West Dock breach first became operational in the summer of 1996. This paper describes what appears to be a major shift in the coastal distribution of humpback whitefish in the Prudhoe Bay region as a result of the new breach.

STUDY AREA

The study area covers 120 km of coastline, from the Colville River eastward through Prudhoe Bay to the delta of the Sagavanirktok River (Fig. 1). Much of the coastline between the Colville River and Prudhoe Bay is bounded by a chain of barrier islands, which encloses Simpson Lagoon. West Dock, constructed incrementally during the winters 1976–77, 1978–79, and 1979–80, is located at the eastern end of Simpson Lagoon and the western edge of Prudhoe Bay. Approximately 4.3 km long, it has a breach 15 m wide located 2.8 km offshore. Although the original breach was built as a passageway for fish moving along the coast, virtually everyone who has studied the dynamics of the causeway has agreed that few fish actually use the breach because of its small size and its location (Fechhelm et al., 1989). The breach silted in during the mid-1980s, and no attempts have been made to dredge it open. The new 200 m breach is the only opening in the causeway.

The Sagavanirktok Delta is located immediately east of Prudhoe Bay, approximately 12 km east of West Dock. It is fronted by a shallow shelf (≤ 1.5 m deep) approximately 16 km wide (east to west) that extends seaward for 3–4 km. The Endicott Causeway was constructed in the middle of the delta shelf during the winter 1984–85. The mainland segment of the causeway was originally constructed with a nearshore breach 152 m wide and an offshore breach 61 m wide. In the winter of 1993–94, a third breach 200 m wide was added to the mainland section.

The only known source of humpback whitefish in the region is the Colville River, located 90 km west of Prudhoe

Bay. Thus the underlying premises of the present analysis are that summer foraging dispersals in the study area originate from a point (or points) west of West Dock, and that alongshore movement initially occurs from west to east along the coast.

METHODS

Humpback whitefish were collected in fyke nets (live-capture entrapment devices) located in the vicinity of Prudhoe Bay and the Sagavanirktok River delta during the summers of 1985–97 (see Fig. 1). Although not all sites were sampled each year, net arrays did extend along the coast from the Kuparuk River delta in the west to the eastern Sagavanirktok River delta in the east in all years, thereby providing reasonable geographic cross-sections of the study area. The exceptional year was 1997, when only a two-net survey was conducted in the vicinity of West Dock.

Surveys were conducted during the open-water season, which typically lasted from late June to late August–mid September. Except during periods of inclement weather, sampling continued 24 hours a day throughout the summer, and nets were emptied at approximately the same time each day. Captured fish were placed in floating holding pens, anesthetized in a dilute solution of tricaine (MS-222), measured (fork length in mm), and then released after the effects of the anesthetic had worn off. Because humpback whitefish were treated as an incidental species, no specimens were measured, although fish were enumerated at each site. Counts therefore include all size classes. In general, humpback whitefish collected in the 1985–97 studies were adults (≥ 200 mm fork length).

Catch is designated as catch-per-unit-effort (CPUE), or the number of fish caught per fyke net per 24 h of fishing effort (fish•net^{-1}•24 h^{-1}). Pooled, pre-1996 $\log_e$-transformed CPUE values were not normally distributed (Lilliefors test; $p < 0.001$), so the nonparametric Wilcoxin-Mann-Whitney-U test (Sprent, 1993) was used to test for differences in catch rates.

RESULTS AND DISCUSSION

During 11 consecutive summers from 1985 to 1995, 7881 humpback whitefish were collected throughout the study area. Of these fish, 95% (7495) were caught in early summer, before 5 August (Fig. 2). Low catch in the later part of the open-water season probably reflects fish emigrating from the study area back to their overwintering grounds to the west. So as not to dilute catch data with numerous observations of zero CPUE in late summer, the following analyses focus on data collected prior to 5 August of each year.

