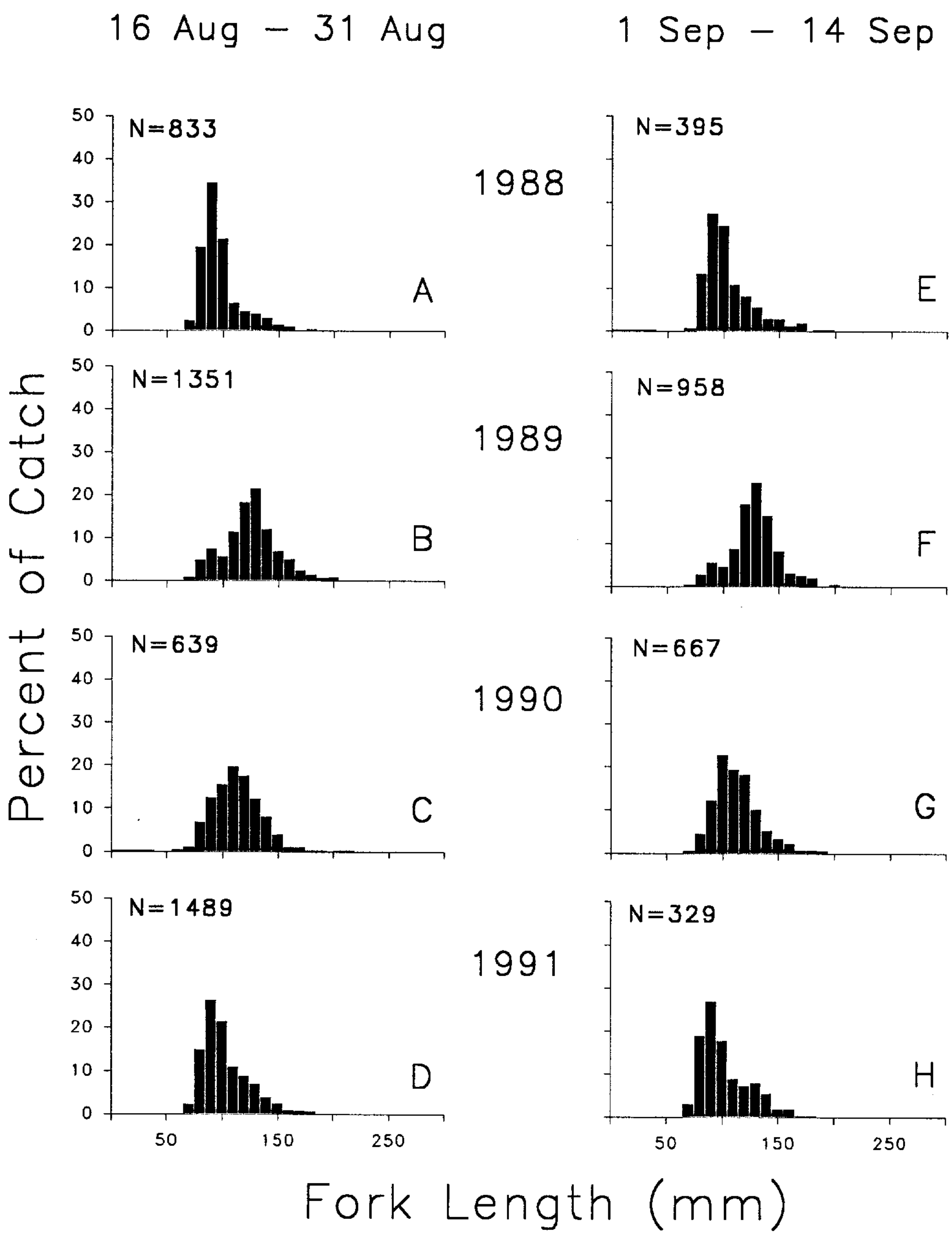


FIGURE 4.29.– Length frequencies of Arctic cod captured by fyke nets in Simpson Cove, plotted by year for August 16 to September 14.

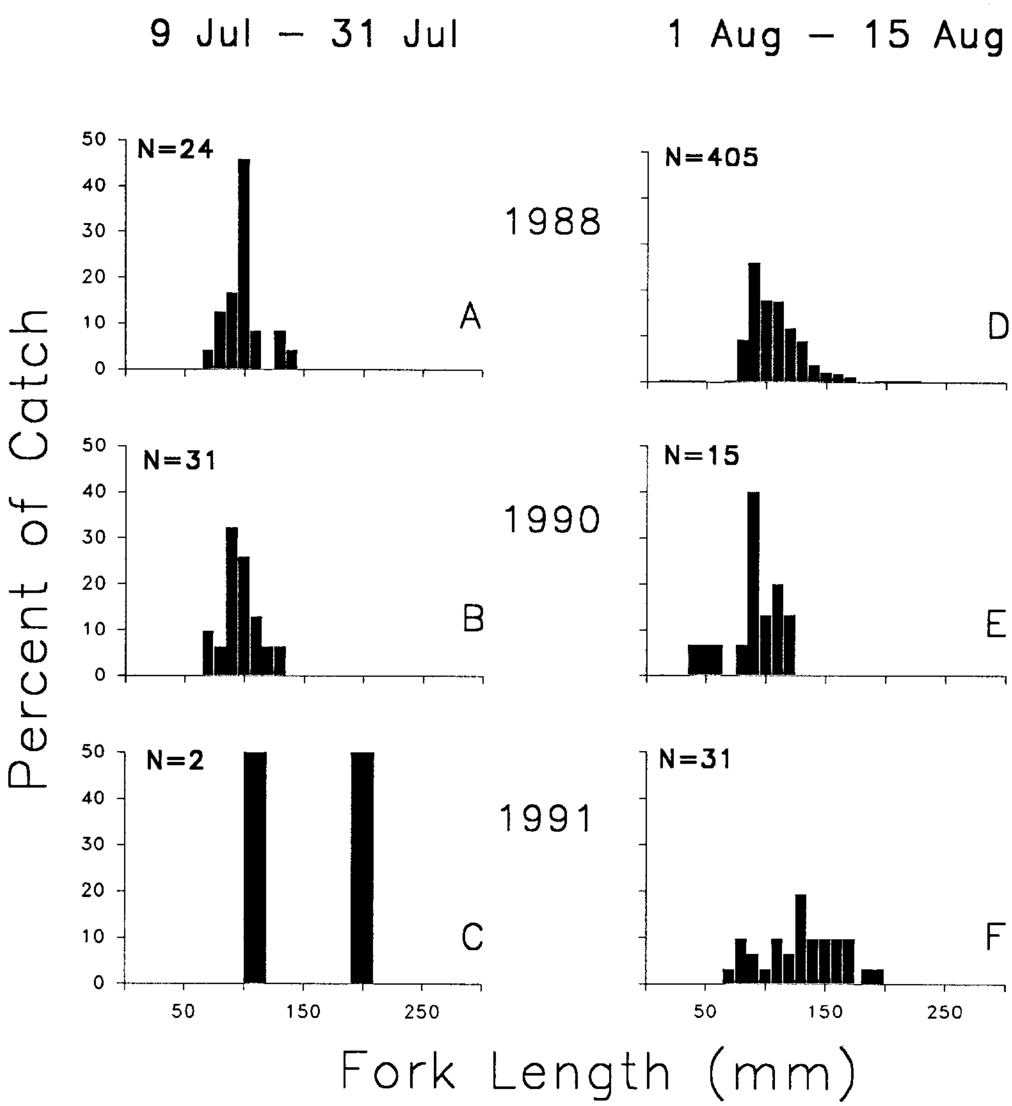


FIGURE 4.30.– Length frequencies of Arctic cod captured by fyke nets in Kaktovik Lagoon, plotted by year for July 9 to August 15.

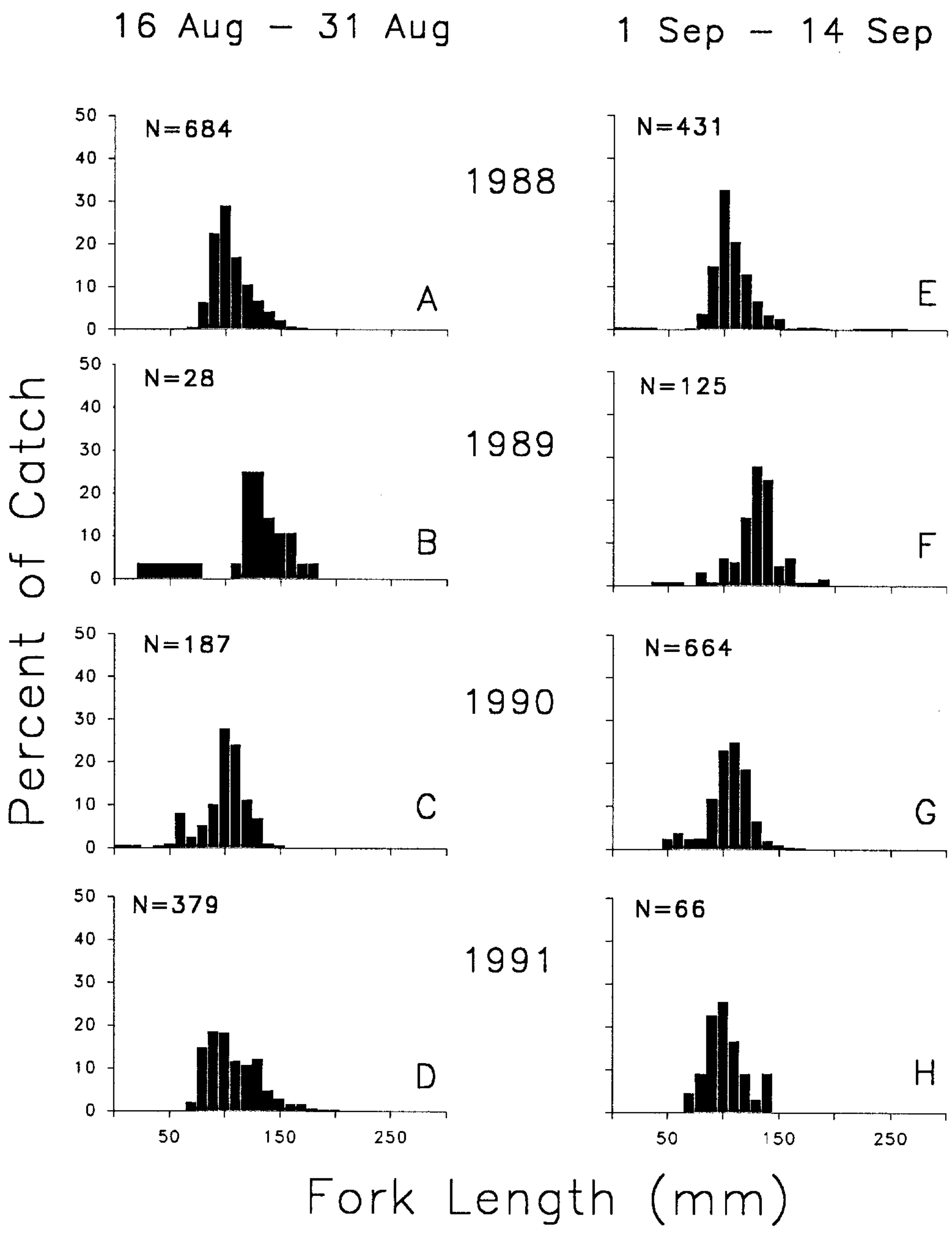


FIGURE 4.31.– Length frequencies of Arctic cod captured by fyke nets in Kaktovik Lagoon, by year for August 16 to September 14.

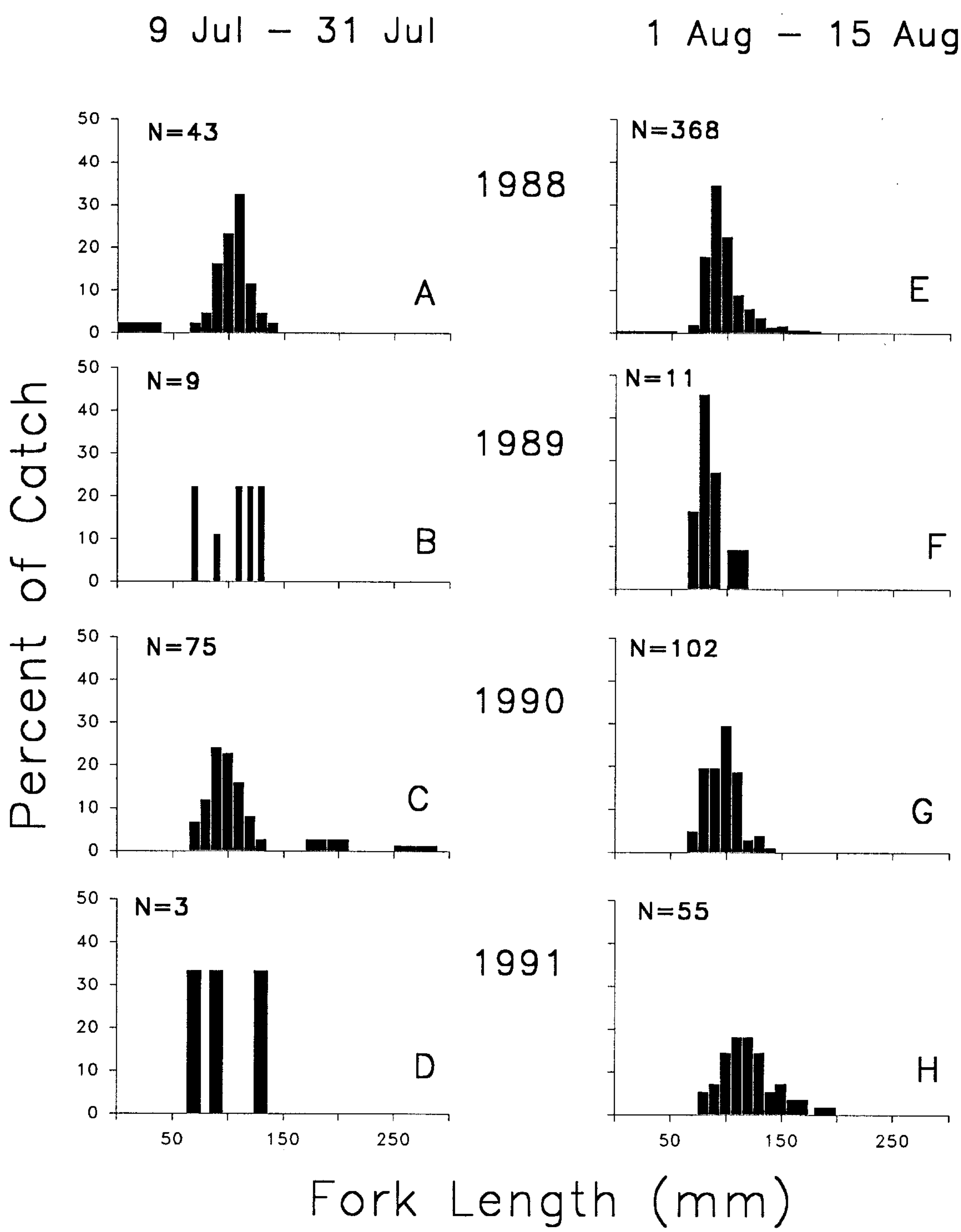


FIGURE 4.32.– Length frequencies of Arctic cod captured by fyke nets in Jago Lagoon, plotted by year for July 9 to August 15.

