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SALMONID SMOLT DISTRIBUTION IN THE FOREBAY OF PRIEST RAPIDS DAM

by

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Director

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1.0 ABSTRACT

In May of 1980 a townet was used to study the relative abundance and distribution of seaward-migrating juvenile salmonids in the forebay of the Priest Rapids Dam. During 40.35 hrs of sampling 2453 salmonids were collected. Seventy-five percent of the fish were juvenile chinook salmon. Significantly ($\alpha = 0.05$) more chinook and sockeye salmon were distributed along the east and west banks of the reservoir than in front of the dam or the middle of the forebay. Conversely, steelhead were collected principally in front of the dam and appear to migrate down the middle of the reservoir. The distribution and abundance of juvenile coho salmon were not established because few were caught. Except for the chinook salmon, which were both hatchery and wild stock of two distinct size classes, no relationship existed between fork length and time of month or catch location. Recommendations for additional research to develop fish by-pass facilities at Priest Rapids Dam were made.

2.0 ACKNOWLEDGEMENTS

The Public Utility District of Grant County provided financial support for this study, as well as vessels and operators for the townet sampling operation. Bechtel Incorporated (engineers-constructors) coordinated this research effort with other studies designed to develop fisheries information needed in development of fish by-pass facilities for new turbine units to be added to the Priest Rapids powerhouse. We acknowledge Mr. Richard Tyler for his guidance of the initial deployment of the townet. We thank Dr. Lawrence Gales for providing the special computer programs used to analyze these data.

3.0 INTRODUCTION

Construction of hydroelectric dams on the Columbia River has severely compromised the production of Pacific salmon, *Oncorhynchus* spp., and steelhead trout, *Salmo gairdneri*. The fish passage problems at each dam for adult salmonids have been dealt with by the development and installation of fish ladders. However, little progress has been made to reduce the mortality and delay dams cause seaward-migrating juvenile salmon and steelhead.

Early in the development of the hydroelectric potential of the Columbia River, a measure of balance existed with regard to the "health" of this valuable fishery resource. Spring and early summer freshets created high river flows which exceeded the hydroelectric capacity of a fewer number of existing dams. This resulted in the spilling of water over the dams and the flow of a large amount of water downstream at a time that coincided with the annual spring emigration of salmonid smolts to sea (Hays *et al*. 1978). Today eleven hydroelectric projects operate on the middle and lower Columbia River in Washington State, and only one free-flowing section of the river remains. Even during spring floods relatively small amounts of water are now spilled from hydroelectric reservoirs due to the increased generating capacity at the dams and the upstream storage in the Columbia River Basin. As a result, the downstream-migrating smolts must pass through from one to as many as nine turbines where it is estimated that from 11 to 14 percent are killed or stunned and left highly susceptible to predation at each dam (Schoeneman *et al*. 1961, Long and Marquette 1967). In the past ten years smolt mortality on the Columbia increased to greater than 95 percent in 1973 and 1977, and it became necessary to drastically increase smolt production through hatchery development to make up for the losses in order to sustain the run (Ebel et al. 1979).

It is currently believed by the regulatory and fishery management agencies that the only viable means of minimizing the dam-related mortality of juvenile salmonids is to require the spilling of water at each dam during the spring to allow some of the migrating fish to escape downstream without passing through the turbines. Each year the U.S. Army Corps of Engineers (C of E) and the Public Utility Districts (PUD) operating the dams carefully spill water during those periods the fish are thought to be moving past. Yet, because of the growth taking place in the Pacific Northwest and the national energy crisis, the value of water for power generation has continued to escalate. The C of E and mid-Columbia PUD's are working toward a "no-spill" condition where all the water in the river can be used for power production when needed (Seligman 1980). Plans are currently being implemented to increase the number of turbine units at Priest Rapids Dam for the production of additional power. Alternatives to the spilling of water are now being investigated for the safe downstream passage of juvenile salmon and steelhead.

