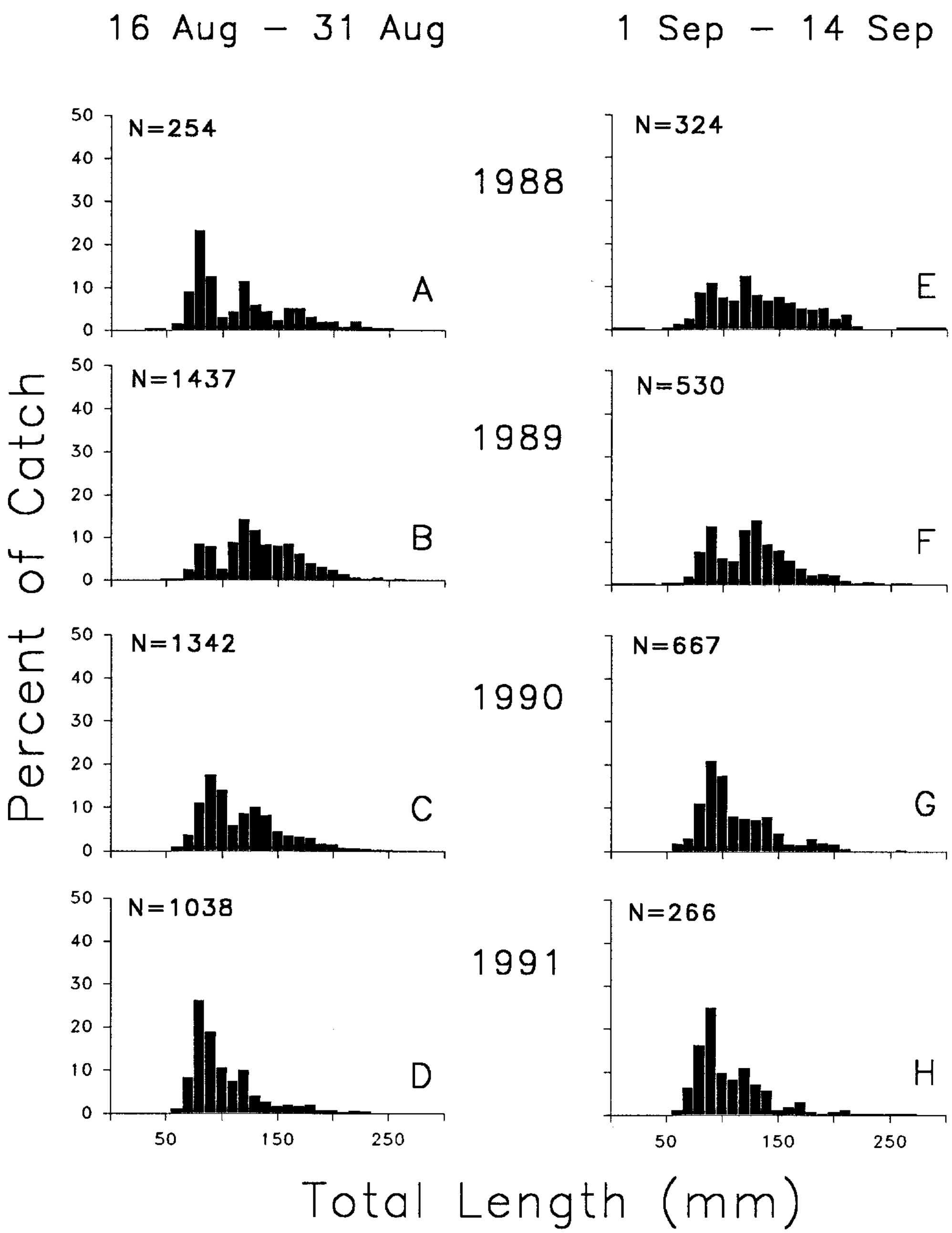

FIGURE 5.31.- Length frequencies of fourhorn sculpin captured by fyke nets in Simpson Cove, plotted by year for 16 August to 14 September.

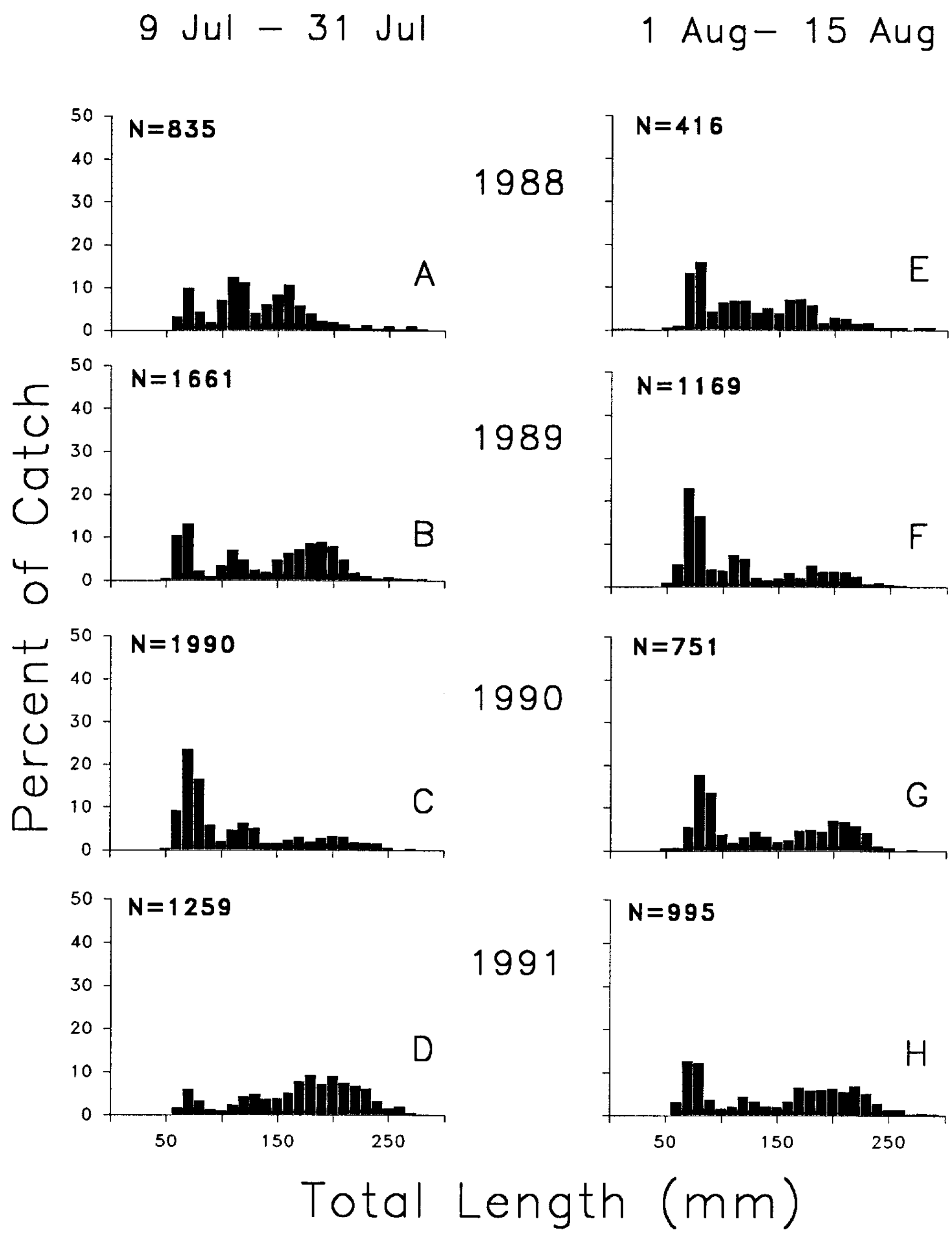

FIGURE 5.32.— Length frequencies of fourhorn sculpin captured by fyke nets in Kaktovik Lagoon, plotted by year for 9 July to 15 August.

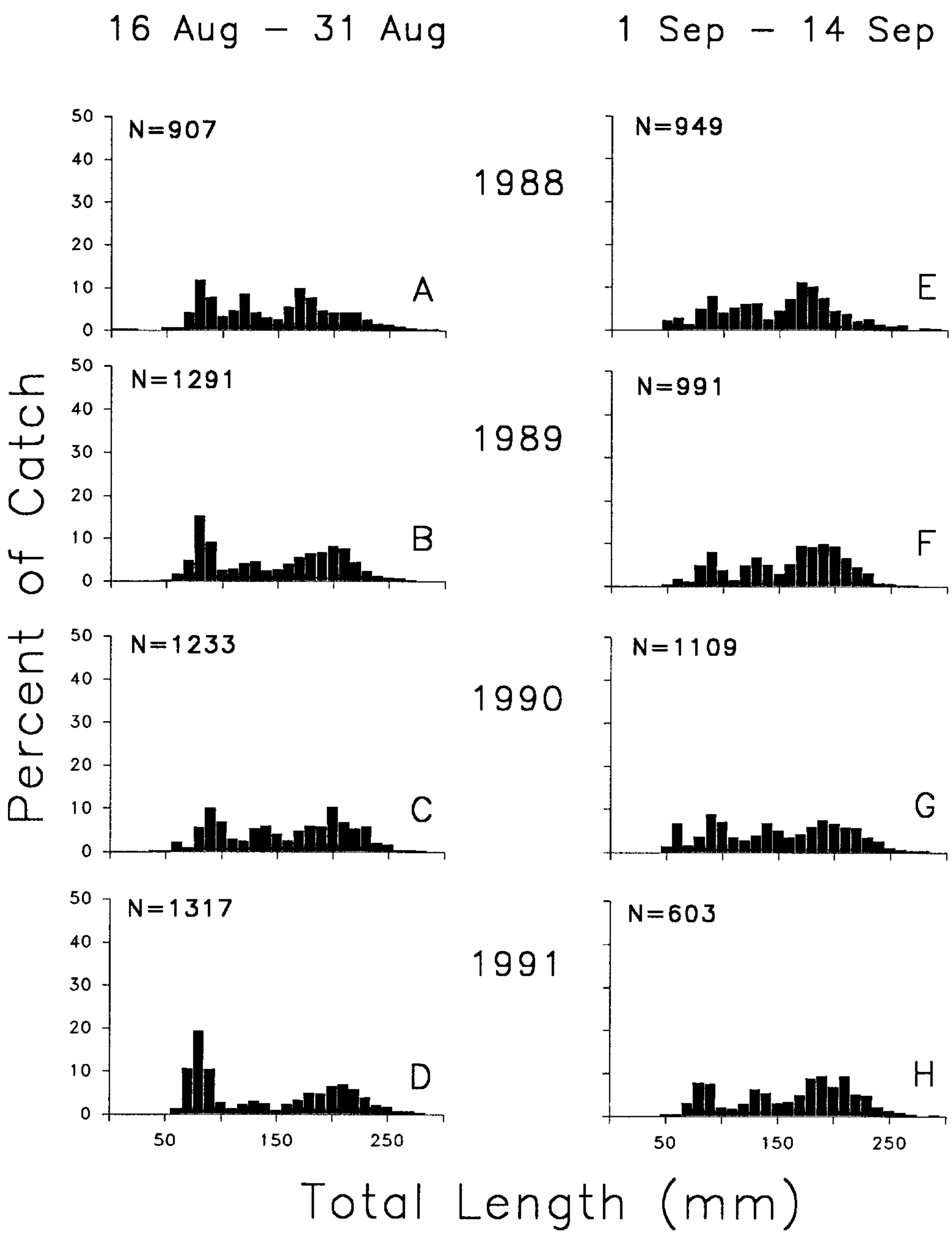

FIGURE 5.33.– Length frequencies of fourhorn sculpin captured by fyke nets in Kaktovik Lagoon, by year for 16 August to 14 September.

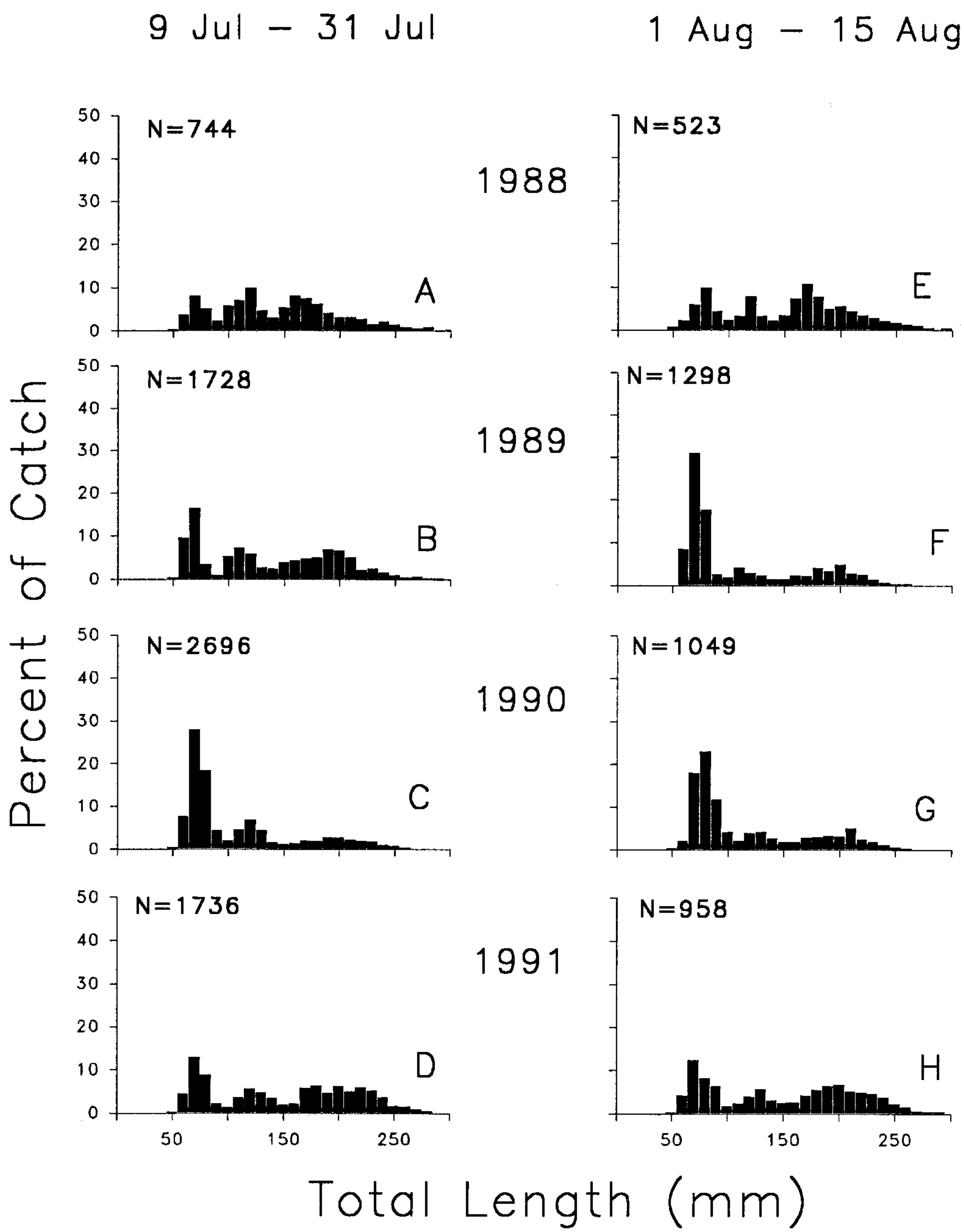

FIGURE 5.34.– Length frequencies of fourhorn sculpin captured by fyke nets in Jago Lagoon, plotted by year for 9 July to 15 August.