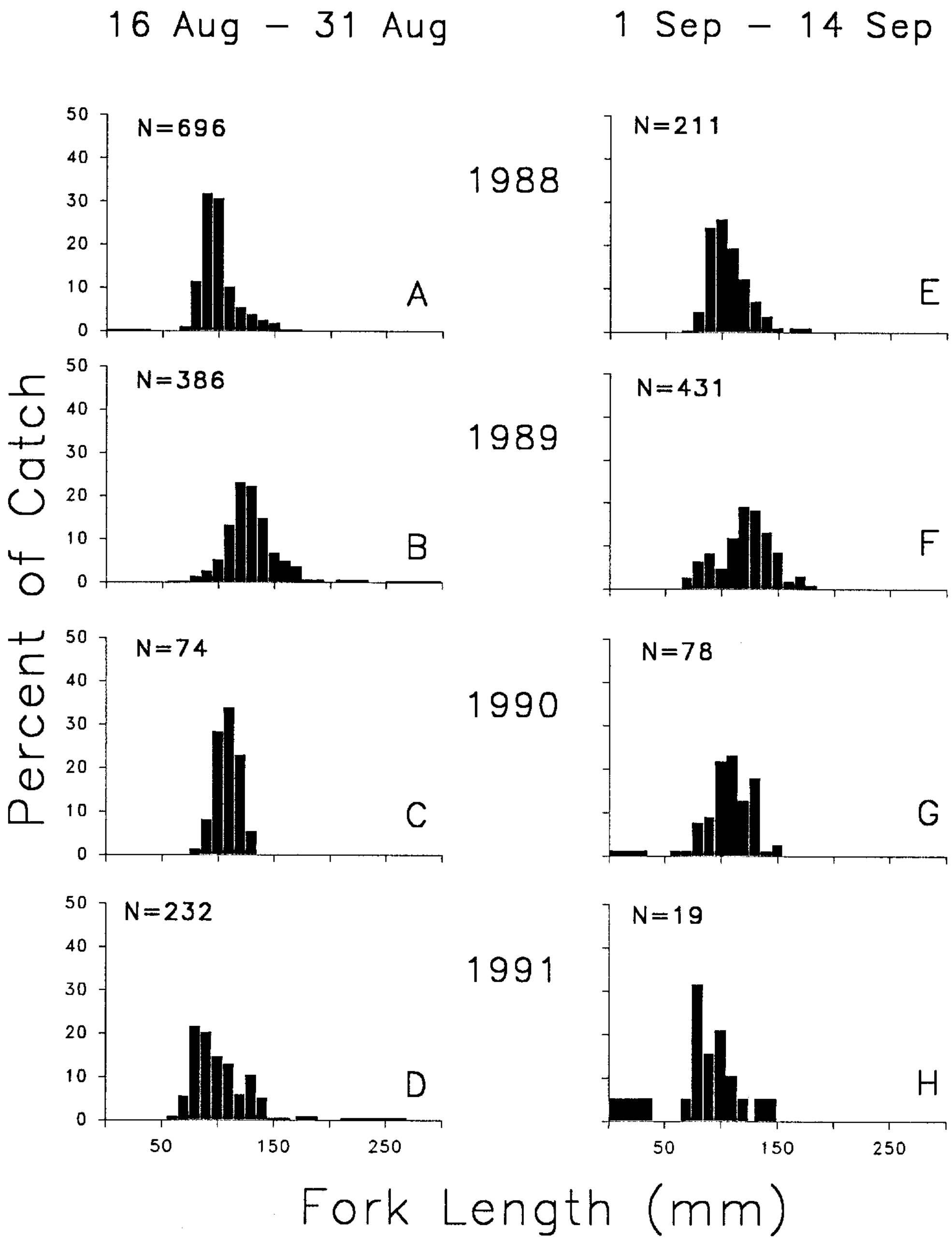


FIGURE 4.33.– Length frequencies of Arctic cod captured by fyke nets in Jago Lagoon, plotted by year for August 16 to September 14.

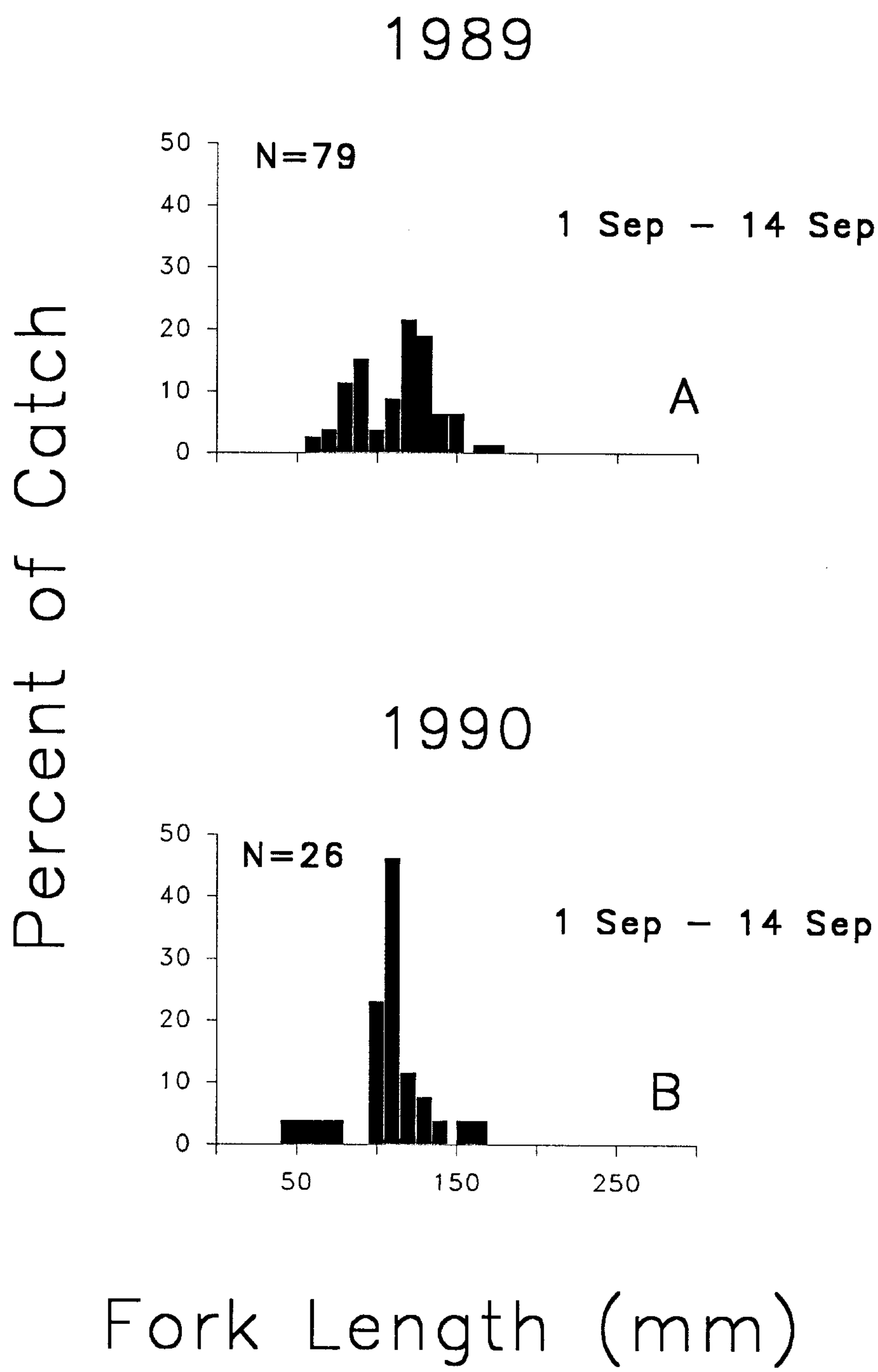


FIGURE 4.34.– Length frequencies of Arctic cod captured by fyke nets in Beaufort Lagoon, plotted by year for September 1-14.

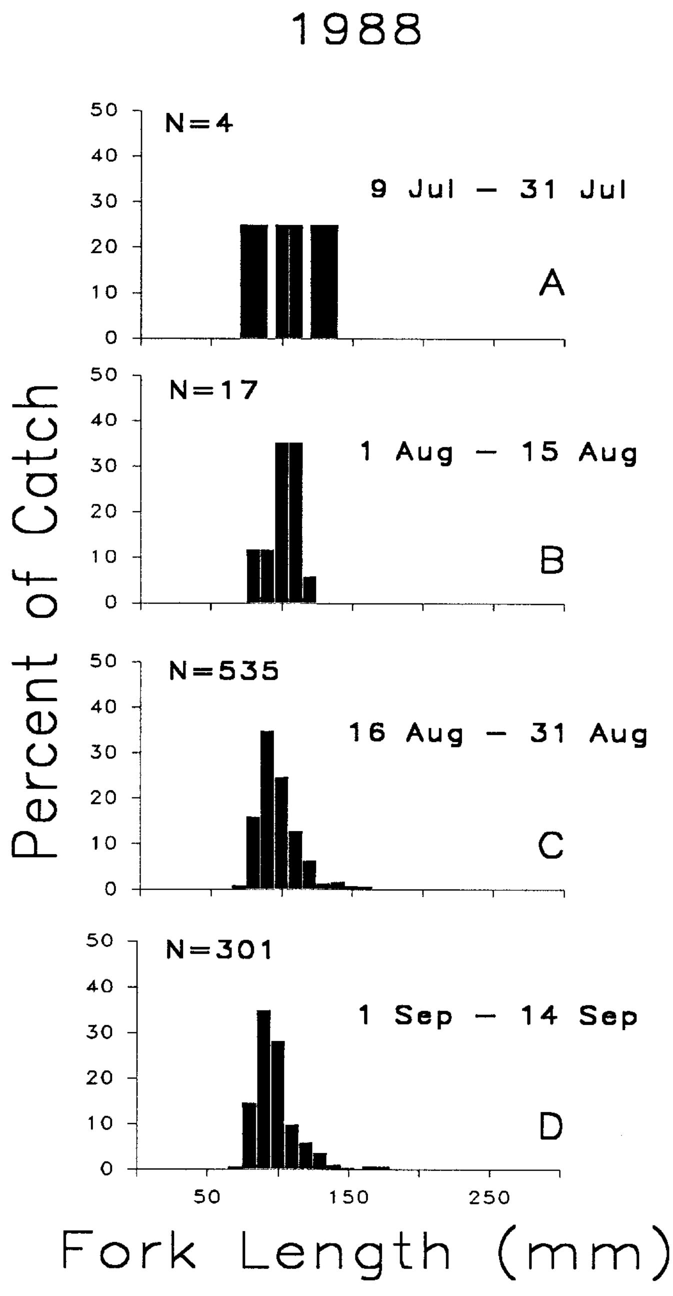


FIGURE 4.35.— Length frequencies of Arctic cod captured by fyke nets in Pokok Bay, plotted for July 9 to September 14, 1988.

and 130-140 mm FL, respectively (Figure 4.31). In 1991, a mode occurred at 130 mm FL during the second sampling period and between 90-100 mm FL during the third and fourth periods (Figures 4.30, 4.31).

During the third and fourth periods, modes occurred between 120-130 mm FL in 1989 and at 90-110 mm FL during the remaining years (Figure 4.33). In Jago Lagoon, sample sizes were too small for interpretation in 1989 during July 9 to August 15, and in 1991 during July 9-31. In 1988 and 1990, modal distributions occurred at 90-100 mm FL (Figure 4.32).

In Beaufort Lagoon and Pokok Bay, sample collection was sporadic and sample sizes were small (Figures 4.34, 4.35). Length frequency modes for Arctic cod caught between September 1-14 in Beaufort Lagoon occurred at 90 and 120 mm FL in 1989, and at 110 mm FL in 1990 (Figure 4.34). In Pokok Bay, samples from August 16 through September 14 exhibited a mode of 90 mm FL (Figure 4.35). Few Arctic cod were present in earlier samples from Pokok Bay.

Condition

Gender differences.— We detected no significant differences in condition between male and female Arctic cod collected in July, 1988-91 (Table 4.13). Sample sizes were inadequate for independent annual analyses. No outliers were present (Figure 4.36A, B). Plots of transformed data were similar in size ranges represented and variation.

Seasonal differences.— Significant differences in condition over season were evident for pooled data and data within 1990 (Table 4.14). Intercept estimates for the pooled data indicated an increase in condition during the open-water season. We obtained similar results when outliers were removed. No change in condition was detected in 1988 or 1989. No significant differences in slopes were detected. Plots of transformed data showed more large Arctic cod late in the season (Figure 4.36).

Overwintering.— Only the winter of 1989-90 provided adequate sample sizes for overwintering comparisons. Differences in slopes precluded statements about condition (Table 4.15). Plots of transformed data indicated differences in the data (Figure 4.37). We sampled few Arctic cod over 150 mm in July of 1990. When the data set was truncated to exclude the large fish (FL > 150 mm) of fall 1989, then slopes (P = 0.061) were similar while intercepts differed significantly (P = 0.0001; Table 4.15). Differential intercepts indicated that condition declined over the winter. No outliers were present.

Spatial differences.— No significant differences in condition were evident among areas for the early and late-season samples (Tables 4.16, 4.17). Slope estimates within each time period were similar. Beaufort Lagoon provided too few fish for analysis. Plots of transformed data showed differences between Simpson Cove, and Kaktovik and Jago lagoons in the size range of fish for July (Figure 4.38).

Annual differences.— We detected significant differences in condition during July among years, when data were pooled over areas (Table 4.18). Pairwise comparisons indicated that condition was significantly higher in 1989 than in

TABLE 4.13.— Condition comparisons between female and male Arctic cod collected in July. Analyses were done for data pooled over years because sample sizes within years were not adequate. Asterisks (*) indicate significant differences in condition.

		Slopes		Intercepts		
Group	*N*	*b*(SE)	*P*-values	$\log_e a$(SE)	*P*-values	r^2
Females	92	3.05(0.08)		-12.23(0.38)		0.95
Males	58	3.00(0.12)		-12.04(0.58)		0.92
			P = 0.74		*P* = 0.18	
	Without outliers		*P* = 0.74		*P* = 0.18	

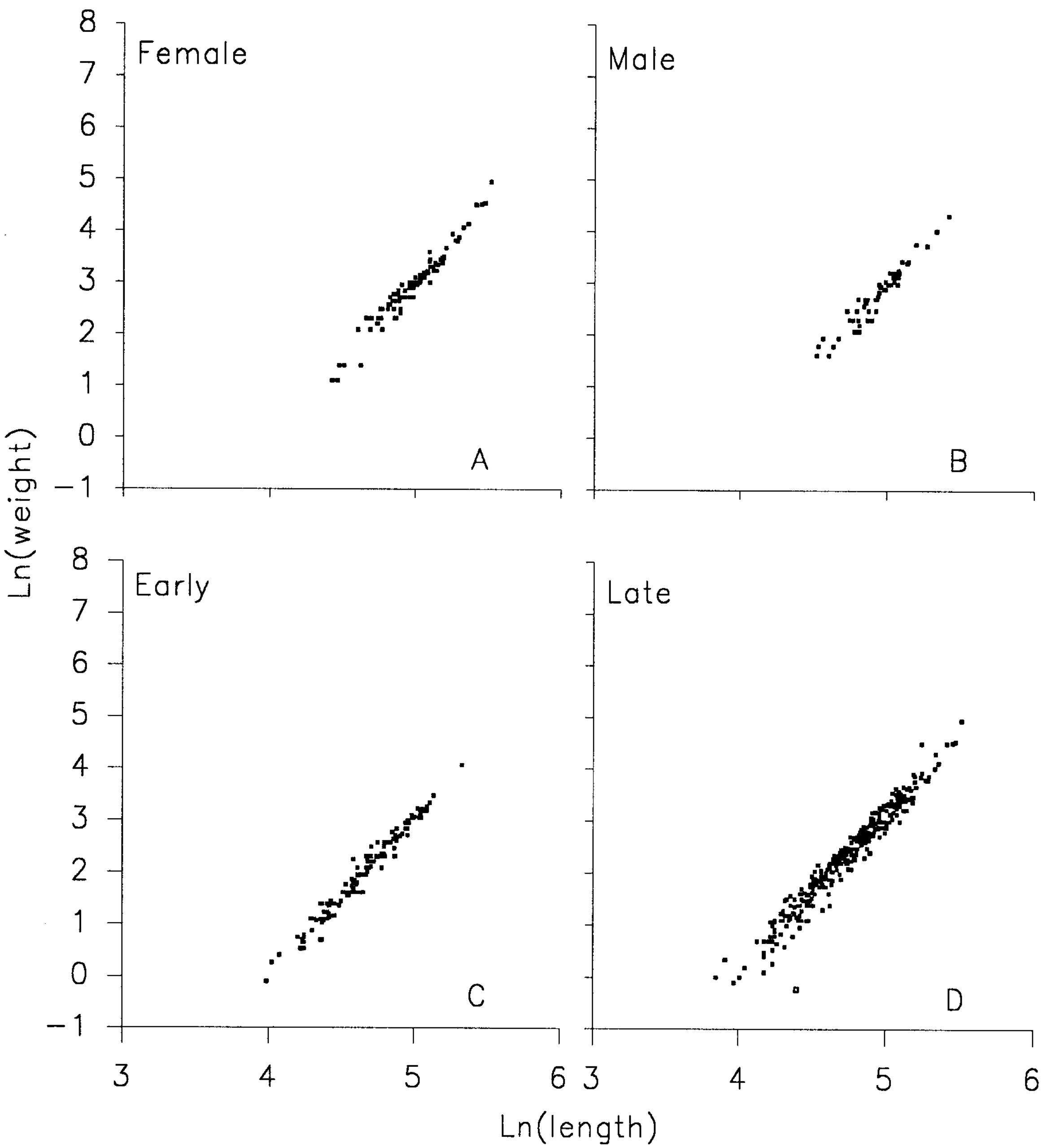


FIGURE 4.36.— Log-transformed weight-length data for comparisons between sexes (A, B) in July and between seasons (C, D). Seasonal data corresponds to early (July 9-31) and late (August 27 - September 14) time periods.