The Priest Rapids Dam on the mid-Columbia River (Figure 1) has been operated with ten turbine units by the Public Utility District of Grant County since 1961. To meet future power requirements Bechtel Incorporated (engineers-constructors) has been contracted to design and build four additional turbine units for the Priest Rapids powerhouse. In response to the problems associated with providing juvenile salmonids safer passage at Columbia River dams, this research is attempting to provide the basic information defining the distribution and behavior in the forebay of the dam. It is hoped that this information will aid in the design of fish by-pass

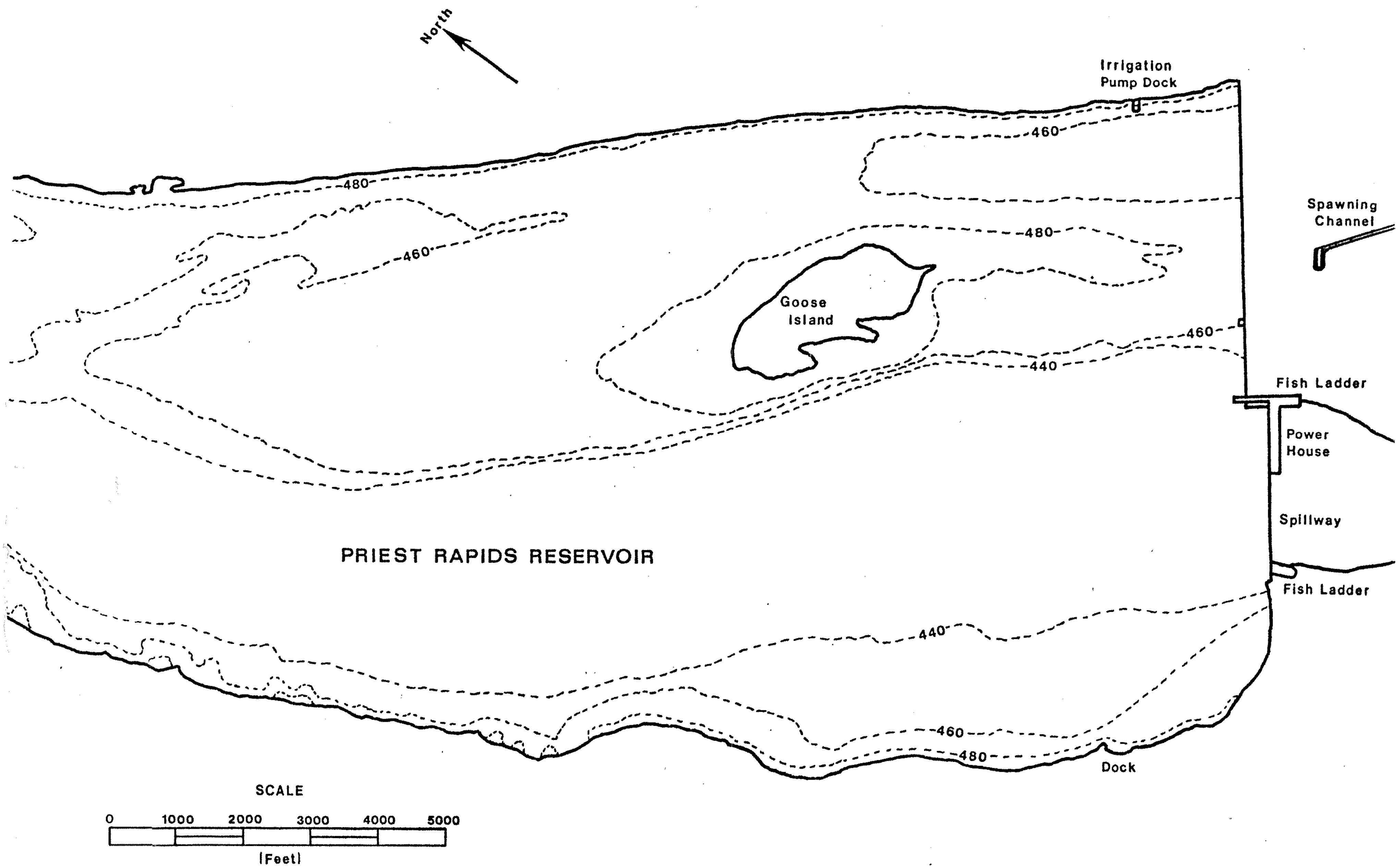

Figure 1. Priest Rapids Reservoir with bottom contours.

facilities and other modifications which will minimize the mortality of juvenile salmonids.