Of 7495 fish caught from 1985 to 1995, only 1007 fish (14%) were caught east of West Dock despite the fact that

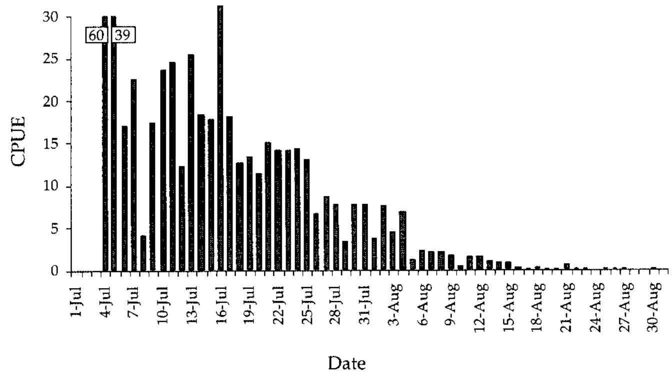

FIG. 2. Catch-per-unit-effort (CPUE: fish•net^{-1}•24 h^{-1}) by date, compiled from all stations operating west of West Dock across all pre-breach years, from 1985 to 1995. Values of CPUE beyond the scale of the y-axis are designated within boxes. Data illustrate that most humpback whitefish were caught in July.

82% (3160 net days) of the total fishing effort (3841 net days) was expended east of the causeway. Overall catch-per-unit effort prior to 1996 was 28 times higher (9.4 fish•net^{-1}•24 h^{-1}) west of West Dock than east of it (0.3 fish•net^{-1}•24 h^{-1}). Mean seasonal CPUE by station indicated that most humpback whitefish were taken west of West Dock, at mainland stations 220 and 223 (Figs. 3 and 4).

The pattern in catch over the years 1985–95 indicates that humpback whitefish from the Colville River moved eastward through Simpson Lagoon in early summer and took up temporary refuge in the fresher waters of the Kuparuk River delta (Station 223), often venturing as far east as the western base of West Dock (Station 220). Few fish moved east of West Dock.

During the first post-breach study of 1996, six sites were sampled: five east of West Dock (stations 218, 211, 230, 231, and 232) and Station 220 immediately west of the causeway (see Fig. 1). The five nets operating east of West Dock (177 net days total effort) caught a total of 1252 humpback whitefish (7.1 fish•net^{-1}•24 h^{-1}), more than the cumulative total of fish caught east of the causeway among all nets over the previous 11 years (see Figs. 3 and 4). CPUE increased significantly ($p < 0.05$) at all five stations relative to pooled pre-breach catch rates (Fig. 5; Table 1).

In 1997, a two-net study was conducted in the vicinity of West Dock (Stations 218 and 220; see Fig. 1). Station 218 therefore became the only measure of catch east of the causeway. CPUE at Station 218 for 1997 was 13.2 fish•net^{-1}•24 h^{-1}, four times greater than CPUE during the most productive summer before construction of the breach and significantly higher than pooled pre-breach CPUE (see Fig. 5, Table 1).

The substantial increase in CPUE east of West Dock indicates that greater numbers of humpback whitefish moved east of the causeway in 1996 and 1997. If the new breach was responsible for this change in distribution, it follows that the unbreached causeway had been blocking alongshore movement before 1996. The intolerance of the fish for marine water may have enhanced the blocking effect of the causeway itself. West Dock extends 4.3 km