TABLE 4.14.— Seasonal body condition comparisons for Arctic cod, all years pooled and years analyzed individually. Asterisks (*) indicate significant differences in condition between periods.

		Slopes		Intercepts		
Group	*N*	*b*(SE)	*P*-values	a(SE)	*P*-values	r^2
			All years			
Early	153	3.03 (0.04)		-12.10 (0.21)		0.97
Late	437	2.97 (0.03)		-11.78 (0.15)		0.95
			P = 0.42		*P* = 0.0001	*
	Without outliers		*P* = 0.30		*P* = 0.0001	*
			1988			
Early	41	3.09 (0.17)		-12.49 (0.78)		0.90
Late	67	3.02 (0.07)		-12.17 (0.35)		0.96
			P = 0.68		*P* = 0.22	
	Without outliers		*P* = 0.68		*P* = 0.22	
			1989			
Early	57	2.90 (0.06)		-11.44 (0.29)		0.97
Late	147	2.90 (0.04)		-11.45 (0.17)		0.97
			P = 0.97		*P* = 0.90	
	Without outliers		*P* = 0.97		*P* = 0.90	
			1990			
Early	54	3.03 (0.07)		-12.11 (0.32)		0.97
Late	116	3.09 (0.04)		-12.17 (0.18)		0.98
			P = 0.43		*P* = 0.0001	*
	Without outliers		*P* = 0.43		*P* = 0.0001	*

TABLE 4.15.— Condition comparisons for overwintering Arctic cod during the winter of 1989-90. Asterisks (*) indicate significant differences in condition between season.

		Slopes		Intercepts		
Group	*N*	*b*(SE)	*P*-values	a(SE)	*P*-values	r^2
			1989 - 1990			
Fall	54	3.03 (0.07)		-12.11 (0.32)		0.97
Spring	74	2.84 (0.05)		-11.11 (0.22)		0.98
			$P = 0.031$		$P = 0.0001$	
	Without outliers		$P = 0.031$		$P = 0.0001$	

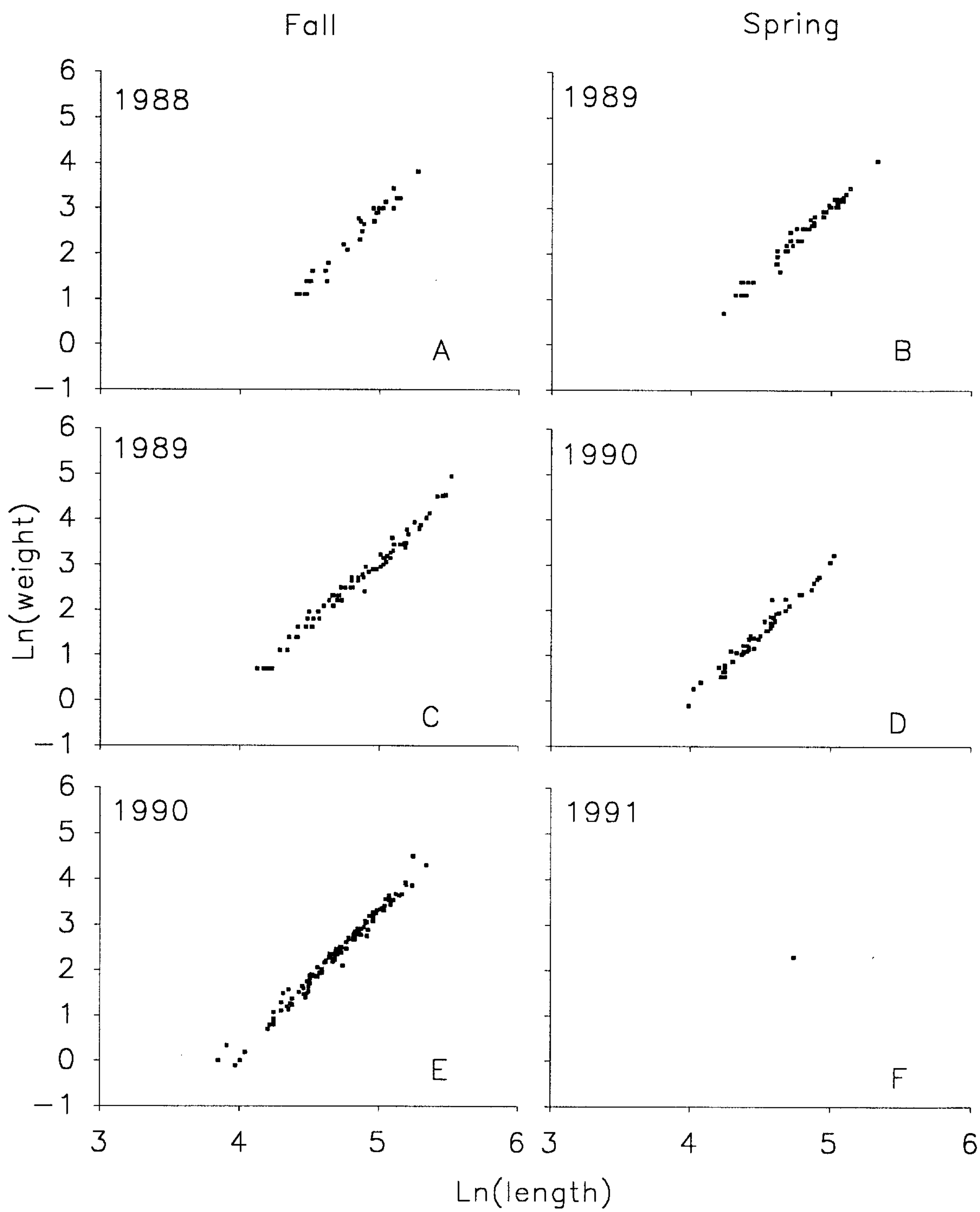


FIGURE 4.37.— Log-transformed weight-length data for three comparisons, winter 1988-89, 1989-90, and 1990-91.

TABLE 4.16.— Condition comparisons among areas for Arctic cod collected in July pooled over all years. Samples within individual years did not meet minimum sample size requirements. Asterisks (*) indicate significant differences in condition.

Group	*N*	Slopes		Intercepts			
		b(SE)	*P*-values	a(SE)	*P*-values	r^2	Pairwise results
Kaktovik/Jago	46	3.08(0.10)		-12.35(0.45)		0.96	
Simpson Cove	107	3.01(0.05)		-12.01(0.25)		0.97	
			P = 0.56		P = 0.53		
Without outliers			P = 0.56		P = 0.53		

TABLE 4.17.— Condition comparisons among areas for Arctic cod collected after August 27 for all years pooled, 1990, and 1991. Asterisk (*) indicate significant differences in condition.

		Slopes		Intercepts			
Group	*N*	*b*(SE)	*P*-values	a(SE)	*P*-values	r^2	Pairwise Results
All Years							
Kaktovik/Jago	104	3.08(0.09)		-12.29(0.42)		0.92	
Simpson Cove	213	2.98(0.04)		-11.79(0.19)		0.97	
			P = 0.24		P = 0.41		
Without outliers			P = 0.48		P = 0.72		
1990							
Kaktovik/Jago	34	3.06(0.08)		-12.08(0.36)		0.98	
Simpson Cove	64	3.15(0.04)		-12.47(0.19)		0.99	
			P = 0.27		P = 0.34		
Without outliers			P = 0.47		P = 0.37		
1991							
Kaktovik/Jago	49	3.11(0.15)		-12.46(0.71)		0.90	
Simpson Cove	59	3.10(0.07)		-12.40(0.35)		0.97	
			P = 0.92		P = 0.72		
Without outliers			P = 0.52		P = 0.24		

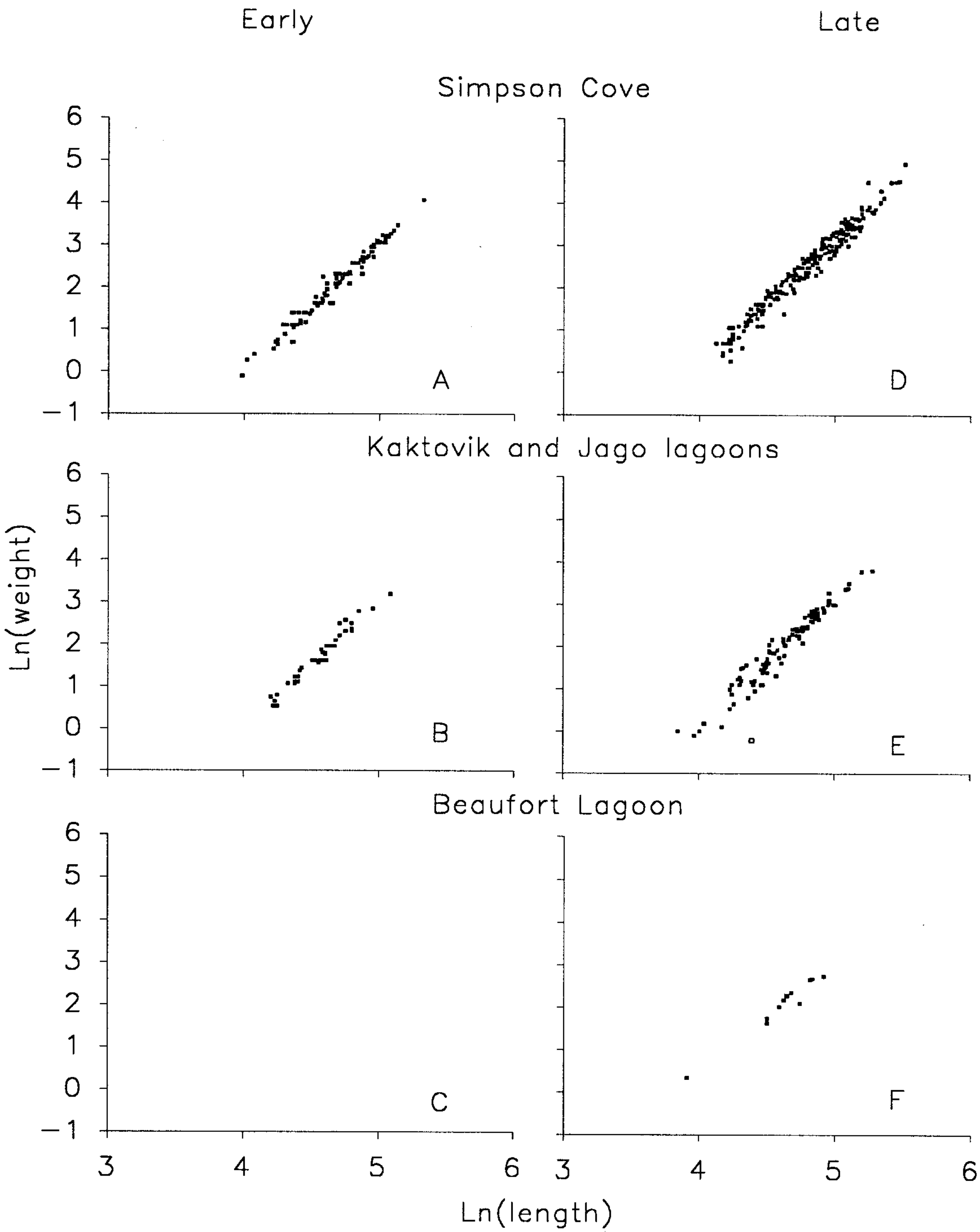


FIGURE 4.38.— Log-transformed Arctic cod weight-length data (□ = outliers) among-area comparisons for early (July, first column) and late (after August 27, second column) with years pooled. Plots are compared down the columns.

TABLE 4.18.— Condition comparisons among years for Arctic cod collected during July pooled over areas and within sampling areas. Within individual sampling areas some years were dropped if sample sizes were inadequate. Asterisks (*) indicate significant differences in condition.

		Slopes		Intercepts			
Group	N	b(SE)	*P*-values	a(SE)	*P*-values	r^2	Pairwise results
			All Areas				
1988	41	3.09 (0.17)		-12.49 (0.78)		0.90	B
1989	57	2.90 (0.06)		-11.44 (0.29)		0.98	A
1990	53	3.01 (0.07)		-12.06 (0.33)		0.97	B
			$P = 0.33$		$P = 0.0001$	*	
	Without outliers		$P = 0.33$		$P = 0.0001$	*	
			Simpson Cove				
1989	52	2.91 (0.06)		-11.51 (0.27)		0.98	
1990	33	3.00 (0.09)		-11.96 (0.42)		0.97	
			$P = 0.40$		$P = 0.063$		
	Without outliers		$P = 0.40$		$P = 0.063$		

other years. In July 1991, we caught few Arctic cod. While slopes did not differ, plots of transformed data showed differences in size range among years (Figure 4.39). No outliers were present. Within Simpson Cove, no significant differences were detected among years (intercept, $P = 0.063$).

Unequal slopes precluded statements about condition for data collected after August 27, pooled over areas and within Simpson Cove (Table 4.19). Condition of Arctic cod from Kaktovik and Jago lagoons differed significantly among years. Plots of transformed data showed a wider dispersion of lengths in 1991 (Figure 4.40). Inclusion of outliers did not affect the analyses.

Age and Growth

Arctic cod collected during July for 1988 and 1989 ranged from 1 to 5 years of age. Age-3 fish occurred most frequently (47%, $N = 30$), with age-2 fish second in frequency (34%, $N = 22$). The overall mean age was 2.8 years ($N = 64$, SE = 0.1), and the overall mean length was 118.6 mm FL ($N = 64$, SE = 4.0). Overlap of length ranges between ages was considerable (Table 4.20). Mean lengths at age indicated Arctic cod grew relatively fast up to age 4, after which growth rates slowed (Figure 4.41A).

No significant differences in mean lengths at age were present among areas or years, although absolute means were generally largest in Jago Lagoon compared with other regions (Tables 4.21, 4.22).

Length frequency distributions for all areas pooled from 1988 and 1989 peaked around 90 mm FL and again at 120 mm FL, with most fish (82%) being larger than 90 mm FL (Figure 4.41). Age frequencies showed a single mode at 3 years.

In Simpson Cove, similar to the overall length frequencies, length frequency modes occurred at 90 and 120 mm FL. Age-3 fish were the most common age group in Simpson Cove (Figure 4.42). Age and length data for areas other than Simpson Cove were insufficient to allow for graphical interpretation. Yearly length frequencies showed different distributions between 1988 and 1989 (Figure 4.43). In 1988, the mode occurred around 90-100 mm FL while, in 1989, the mode occurred around 120-130 mm FL (Figure 4.43). This shift, between 1988 and 1989, of a strong mode to the right may indicate one year of growth of a dominant year class.

Environmental Influences on CPUE

Simpson Cove.— While Arctic cod were abundant in Simpson Cove throughout the 1988 sampling season, hydrographic data were limited. High correlations between Arctic cod catch and temperature ($r = 0.82$) and salinity ($r = -0.92$) resulted from only 10 daily observations in late August (Figure 4.44).

Salinity was most associated with the variation in catch for the limited 1988 data ($R^2 = 0.80$; Table 4.23). Contrary to what may be expected for a resident marine species, the highest catch rate for the year (2,673 fish/d) was recorded at the lowest measured salinity (13 ppt) on August 23. Conclusions about environmental influences on CPUE are weakened by the paucity of thermohaline data during the 1988 sampling season.