Grant County PUD and Bechtel engineers are relying principally on hydroacoustic fish sensing techniques, provided by the Applied Physics Laboratory (APL) of the University of Washington to obtain quantitative information on the distribution and behavior of juvenile salmonids in the immediate vicinity of the dam. The Fisheries Research Institute at the University of Washington conducted townet sampling to obtain information on species composition and salmonid distribution in the forebay at points further removed from the dam. This report details the results of the townet study which was conducted during the month of May 1980, when the majority of both the hatchery-reared and naturally occurring salmonid smolts moved past the dam.

4.0 MATERIALS AND METHODS

4.1 Townet Sampling

Smolt samples were collected with a 14.9 m long townet surface trawl. The trawl graded, in cross-sectional area and mesh size, from an opening 6.1 m wide by 3.1 m deep constructed of 7.6 cm square mesh, to a zippered cone-shaped cod-end 1.2 m long by 0.8 m across at the mouth, constructed of a double layer of 0.3 cm braided mesh (Schreiner et al. 1977). The net was floated with two 60 cm (dia.) buoys secured to the upper end of 3.5 m long steel spreader bars attached to the forward vertical leading edges of the trawl (Figure 2). Bridles, made of 1.6 cm (dia.) polypropylene line, were attached to the spreader bars on either side of the net and run forward to single lines leading to the towing vessels which kept the net spread horizontally.

The net was towed through the water at approximately 1.0 m/sec by the M/V Jenny, a 12.2 m twin-engine diesel-powered barge, and a 5.5 m inboard-outboard gasoline-powered Starcraft. Both vessels were owned and operated by the Grant County PUD. Fish sampling was conducted from a third boat, a 5.2 m Boston whaler, secured fore and aft to the midline of the townet in such a way as to place the transom of the boat over the zippered cod-end (Figure 2). A purse line running from a hand-operated boom-mounted winch in the stern of the whaler around the net at a point just forward of the zippered cod-end made it possible to remove and identify fish samples while the trawl continued to sample.

Figure 2. Surface trawl deployed showing Boston Whaler in position over cod-end of the net.

4.2 Sampling Schedule and Design

Fourteen days were spent sampling fish with the trawl in the forebay of the Priest Rapids Dam between May 7 and 30, 1980. High winds, common to the region, and ashfall from the Mt. St. Helens eruption prevented more sampling from occurring during that period. Attempts at adherence to an eight-hour two-week work schedule for the Electrical Workers Union boat operators of the Grant County PUD placed additional restaints on sampling. Sampling occurred roughly between 1930 and 0400 hrs from May 7 to May 16, and between 1200 and 2030 hrs from May 23 to May 30, 1980.

The net was towed along three transect patterns which ran parallel to the shore or dam on the surface of the forebay (Figure 3). Transect patterns were divided into distinct legs which were defined by various geographical boundaries and physical objects that made up the shoreline of the Priest Rapids Reservoir. At the end of each transect leg, time was recorded and the fish present in the cod-end of the net removed and placed in a bucket of water containing the anesthetic MS-222 (tricaine-methane-sulfonate). All fish were counted, identified and measured before being released. In a few instances where large numbers of salmonids were collected in the trawl, excessive mortality was avoided by measuring only fifty fish of a species before the rest were counted and released.

4.3 Catch Analysis

The catch per unit effort was calculated per minute of towing time (CPM) for each salmonid species and the total catch of all salmonids caught on each leg of each transect pattern every time the trawl was towed along each leg of