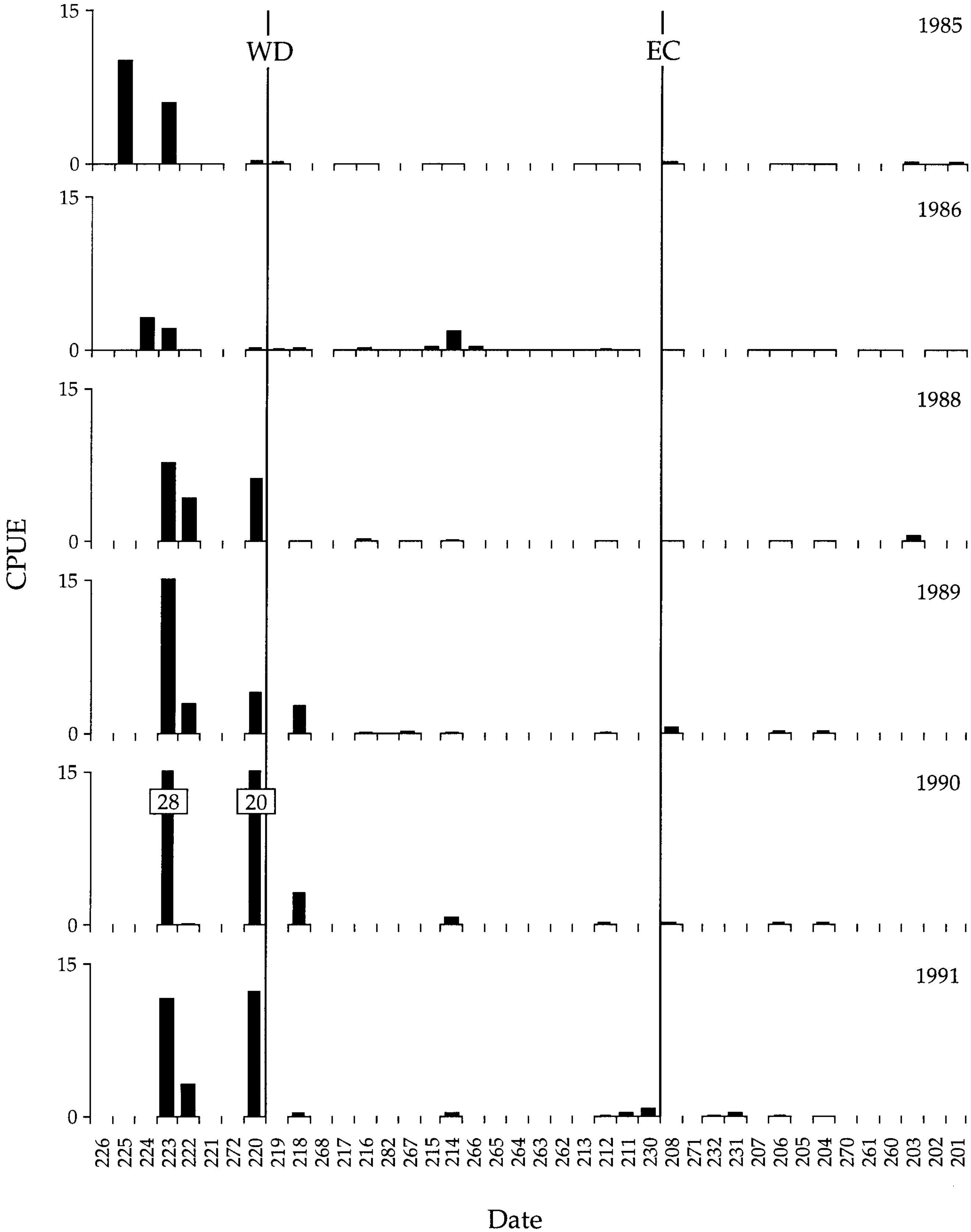

FIG. 3. Catch-per-unit-effort (CPUE: fish•net^{-1}•24 h^{-1}) for humpback whitefish by station from 1985 to 1991. Stations are arrayed relative to their west-to-east locations along the coast. Vertical lines indicate the locations of West Dock (WD) and the Endicott Causeway (EC). The open spaces in the horizontal axes indicate no fishing effort for that site; solid lines indicate effort but nominal catch. Values of CPUE beyond the scale of the y-axis are designated within boxes. Data for 1987 are not presented because none of the primary sites located west of West Dock were sampled that year.