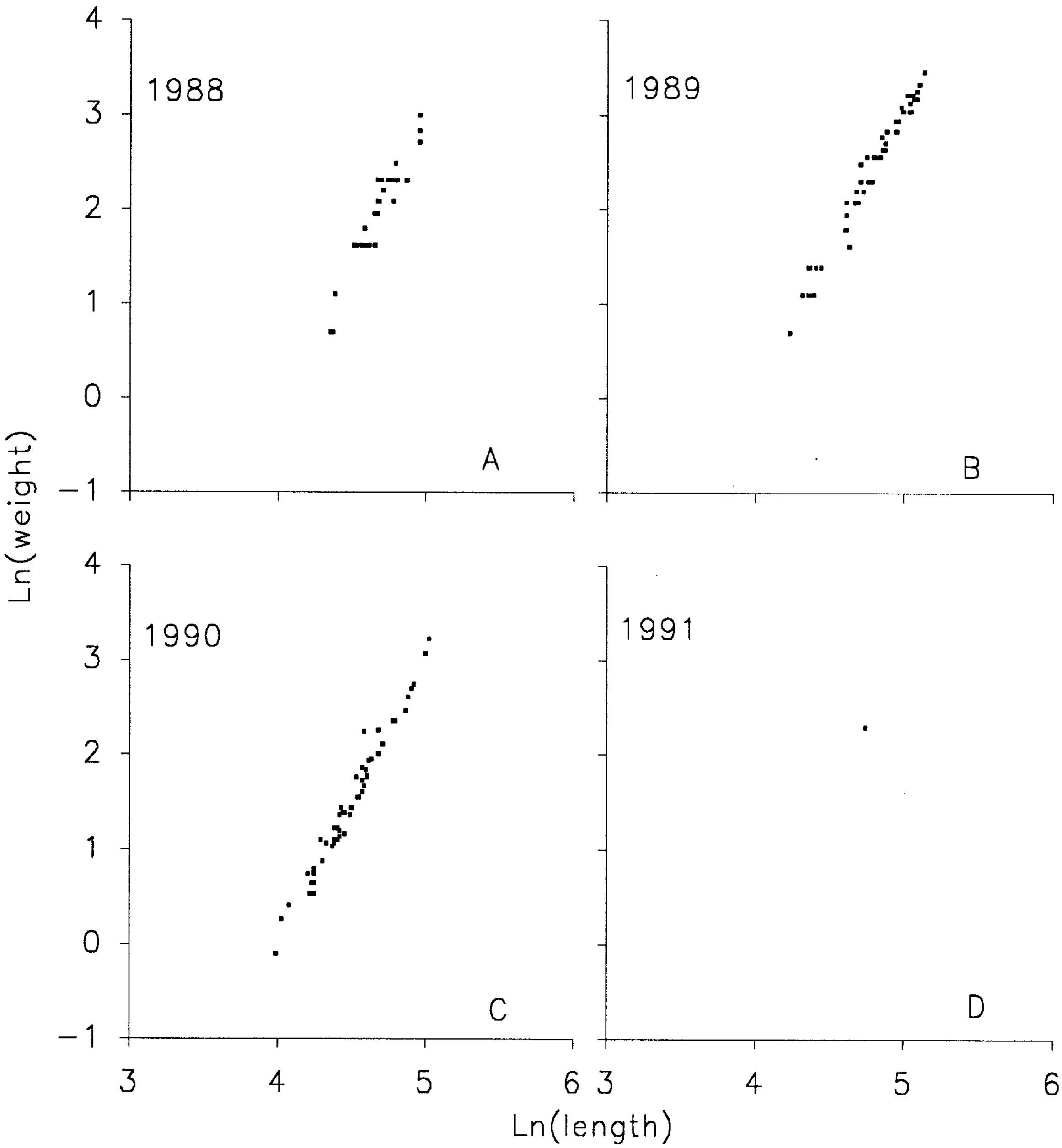


FIGURE 4.39.— Log-transformed Arctic cod weight-length data collected during July in all areas for comparisons among-years.

TABLE 4.19.— Condition comparisons among years for Arctic cod collected after August 27 pooled over sampling areas and within sampling areas. Within individual sampling areas, some years were dropped if sample sizes were inadequate. Asterisks (*) indicate significant differences in condition.

		Slopes		Intercepts			
Group	N	b(SE)	*P*-values	a(SE)	*P*-values	r^2	Pairwise results
			All Areas				
1988	33	3.24 (0.10)		-13.28 (0.50)		0.97	–
1989	74	2.84 (0.05)		-11.11 (0.22)		0.98	–
1990	113	3.08 (0.04)		-12.15 (0.19)		0.98	–
1991	107	3.05 (0.06)		-12.17 (0.29)		0.96	–
			$P = 0.0003$		$P = 0.0001$		–
	Without outliers		$P = 0.0003$		$P = 0.0001$		
			Kaktovik and Jago lagoons				
1990	36	3.04 (0.10)		-11.970 (0.46)		0.97	
1991	48	3.01 (0.11)		-11.966 (0.50)		0.94	
			$P = 0.86$		$P = 0.001$	*	
	Without outliers		$P = 0.86$		$P = 0.001$	*	
			Simpson Cove				
1989	74	2.84 (0.05)		-11.11 (0.22)		0.98	
1990	64	3.15 (0.04)		-12.47 (0.19)		0.99	
1991	59	3.10 (0.07)		-12.40 (0.35)		0.97	
			$P = 0.0001$		$P = 0.0001$		
	Without outliers		$P = 0.0001$		$P = 0.0001$		

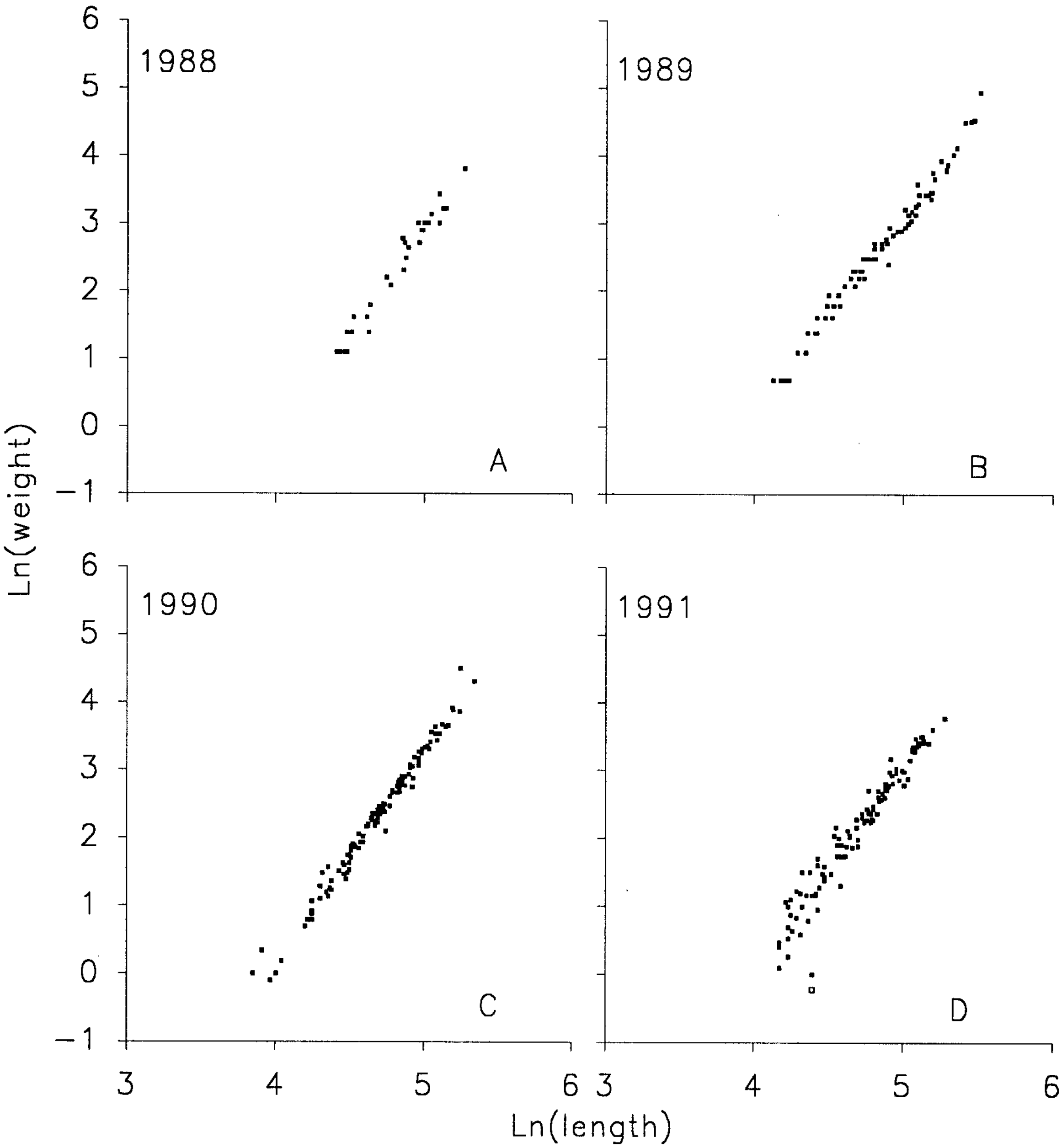
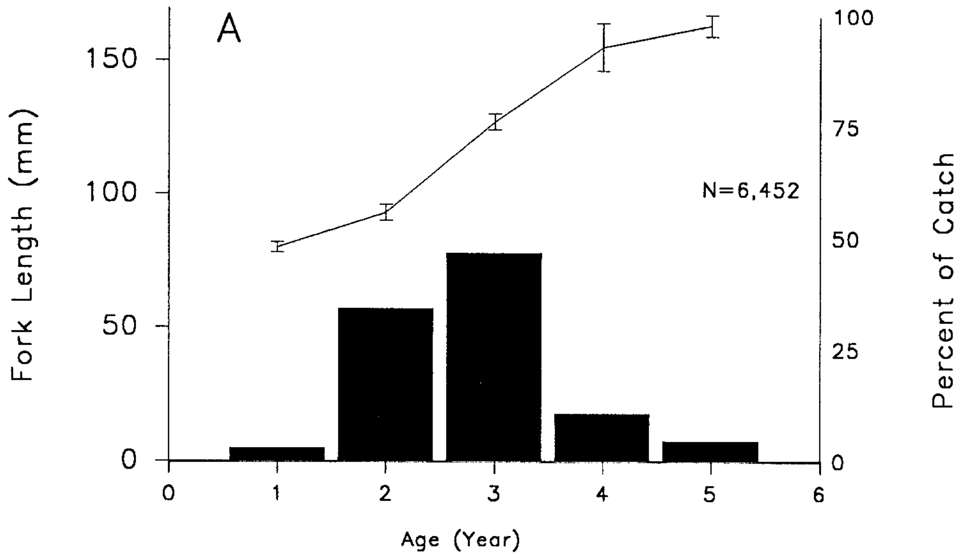


FIGURE 4.40.— Log-transformed Arctic cod weight-length data (□ = outliers) collected after August 27 pooled over areas for comparison among years.

TABLE 4.20.– Mean length at age, standard error (SE), and ranges of Arctic cod collected during July, all years and areas pooled.

Age	*N*	$\bar{x}$(SE)	Range
1	2	80(2)	78-82
2	22	93(3)	75-123
3	30	127(3)	100-162
4	7	155(9)	130-206
5	3	163(4)	155-170
$\bar{x}$ = 2.8	*N* = 64	$\bar{x}$ = 118.6	



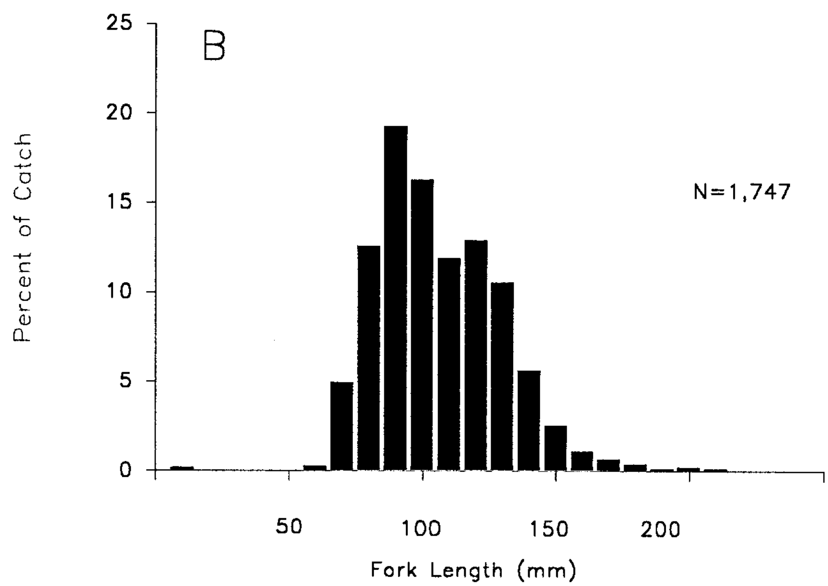


FIGURE 4.41.– Mean length at age (±SE), age frequencies (A) (1988 and 1989), and standard fyke net length frequencies (10 mm intervals, B) (1989-91) for Arctic cod collected during July, years and areas pooled.

TABLE 4.21.– Mean lengths at age and standard error (SE) for Arctic cod collected during July, 1988 and 1989. Similar letters represent no significant differences between those means on a single row.

Age	Simpson Cove			Jago Lagoon			Kaktovik Lagoon		
	N	$\bar{x}$(SE)		*N*	$\bar{x}$(SE)		*N*	$\bar{x}$(SE)	
1	2	80(2)		--	--		--	--	
2	14	90(4)	A	6	102(3)	A	2	85(7)	A
3	26	126(3)	A	4	132(13)	A	--	--	
4	7	155(9)		--	--		--	--	
5	3	163(4)		--	--		--	--	

TABLE 4.22.— Mean lengths, standard error (SE), and ranges of Arctic cod collected during July, areas pooled. Similar letters represent no significant difference between those means.

Age	1988				1989			
	N	$\bar{x}$(SE)	Range		*N*	$\bar{x}$(SE)	Range	
1	1	78(--)	--		1	82(--)	--	
2	8	98(4)	79-119	A	14	90(4)	75-123	A
3	5	126(8)	107-142	A	25	127(4)	100-162	A
4	1	130(--)	140-206		6	159(10)	140-160	
5	--	--	155-170		3	163(4)	155-170	

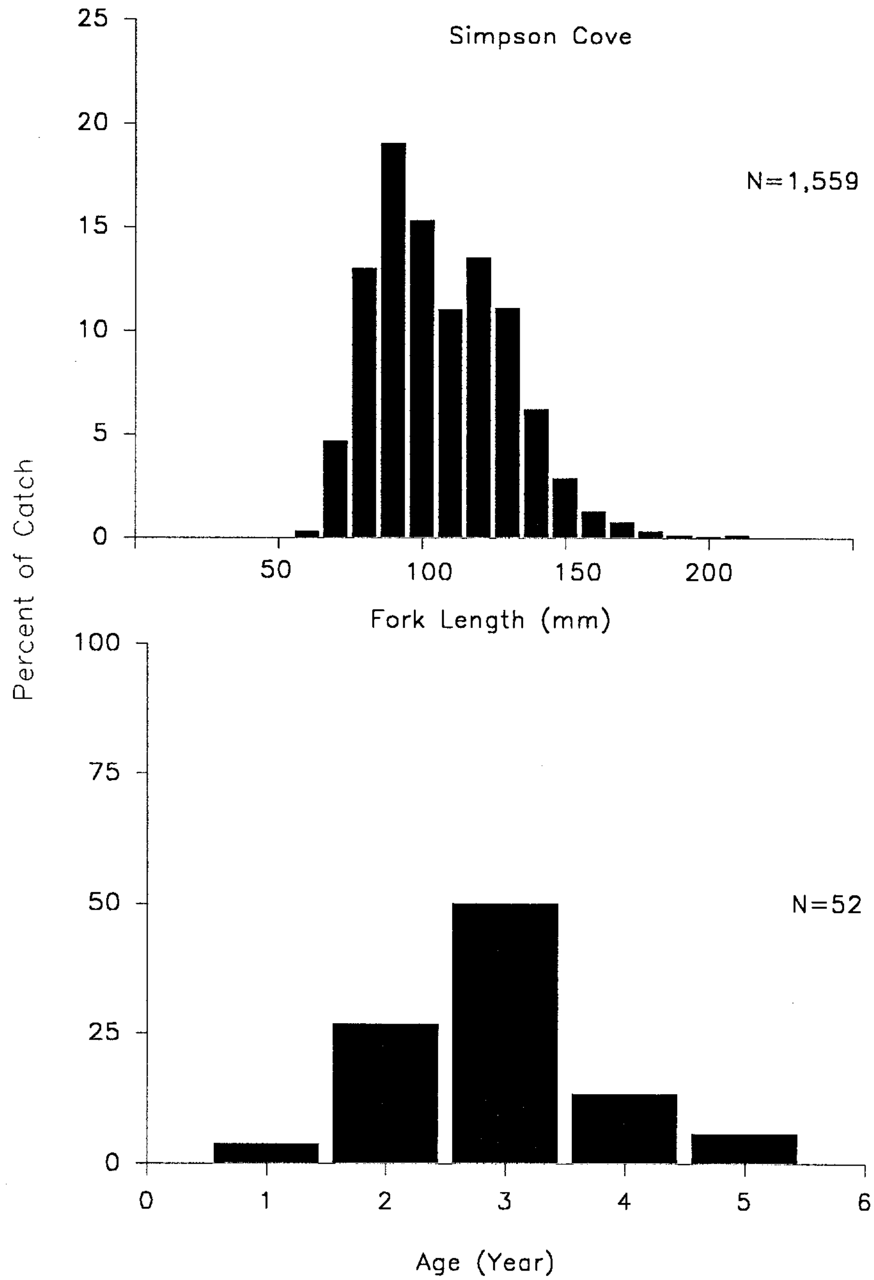


FIGURE 4.42.— Length frequencies (10 mm intervals) for standard fyke net catches (1988-91) and age frequencies for Arctic cod collected during July (1988 and 1989) for Simpson Cove.