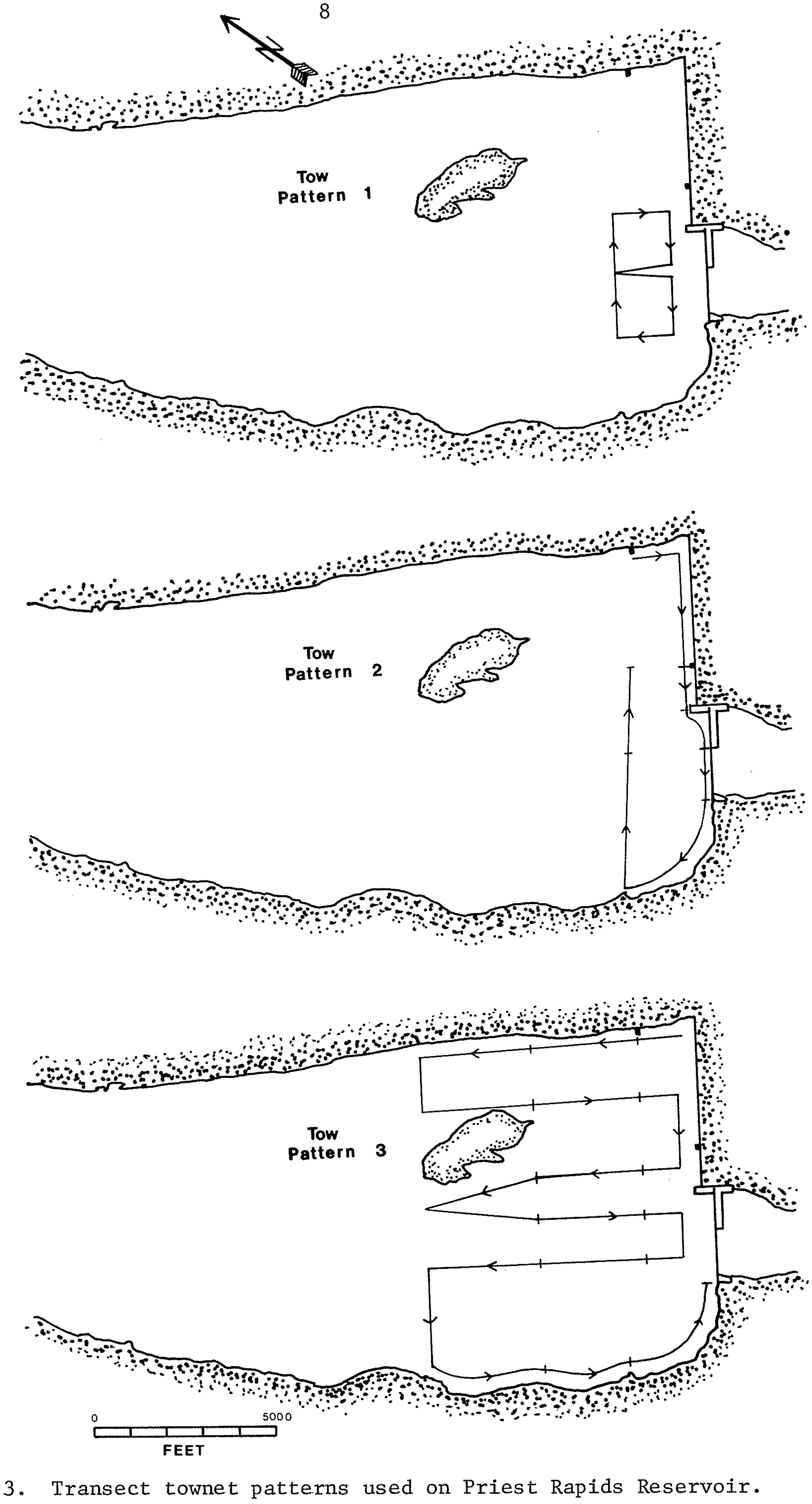

Figure 3. Transect townet patterns used on Priest Rapids Reservoir.

a pattern. The forebay of the Priest Rapids Reservoir was divided into nine different areas which included from one to as many as twenty-two of the transect pattern legs (Figure 4). The mean CPM was determined for each of these areas, by species and for the total salmonids for the entire sampling season. The CPM data for each area were treated by log transformation:

$$x = \ln (10 \cdot \text{CPM} + 1)$$

to smooth the variance. A Statistical Package for the Social Sciences (SPSS) one-way analysis of variance (ANOVA) was then used to test for significant differences in the geometric mean catch per minute in the nine defined areas of the forebay and the 95 percent confidence intervals for each mean value plotted. To aid the analysis and increase sample size by area mean CPM values were determined for four larger and more naturally delimited areas shown in Figure 5. Following one-way ANOVA, these mean values were compared with Scheffe's multiple contrasts test.