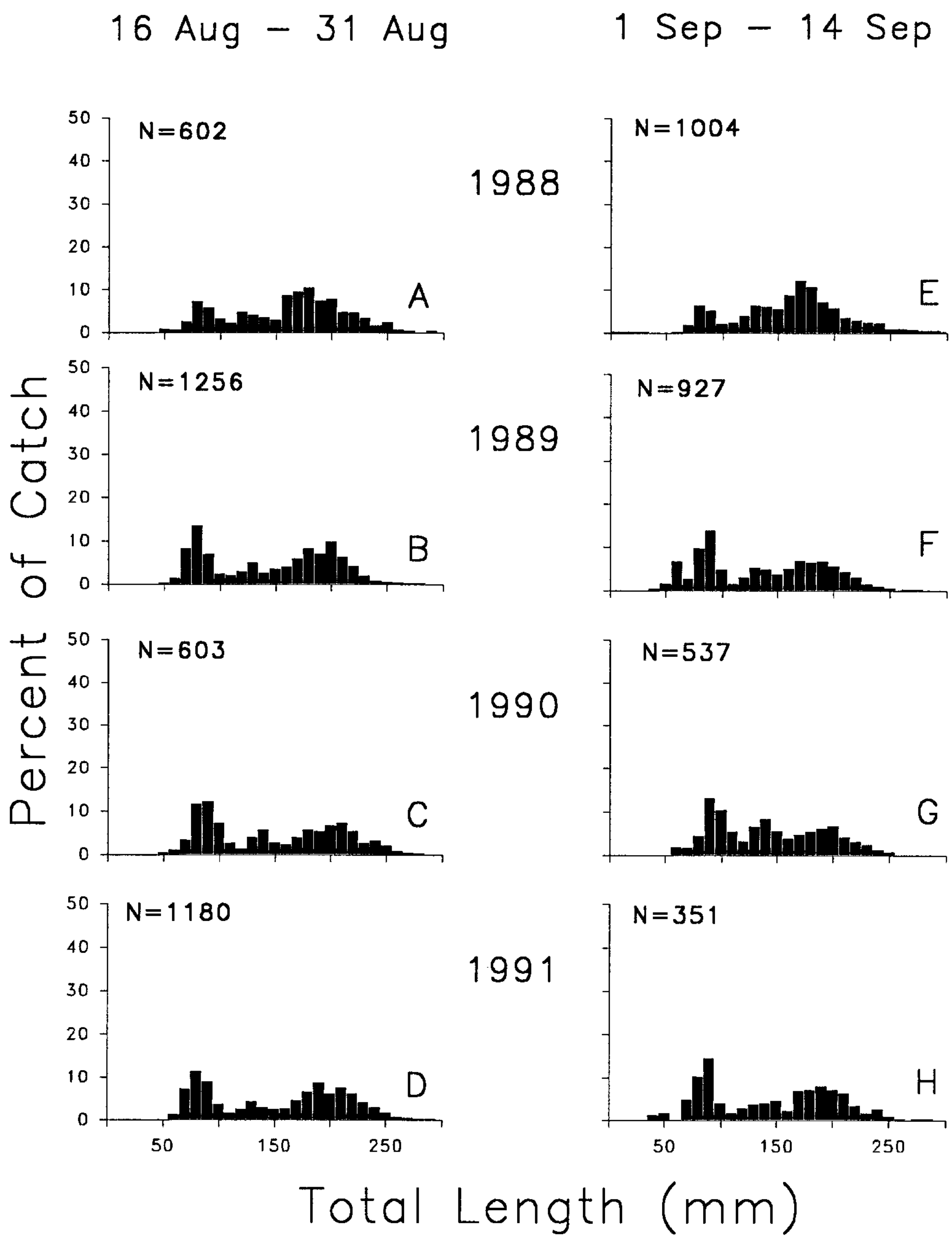

FIGURE 5.35.— Length frequencies of fourhorn sculpin captured by fyke nets in Jago Lagoon, plotted by year for 16 August to 14 September.

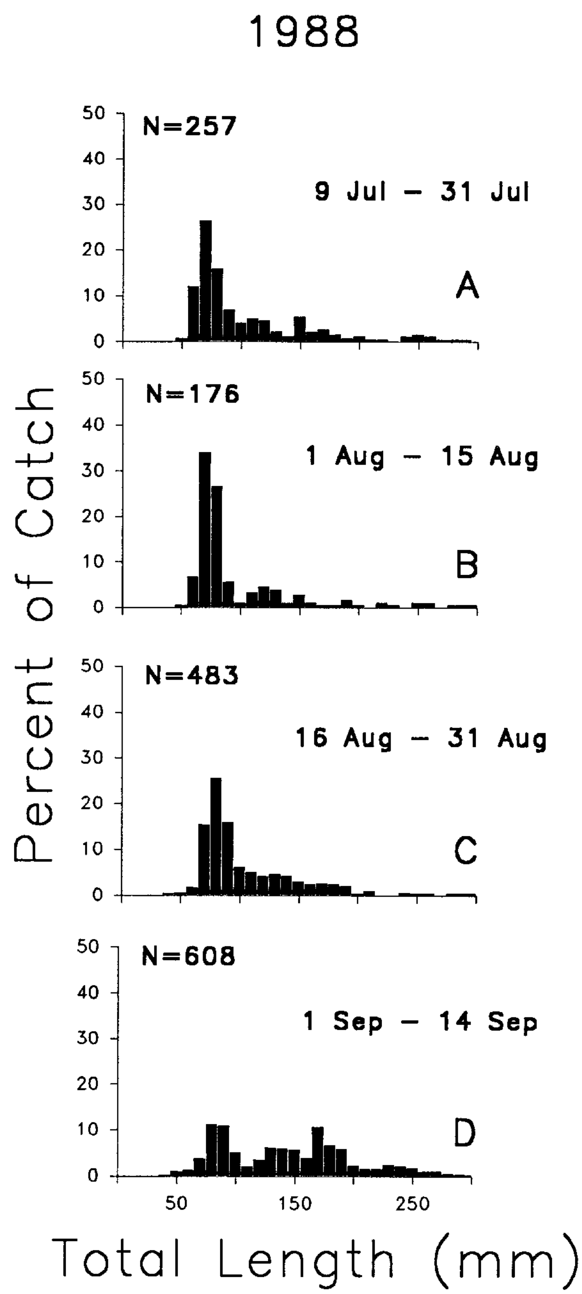

FIGURE 5.36.– Length frequencies of fourhorn sculpin captured by fyke nets in Pokok Bay, plotted for 9 July to 14 September, 1988.

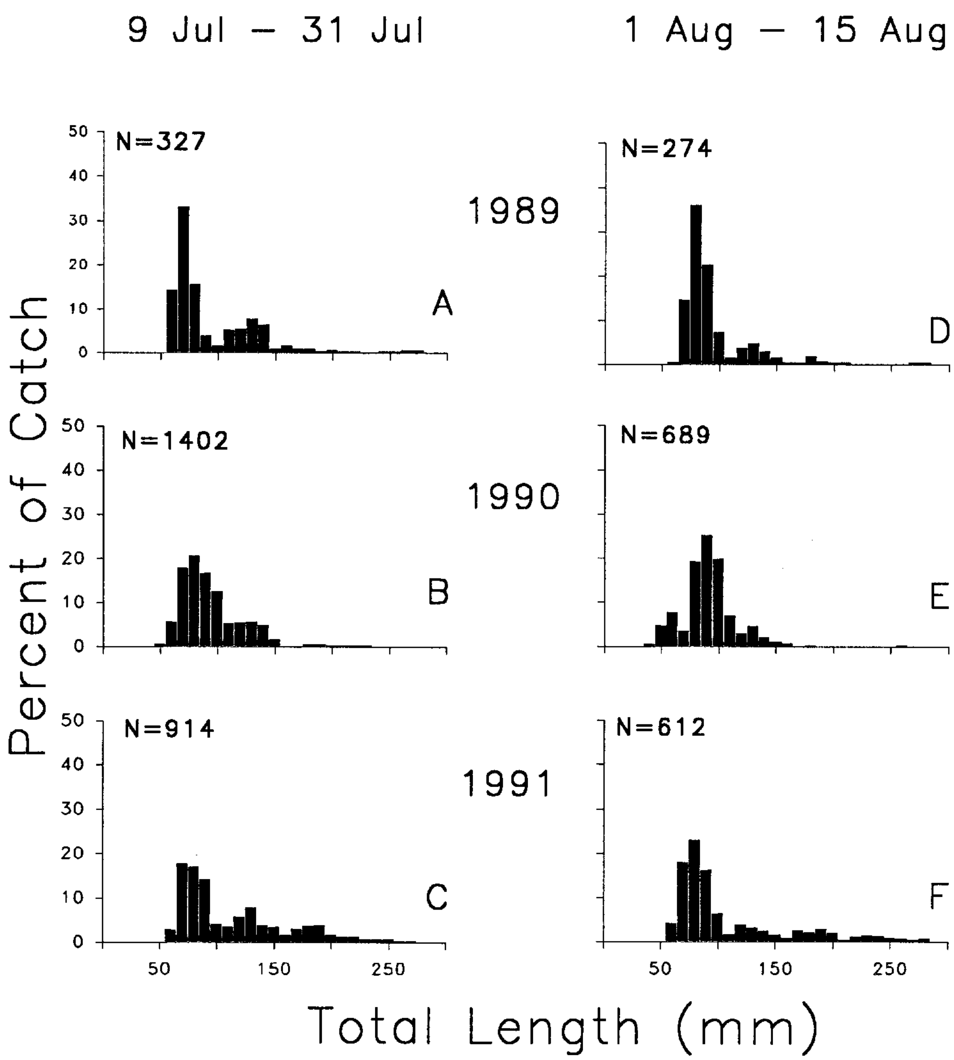

FIGURE 5.37.— Length frequencies of fourhorn sculpin captured by fyke nets in Beaufort Lagoon, plotted by year for 9 July to 15 August.

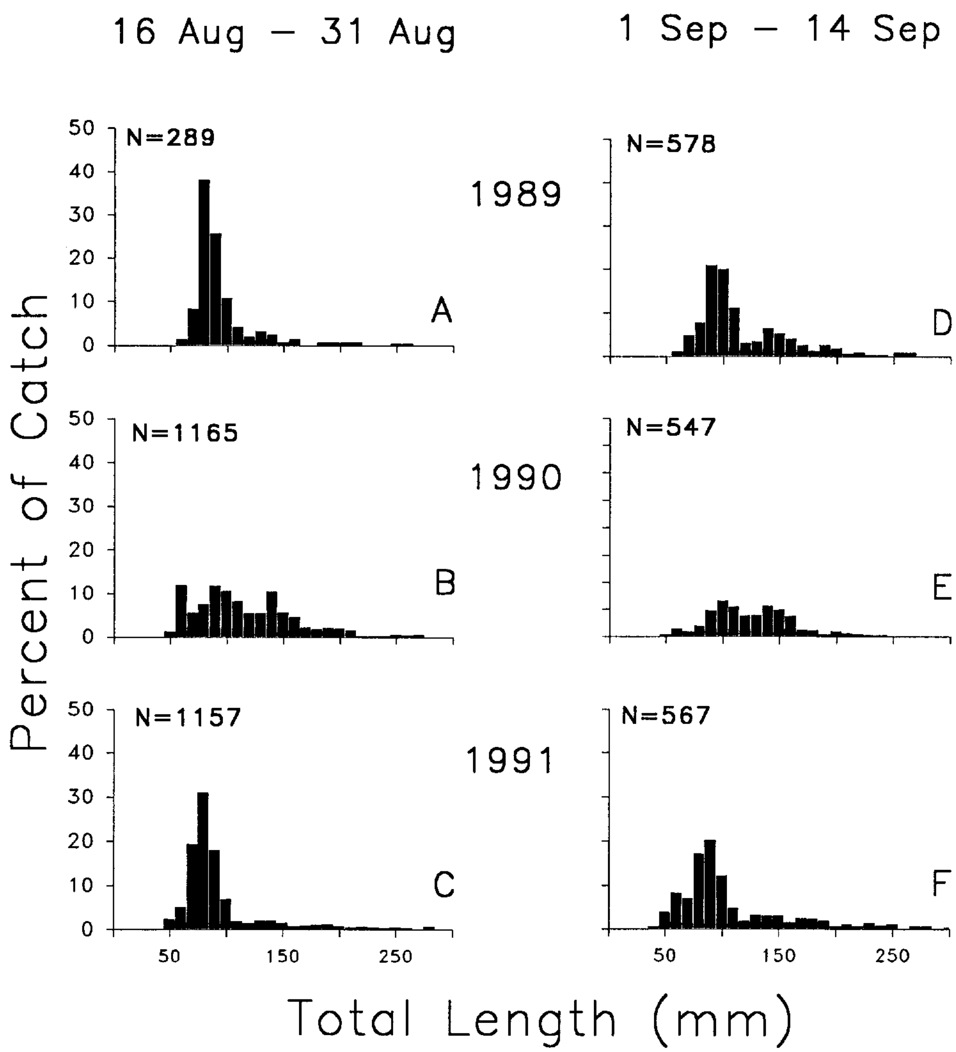

FIGURE 5.38.— Length frequencies of fourhorn sculpin captured by fyke nets in Beaufort Lagoon, plotted by year for 16 August to 14 September.

TABLE 5.13.— Condition comparisons between female and male fourhorn sculpin collected in July. Analyses were done for combined years and within individually sampled years. Asterisks (*) indicate significant changes in condition.