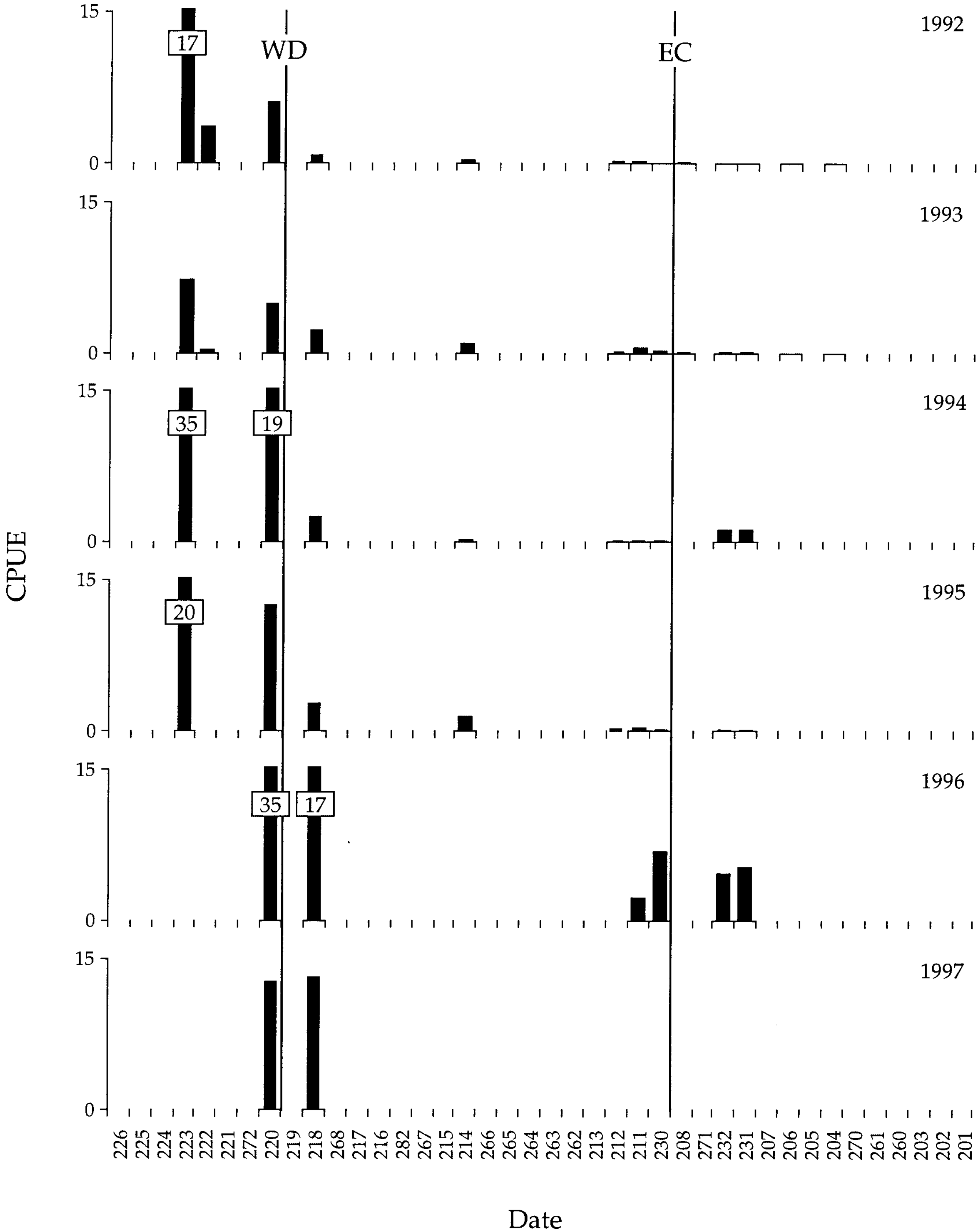

FIG. 4. Catch-per-unit-effort (CPUE: fish•net^{-1}•24 h^{-1}) for humpback whitefish by station from 1992 to 1997. Stations are arrayed relative to their west-to-east locations along the coast. Vertical lines indicate the locations of West Dock (WD) and the Endicott Causeway (EC). The open spaces in the horizontal axes indicate no fishing effort for that site; solid lines indicate effort but nominal catch. Values of CPUE beyond the scale of the y-axis are designated within boxes.