Length-frequency distributions were determined for each salmonid species collected for the season by week and for the four areas depicted in Figure 5. SPSS one-way ANOVA and Scheffe's multiple contrasts tests were used to detect significant differences in the mean size of each salmonid species collected with the trawl by week and by area.

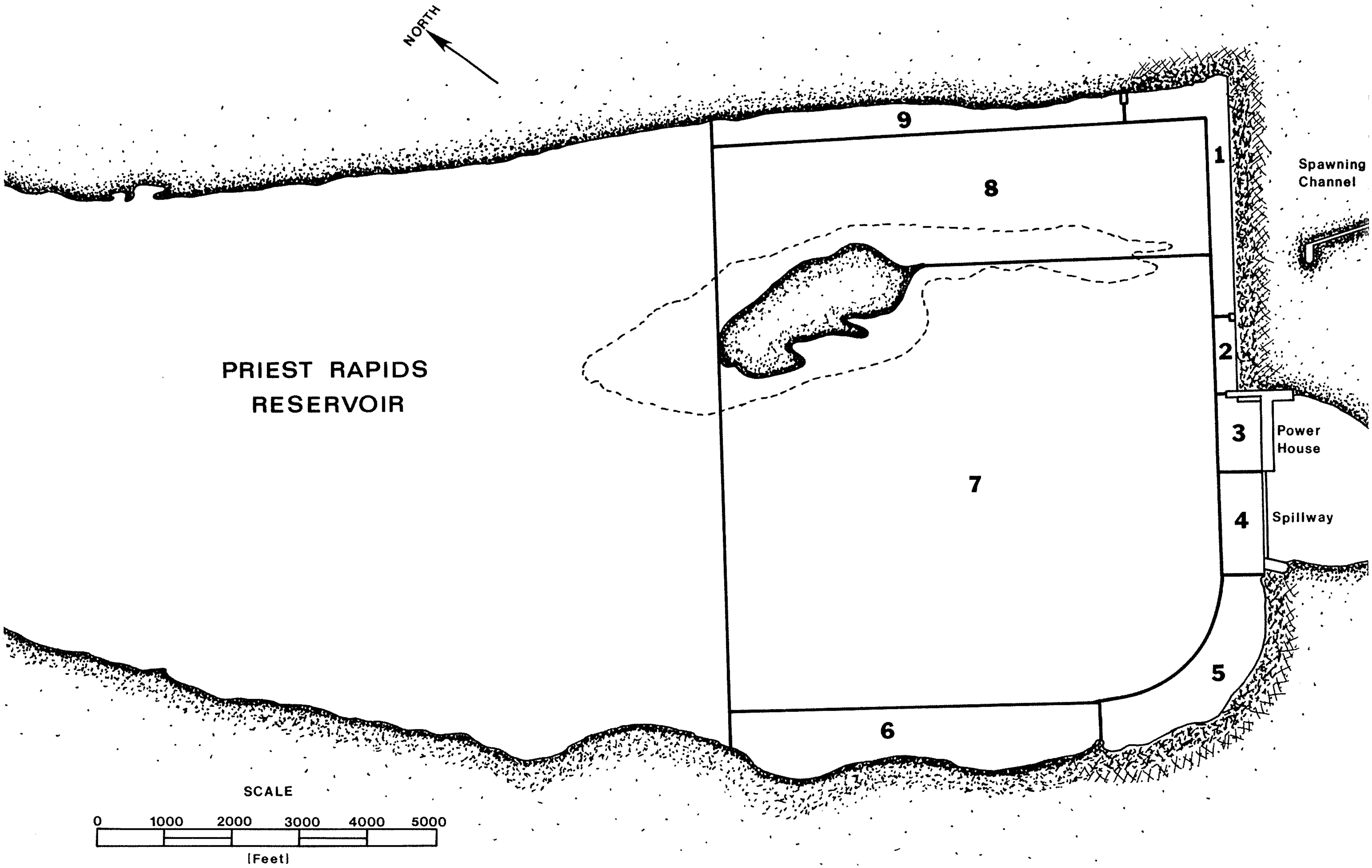

Figure 4. Nine areas dividing the forebay of the Priest Rapids Reservoir.