		Slopes		Intercepts		
Group	*N*	*b*(SE)	*P*-values	*a*(SE)	*P*-values	r^2
			All years			
Females	164	3.41 (0.04)		-13.63 (0.21)		0.98
Males	119	3.19 (0.06)		-12.63 (0.31)		0.95
			P = 0.003		P = 0.0001	
Without outliers			P = 0.0001		P = 0.0001	
			1989			
Females	64	3.32 (0.07)		-13.05 (0.36)		0.97
Males	37	3.29 (0.05)		-13.08 (0.25)		0.99
			P = 0.81		P = 0.0001	*
Without outliers			P = 0.81		P = 0.0001	*
			1991			
Females	79	3.34 (0.05)		-13.30 (0.27)		0.98
Males	69	3.07 (0.05)		-12.04 (0.23)		0.98
			P = 0.0002		P = 0.0025	
Without outliers			P = 0.0002		P = 0.0025	

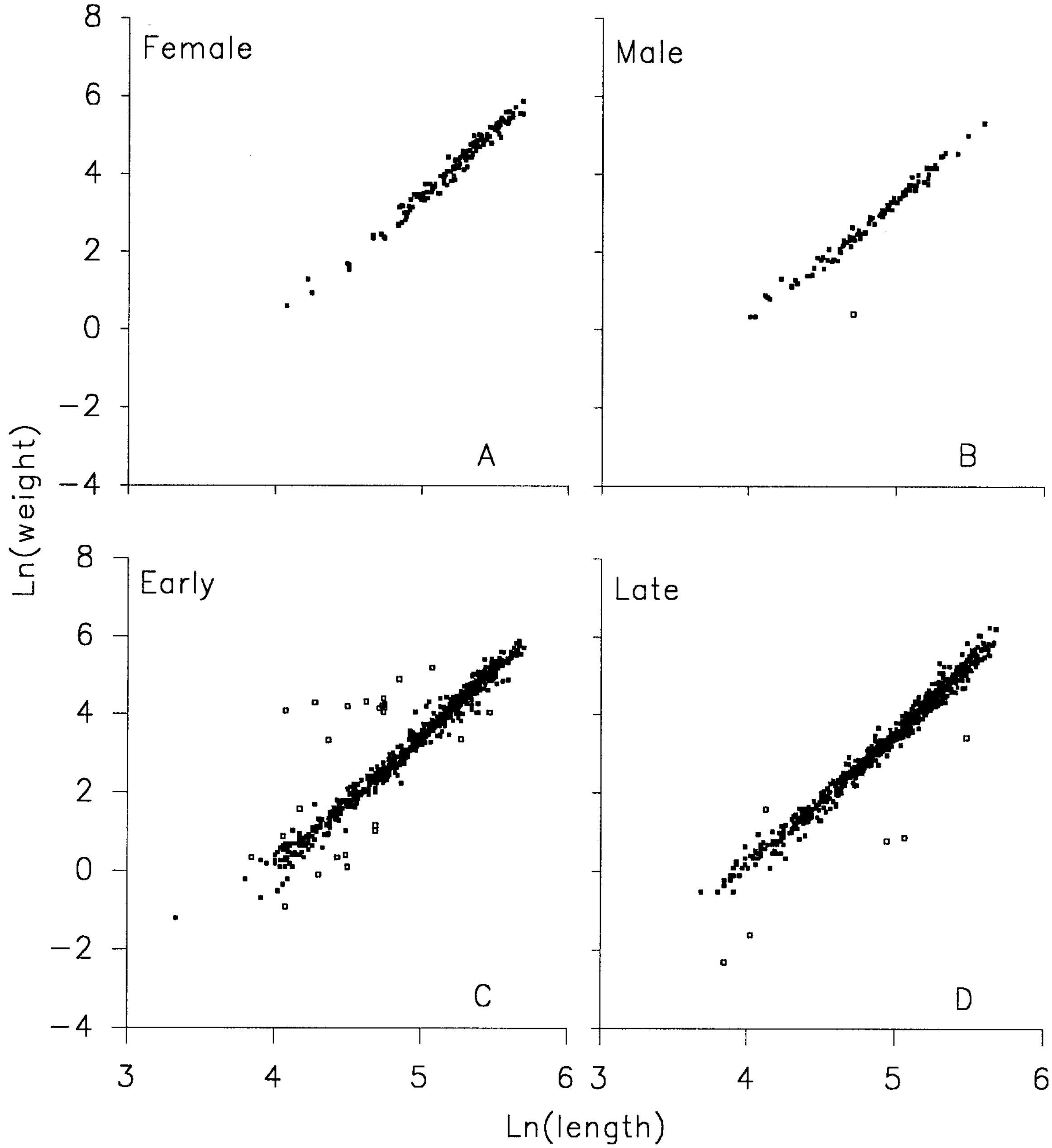

FIGURE 5.39.— Log-transformed weight-length data (□ = outliers) for comparisons between sexes (A, B) in July and between seasons (C, D). Seasonal data are from early (July 9-31) and late (August 27 - September 14).

B) showed similar size ranges of fish, but fewer small fish were measured and weighed. During 1989 a significant difference in condition between sexes was detected (Table 5.13). Intercept values (Table 5.13) for female fourhorn sculpin were higher than that of males in 1989 indicating higher condition.

Seasonal differences.— Significant differences in slope ($P = 0.0001$) precluded statements about condition of early verses late collected fish for data pooled over all years (Table 5.14). We obtained similar results when outliers were removed. Plots of transformed data (Figure 5.39C, D) indicated similar size ranges of fish were represented in each group. Results of comparisons within individual years were similar except for those of 1988 when no slope differences were detected. In 1988 no significant differences in seasonal condition were detected.

Overwintering.— We detected significant differences in condition between fish used to examine overwintering changes during the 1989-90 and 1990-91 winter seasons (Table 5.15). Outliers present in the spring of 1990 (Figure 5.40) caused slope estimates to differ ($P = 0.01$, Table 5.15). This difference disappeared with the removal of outliers. Other plots of transformed data indicated that size ranges of fish were similar by season and year (Figure 5.40). Intercept values indicated condition increased (-13.57 to -12.58) in the winter of 1989-90 and decreased (-13.42 to -13.79) in 1990-91. Sample size for fall 1988 data was too small for analysis.

Spatial differences.— During July, differences in slopes ($P = 0.0001$) precluded statements about condition for data pooled over years with and without outliers (Table 5.16). Plots of transformed data (Figure 5.41) indicated similar size ranges were sampled from each area. Of the within-year comparisons, 1989 was the only year when slopes were not significantly different. Pairwise comparisons for 1989 indicated that fish in Simpson Cove, Kaktovik, and Jago lagoons had higher condition than those in Beaufort Lagoon.

For data collected after August 27, significant slope differences precluded statements about fish condition when data were pooled over years (Table 5.17). Plots of transformed data (Figure 5.41) indicated more small fish were measured in Beaufort Lagoon possibly causing a slope difference. Slope differences were also found in the 1989 and 1991 individual analyses. In 1990, however, slope differences were not evident ($P = 0.50$) and no differences in condition were detected (Table 5.17).

Annual differences.— Significant differences in condition were detected when July data were pooled over all areas (Table 5.18). Pairwise comparisons indicated that condition during the years 1988 and 1991 were similar and intercepts showed lower condition than in 1989 and 1990. Plots of transformed data (Figure 5.42) showed slight differences in the size range of fish used in the analysis, especially in 1988. Slope differences were detected when outliers were removed from the analyses.

Within sampling areas, the results were varied. In Beaufort Lagoon no significant differences in condition were detected. In Kaktovik and Jago

TABLE 5.14.— Seasonal fish condition comparisons for fourhorn sculpin for combined years and within individually sampled years. Asterisks (*) indicate significant changes in condition.

		Slopes		Intercepts		
Group	*N*	*b*(SE)	*P*-values	a(SE)	*P*-values	r^2
			All years			
Early	802	3.32 (0.03)		-13.17 (0.14)		0.94
Late	968	3.46 (0.02)		-13.80 (0.09)		0.98
			P = 0.0001		*P* = 0.0005	
	Without outliers		*P* = 0.0013		*P* = 0.0001	
			1988			
Early	35	3.64 (0.09)		-14.82 (0.47)		0.98
Late	54	3.70 (0.07)		-15.16 (0.38)		0.98
			P = 0.65		*P* = 0.23	
	Without outliers		*P* = 0.65		*P* = 0.23	
			1989			
Early	158	3.35 (0.02)		-13.26 (0.12)		0.99
Late	349	3.42 (0.02)		-13.64 (0.10)		0.99
			P = 0.03		*P* = 0.17	
	Without outliers		*P* = 0.03		*P* = 0.17	
			1990			
Early	304	3.21 (0.06)		-12.58 (0.28)		0.91
Late	273	3.40 (0.04)		-13.42 (0.18)		0.97
			P = 0.006		*P* = 0.009	
	Without outliers		*P* = 0.04		*P* = 0.001	
			1991			
Early	305	3.43 (0.05)		-13.79 (0.22)		0.95
Late	292	3.56 (0.04)		-14.33 (0.17)		0.97
			P = 0.023		*P* = 0.0001	
	Without outliers		*P* = 0.001		*P* = 0.0001	

TABLE 5.15.– Condition comparisons in overwintering fourhorn sculpin for the winters of 1989-90, and 1990-91. Asterisks (*) indicate significant changes in condition.

		Slopes		Intercepts		
Group	*N*	*b*(SE)	*P*-values	a(SE)	*P*-values	r^2
			1989 - 1990			
Fall	162	3.41 (0.03)		-13.57 (0.14)		0.99
Spring	304	3.21 (0.06)		-12.58 (0.28)		0.91
			$P = 0.01$		$P = 0.93$	
	Without outliers		$P = 0.27$		$P = 0.001$	*
			1990 - 1991			
Fall	273	3.40 (0.04)		-13.42 (0.18)		0.97
Spring	305	3.43 (0.05)		-13.79 (0.22)		0.95
			$P = 0.60$		$P = 0.0001$	*
	Without outliers		$P = 0.10$		$P = 0.0001$	*

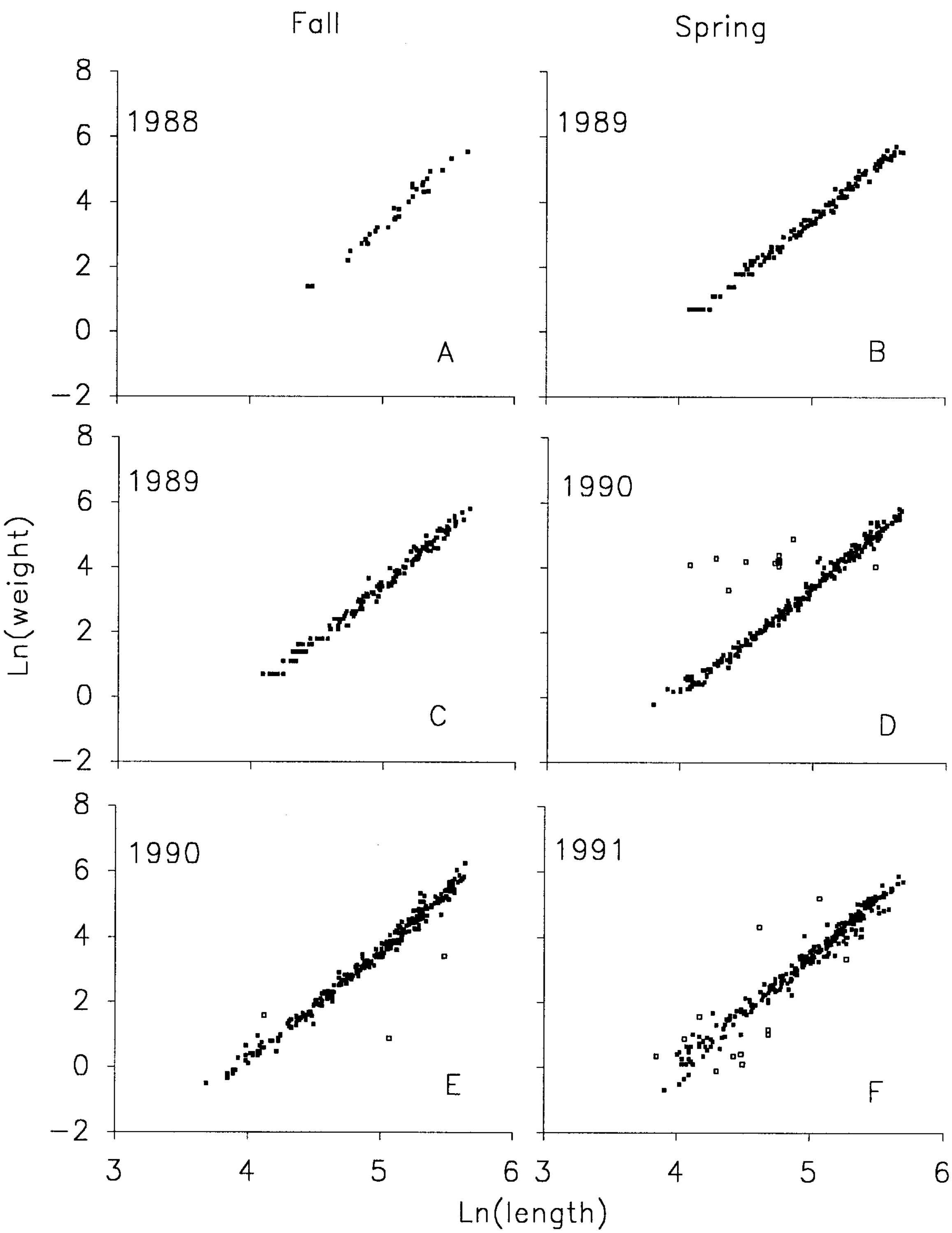

FIGURE 5.40.— Log-transformed weight-length data (□ = outliers) for three comparisons, winter 1988-89, 1989-90, and 1990-91.

TABLE 5.16.— Spatial condition comparisons for fourhorn sculpin collected in July for combined years and within individually sampled years. In 1988 sample sizes were too small to analyze separately, but were included in the overall analyses. Asterisks (*) indicate significant differences in condition.

Group	N	Slopes b(SE)	Slopes P-values	Intercepts a(SE)	Intercepts P-values	r^2	Pairwise results
All Years							
Beaufort Lagoon	222	3.34 (0.03)		-13.31 (0.16)		0.98	
Kaktovik/Jago	319	3.10 (0.06)		-11.99 (0.29)		0.90	
Simpson Cove	250	3.53 (0.04)		-14.27 (0.21)		0.97	
			P = 0.0001		P = 0.0001		
Without outliers			P = 0.0001		P = 0.01		
1989							
Beaufort Lagoon	40	3.32 (0.05)		-13.19 (0.22)		0.99	A
Kaktovik/Jago	59	3.22 (0.03)		-12.57 (0.17)		0.99	B
Simpson Cove	50	3.32 (0.05)		-13.11 (0.23)		0.99	B
			$P = 0.10$		$P = 0.0002$	*	
Without outliers			$P = 0.10$		$P = 0.0002$	*	
1990							
Beaufort Lagoon	77	3.25(0.07)		-12.88(0.34)		0.97	
Kaktovik/Jago	126	2.99(0.12)		-11.39(0.57)		0.84	
Simpson Cove	101	3.44(0.03)		-13.80(0.15)		0.99	
			$P = 0.002$		$P = 0.0002$		
Without outliers			$P = 0.03$		$P = 0.01$		

TABLE 5.16.– Continued.