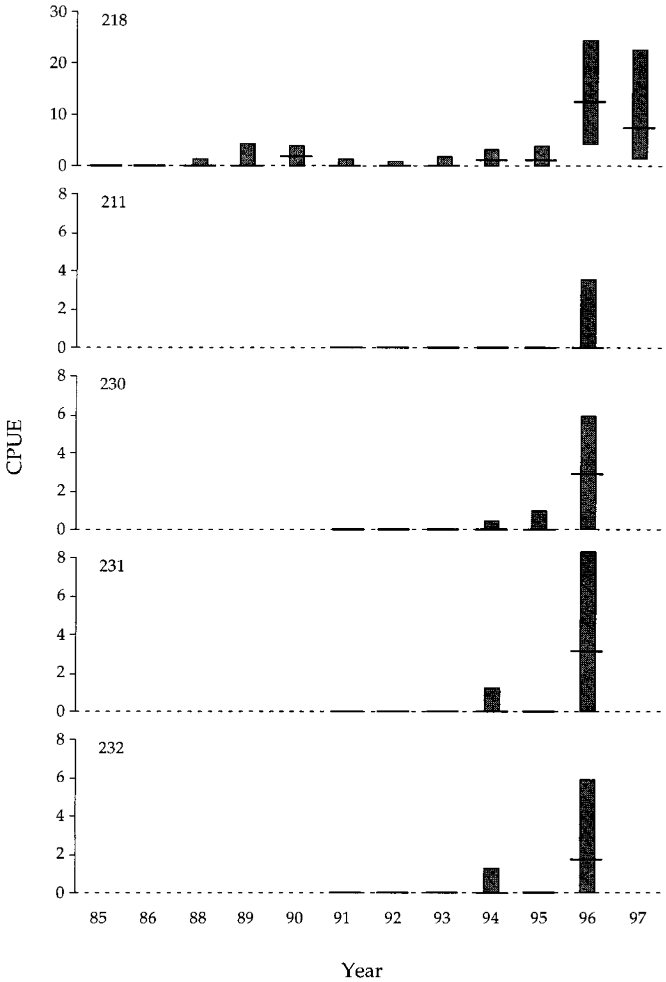

FIG. 5. Daily catch-per-unit-effort (CPUE: fish•net^{-1}•24 h^{-1}) expressed as median and interquartile range for humpback whitefish collected east of West Dock by year. These are the five nets that were fished in 1996–97.

TABLE 1. Summary results of the Mann-Whitney-U test comparing daily pooled CPUE for stations east of the causeway before and after construction of the West Dock breach.

Location	Station	Years[1]	N	*p*
Endicott	211	1991–95	183	< 1.0 E-9
		1996	36	
	230	1991–95	220	< 1.0 E-9
		1996	38	
	231	1991–95	205	< 1.0 E-9
		1996	38	
	232	1991–95	207	< 1.0 E-9
		1996	30	
West Dock	218	1987–95	182	< 1.0 E-9
		1996	30	
		1987–95	182	4.8 E-6
		1997	20	

[1] Data for 1985 and 1986 were not included in the analyses of Station 218 CPUE. CPUE at Station 220 was nominal in both years, suggesting that humpback whitefish did not reach the causeway in substantial numbers. Data for those years are therefore irrelevant to any analyses relating to potential blockage or breach effectiveness.

seaward from the shore, and conditions around its tip tend to be colder and more saline than those in the protected waters of Simpson Lagoon (Moulton et al., 1986). In addition, a wake-eddy phenomenon occurs at West Dock. Coastal currents along the Beaufort Sea coast are primarily wind-driven, with east winds causing flow to the west and vice versa. During periods of sustained east winds (i.e., westward-flowing currents), an eddy forms on the western (lee) side of the causeway, enhancing the vertical mixing of cold, saline marine water into the nearshore zone (Mangarella et al., 1982; Savoie and Wilson, 1983, 1986; Niedoroda and Colonell, 1990). A cell of cold, saline water develops immediately west of West Dock, at the eastern end of Simpson Lagoon. There is evidence that this wake-eddy phenomenon can occasionally block the eastward dispersal of another whitefish species, least cisco *C. sardinella* (Fechhelm et al., 1989, 1999). These same mechanisms could have been affecting humpback whitefish.