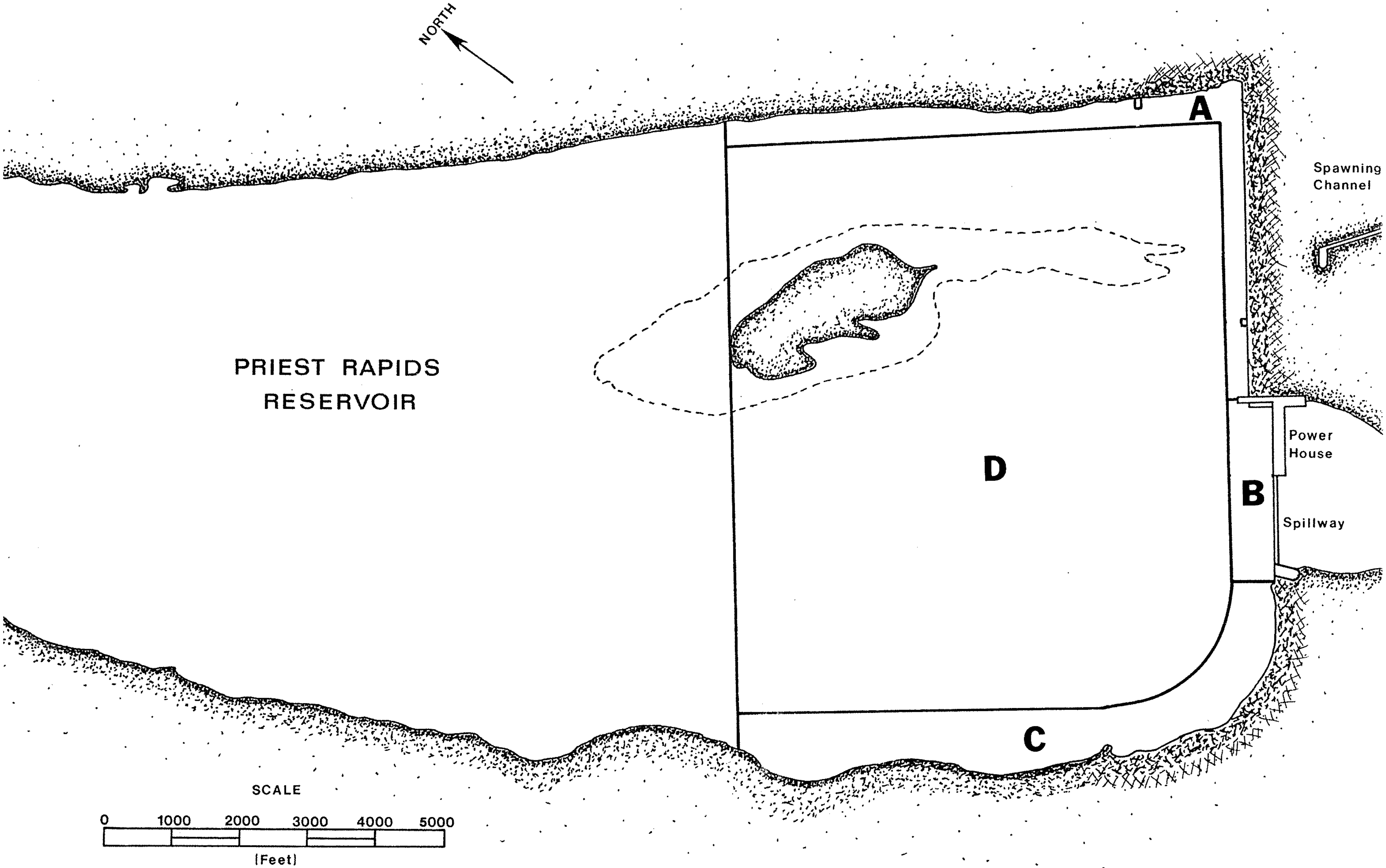

Figure 5. Four areas dividing the forebay of the Priest Rapids Reservoir.