Group	N	Slopes b(SE)	Slopes *P*-values	Intercepts a(SE)	Intercepts *P*-values	r^2	Pairwise results
			1991				
Beaufort Lagoon	105	3.41 (0.04)		-13.65 (0.20)		0.99	
Kaktovik/Jago	119	3.17 (0.08)		-12.42 (0.39)		0.94	
Simpson Cove	79	3.75 (0.11)		-15.45 (0.55)		0.93	
			$P = 0.0001$		$P = 0.002$		
Without outliers			$P = 0.0001$		$P = 0.43$		

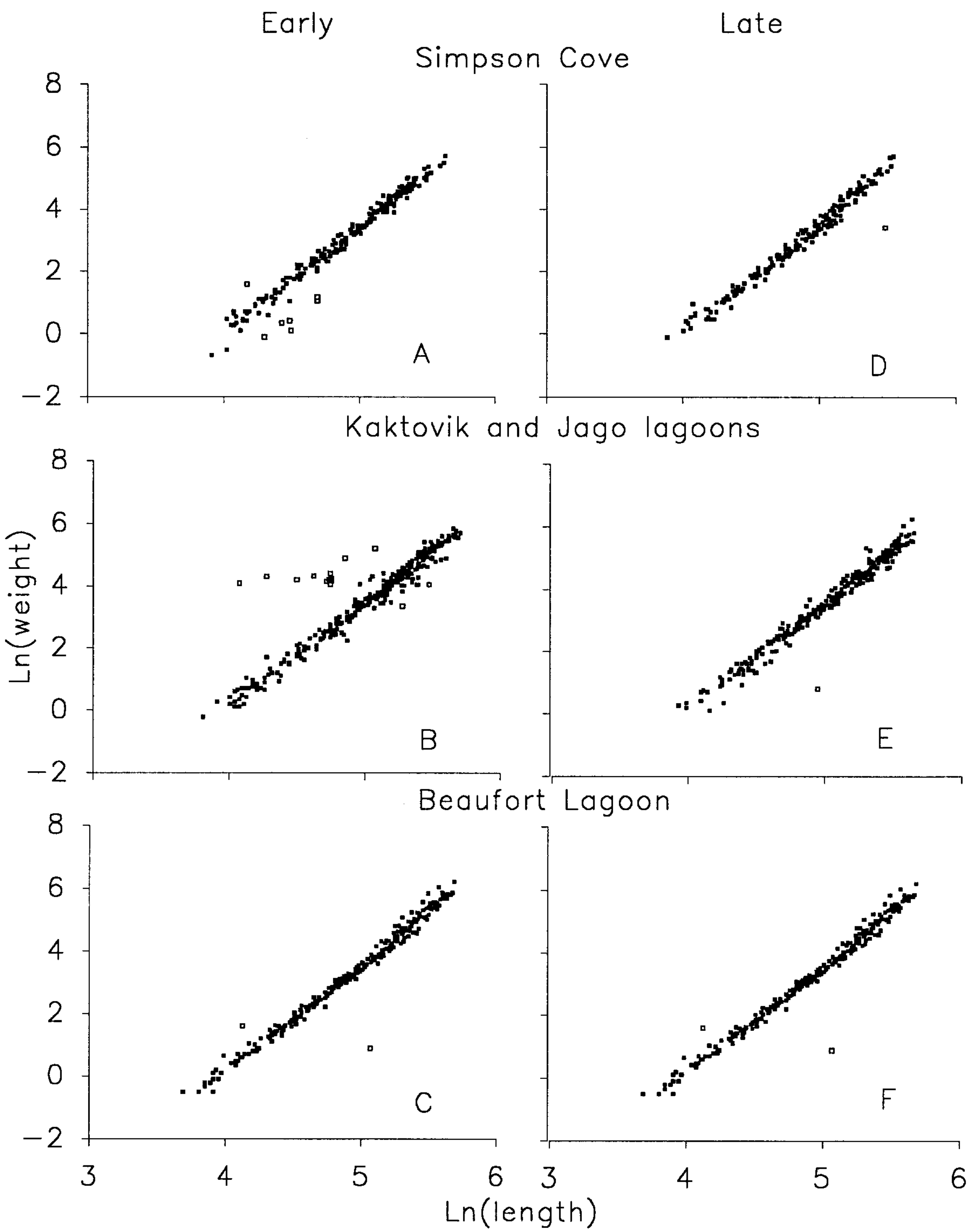

FIGURE 5.41.— Log-transformed weight-length data (□ = outliers) for among-area comparisons, early (July, first column) and late (after August 27, second column) of each year. Plots are compared down the columns.

TABLE 5.17.– Spatial condition comparisons for fourhorn sculpin collected after August 27 for combined years and within individually sampled years. Sample sizes in 1988 were to low for separate analyses. Asterisks (*) indicate significant changes in condition.

		Slopes		Intercepts			
Group	*N*	*b*(SE)	*P*-values	a(SE)	*P*-values	r^2	Pairwise results
All years							
Beaufort Lagoon	263	3.40 (0.03)		-13.49 (0.16)		0.98	
Kaktovik/Jago Lagoon	281	3.53 (0.04)		-14.15 (0.21)		0.96	
Simpson Cove	198	3.51 (0.04)		-14.08 (0.21)		0.97	
			$P = 0.03$		$P = 0.06$		
Without outliers			$P = 0.04$		$P = 0.01$		
1989							
Beaufort Lagoon	55	3.39 (0.05)		-13.46 (0.23)		0.99	
Kaktovik/Jago Lagoon	57	3.37 (0.05)		-13.63 (0.24)		0.98	
Simpson Cove	41	3.55 (0.06)		-14.34 (0.29)		0.99	
			$P = 0.04$		$P = 0.0001$		
Without outliers			$P = 0.04$		$P = 0.0001$		

TABLE 5.17.– Continued.

Group	N	Slopes		Intercepts		r^2	Pairwise results
		b(SE)	P-values	a(SE)	P-values		
1990							
Beaufort Lagoon	100	3.35 (0.07)		-13.21 (0.35)		0.96	
Kaktovik/Jago Lagoon	101	3.45 (0.04)		-13.63 (0.22)		0.98	
Simpson Cove	70	3.37 (0.08)		-13.31 (0.38)		0.96	
			P = 0.50		P = 0.17		
Without outliers			P = 0.57		P = 0.23		
1991							
Beaufort Lagoon	108	3.46 (0.03)		-13.77 (0.16)		0.99	
Kaktovik/Jago Lagoon	106	3.69 (0.09)		-15.06 (0.43)		0.95	
Simpson Cove	75	3.67 (0.06)		-14.85 (0.28)		0.98	
			P = 0.008		P = 0.0008		
Without outliers			P = 0.04		P = 0.02		

TABLE 5.18.— Annual condition comparisons for fourhorn sculpin collected in July for combined areas combined and within individually sampled areas. Within sampling areas, some years were dropped from the analyses if sample sizes were below the minimum (N=32). Asterisks (*) indicate significant changes in condition.

Group	N	Slopes b(SE)	Slopes P-values	Intercepts a(SE)	Intercepts P-values	r^2	Pairwise Results
All Areas							
1988	35	3.64 (0.09)		-14.82 (0.47)		0.98	A
1989	149	3.30 (0.02)		-13.00 (0.12)		0.99	B
1990	302	3.23 (0.06)		-12.68 (0.29)		0.91	B
1991	297	3.35 (0.05)		-13.36 (0.22)		0.95	A
			P = 0.11		P = 0.001	*	
	Without outliers		P = 0.006		P = 0.0001		
Beaufort Lagoon							
1989	40	3.32 (0.05)		-13.19 (0.22)		0.99	
1990	77	3.25 (0.07)		-12.88 (0.34)		0.97	
1991	103	3.36 (0.04)		-13.39 (0.19)		0.99	
			P = 0.31		P = 0.60		
	Without outliers		P = 0.009		P = 0.05		
Kaktovik and Jago lagoons							
1989	59	3.22 (0.03)		-12.57 (0.17)		0.99	A
1990	124	3.00 (0.13)		-11.41 (0.63)		0.82	A
1991	119	3.17 (0.08)		-12.42 (0.39)		0.93	B
			P = 0.31		P = 0.04	*	
	Without outliers		P = 0.04		P = 0.004		
Simpson Cove							
1989	50	3.32 (0.05)		-13.11 (0.23)		0.99	
1990	101	3.44 (0.03)		-13.80 (0.15)		0.99	
1991	75	3.64 (0.12)		-14.86 (0.60)		0.92	
			P = 0.02		P = 0.0001		
	Without outliers		P = 0.03		P = 0.0001		

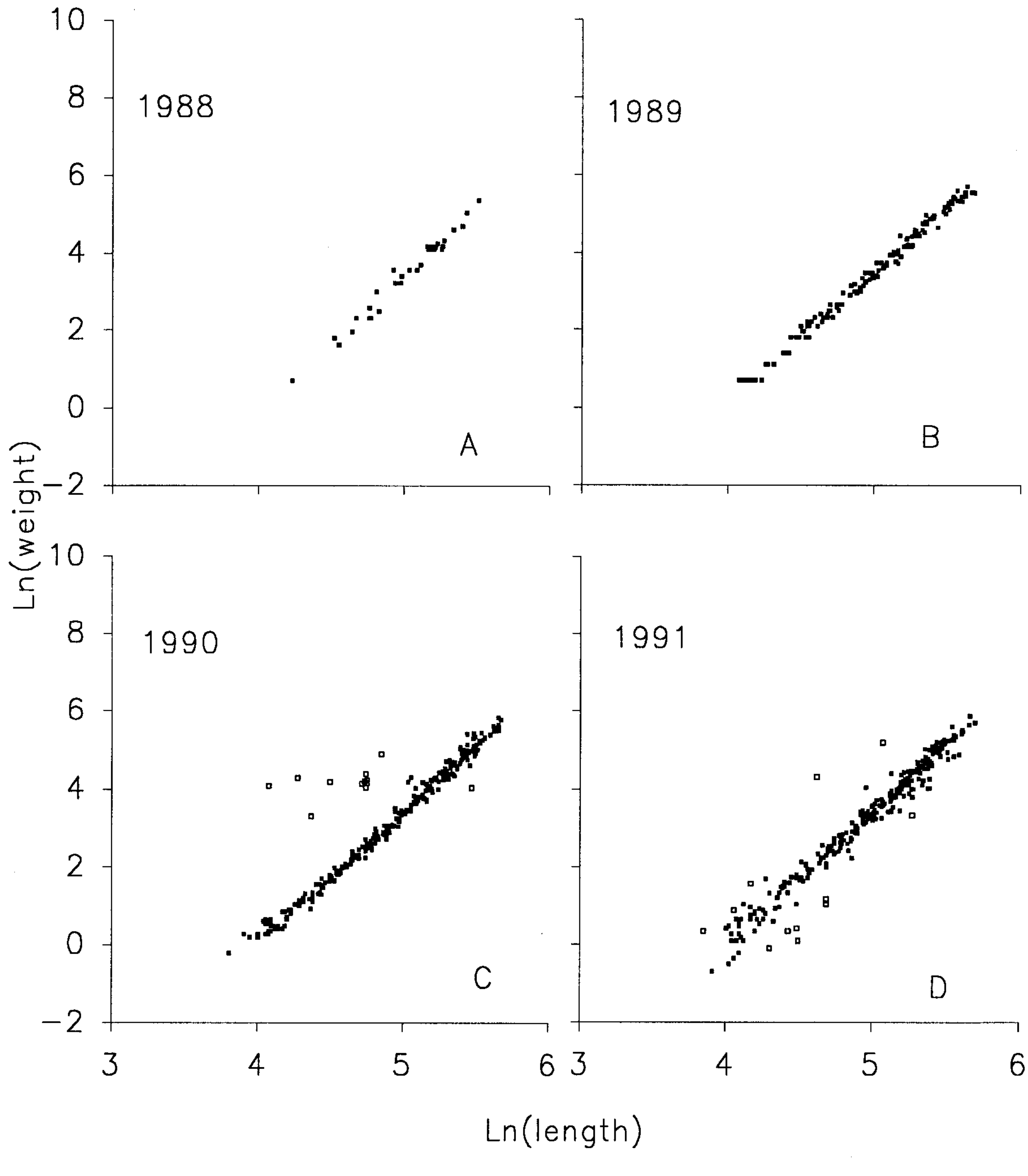

FIGURE 5.42.— Log-transformed fourhorn sculpin weight-length data (□ = outliers) collected during July in all areas for among-year comparisons.

lagoons, significant differences in condition were similar to the pooled data results (Table 5.18). The Simpson Cove analyses indicated slope differences which precluded statements about condition. In all three areas, slope differences were detected when outliers were discarded.

Fourhorn sculpin collected after August 27 showed significant differences in condition when pooled over areas (Table 5.19). Pairwise comparisons indicated that condition in 1990 was significantly different from that in other years. Intercept values showed that 1990 condition was higher than in 1989 and 1991. Plots of transformed data (Figure 5.43) indicated similar size ranges of fish in each year.

Within sampling areas, significant differences in condition were detected in Kaktovik and Jago lagoons, regardless of the presence of outliers, and in Simpson Cove and Beaufort Lagoon without outliers. Condition was highest in 1990 except in Kaktovik and Jago lagoons where the intercept value of 1989 was higher (Table 5.19).

Age and Growth

Fourhorn sculpin collected during July of 1988, 1989, and 1991 ranged from 1 to 10 years of age and from 46 to 295 mm TL. Age-2 fish occurred most frequently (25%, N=81), with age-3 fish second in frequency (22%, N=72). The overall mean age was 3 years (N=324, SE=0.2) and the overall mean length was 138 mm TL (N=324, SE=0.4). Overlap of length ranges among ages, as with the other species we studied, was considerable (Table 5.20). Plots of overall mean length at age showed steady growth increases until the age of 6 when growth appeared to immediately reach an asymptote at 250 mm TL (Figure 5.44). Overall length frequency distributions showed a trimodal pattern (Figure 5.44), similar to the distributions occurring in the length frequency section, above (Figures 5.30-5.38): The first mode occurred at 50-100 mm TL, the second at 100-150 mm TL, and the third, more weak distribution occurred at 150-200 mm TL).

No significant differences in mean lengths at age were found among areas (Table 5.21). Generally, mean lengths were greater in Beaufort Lagoon than in the other areas, although small sample sizes (<10) causes interpretation to be ambiguous. No significant differences were found among yearly-mean lengths at age (Table 5.22), but, when visual comparisons of the data were possible, mean lengths were larger in 1989 and 1991 than in 1988. Analysis of age frequencies did not show any consistent pattern among areas (Figure 5.45). However, the length frequency distributions showed a third mode (150-200 mm TL) similar to that in the overall distributions (Figure 5.44), and fourhorn sculpin from 50-100 mm TL were strongly represented in each area (Figure 5.45). In Simpson Cove, a large percent of fish between 100 and 150 mm TL was reflected in the age-2 fish in the corresponding age frequencies for that area (Figure 5.45). When stratified by year, the length frequency data indicated trimodal patterns, while the age distributions failed to show any distinct pattern from year to year (Figure 5.46). In 1989, a larger percent of 1-year old fish was present than in other years, and was also represented by the large mode (50-100 mm TL) in the corresponding length frequency distribution for that year (Figure 5.46).

TABLE 5.19.— Annual condition comparisons for fourhorn sculpin collected after August 27 for combined areas and within individual sampled areas. Asterisks (*) indicate significant changes in condition.