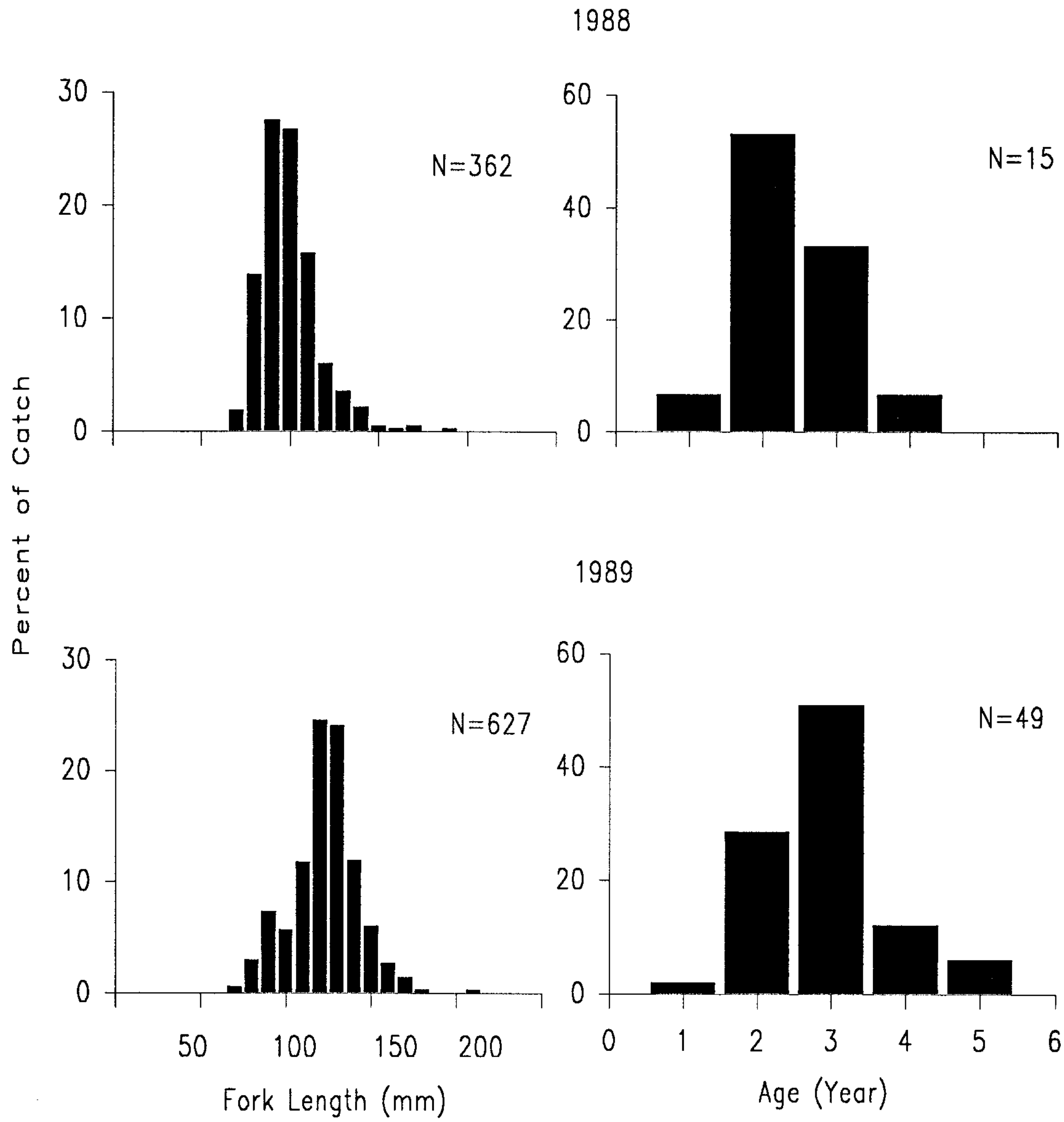


FIGURE 4.43.— Length frequencies (10 mm intervals) for standard fyke net catches and age frequencies for Arctic cod collected during July, 1988 and 1989 with areas pooled.

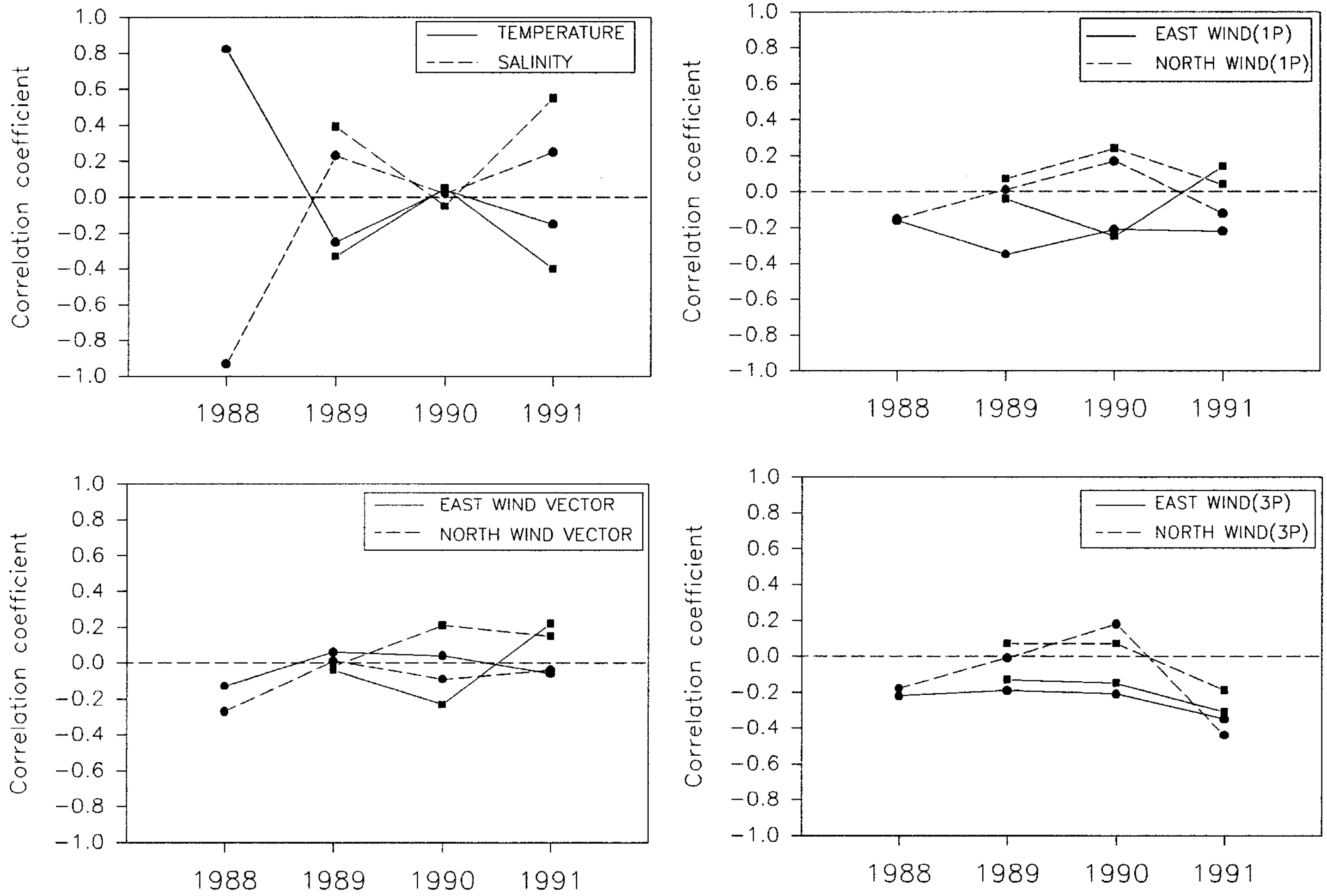


FIGURE 4.44.– Correlations between environmental variables and Arctic cod CPUE from fyke net stations SC01 (•) and SC04 (▪) (1988-91) in Simpson Cove. [1P=mean wind vector for previous day; 3P=mean of wind vector over 3 previous days].

TABLE 4.23.— Environmental variables[a] influencing Arctic cod CPUE (fish/d), followed by R^2-value of overall model. Parameter estimate is positive unless followed by "(-)". ("nv" = no eligible variables.)

Station	Year 1988	1989	1990	1991
Simpson Cove				
SC01	SAL(-) (0.80)	SAL EW1P(-) NW3P(-) (0.47)	EW3P(-) (0.22)	SAL EW3P(-) (0.58)
SC04		SAL (0.23)	EW(-) EW3P(-) (0.30)	SAL (0.73)
Kaktovik Lagoon				
KL05	nv	TEMP(-) (0.37)	NW(-) (0.14)	TEMP(-) EW NW3P(-) (0.55)
KL10	SAL(-) EW3P(-) NW3P(-) (0.72)	TEMP(-) EW3P(-) NW3P(-) (0.55)	EW3P(-) (0.25)	TEMP(-) NW1P(-) (0.48)
Jago Lagoon				
JL12	SAL(-) EW (0.34)	TEMP(-) NW3P (0.67)	nv	nv
JL14	SAL(-) EW1P (0.43)	TEMP(-) NW3P (0.49)	nv	NW1P (0.23)
Beaufort Lagoon				
	Insufficient data			
Pokok Bay				
PB01	nv			
PB02	SAL NW3P EW3P NW1P(-) (0.52)			

[a] EW=mean east wind vector; EW1P=mean east wind vector for previous day; EW3P=mean of east wind vector over 3 previous days; NW=mean north wind vector; NW1P=mean north wind vector for previous day; NW3P=mean north wind vector over 3 previous days; SAL=salinity(ppt); TEMP=temperature(C).

Salinity was again the variable most associated with catch variability in Simpson Cove in 1989, for both the area-wide (Table 4.24) and station-specific (Table 4.23) analyses. East wind components were significant in the area-wide and station SC01 stepwise analyses, and were negatively related to catch in each case. We observed a noticeable jump in catch of Arctic cod during 1989 in Simpson Cove starting August 19 (2,528 fish/d). The highest observed catch at station SC04 during the two weeks prior to this date was 286 fish/d. The observed rise in catch rates coincided with a coastal upwelling event precipitated by a four-day period of strong easterly winds and the resultant offshore movement of warmer, coastal surface waters. The upwelling event was followed by mostly westerly winds at the end of the sampling season which held offshore water against the coast. Catch rates for Arctic cod remained high throughout this late summer period of westerly winds.

In 1990, similar to previous years, large numbers of Arctic cod appeared in Simpson Cove in August. Although salinities were relatively high during the 1990 sampling season, catches were generally lower than those of the 1988 and 1989 sampling seasons (Figure 4.45). East wind components were the only significant factor associated with seasonal variability in 1990 catch rates, but these relationships were weak ($R^2 \leq 0.30$) at both the area and station levels (Tables 4.23, 4.24). A large pulse of Arctic cod was present in Simpson Cove in early August, when the catch peaked at 67,875 fish/d at station SC01 on August 4. This pulse of fish in the nearshore waters occurred during a brief period of west winds on August 2-3 which had been preceded by a 10-day period of east winds, coinciding with the sequence of upwelling and subsequent onshore advection of colder waters.

In 1991, Arctic cod entered Simpson Cove in early August after nearshore salinities reached and exceeded 10 ppt. Salinity was most associated with variation in catch for station and area-wide analyses (Tables 4.23, 4.24). A negative east wind effect was also present during the 1991 sampling season, i.e. west winds were associated with higher catches. Our data suggest that the highest catch rates occurred at the lower end of the distribution of temperatures available over the sampling season (Figure 4.46). We expected this result since Arctic cod are relatively absent during the early season when coastal waters were more influenced by the warmer and less saline terrestrial runoff.

Overall, Arctic cod daily catch rates and mean salinity were highest in Simpson Cove during each year of our study (Table 4.25). Mean temperatures were generally lower than in other sampling areas, as might be expected due to the relatively exposed nature of Simpson Cove when compared to the remaining barrier island/lagoon systems.

Kaktovik Lagoon.– In 1988, Arctic cod entered Kaktovik Lagoon around August 6-7 when water temperature was near 10°C and salinity was 10 ppt and maintained a presence through the end of sampling in mid-September. During the four years of this study, the highest Arctic cod catch in Kaktovik Lagoon coincided with the lowest observed seasonal temperatures in 1988 (Figure 4.47). However, early season thermohaline data were missing and thus

TABLE 4.24.— Environmental variables[a] influencing Arctic cod CPUE (pooled over stations). Coefficient of partial correlation (r^2_p) for each effect and overall R^2 shown as determined by stepwise selection procedure. ("nv" = no eligible variables.)

Year	Environmental variable	r^2_p	R^2
	Simpson Cove		
1988	SAL	0.80	0.80
1989	SAL	0.24	
	EW1P	0.07	
	EW3P	0.05	
	NW3P	0.04	0.33
1990	EW3P	0.22	0.22
1991	SAL	0.59	
	EW3P	0.19	0.63
	Kaktovik Lagoon		
1988	EW3P	0.18	0.18
1989	TEMP	0.44	
	NW	0.08	
	SAL	0.06	
	EW	<0.01	0.49
1990	SAL	0.21	
	TEMP	0.09	
	EW3P	0.08	0.31
1991	TEMP	0.38	
	NW1P	0.14	
	EW	0.12	0.48
	Jago Lagoon		
1988	SAL	0.25	
	EW1P	0.08	0.30
1989	TEMP	0.55	
	NW3P	0.10	0.57
1990	nv		
1991	nv		
	Beaufort Lagoon		
	Insufficient data		
	Pokok Bay		
1988	nv		

[a] EW=mean east wind vector; EW1P=mean east wind vector for previous day; EW3P=mean of east wind vector over 3 previous days; NW=mean north wind vector; NW1P=mean north wind vector for previous day; NW3P=mean north wind vector over 3 previous days; SAL=salinity(ppt); TEMP=temperature(C).