5.0 RESULTS

5.1 Catch Distribution

The townet sampling captured 2468 fish during a total of 2601 minutes of trawling in the forebay of Priest Rapids Reservoir between May 7 and 30, 1980. Greater than 99 percent of these fish were juvenile salmonids, and 271 bore marks (Appendix I). Nearly 75 percent of the total were juvenile chinook salmon (Table 1). The average number of salmonids caught per minute of sampling for the entire period was 0.94. Figure 6 shows the average daily catch per minute ($\overline{CPM}$) of chinook, steelhead, coho and sockeye during the fourteen days in May these fish were sampled. Salmonid catch and the time spent fishing each week are presented in Table 2.

Table 3 shows the salmonid catch by species and the mean CPM for each species and total salmonids for each of the nine areas defined in Figure 4. One-way analysis of variance performed on the log-transformed data showed that significant differences exist among the mean CPM's of chinook, steelhead, coho, sockeye and total salmonids from the nine areas, where $\alpha \leq 0.01$. Plots of the geometric mean CPM's, grouped into four areas shown in Figure 5, and the 95% confidence intervals obtained from the ANOVA for each species and total salmonids are presented in Figures 7-11. These plots reflect the differences detected in the areal mean CPM's by the ANOVA but also show the overlap and ambiguity which exist between pairs, in part a result of the small sample sizes defining most of the means. Separate analyses of variance of the log-transformed data excluding the 165 data points from area 7 (see Table 3) to smooth the variances further, revealed that significant ($\alpha = 0.05$)

Table 1. The number and percent total of all species caught during 40.35 hrs of townet sampling in the Priest Rapids Reservoir between May 7 and May 30, 1980. The number of hatchery-marked fish is also shown.

Species	Catch No.	Catch %	Marks No.
Chinook salmon, *Oncorhynchus tshawytscha*	1841	74.6	124
Sockeye salmon, *Oncorhynchus nerka*	322	13.0	0
Steelhead, *Salmo gairdneri*	229	9.3	101
Coho salmon, *Oncorhynchus kisutch*	61	2.3	46
Redside shiner, *Richardsonius balteatus*	4	0.2	
Three-spine stickleback, *Gasterosteus aculeatus*	4	0.2	
Northern squawfish, *Ptychocheilus oregonensis*	2	0.1	
Black bullhead, *Ictalurus melas*	1	+	
Bridgelip sucker, *Catostomus columbianus*	1	+	
Peamouth, *Mylocheilus caurinus*	1	+	
River lamprey, *Lampetra ayresi*	1	+	
Yellow perch, *Perca flavescens*	1	+	
Totals	2468	100.0	271
Total salmonids	2453	99.4	