Evidence for blockage prior to 1996 is further suggested by the sharp west-to-east decrease in CPUE that occurred in the vicinity of West Dock before 1996 (see Figs. 3 and 4). Seasonal CPUE east of West Dock was significantly ($p < 0.05$) lower than that observed west of the causeway in all pre-breach years from 1988 to 1995.

However, these statistical comparisons may be biased. The summer feeding dispersals of anadromous fishes are spatially constrained, and fish density is likely to decrease as one moves from the point of origin to the limits of the dispersal. Fyke net sites east of West Dock have historically extended some 35 km along the coast, and the lower CPUE in the Sagavanirktok Delta may be partially a function of distance.

The comparison least biased by distance is the one between stations 220 and 218 (see Fig. 1). These two sites are only 11–12 km apart, including the distance around the causeway. From 1988 to 1995, CPUE at Station 218 was significantly lower than CPUE at Station 220 in six of eight years (Table 2). The two years of no significant difference (1989 and 1993) were characterized by low CPUE at Station 220, as opposed to high catch at 218 (see Figs. 3 and 4). There was no significant difference in CPUE between the two sites in 1996 and 1997, two years of relatively high CPUE. Results are again consistent with the argument that there was a sharp decline in CPUE east of West Dock (i.e., a blockage) prior to 1996 and no sharp decline afterwards.

Factors other than the breach could have accounted for the increase in CPUE east of West Dock in 1996 and 1997. One hypothesis is a population increase: greater numbers of fish might have caused an extended dispersal beyond West Dock. Long-term trends in CPUE could provide a measure of such change. Unfortunately, there are no data available to test this hypothesis. If West Dock did prevent humpback whitefish from dispersing eastward, then all catch data collected east of the causeway are biased. Long-

TABLE 2. Summary results of the Mann-Whitney-U test comparing daily CPUE for station 220 versus station 218 by year.[1]

Year	Station	N	*p*
1988	218	14	1.4 E-4
	220	21	
1989	218	28	0.90
	220	27	
1990	218	21	7.3 E-6
	220	21	
1991	218	17	3.6 E-4
	220	20	
1992	218	24	1.4 E-3
	220	22	
1993	218	18	0.91
	220	25	
1994	218	19	3.7 E-4
	220	25	
1995	218	26	1.7 E-3
	220	32	
1996	218	30	0.10
	220	30	
1997	218	18	0.91
	220	20	

[1] Data for 1985 and 1986 were not included in the analyses. CPUE at Station 220 was nominal in both years, suggesting that humpback whitefish did not reach the causeway in substantial numbers. Data for those years are therefore irrelevant to any analyses relating to potential blockage or breach effectiveness. Data for 1987 were not included because Station 220 was not sampled that year.

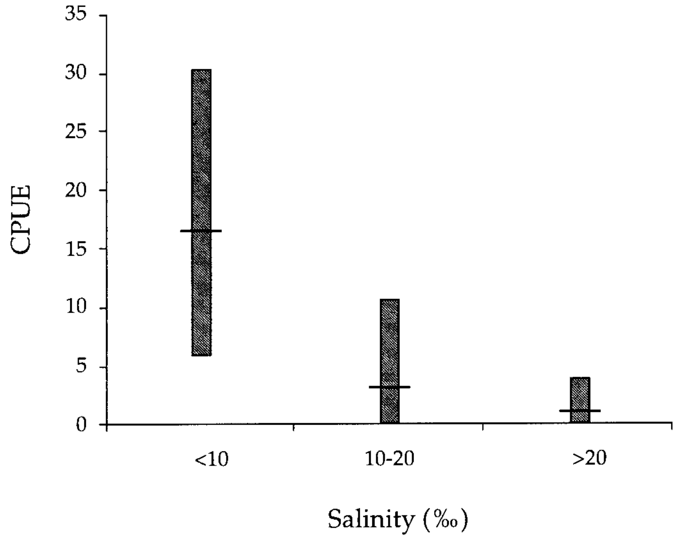

FIG. 6. Catch-per-unit-effort (CPUE: fish•net^{-1}•24 h^{-1}) for humpback whitefish collected at Station 220 expressed as median and interquartile range for different salinities. Only data collected prior to 5 August are included (see text).

term patterns in CPUE for stations west of West Dock might provide evidence of changes in stock size; however, only Station 220 remained in operation after construction of the breach. Data from this, or any single fyke net, are potentially biased for a number of reasons.