		Slopes		Intercepts			
Group	*N*	*b*(SE)	*P*-values	a(SE)	*P*-values	r^2	Pairwise results
			All Areas				
1989	153	3.44 (0.03)		-13.70 (0.16)		0.99	A
1990	265	3.41 (0.04)		-13.50 (0.20)		0.97	B
1991	280	3.51 (0.03)		-14.08 (0.17)		0.98	A
			P = 0.11		P = 0.0001	*	
	Without outliers		P = 0.15		P = 0.0001	*	
			Beaufort Lagoon				
1989	55	3.39 (0.05)		-13.46 (0.23)		0.99	A
1990	92	3.37 (0.08)		-13.31 (0.41)		0.95	B
1991	102	3.45 (0.04)		-13.73 (0.19)		0.99	A,B
			P = 0.57		P = 0.22		
	Without outliers		P = 0.59		P = 0.008	*	
			Kaktovik and Jago lagoons				
1989	57	3.37 (0.05)		-13.28 (0.24)		0.99	A
1990	101	3.45 (0.04)		-13.63 (0.22)		0.98	B
1991	104	3.51 (0.08)		-14.14 (0.38)		0.96	B
			P = 0.31		P = 0.0001	*	
	Without outliers		P = 0.18		P = 0.0001	*	

TABLE 5.19.— Continued.

		Slopes		Intercepts			
Group	*N*	*b*(SE)	*P*-values	a(SE)	*P*-values	r^2	Pairwise results
			Simpson Cove				
1989	41	3.55 (0.06)		-14.34 (0.29)		0.99	A
1990	69	3.38 (0.08)		-13.35 (0.40)		0.96	B
1991	74	3.63 (0.05)		-14.65 (0.25)		0.98	A
			$P = 0.02$		$P = 0.0009$		
	Without outliers		$P = 0.11$		$P = 0.0001$	*	

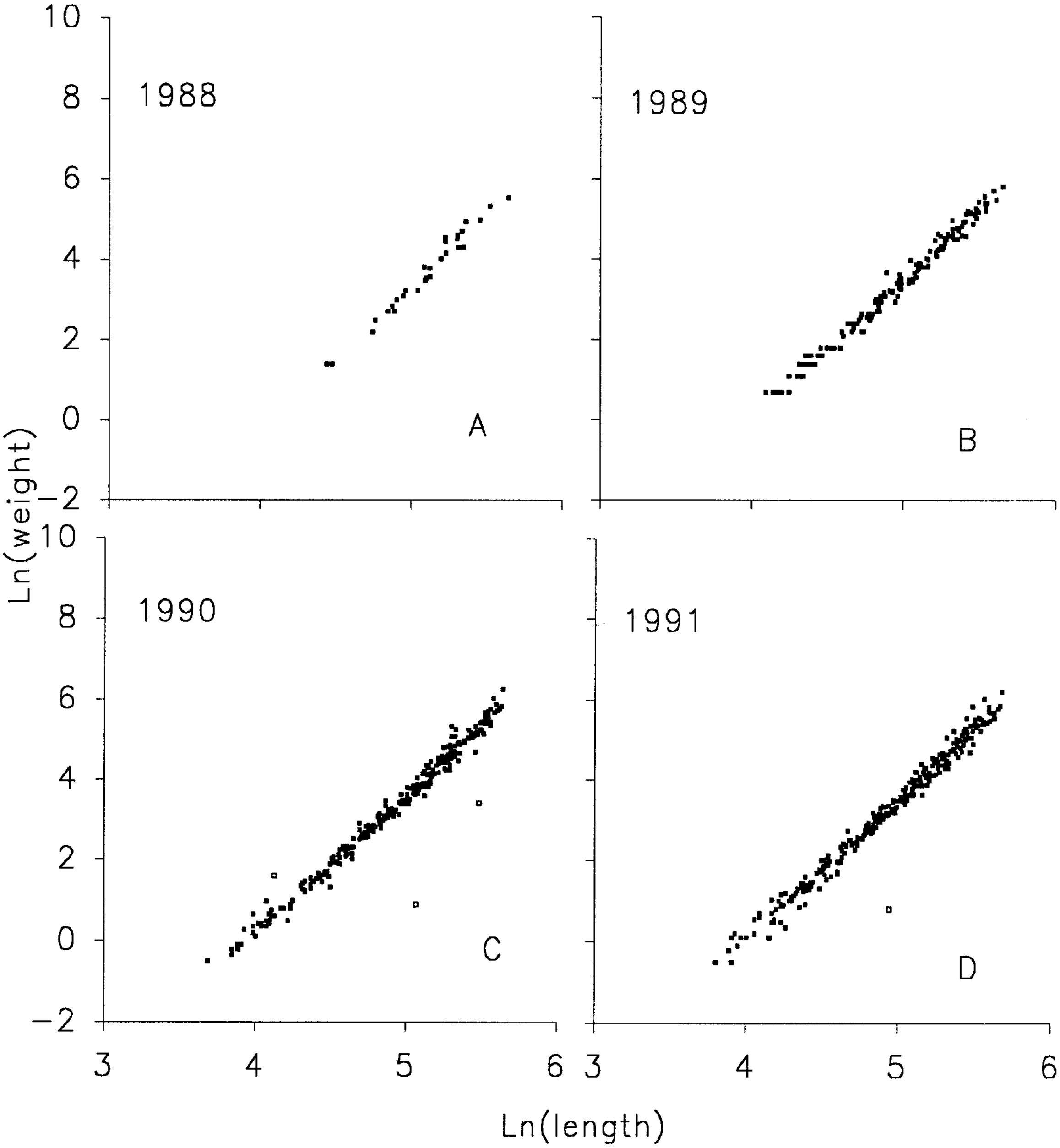

FIGURE 5.43.— Log-transformed fourhorn sculpin weight-length data (□ = outliers) collected after August 27 in all areas for among-year comparisons.

TABLE 5.20.— Mean length at age, standard errors (SE), and ranges for fourhorn sculpin collected during July, all years and areas pooled.

Age	*N*	$\bar{x}$(SE)	Range
1	62	66(1)	46-93
2	81	105(2)	59-162
3	72	148(3)	91-208
4	69	183(4)	100-250
5	26	206(6)	143-268
6	7	245(5)	226-266
7	1	246(--)	--
8	2	250(20)	230-269
9	3	249(23)	220-295
10	1	221(--)	--
	N = 324	$\bar{x}$ = 138	

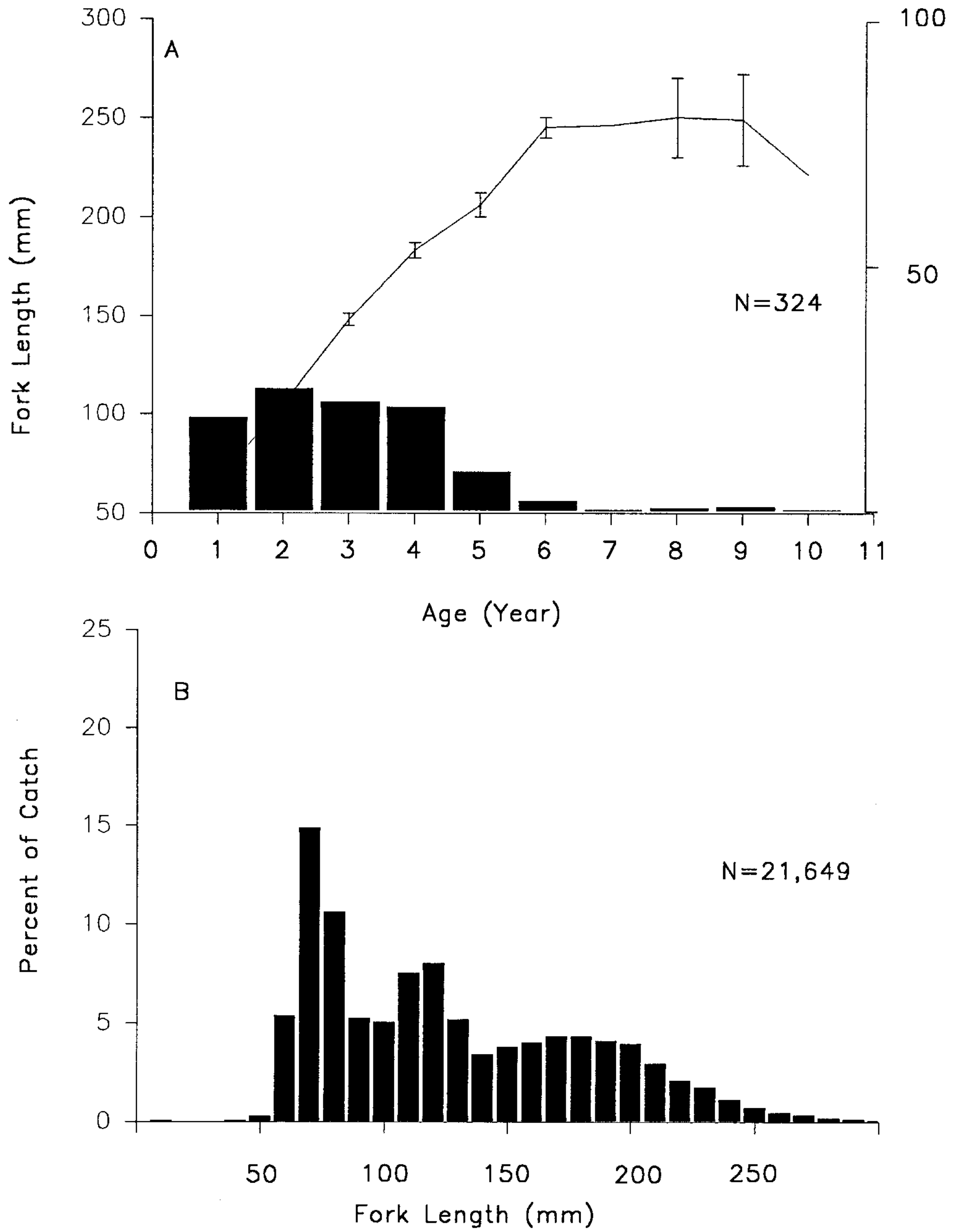

FIGURE 5.44.— Mean length at age (±SE), age frequencies (A), and standard fyke net length frequencies (10 mm intervals, B) for fourhorn sculpin collected during July, years and areas pooled.

TABLE 5.21.– Mean lengths at age and standard errors (SE) for fourhorn sculpin collected during July, 1988, 1989, and 1991. Means across rows with similar letters are not significantly different.

Age	Simpson Cove			Kaktovik Lagoon			Jago Lagoon			Beaufort Lagoon		
	N	$\bar{x}$(SE)		N	$\bar{x}$(SE)		N	$\bar{x}$(SE)		N	$\bar{x}$(SE)	
1	20	63(2)	A	1	60(--)		8	58(2)	A	31	70(2)	A
2	36	102(3)	A	81	90 (9)	A	10	98(6)	A	32	111(4)	A
3	29	142(5)	A	1	140(--)		11	144(5)	A	31	156(5)	A
4	27	174(6)	A	5	213 (5)	A	12	177(7)	A	25	190(7)	A
5	15	192(5)	A	1	254(--)		2	236(9)	A	7	221(12)	A
6	2	237(11)	A	--	--		--	--		4	252(6)	A
7	--	--		--	--		--	--		--	--	
8	1	230(--)		--	--		--	--		1	269(--)	
9	1	220(--)		--	--		--	--		2	263(32)	
10	--	--		--	--		1	221(--)		--	--	

TABLE 5.22.— Mean lengths, standard errors (SE), and ranges for fourhorn sculpin collected during July, areas pooled. Means across rows with similar letters are not significantly different.

Age	1988				1989				1991			
	N	$\bar{x}$(SE)	Range		*N*	$\bar{x}$(SE)	Range		*N*	$\bar{x}$(SE)	Range	
1	2	58(0)	58-58	A	31	66(2)	51-93	A	29	66(2)	46-89	A
2	6	101(8)	71-123	A	32	105(3)	62-141	A	41	105(4)	59-162	A
3	2	142(3)	140-145	A	26	143(4)	97-187	A	44	151(4)	91-208	A
4	5	169(22)	117-224	A	26	182(4)	144-221	A	38	186(6)	100-250	A
5	4	203(11)	178-228	A	5	229(9)	211-254	A	17	200(7)	143-268	A
6	2	241(6)	236-247	A	--	--	--		5	247(7)	226-266	A
7	1	246(--)	--		--	--	--		--	--	--	
8	--	--	--		--	--	--		2	250(19)	230-269	
9	--	--	--		--	--	--		3	249(23)	220-295	
10	1	221(--)	--		--	--	--		--	--	--	

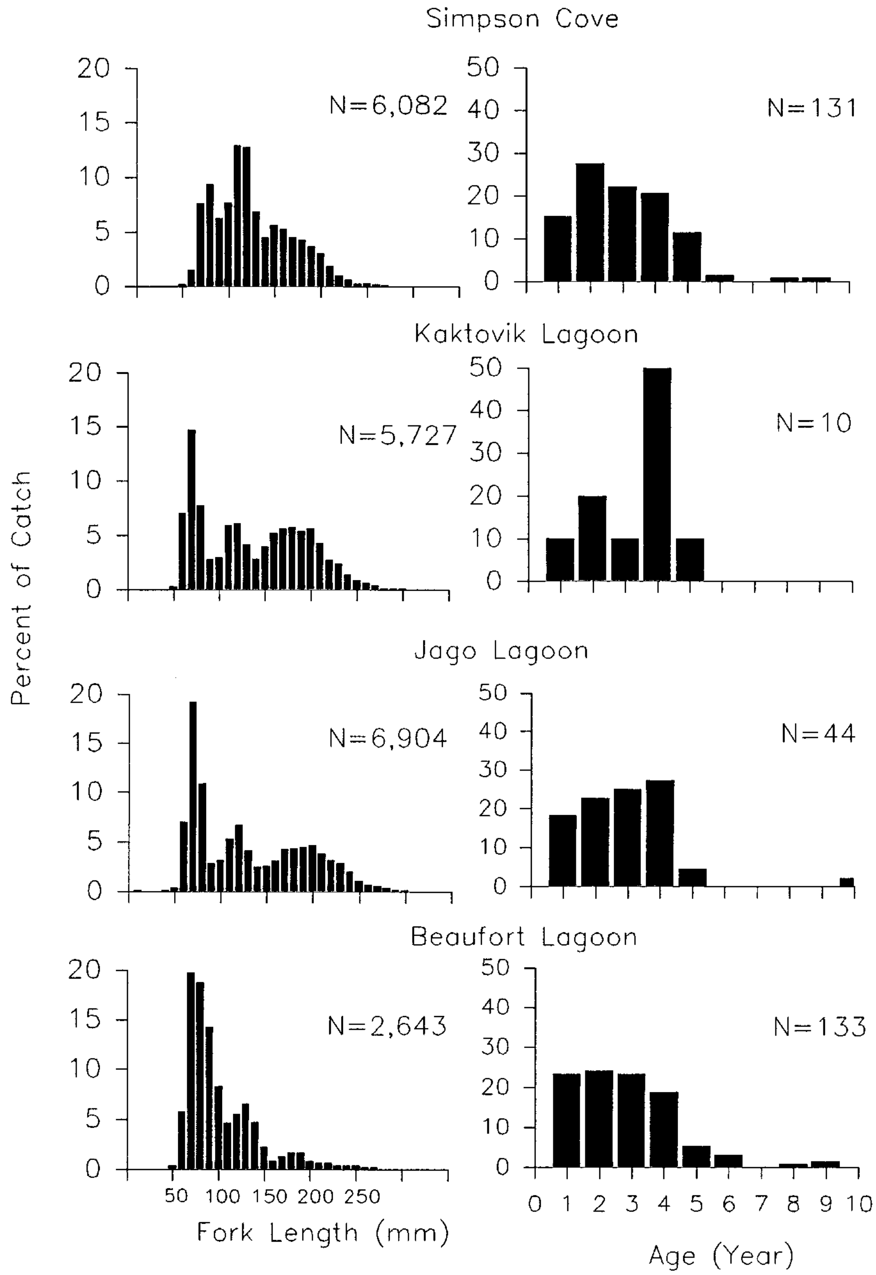

FIGURE 5.45.- Length frequencies (10 mm intervals) for standard fyke net catches and age frequencies for fourhorn sculpin collected during July, with years pooled.