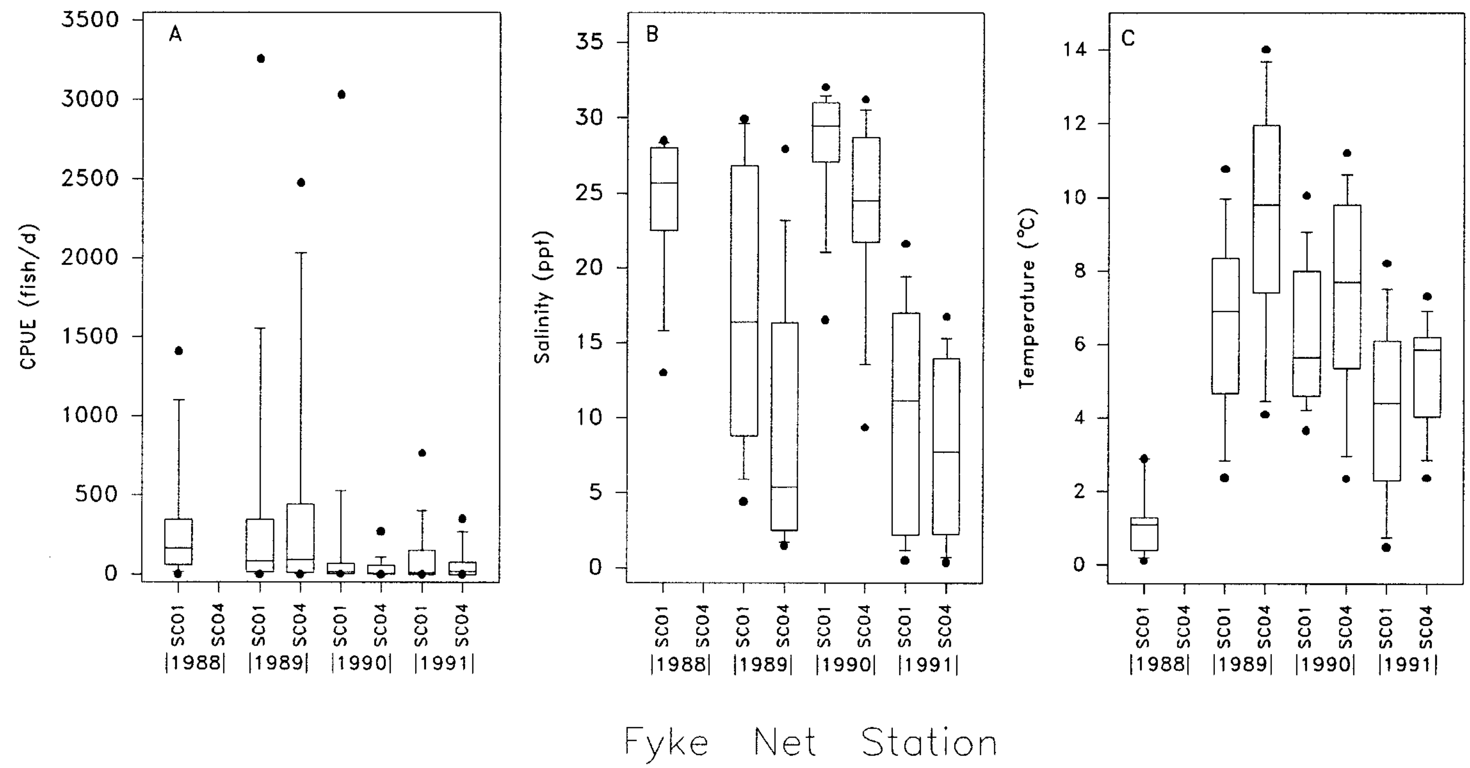


FIGURE 4.45.– Boxplots of (A) catch per unit effort for Arctic cod, (B) salinity, and (C) temperature for Simpson Cove fyke net stations during 1988-91.

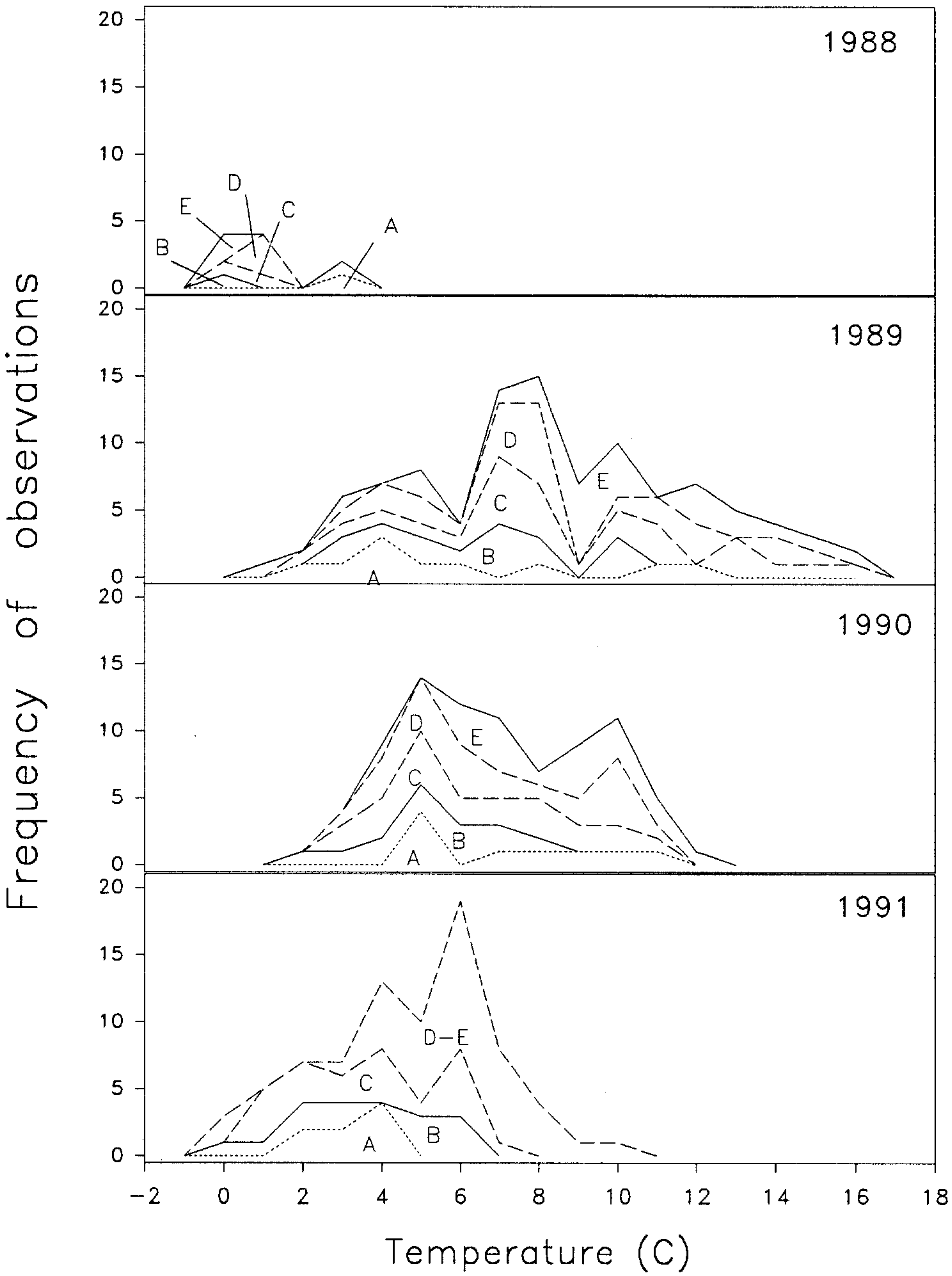


FIGURE 4.46.— Frequency of occurrence, by mean daily water temperature, of top 10 (A), 25 (B), 50 (C), 75 (D), and 100 (E) percentile catch per effort data points for Arctic cod in Simpson Cove, 1988-91.

TABLE 4.25.— Comparisons of daily Arctic cod CPUE (fish/d), mean daily water temperature (C), and mean daily salinity (ppt) between sampling areas, 1988-91. Areas connected by a common underline are not significantly different (ANOVA, Scheffé multiple comparisons, $\alpha=0.05$). Where different, areas are ordered from larger to smaller mean values for the comparison variable.

Variable	Scheffé grouping			
		1988		
CPUE	Simpson	Pokok	Jago	Kaktovik
Temp.	Kaktovik	Jago	Pokok	Simpson
Salinity	Simpson	Kaktovik	Jago	Pokok
		1989		
CPUE	Simpson	Jago	Kaktovik	
Temp.	Jago	Kaktovik	Simpson	
Salinity	Simpson	Jago	Kaktovik	
		1990		
CPUE	Simpson	Jago	Kaktovik	Beaufort
Temp.	Beaufort	Kaktovik	Simpson	Jago
Salinity	Simpson	Jago	Beaufort	Kaktovik
		1991		
CPUE	Simpson	Jago	Kaktovik	Beaufort
Temp.	Beaufort	Kaktovik	Jago	Simpson
Salinity	Simpson	Kaktovik	Jago	Beaufort

associations between catch and environmental trends reflected only late season conditions. Catch rates for the two fyke net stations within the lagoon appeared to be relatively independent in 1988. No environmental variables were significantly associated with catch rate variability at station KL05 in 1988, while salinity and both east and north wind components accounted for a high proportion of catch variation ($R^2 = 0.72$) at station KL10 (Table 4.23). Salinity was negatively correlated with catch of Arctic cod at station KL10 (Figure 4.48).

Arctic cod catch rates in Kaktovik Lagoon were low during the 1989 sampling season. Low catch rates coincided with a general trend of lower salinities and higher temperatures in the lagoon (Figure 4.47). On a seasonal basis, temperature was most strongly associated with variation in catch rate at both the area-wide and station-specific level (Tables 4.23, 4.24). As expected, catch and temperature were negatively correlated in 1989 (Figure 4.48). In 1990, Arctic cod moved into Kaktovik Lagoon in late August when salinities were generally above 28 ppt and water temperature was below 8°C. We detected few distinct patterns of association between catch and environmental conditions at the area-wide and station-specific levels ($R^2 \leq 0.31$; Tables 4.23, 4.24). As expected from the late August arrival of Arctic cod in 1990, higher catch rates appeared to occur at the colder water temperatures available over the course of the entire sampling season (Figure 4.49). Peaks in CPUE on September 4-5 and September 12 appeared to coincide with or immediately follow wind shifts from east to west.

Temperature was again the primary influence on seasonal catch rates of Arctic cod in Kaktovik Lagoon in 1991. The highest catch rates occurred at the lower available temperatures during the sampling season, reflecting the relatively late arrival of Arctic cod into the coastal waters (Figure 4.49). Coefficients of determination from stepwise regression were high for both station KL05 ($R^2 = 0.55$) and KL10 ($R^2 = 0.48$; Table 4.23), and for the pooled area-wide data ($R^2 = 0.48$; Table 4.24). Associations between catch peaks and episodic upwelling events were hampered by numerous east-west wind shifts during the 1991 sampling season.

Jago Lagoon.— Although we occasionally caught Arctic cod in July samples in Jago Lagoon, appreciable numbers first appeared in the middle of August during all four study years. Catch rates were relatively low for this abundant marine species for all years except 1988 (Figure 4.50). Water temperatures in Jago Lagoon were also lowest during the 1988 sampling season. The unexpected positive correlation between catch rate and temperature in 1988 (Figure 4.51) may be an artifact of the overall low temperature; all cod were caught in temperatures less than 8°C. Salinity appeared to affect catch rates in 1988, but again not in the expected direction. The relatively strong negative correlation between catch and salinity in 1988 is reflected in the stepwise regression results for both individual and pooled station data (Tables 4.23, 4.24). Small R^2-values ($R^2 < 0.35$) for both analyses indicate the relationships between catch rates and salinity were weak. A small positive association between catch and east wind components was also evident in 1988.

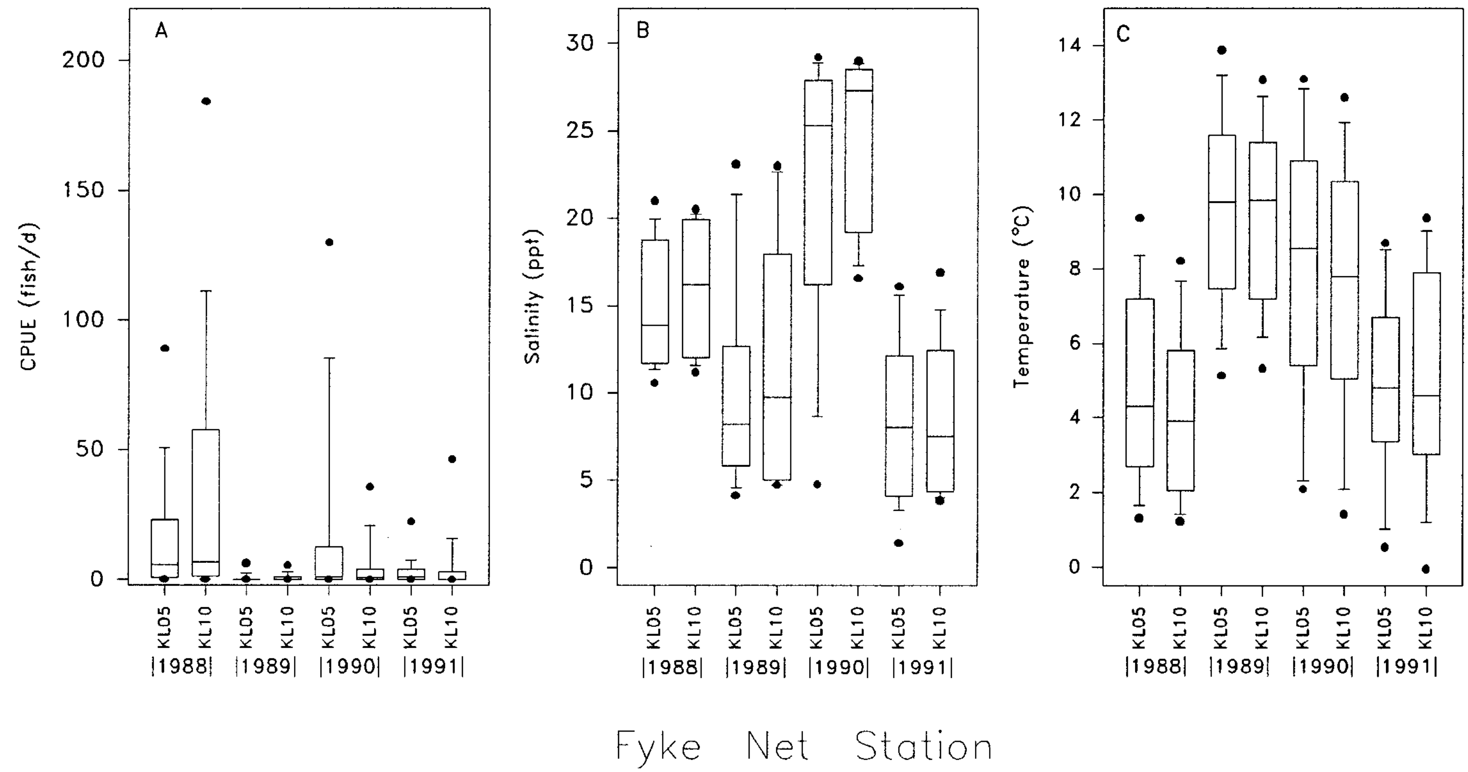


FIGURE 4.47.— Boxplots of (A) catch per unit effort for Arctic cod, (B) salinity, and (C) temperature for Kaktovik Lagoon fyke net stations during 1988-91.