Studies of least cisco indicate that marine conditions that develop in the lee of West Dock during east winds not only prevent fish from moving around the causeway, but may even cause them to retreat to the shelter of Simpson Lagoon (Fechhelm et al., 1989, 1999). Shorter residency time in the vicinity of Station 220 would translate into lower seasonal CPUE, and longer residency time would mean higher CPUE. To determine whether humpback whitefish might similarly be affected, I compared daily bottom salinity measurements at Station 220 to corresponding CPUE for humpback whitefish across all years prior to breach installation. The highest catches indeed occurred at lower salinities (Fig. 6). It is therefore quite likely that seasonal CPUE at Station 220 varies to some degree with meteorological conditions (i.e., wake eddy) that are unique to any given year.

Another factor influencing seasonal CPUE at Station 220 is the date on which sampling begins. Sampling commenced as early as 4 July in 1995 and as late as 16 July in 1990, 1991, and 1997. Given the general trend of decreasing abundance as the summer progresses, the earlier sampling begins, the more seasonal CPUE will be weighted by high early-season catch. In 1996, sampling began on 8 July; the resultant seasonal CPUE was 35.8 fish•net^{-1}•24 h^{-1}. CPUE would have been calculated as 16.1 fish•net^{-1}•24 h^{-1} if sampling had begun a mere eight days later, on 16 July. Numerous pseudo start dates were explored to determine if variation in the exact dates of sampling within each year at different nets could affect results. While altering start dates did change seasonal values of CPUE, I could find no reasonable combinations capable of changing the statistical results reported in Tables 1 and 2.

Still another variable that could affect catch at Station 220 is gear type. Because fyke nets are passive fishing devices, catch is a function of both fish abundance and movement. Assuming that the new breach has allowed humpback whitefish to extend their dispersal farther east, greater numbers of fish could be moving past Station 220 than might previously have been the case. Station 220 would be ideally situated to sample a more persistent stream of fish moving along the coast from Simpson Lagoon eastward into Prudhoe Bay and beyond. The result could be a substantial increase in overall CPUE that is independent of any actual increase in stock size.

The potential sources of variability in CPUE discussed above are the reasons why this paper focuses on broad-scale trends in catch/abundance and tries to rely on corroborating evidence from multiple sites and years. In general, 1985–95 catch rates for humpback whitefish at fyke net sites east of West Dock were markedly lower than catch rates reported west of the causeway. This west-to-east decline in CPUE appears to have occurred rather abruptly in the vicinity of West Dock. In 1996, the first summer after construction of the breach, catch rates at all five fyke nets located east of West Dock increased significantly over their pre-breach levels. The significant difference in CPUE between stations 218 and 220 that existed prior to breach installation was no longer evident afterwards. Collectively, these data suggest that West Dock had been blocking the alongshore movements of humpback whitefish, but that the new breach passageway allows fish to disperse farther to the east.

While other explanations in addition to increased population size (e.g., shifts in feeding ecology or prey distribution) could account for the increase in CPUE east of West Dock in 1996 and 1997, I know of nothing in the historical database that would allow for the testing of these hypotheses. If the apparent shift in humpback whitefish distribution is not related to the breach, then we are left with a case of an irreconcilable coincidence. If the primary hypothesis is given weight, it means that the new breach mitigated blockage of humpback whitefish at West Dock. Whether the breach likewise eliminates the blockage reported for juvenile least cisco (Fechhelm et al., 1989, 1999) has yet to be determined.

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