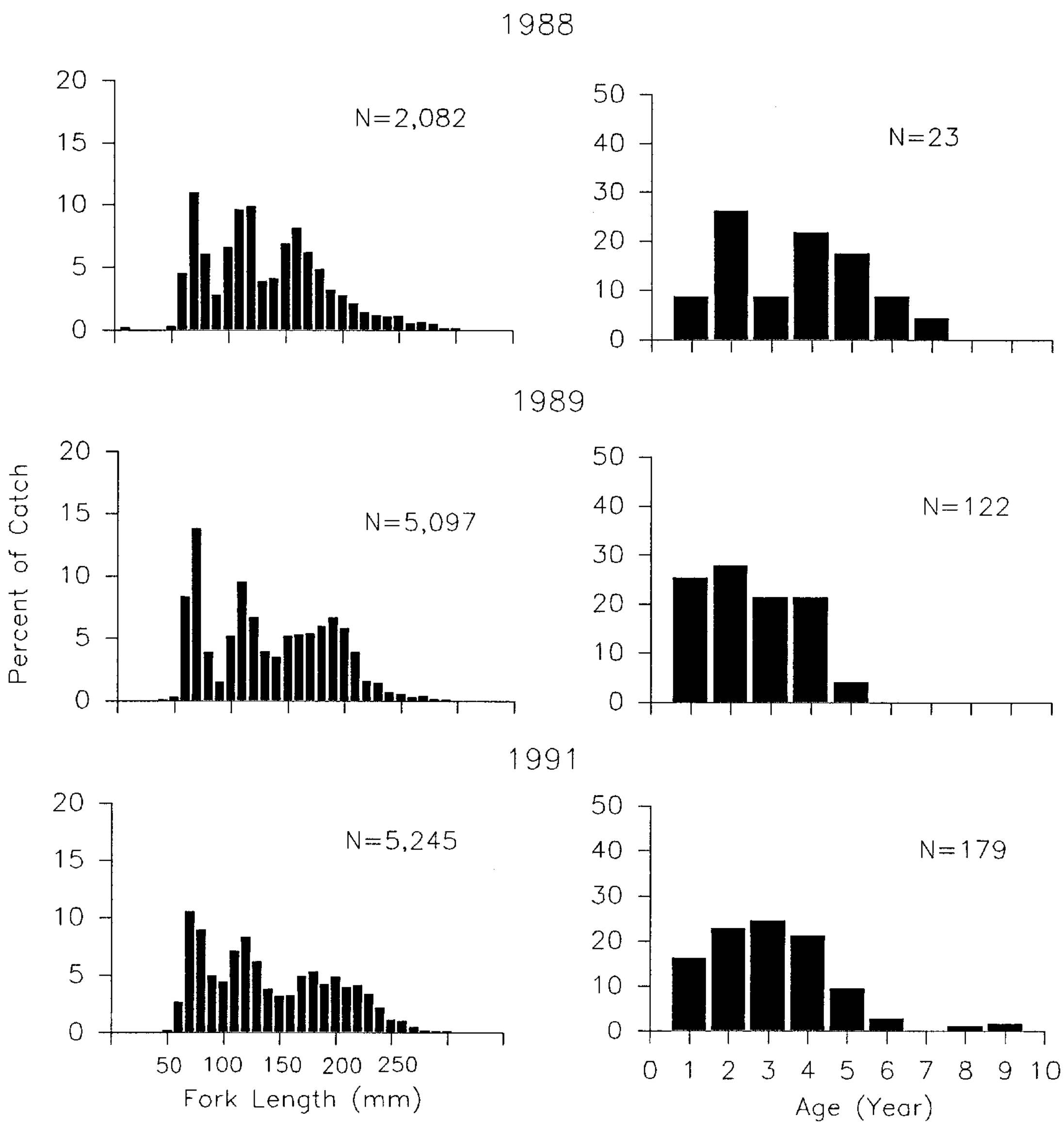

FIGURE 5.46.— Length frequencies (10 mm intervals) for standard fyke net catches and age frequencies for fourhorn sculpin collected during July, with areas pooled.

Movements

We tagged and released a total of 849 fourhorn sculpin in Arctic Refuge coastal waters between 1988 and 1991. Of these fish, 35 (4%) were recaptured (Table 5.23). Four fish were recaptured in areas different from those where tagging occurred, and 31 fish were recaptured within the original tagging location (Table 5.23). Eight of the recaptured fish had been tagged in previous field seasons. Two tagged fourhorn sculpin moved east between Simpson Cove and the Kaktovik and Jago lagoon complex (one in 44 d), and two fourhorn sculpin moved west within the Kaktovik and Jago lagoon complex. No movement of tagged fourhorn sculpin was documented east of Jago Lagoon, or between Pokok Bay and Beaufort Lagoon.

Environmental Influences on CPUE

Simpson Cove.— Fourhorn sculpin were present in Simpson Cove throughout the 1988 sampling season from July 21 to September 14. Daily catch rate during 1988 was positively correlated with temperature (r = 0.32), but was not significantly associated with any environmental variable (Tables 5.24, 5.25). Daily catch rates were again positively related to water temperature during the 1989 sampling season, for both the station and area-wide analyses (Figure 5.47). Most noticeable was a progressive decline in fourhorn sculpin catch throughout the season at station SC04, coincident with a general temperature drop from around 13°C at first sampling (July 18) to less than 5°C near the end of sampling (September 11). This linear relationship was less strong at station SC01 (Table 5.24).

Catch rates in Simpson Cove fluctuated throughout the summer during the 1990 and 1991 open-water seasons. A strong association (R^2 = 0.60) between CPUE and salinity was present for the 1991 fourhorn sculpin catch at station SC04, where high catch rates occurred in late July when salinities were less than 5 ppt. Gross annual trends in salinity and temperature (e.g. high overall salinities in 1990) did not appear to greatly influence CPUE among years, except that both catch and overall temperature in Camden Bay were low during 1988 (Figure 5.48).

Kaktovik Lagoon.— Fourhorn sculpin were present in varying abundances in Kaktovik Lagoon throughout the sampling seasons of each of the four study years. Few consistent relationships between CPUE and temperature or salinity were observed. Among years, catch rates were relatively constant despite varying thermohaline regimes (Figure 5.49). During 1988, the high correlations between CPUE and salinity (positive) and temperature (negative) resulted from a late season increase in catch, coincident with intrusion of a more marine water mass into Kaktovik Lagoon (Figure 5.50). Environmental data are lacking for a similar period of high catch early in the 1988 sampling season.

The correlation between salinity and CPUE was positive for station KL10 in 1989 and negative for station KL05. This differential relationship was also reflected in the stepwise regression results (Table 5.24), although linear associations between CPUE and environmental variables were weak ($R^2 \leq 0.43$). While catch between stations did not differ significantly, fourhorn sculpin were consistently more abundant at station KL10 during the latter half of the

TABLE 5.23.— Number of fourhorn sculpin tagged (N) and recaptured by location in Arctic Refuge coastal waters, 1988-91.

		Recapture area				
Tagging area	N	Simpson Cove	Kaktovik Lagoon	Jago Lagoon	Beaufort Lagoon	Pokok Bay
Simpson Cove	131	5	1	1	0	0
Kaktovik Lagoon	214	0	13	0	0	0
Jago Lagoon	317	0	2	10	0	0
Beaufort Lagoon	121	0	0	0	2	0
Pokok Bay	66	0	0	0	0	1

TABLE 5.24.– Environmental variables[a] influencing fourhorn sculpin CPUE (fish/d), followed by R^2 value of overall model. Parameter estimate is positive unless followed by "(-)". ("nv" = no eligible variables.)

Station	1988	1989	1990	1991
Simpson Cove				
SC01	nv	TEMP NW NW3P (0.27)	SAL(-) NW3P(-) EW1P(-) NW1P (0.48)	EW3P(-) TEMP (0.26)
SC04		TEMP SAL (0.50)	TEMP (0.28)	SAL(-) NW3P (0.60)
Kaktovik Lagoon				
KL05	SAL EW3P (0.79)	SAL(-) EW3P TEMP (0.43)	NW(-) EW(-) SAL(-) (0.58)	EW1P (0.21)
KL10	TEMP(-) EW3P (0.80)	SAL NW3P (0.38)	nv	EW1P TEMP SAL (0.56)
Jago Lagoon				
JL12	SAL (0.56)	nv	SAL EW(-) (0.35)	EW NW1P(-) NW (0.62)
JL14	TEMP(-) EW1P (0.76)	SAL(-) (0.06)	nv	EW SAL(-) NW3P EW1P (0.70)
Beaufort Lagoon				
BL02			NW1P (0.19)	NW3P (0.20)
BL04			TEMP(-) (0.54)	NW1P(-) EW3P(-) TEMP(-) NW(-) (0.66)
Pokok Bay				
PB01	TEMP(-) EW1P NW3P (0.77)			
PB02	TEMP(-) EW3P NW3P EW(-) (0.60)			

[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).

TABLE 5.25.— Environmental variables[a] influencing fourhorn sculpin 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	nv		
1989	TEMP	0.27	
	NW1P	0.06	
	NW	0.05	0.33
1990	TEMP	0.24	
	SAL	0.06	0.28
1991	SAL	0.29	
	EW3P	0.07	0.32
	Kaktovik Lagoon		
1988	SAL	0.46	
	EW3P	0.18	0.52
1989	TEMP	0.03	0.03
1990	NW	0.26	
	EW	0.07	
	SAL	0.02	0.31
1991	EW1P	0.21	
	TEMP	0.07	0.26
	Jago Lagoon		
1988	TEMP	0.63	
	EW3P	0.11	0.65
1989	EW3P	0.09	
	NW3P	0.05	
	NW1P	0.02	0.15
1990	nv		
1991	EW	0.43	
	NW	0.16	
	EW1P	0.13	0.52
	Beaufort Lagoon		
1990	EW3P	0.11	
	TEMP	0.10	0.19
1991	EW3P	0.10	
	TEMP	0.09	
	NW1P	0.06	0.22
	Pokok Bay		
1988	TEMP	0.23	0.23

[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).

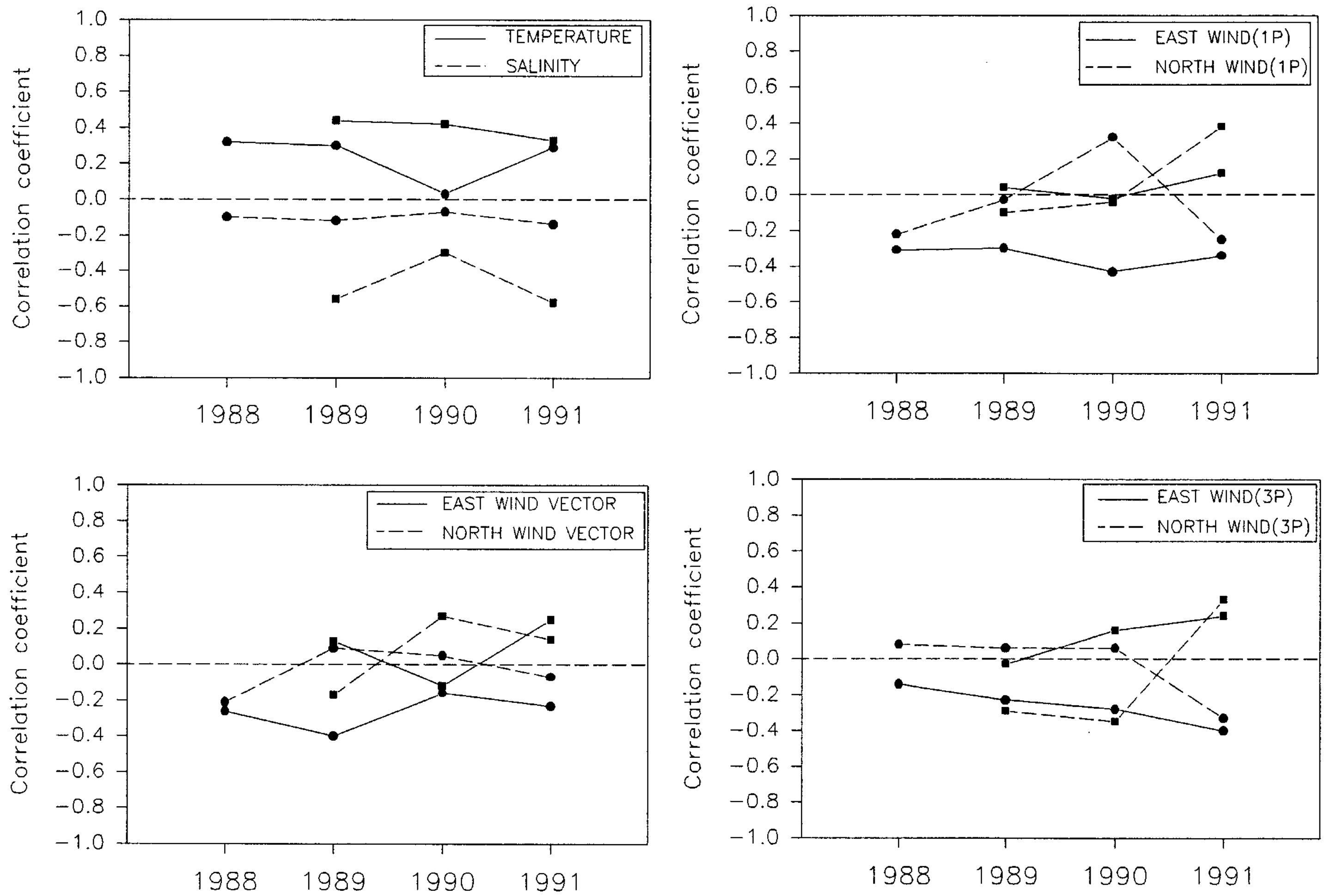

FIGURE 5.47.— Correlations between environmental variables and fourhorn sculpin CPUE from net stations SC01 (•) and SC04 (▪) (1988-91) in Simpson Cove. [1P=mean wind vector for previous day; 3P=mean of wind vector over 3 previous days].