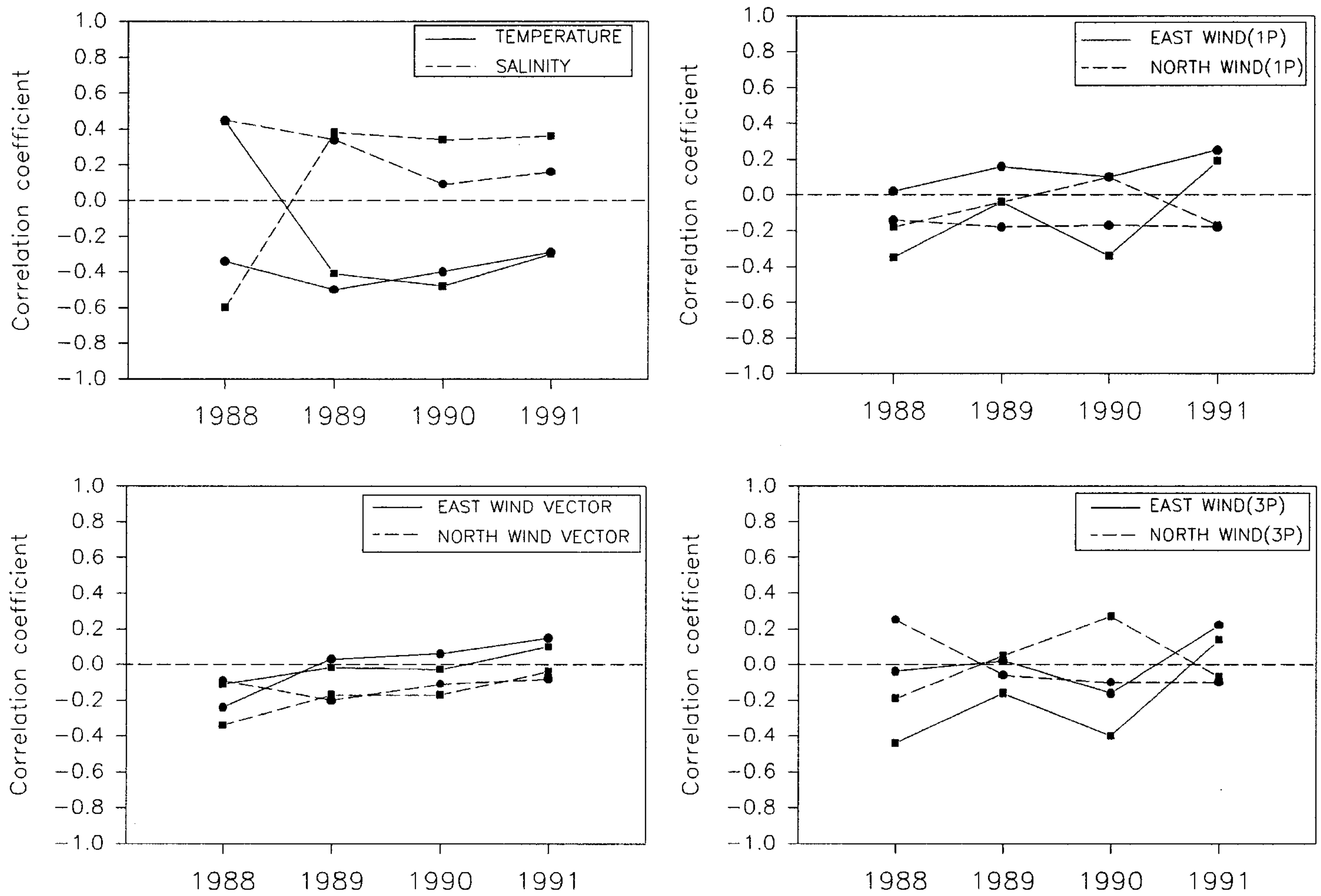


FIGURE 4.48.– Correlations between environmental variables and Arctic cod CPUE from fyke net stations KL05 (•) and KL10 (▪) in Kaktovik Lagoon, 1988-91. [1P=mean wind vector for previous day; 3P=mean of wind vector over 3 previous days].

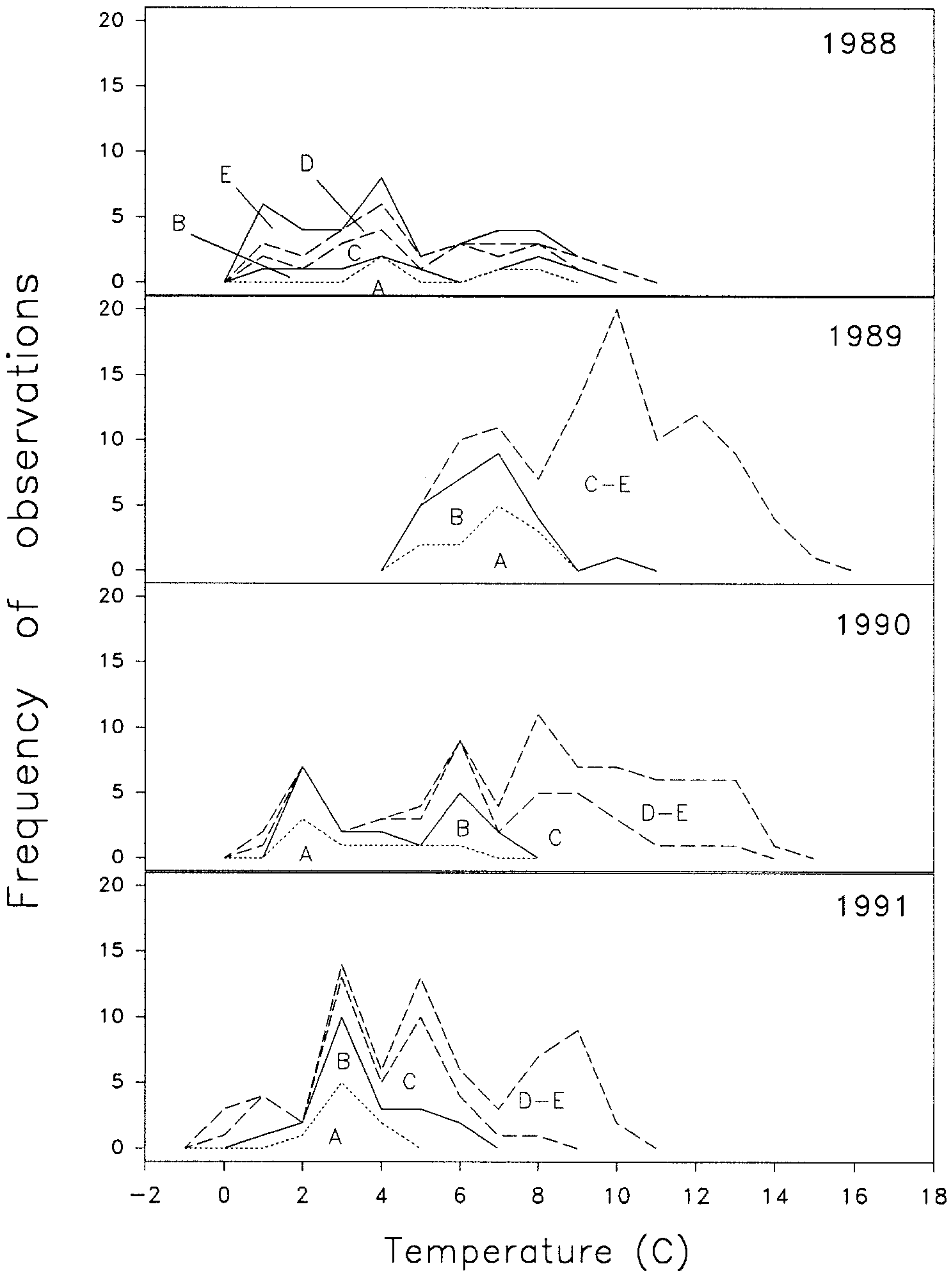


FIGURE 4.49.— Frequency of occurrence, by mean daily water temperature, of top 10 (A), 25 (B), 50 (C), 75 (D), and 100 (E) percentile catch per effort data points for Arctic cod in Kaktovik Lagoon, 1988-91.

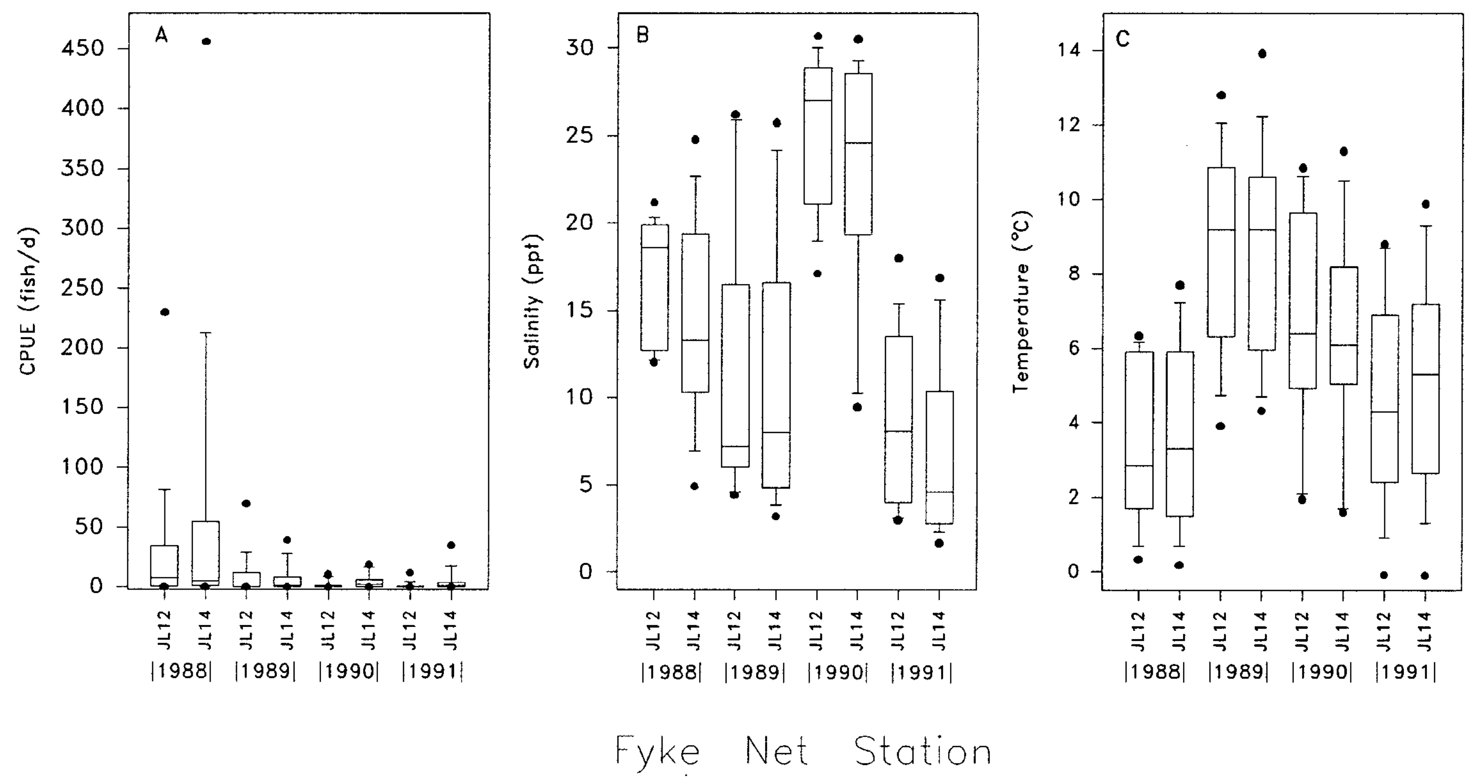


FIGURE 4.50.– Boxplots of (A) catch per effort for Arctic cod, (B) salinity, and (C) temperature for Jago Lagoon fyke net stations during 1988-91.

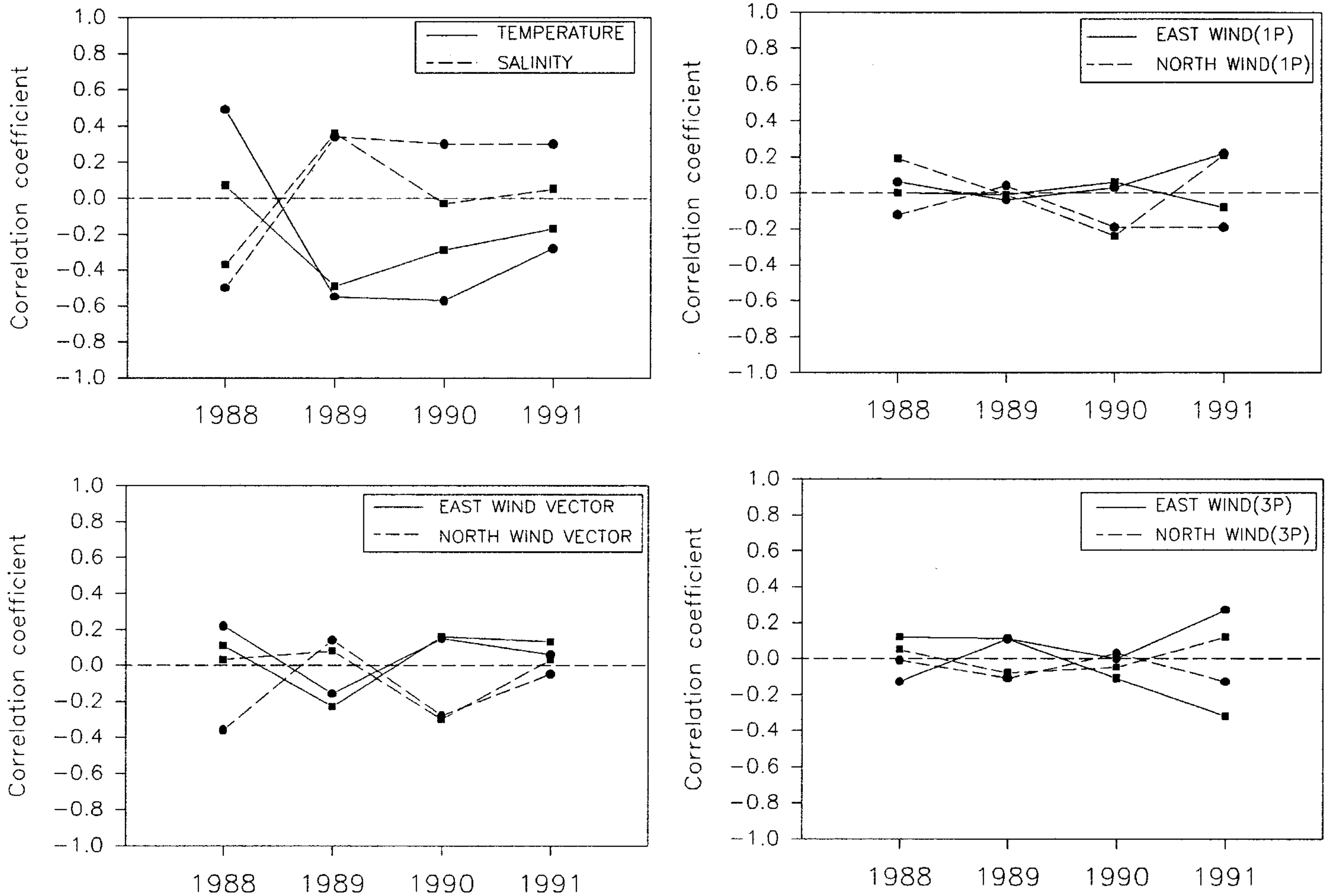


FIGURE 4.51.– Correlations between environmental variables and Arctic cod CPUE from fyke net stations JL12 (•) and JL14 (▪) in Jago Lagoon, 1988-91. [1P=mean wind vector for previous day; 3P=mean of wind vector over 3 previous days].