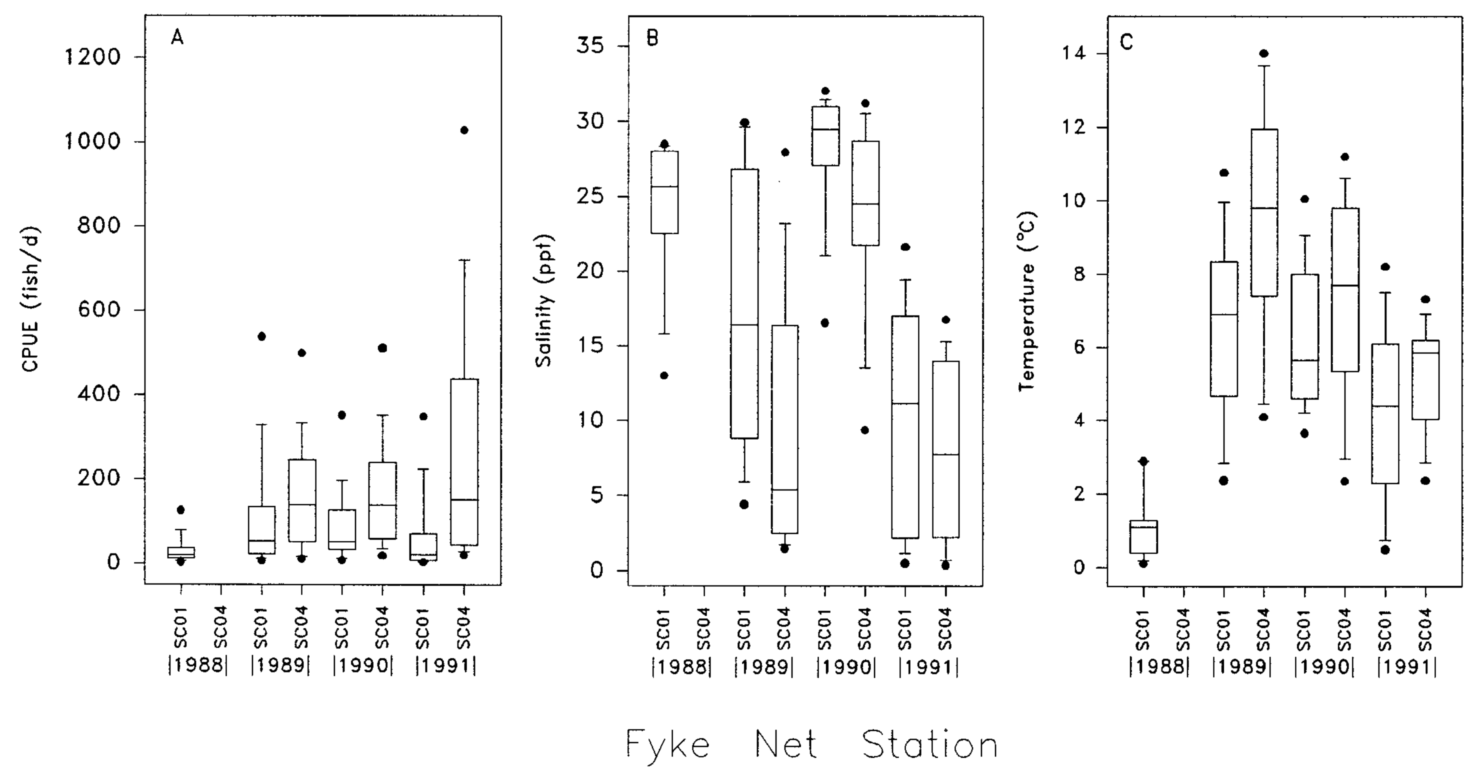

FIGURE 5.48.– Boxplots of (A) catch per unit effort for fourhorn sculpin, (B) salinity, and (C) temperature for Simpson Cove fyke net stations during 1988-91.

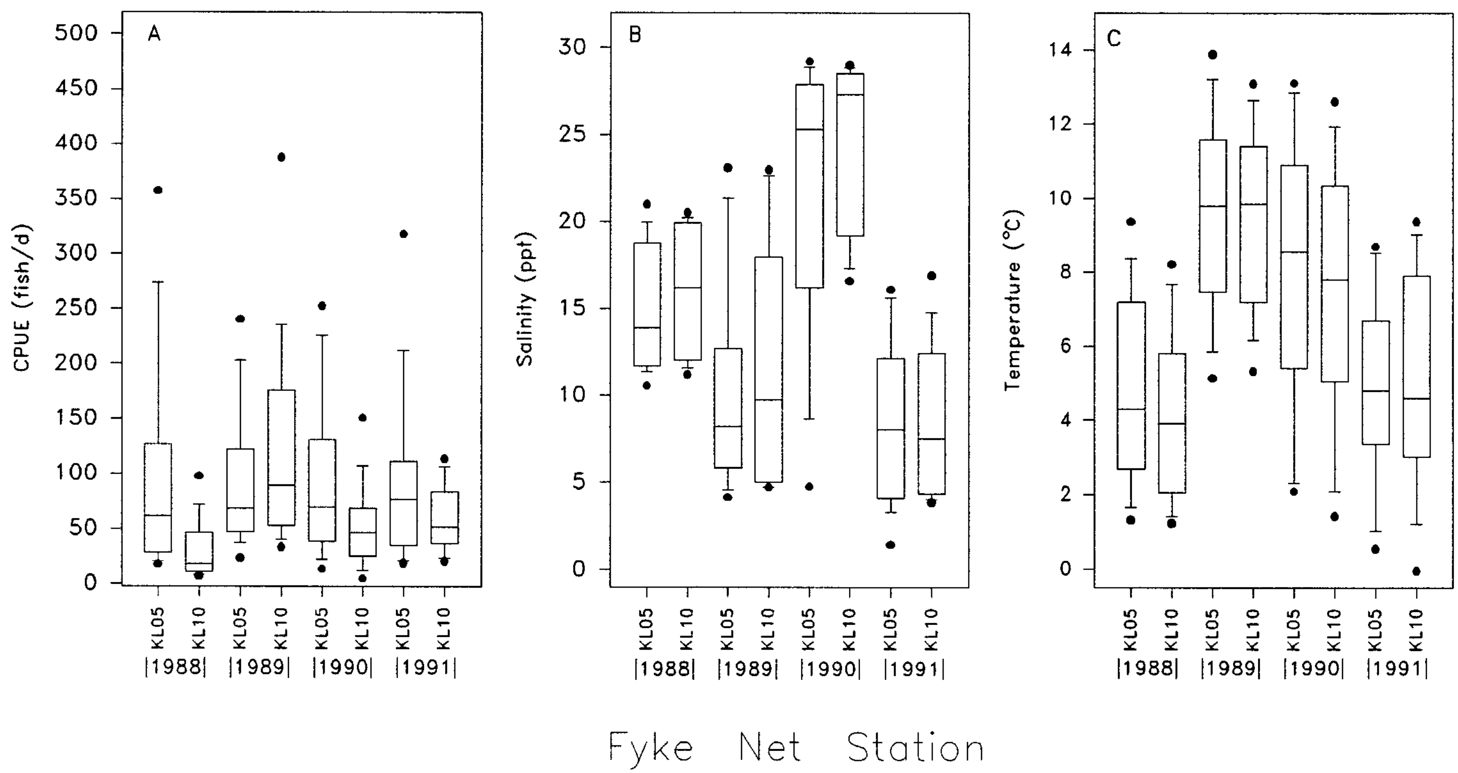

FIGURE 5.49.— Boxplots of (A) catch per effort for fourhorn sculpin, (B) salinity, and (C) temperature for Kaktovik Lagoon fyke net stations during 1988-91.

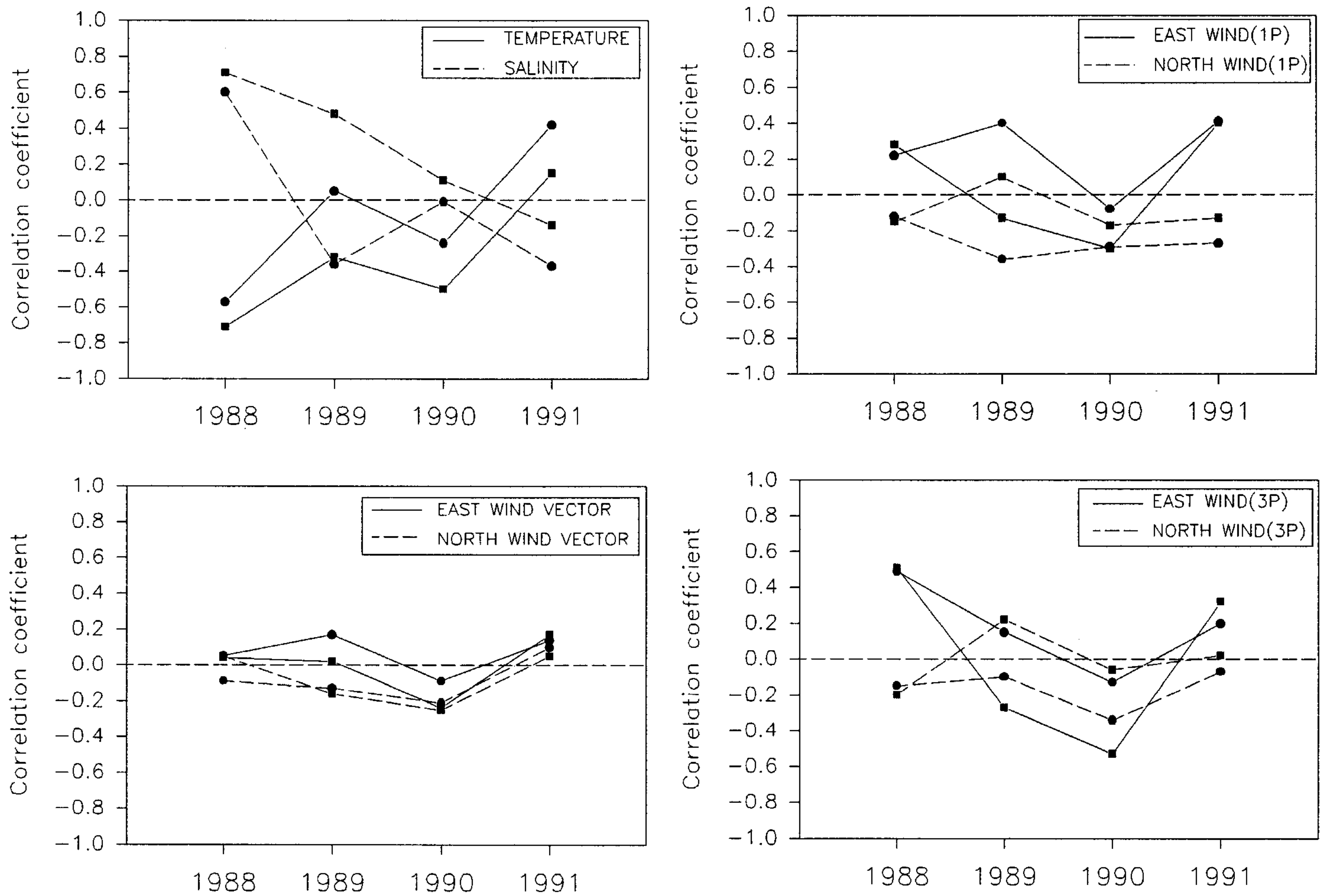

FIGURE 5.50.– Correlations between environmental variables and fourhorn sculpin CPUE from net stations KL05 (•) and KL10 (▪) in Kaktovik Lagoon, 1988-91. [1P=mean wind vector for previous day; 3P=mean of wind vector over 3 previous days].

sampling season. Salinity and temperature regimes, however, were very similar between the two stations (Table 5.26).

During 1990, fourhorn sculpin were again more numerous during the latter half of the sampling season (late August to early September) when water temperatures in Kaktovik Lagoon were below 10°C and salinities were above 25 ppt. No consistent patterns were evident between wind and CPUE. For example, northerly and easterly winds were negatively related to catch rates during 1990, while east winds were positively correlated with catches during 1991 (Tables 5.24, 5.25). High catch rates occurred early during the 1991 season, coincident with a period of colder water temperatures (< 10°C) that was not present in previous years. No strong relationships were detected by stepwise regression in the 1991 data ($R^2 \leq 0.56$), although a positive east wind component was selected in both the station-specific and pooled analyses.

Jago Lagoon.— Fourhorn sculpin were present in Jago Lagoon throughout the entire sampling season of each year. Within-year catch rates were not significantly different than those in adjacent Kaktovik Lagoon (Table 5.26).

Temperature and salinity were negatively and positively correlated with CPUE, respectively, during the 1988 sampling season (Figure 5.51). These associations were also revealed in the stepwise regression results, where temperature was the dominant explanatory variable for CPUE at station JL14 and pooled stations, and salinity was important at station JL12 (Tables 5.24, 5.25).

No strong relationships between CPUE and environmental variables were detected in the 1989 or 1990 data. In 1991, east winds were positively associated with catch rates at both Jago Lagoon stations. The bulk of the fourhorn sculpin catch in 1991 occurred in mid-July, however, prior to collection of environmental variables.

Beaufort Lagoon.— Although fourhorn sculpin were present in Beaufort Lagoon throughout the sampling period, annual catches were low when compared to the other sampling areas, whereas temperatures were generally higher and salinities were lower (Table 5.26). Catch per unit effort was negatively associated with temperature for the sampling area and station BL04 during 1990 and 1991 (Tables 5.24, 5.25; Figure 5.52). The association between wind patterns and catch rates was highly variable between years and sampling stations (Figure 5.52). No consistent patterns were detected.

Pokok Bay.— A strong negative association between fourhorn sculpin catch rates and temperature existed during the 1988 sampling season in Pokok Bay. Temperature was the most influential variable in both the pooled and station-specific stepwise regression analyses (Tables 5.24, 5.25). The increased catch at station PB01 late in the sampling season (September 7 to 14) was coincident with colder temperatures, although high catches were also observed in late July when no environmental variables were available. The lack of synoptic data hindered interpretation of associative trends.

TABLE 5.26.— Comparisons of daily fourhorn sculpin 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, α=0.05). Where different, areas are ordered from larger to smaller mean values for the comparison variable.