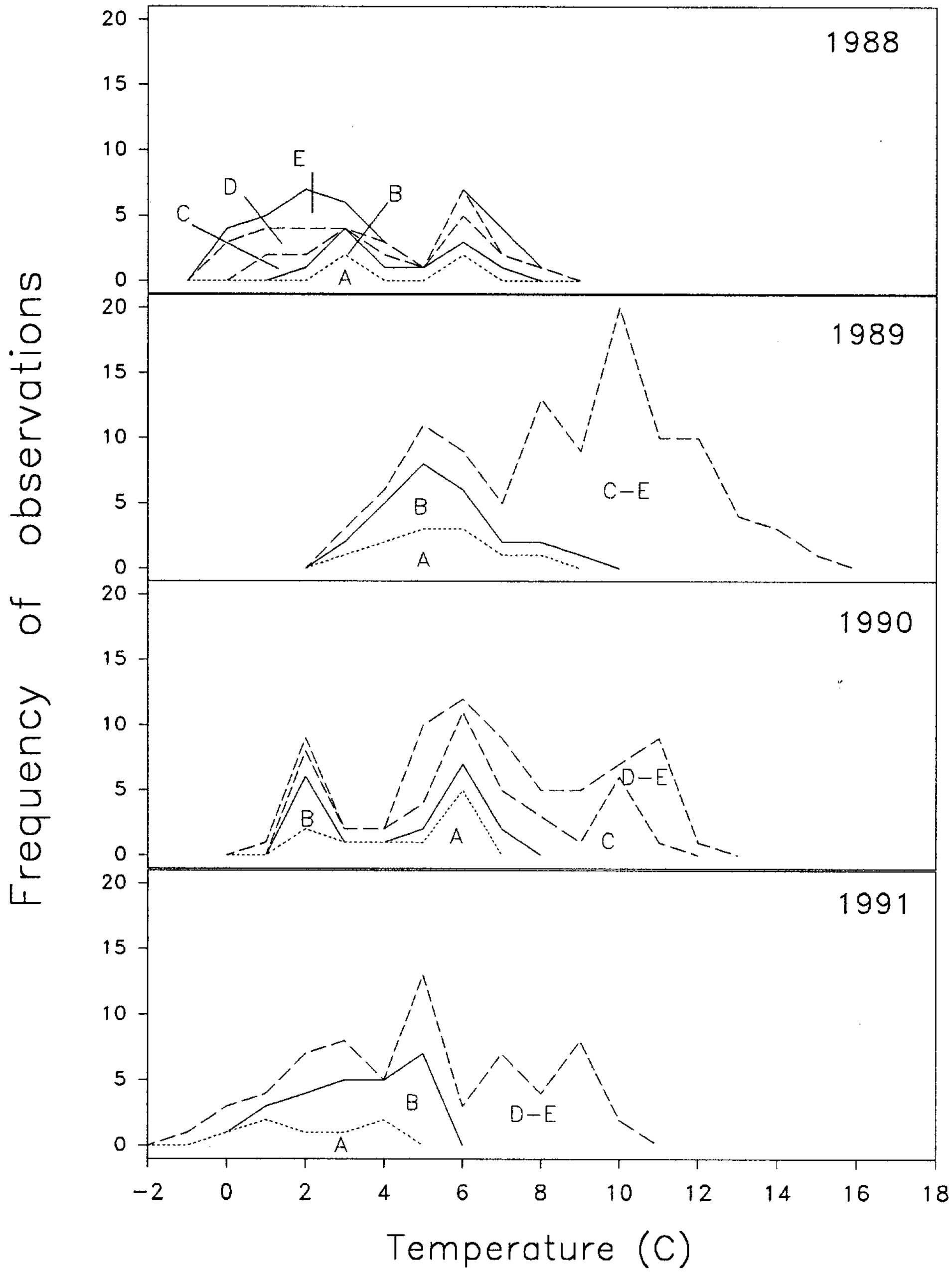


FIGURE 4.52.- Frequency of occurrence, by mean daily water temperature, of top 10 (A), 25 (B), 50 (C), 75 (D), and 100 (E) percentile catch per effort data points for Arctic cod in Jago Lagoon, 1988-91.

Water temperatures were considerably higher in Jago Lagoon in 1989 (Figure 4.50), and were negatively correlated with catch rates (Figure 4.51). Arctic cod did not appear in Jago Lagoon in 1989 in significant numbers until mid-August, when water temperatures dropped below 10°C for the remainder of the sampling season. The corresponding stepwise regressions revealed temperature as the dominant explanatory variable for station-specific (JL12 $R^2 = 0.67$; JL14 $R^2 = 0.49$) and pooled area ($R^2 = 0.57$) catch rates. This association was also exhibited in the distribution of catch rates over available temperatures in 1989, where the highest relative catch rates occurred at the lower temperatures (Figure 4.52).

Although Jago Lagoon salinities were relatively high in 1990, less than 300 Arctic cod were captured. No environmental variables were strongly correlated with the variation in catch (Tables 4.23 and 4.24). Catch of Arctic cod in 1991 was again low (N < 400), although a weak positive association ($R^2 = 0.23$) with a north wind element was detected by stepwise regression for station JL14. There was a tendency for the highest catch rates to be found at the lower available temperatures again in 1991 (Figure 4.52). Wind elements as a whole exhibited very little association with Arctic cod catch rates in Jago Lagoon throughout the study period.

Beaufort Lagoon.— We caught a total of 32 Arctic cod in Beaufort Lagoon during the 1990 and 1991 sampling seasons. The small number of captured fish precluded any meaningful analyses of environmental influence on catch rate variation.

Pokok Bay.—Salinity was positively correlated with Arctic cod catch rates in Pokok Bay in 1988. Catch rates increased on August 18-19 when water temperatures at the net stations ranged from 5-7°C and salinity was near 15 ppt. Water temperature gradually decreased over the remainder of the sampling season, while salinity remained relatively unchanged. Arctic cod appeared to remain present in Pokok Bay until September 5, when catch rates decreased to less than 15 fish/d through the end of sampling.

Stepwise regression identified an association between north and east wind components and catch rates for station PB02, although the varying directions of the relationships hinder detection of consistent patterns (Table 4.23). No environmental variables were associated with the seasonal variation in catch rates observed at station PB01.

Discussion

Relative Abundance and Distribution

Arctic cod catch rates in Simpson Cove (e.g. 63,752 fish/d) were consistently higher than those in the other sampling areas during the course of the study. Simpson Cove waters could have provided a higher abundance of food items, as described for Simpson Lagoon by Craig (1984). In contrast, the Beaufort Lagoon fyke nets produced only 35 Arctic cod during 1990 and 1991, and thus had daily catch rates which were consistently lower than other sampling areas. Factors such as salinity, temperature, current patterns, pack ice, and prey distribution could have contributed to the observed Arctic cod distribution patterns. It was not surprising to find the highest numbers of Arctic cod, a resident marine species, in Simpson Cove, the system most influenced by offshore conditions.

Arctic cod have been described as inhabiting the nearshore waters during the open-water season, and the deeper offshore waters during the winter months (Craig 1984). This pattern is suggested by the differences observed between the Arctic cod catch rates from the earliest (prior to and including July 31) and latest (after August 31) time periods. If conditions caused a delayed inshore movement, Arctic cod daily catch rates would be expected to increase during the open-water season (e.g., net station SC04 in 1989, 1990, and 1991). Conditions resulting in early inshore movement and delayed offshore movement could produce relatively constant catch rates during sampling (e.g., net station SC01 in 1988 and 1990). Otherwise, if conditions caused delayed inshore movement and early offshore movement, daily catch rates should be seen to start low, increase, then drop off again (e.g., net station JL14 in 1988).

Comparisons of Arctic cod daily catch rates between years indicated that 1988 daily catch rates were higher than in other years in Simpson Cove and Kaktovik and Jago lagoons. For these locations, the decline in daily catch rates from 1988 to 1991 seems to be primarily due to declines during time periods 1 and 2. This suggests temporal differences in the environmental conditions during the early open-water season. The lack of between-year differences observed in Beaufort Lagoon is caused by the very low daily catch rates in this location during the study.

The Arctic cod relative abundance trends observed in this study identify potential concerns for future sampling. Our two-way analysis of variance indicated that, for the duration of this study, Arctic cod distribution was much more variable among sampling areas than between years. The variability evident in daily catch rates between sampling locations (e.g., Simpson Cove and Beaufort Lagoon) indicates the need for determination of probable oil and gas development sites. Our results suggest that development in Simpson Cove may have more of an impact on the Arctic cod population than would development in Beaufort Lagoon. Possible development sites should be sampled with multiple net stations (> 2) to provide a comprehensive description of fish abundance and distribution within these areas.

A long time series of data (i.e., greater than 10 years) is necessary to detect cyclic abundance patterns in cold water marine species. The ability to identify interannual patterns and trends in relative abundance is also dependent on continuous time series of data with no variation in sampling design.

Length Frequency Distributions

Our results on Arctic cod length frequencies indicate one distributional mode (Figures 4.28-4.35). This single mode probably corresponds to a dominant year class (age-2 or age-3) in a population of fast-growing, short-lived individuals. Other work along the Beaufort Sea has shown similar unimodal length distributions (Lowry and Frost 1981; Craig et al. 1982). More intensive sampling in the future would aid detection of patterns of recruitment of young-of-the-year to the sampled population.

The accelerated growth in 1989 shown by the modes at larger lengths is most likely reflective of warmer water temperatures during that year (this study).

Condition

Gender differences.— Separate sampling of female and male fish is recommended when collecting weight-length data because body form is often gender specific (Bagenal and Tesch 1978). We found no differences in condition between female and male Arctic cod; therefore, future analyses may not need to distinguish sex to evaluate condition of Arctic cod.

Seasonal differences.— The observed increases in condition are consistent with the concept that Arctic cod consume and store nutrients and energy during the short summer season in preparation for winter. In addition, Arctic cod gonad development may increase during the summer. Final maturation occurs prior to spawning during the winter months (Lowry and Frost 1981).

These temporal differences in condition suggest that comparative studies should incorporate synchronous sampling (i.e., among years or among areas) to minimize variation. In multi-year studies the time period should be consistent (e.g., samples collected in July of 1988-91). For spatial comparisons within one year, samples should be collected concurrently in all areas (e.g., samples collected in Kaktovik, Jago, and Beaufort lagoons in September.)

Overwintering.— Plots of log-transformed data indicated obvious differences in fall and spring data sets (Figure 4.36). The truncated data set confirmed significant differences in condition. The observed lower condition is consistent with concepts of energetics and spawning behavior of Arctic cod discussed above (seasonal differences).

In the non-truncated data larger fish present in the fall sample caused statistical differences in slope possibly because of gonad maturity. Bagenal and Tesch (1978) noted that differences in slope can be expected when different stanzas are sampled. Exclusion of larger fish from our analysis allowed comparisons of equivalent size groups of cod and significant condition differences were then detected. In future studies it may be reasonable to analyze data from size intervals which are fully represented in all treatment groups.

Spatial differences.— The lack of differences in condition between sampling areas may reflect the marine life history of Arctic cod. If cod spend more time in marine waters (which are more uniform than lagoons in terms of temperature and salinity within each year) and minimize time spent in lagoons during summer, few spatial differences in condition would be expected. The spatial results indicate that site-specific collection of condition data may not be needed to establish a baseline.

Low catches of Arctic cod in Beaufort Lagoon resulted in inadequate sample sizes. If condition information was necessary, additional sampling effort would be needed to collect sufficient data. This may be irrelevant, however, because results in other areas imply no differences would be found. In addition, Arctic cod catch in Beaufort Lagoon was low, indicating that the area may not be preferred habitat (CPUE Analysis this chapter).

Annual differences.— Differences in annual condition found in fish collected in July may reflect annual variation in food availability caused by differential primary production (Lowry and Frost 1981). Various mechanisms may affect food availability and thus, affect condition. For example, ice pack varied among the years affecting water temperatures, nutrient transport from marine waters, and primary productivity through shading. We documented temperature and salinity difference between some years (Figures 4.45, 4.47, 4.50). Salinities in Simpson Cove were lower in 1989 than in 1988 and 1990 (Figure 4.45). These results are similar to condition comparisons (Table 4.15). Interannual temperature differences were observed (1988 < 1991 < 1990 < 1989) (Figures 4.45, 4.47, 4.50), but differed in order relative to the salinity results. Annual differences in wind direction and velocity affect the transport of nutrients from cold offshore marine waters into the nearshore environment (Craig 1984).

Our results indicated that annual variation is a major component of the variability seen in body condition. Further research on the mechanisms responsible for annual variation would help assess the potential effects of development projects. Future study designs should address these questions.

Age and Growth

Our age data suggest one year class (age-3) dominated the Arctic cod of our sample. However, the length frequencies showed two modes in the overall and Simpson Cove distributions (Figures 4.41, 4.42). These two modes probably represent 2- and 3-year-olds, respectively (Table 4.20). Because overlap in length ranges among ages was large and validation is lacking, some 2-year-olds may have been aged as 3-year-olds resulting in the single peak in age frequency distributions.

Lowry and Frost (1981) found 81% of the Arctic cod collected in fall otter trawls in western Beaufort Sea were age-1 and they did not catch fish older than 4 years old. However, their data are not comparable to ours because of the time period (fall) and area (western Beaufort Sea) in which they were collected. Lowry and Frost (1981) suggested that greatest growth of Arctic cod occurs in the second year of life. Our data (Tables 4.20, 4.21, 4.22: 34, 36, 37 mm, respectively) show greatest mean growth occurs between July of age-2 and July of age-3 (i.e., during the third year of life). More extensive and synoptic sampling of Arctic cod across their entire range is needed to determine if geographic differences in growth exist.

Simpson Cove was the only area where large sample sizes for age were collected during July (N = 52). These large samples sizes are reflective of the generally high abundance of Arctic cod in Simpson Cove throughout the four years (Fruge et al. 1989; Palmer and Dugan 1990; Underwood et al. 1992; this study). This area may represent important habitat for Arctic cod and may warrant further study should development become imminent.

In 1988, the length frequency mode at 90-100 mm FL correlates with the other distributions, but the 1989 mode it is 20-30 mm larger (Figure 4.43). This pattern is also evident in the fyke net length distributions in the preceding section (Figures 4.28-4.35). As our hydrographic data show, water temperatures in all sampling areas were warmer in 1989 than in 1988. The larger mode in 1989 length frequencies may indicate that Arctic cod had begun responding to the increase in food availability associated with warmer temperatures with increased growth before our sampling commenced in July.

Environmental Influences on CPUE

The movement of large numbers of Arctic cod into nearshore waters in August has been reported in similar distributional studies from the Arctic coast (Craig et al. 1982; Griffiths and Gallaway 1982; Cannon et al. 1987). Nearshore waters, particularly Simpson Cove, exhibited more marine characteristics as the summer progressed and riverine influence decreased. Within a sampling season, Arctic cod were always more abundant in the exposed waters of Simpson Cove and least abundant in the sheltered Beaufort or Kaktovik lagoon systems. The association of Arctic cod in nearshore waters in late summer, coincident with colder, more saline water, is consistent with their status as a marine species. The statistical relationships between catch rates and both temperature and salinity reflect seasonal trends, i.e., they do not identify the mechanisms governing the daily horizontal movement of Arctic cod. The conditions governing short-term onshore and offshore movements by Arctic cod remain difficult to quantitatively characterize.

We documented few consistent linear associations between east or north wind components in this study. Localized peaks in catch were often coincident with west winds which had succeeded longer periods of easterly winds. Oceanographic work in the same system by Hale (1990, 1991) suggested that extended periods of easterly winds create upwelling along the coast. Subsequent west winds then advected the marine water mass to the shoreline areas. Arctic cod may be moving onshore with, or in front of, this colder water mass. This association of Arctic cod with the leading edge of the marine water mass was also suggested by Moulton and Tarbox (1987) and Cannon et al. (1987). The implication may be that wind-induced coastal upwelling and subsequent onshore advection of the marine water mass prompts the movement of large numbers of Arctic cod into nearshore zones.

The effect of wind on nearshore water dynamics is modified by the occurrence of pack ice. In 1988, heavy pack ice persisted through August in the Pokok Bay sample area, preventing the occurrence of an upwelling event in response to the strong easterly winds between August 18-22 (Hale 1990). Instead, the subsequent north wind advected the colder and fresher meltwater into the system, lowering the temperature and salinity in Pokok Bay. The observed rise in catch rates at that time suggests that Arctic cod may orient by temperature regimes more so than salinity regimes. This inverse relationship between catch and temperature has previously been reported by Griffiths and

(1982) and Quast (1974) for juvenile Arctic cod. However, the correlation between temperature and salinity in the coastal system precludes the detection of any dominant univariate associations between a single physical variable and catch.

Moulton and Tarbox (1987) reported a net offshore movement of Arctic cod occurred between July and August in 1979 in response to the dynamics of two distinct water masses. The association may be linked with thermal or salinity preferences, or prey concentrations, or both. Although our data do not indicate occurrence of a general offshore movement during summer, our study does not consider offshore fish abundance or distribution. A more synoptic view of offshore and nearshore thermohaline patterns and fish abundance is necessary to test hypotheses concerning horizontal exchange of water masses and fish between the two zones.

Similar to Craig et al. (1982), our results illustrate a large between-year variation in Arctic cod catch. Within a year, significant variation between coastal sites was present and was undoubtedly a function of the varying dynamics of coastal water masses present in the lagoon systems. This natural variation suggests the Arctic cod populations are flexible in their selection of summer habitat and are not restricted to the nearshore corridor for along-shore movement. As such, localized perturbations of coastal hydrography caused by development-related structures would most likely have minor direct effects on resident Arctic cod populations. However, the possible fragmentation of coastal habitat suitable for Arctic cod may indirectly affect the summer migrant species which are predominantly restricted to the coastal band of warmer water. Arctic cod are often numerically dominant in coastal waters and represent an important component of the Arctic Ocean ecosystem (Quast 1974; Lowry and Frost 1981). The existing production and competition pressures experienced by co-dependent species within the ecosystem may be altered by any change in the summer distribution patterns of Arctic cod. As such, more information on the ecology of the Beaufort Sea coast is needed to ensure a prudent approach for development.

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