Variable	Scheffé grouping			
		1988		
CPUE	Jago	Kaktovik	Simpson	Pokok
	————	————		
		————	————	
			————	————
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
	————	————	————	
				————

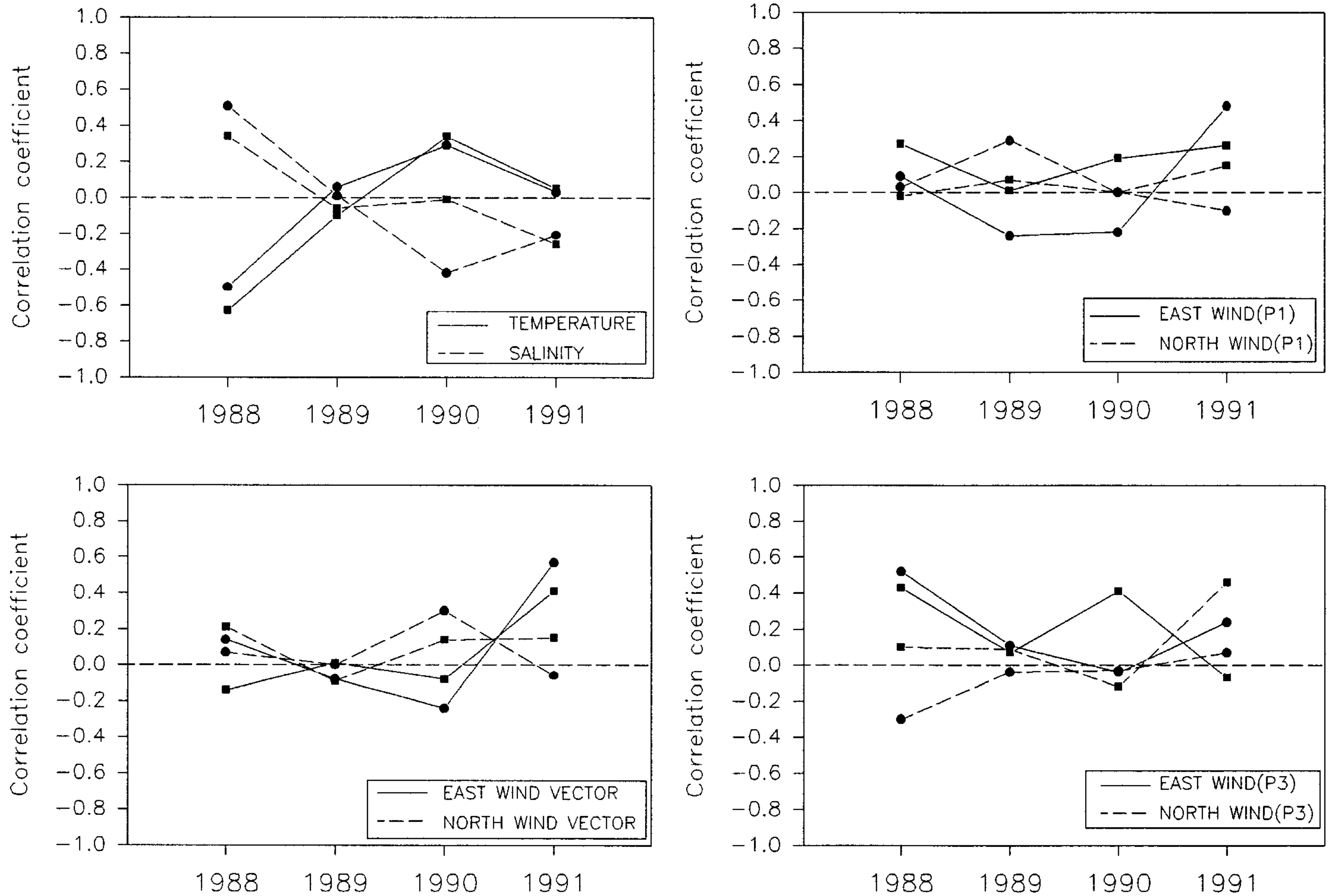

FIGURE 5.51.- Correlations between environmental variables and fourhorn sculpin CPUE from fyke net stations JL12 (•) and JL14 (▪) in Jago Lagoon, 1988-91. [1P=mean wind vector for previous day; 3P=mean of wind vector over 3 previous days].

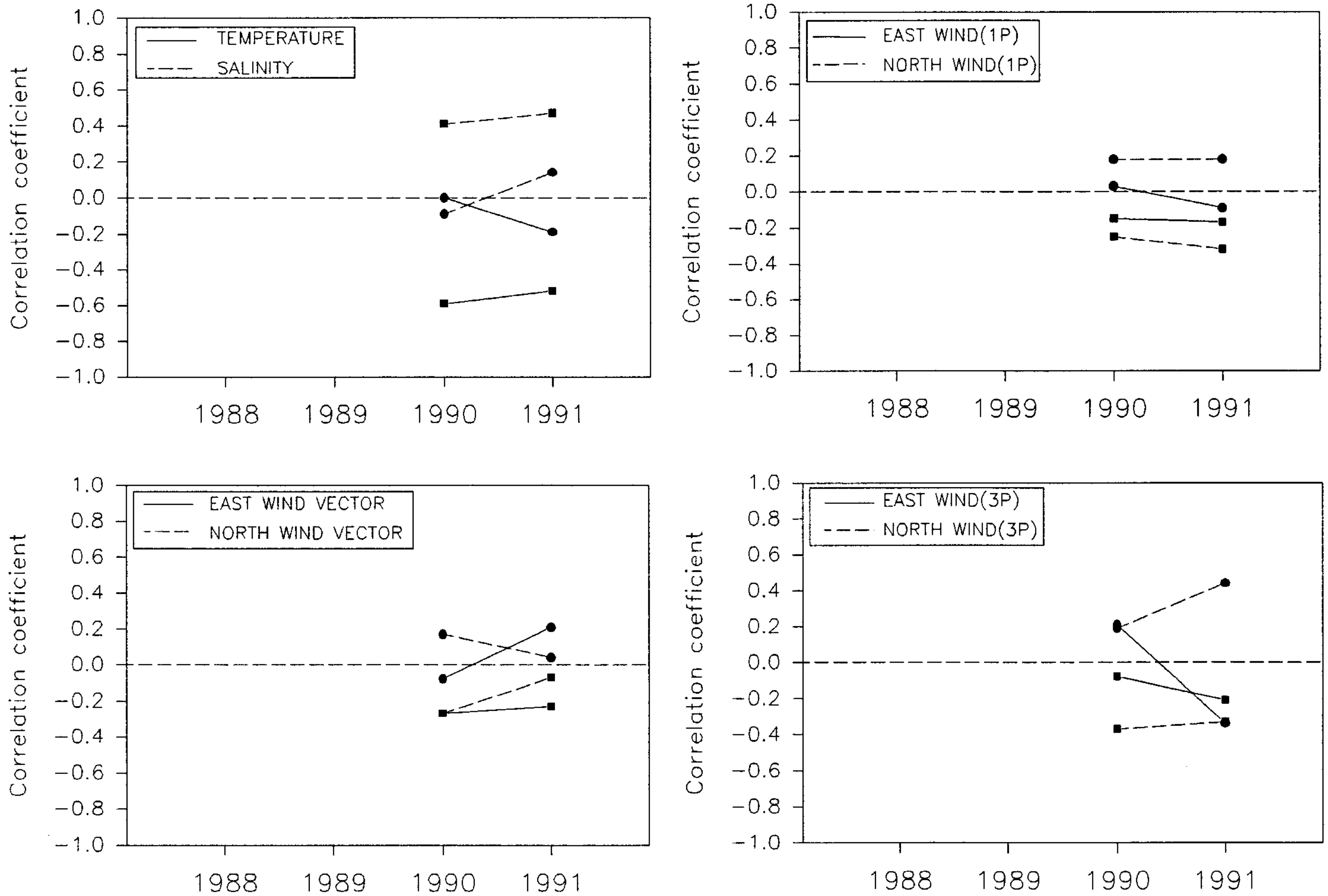

FIGURE 5.52.— Correlations between environmental variables and fourhorn sculpin CPUE from net stations BL02 (•) and BL04 (▪) (1990-1991) in Beaufort Lagoon. [1P=mean wind vector for previous day; 3P=mean of wind vector over 3 previous days].

Discussion

Relative Abundance and Distribution

Previous observations on fourhorn sculpin suggested that relative abundance was fairly constant during sampling (LGL 1983; Bond and Erickson 1989). Daily catch rates during the four years of this study agree with these studies. Although the easternmost sampling areas in 1988, 1990, and 1991 had significantly lower daily catch rates, little other spatial variability was evident. Our two-way ANOVA results suggest that spatial and temporal effects were relatively similar sources of variation in our CPUE data. We interpret the lack of any strong trends in either spatial or temporal variation as an indication that fourhorn sculpin are relatively ubiquitous along the Arctic Refuge coast, i.e., their distribution is not greatly fragmented by ambient environmental influences. One temporal trend observed in each year was that several locations showed relatively constant catch rates during the open-water season. Due to this stability in relative abundance any significant changes may be indicative of environmental perturbations. Fourhorn sculpin could thus be potentially useful as an indicator species.

Length Frequency Distributions

Length frequency distributions of fourhorn sculpin appear, generally, to exhibit a trimodal pattern that is reflective of different age-classes in the sampled population. Our results are similar to work on fourhorn sculpin growth in the Arctic (Griffiths et al. 1977; Lawrence et al. 1984). In these studies, ages 1, 2, and 3 were found to have mean lengths that fell within the ranges of our three length frequency modes. In addition, we found mean lengths at age in our study to fall into the three modes from the length frequency distributions (see below, this study). The decline of the third mode (150-200 mm TL) during the latter sampling periods in Simpson Cove indicates movement of larger fish out of the sampling area. Likewise, the presence of larger fish in the third and fourth sampling periods in Beaufort Lagoon may be a result of movement of fourhorn sculpin into that area.

Condition

Gender differences.— Although interpretation of the comparisons of condition between sexes was precluded by differences in slopes in pooled year analyses, the 1989 data susggest that condition differs by sex. Separate collection of condition data, as encouraged by various authors (Bagenal and Tesch 1978; Anderson and Gutreuter 1983), is appropriate and should continue in the future.

Seasonal differences.— Slope differences between seasons (pooled data) interfered with interpretations of seasonal fish condition. In 1988, the only year where slope comparisons did not preclude statements about condition, no differences in condition were detected. In that year ice pack persistence and cooler water temperatures could have retarded productivity and changes in condition. The influence of gonad maturation on condition during the summer season is unclear. Changes in condition due to summer feeding or gonad development may be expected. Goldberg et al. (1987) recorded summer spawning of fourhorn sculpin in the Beaufort Sea, Alaska. Evidence supports mid-winter spawning in other regions (Westin 1968, 1969; Lawrence et al. 1984; Bond and Erickson 1987).

Overwintering.— Assuming Arctic fish accumulate lipids during the summer and draw upon these reserves during the winter, one would expect fish condition to increase during the summer open-water season and decrease during the winter. However, results for our 1989-90 and 1990-91 winter data differ; one winter (1990-91) follows convention while the other does not. We cannot explain these contrary results.

Spatial differences.— Differences in fish condition among areas might result from variable salinity or temperature, productivity, nutrient inputs, or food availability. Because temperature and salinity data were not collected consistently in Beaufort Lagoon during 1989, no associations can be drawn between those variables and concurrent sampling in Simpson Cove and the Kaktovik and Jago lagoon complex.

Late in the open-water season among-area differences were not evident. These findings indicate that baseline fourhorn sculpin condition information may not need to be site specific at this time of year. Further attempts should be made to find comparable stanzas of fish with equal slope estimates to confirm this hypothesis.

Annual differences.— We detected numerous differences in condition from the comparison between years, both early and late in the open-water season. This may indicate that annual variation is a large component of the total variation compared to seasonal and spatial components (gender-based statistical tests were tenuous for fourhorn sculpin). The paucity of literature on fourhorn sculpin makes comparison of our results with those other findings impossible. Fourhorn sculpin captured in 1989 and 1990 had higher condition than 1988 and 1991, as did several other species examined during this study. The years 1989 and 1990 were characterized by warm water temperatures and substantial withdrawal of the ice pack from coastal waters. In addition, large numbers of age-1 and young-of-the-year Arctic cisco were present in the study area and provided an abundant food supply for local piscivores. Our capture techniques may have artificially elevated fourhorn sculpin condition by providing concentrated prey densities within fyke net cod ends. In 1990, captured fourhorn sculpins gorged themselves and exhibited extended abdomens and mouths filled with young Arctic cisco. Post-capture gorging occurred in other years to a lesser extent. It seems unlikely that similar feeding success normally occurred outside of the fyke nets.

Age and Growth

Age and growth of fourhorn sculpin in our study appears to be similar to other studies (Griffiths et al. 1977; Lawrence et al. 1984; Houston 1990). In these studies, age-1, -2, and -3 fish comprised most of the catch and were represented by the trimodal length frequency pattern similar to what we found (this study). Our mean lengths at age were consistent with those found by Lawrence et al. (1984) in the southeast Beaufort Sea.

Fourhorn sculpin are fast growers during their early lives. Lawrence et al. (1984) found young-of-the-year grew almost 20 mm between July and September of the same season. Also, our data indicated a 41 mm average growth increase between ages 1, 2, and 3 (Table 5.20).

Growth appeared to diminish at age-6 in our study. Because growth would be expected to slow when fish reach maturity, fourhorn sculpin may attain maturity at five or six years of age. Craig and McCart (1976) found age-4 and age-5 fourhorn sculpin to be mature. Although we cannot validly determine maturity status of individual fish from our work, future work on fourhorn sculpin should examine the age-at-maturity and sex ratio of populations.

Movements

Previous findings suggest that the movement of fourhorn sculpin is generally inshore/offshore and localized (Andriyashev 1954; Westin 1970; and Lawrence et al. 1984). Due to study design, the inshore/offshore movement described for this species cannot be inferred by our tag-recapture results. However, our results are consistent with the theory that movement of fourhorn sculpin along the coast is localized. The high incidence of recaptures occurring within the original tagging area suggest the fourhorn sculpin were not moving frequently between the sampling areas. The two fourhorn sculpin which moved between Kaktovik and Jago lagoons can be attributed to the proximity of the lagoons and how they are separated from each other. The lagoons are adjacent to one another and separated by a peninsula of land (Manning Point) which narrows to three meters wide at its base. The lagoons become connected when this small stretch of peninsula becomes submerged during unusually high water. Fish have been observed moving over this spit during high water. Another possible travel route is Nelsaluk Pass connecting the two lagoons at the tip of the peninsula.

Although localized movement is normal, tagged fourhorn sculpin were documented moving considerable distances. Two fourhorn sculpin moved between Simpson Cove and the Kaktovik and Jago lagoon complex, thus traveling a minimum distance of approximately 60 km. The conditions under which this movement occurred also deviated from those normally observed. The open-water season of 1990 was the only season since 1987 in which winds were predominantly from the east and were relatively strong during July and August (LGL 1991). The resultant coastal water currents would impede the observed eastward migration of the two tagged individuals.

Further tag-recapture studies will be necessary to thoroughly examine fourhorn sculpin movement along the coast. To properly document movements, a multi-year tag and recapture study of fourhorn sculpin consisting of both inshore and offshore locations at specific sites along the coast are necessary.

Environmental Influences on CPUE

Fourhorn sculpin were relatively abundant throughout the 1988-91 sampling seasons and exhibited few apparent dependencies upon environmental conditions. Daily variability in catch was high, which increased the difficulty of identifying any longer term CPUE trends which may have resulted from hydrographic events. Previous studies confirm the widespread distribution of this abundant resident species over a wide range of temperatures and salinities along the Beaufort Sea coast (Craig and McCart 1976; Craig et al. 1985; Cannon et al. 1987). Daily movements by fourhorn sculpin may be an avoidance response to vacate less favorable conditions or avoid localized predator concentrations, and may additionally be influenced by differential prey concentrations (Houston 1990). For abundant resident species, these trophic-mediated movements may be the primary determinant of distribution patterns. These factors were not addressed by our study design. Our data indicate that fourhorn sculpin are present in large numbers in a wide range of hydrographic conditions and are thus not likely to suffer significant loss of critical habitat by localized hydrographic perturbations due to development-related activities. More importantly, localized extirpation of fourhorn sculpins near development sites may indicate profound hydrographic alterations had occurred.

The ecology and reproductive biology of the fourhorn sculpin remains relatively unknown, and bears further investigation before impact assessments can be reliably assigned to coastal populations.

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