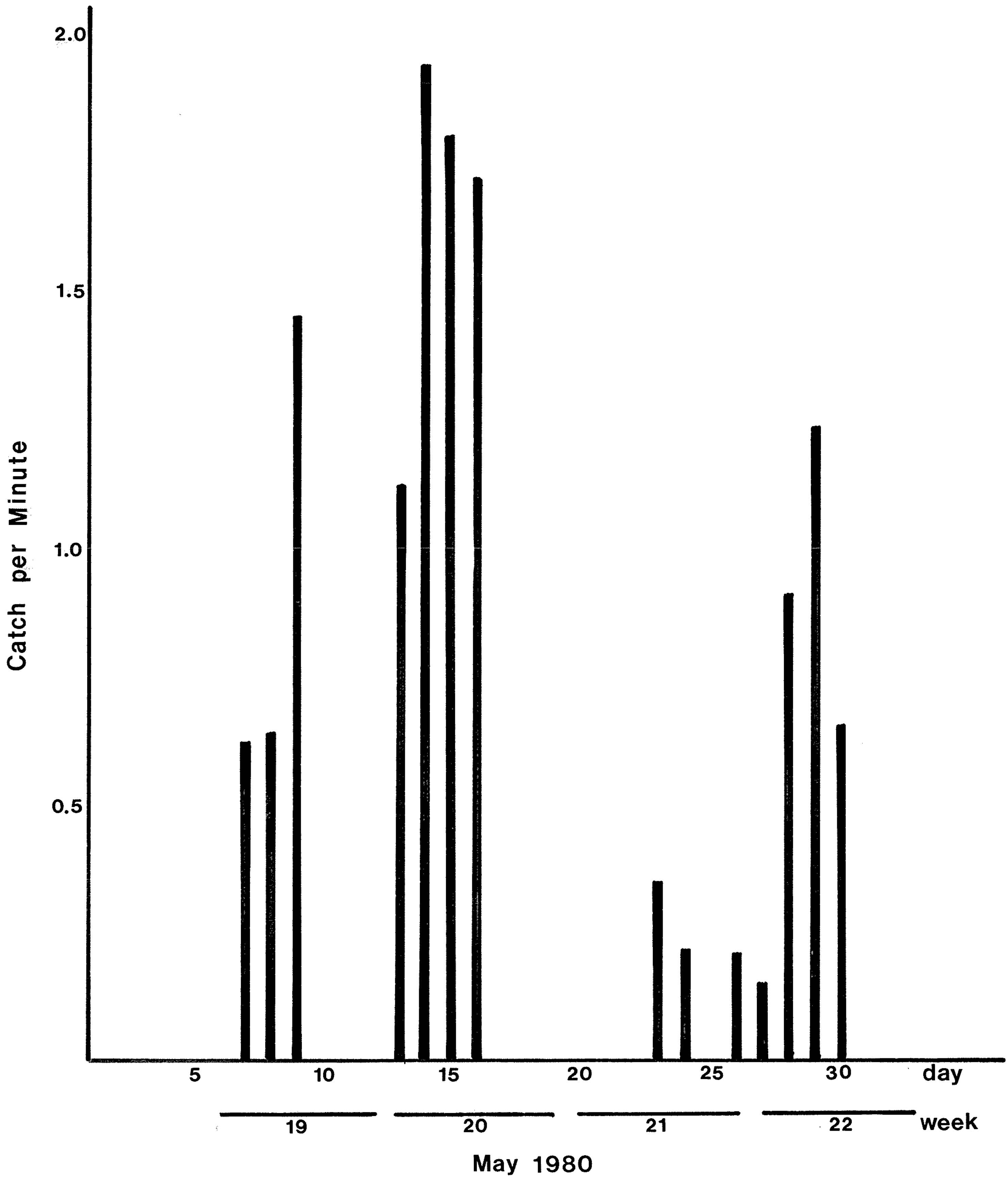

Figure 6. Average daily salmonid catch per minute ($\overline{CPM}$) by townet sampling in the forebay of the Priest Rapids Reservoir between May 7 and 30, 1980.

Table 2. Salmonid catch by species and for total salmonids and townet sampling time in the Priest Rapids Reservoir during four weeks in May, 1980.

Week	Time min.	Tows	Chinook	Steelhead	Number Coho	Sockeye	Salmonids
19	489	47	319	153	0	37	509
20	741	67	1049	54	6	171	1280
21	536	50	110	9	17	12	148
22	835	88	363	13	38	102	516
Totals	2601	252	1841	229	61	322	2453

Table 3. Salmonid catch by species for total salmonids and average catch per minute ($\overline{CPM}$) for four salmonid species and total salmonids in nine areas of the Priest Rapids Reservoir, May 7 through 30, 1980 (See Figure 4).

	Tows	Time		Chinook		Steelhead		Coho		Sockeye		Total salmonids	
Area	No.	Min.	%	No.	$\overline{CPM}$	No.	$\overline{CPM}$	No.	$\overline{CPM}$	No.	$\overline{CPM}$	No.	$\overline{CPM}$
1	16	268	10.3	666	2.44	2	0.01	9	0.04	184	0.58	861	3.07
2	12	57	2.2	111	2.09	4	0.07	0	0.00	22	0.43	137	2.59
3	12	92	3.5	43	0.42	99	0.99	2	0.03	5	0.04	149	1.48
4	12	106	4.1	26	0.26	60	0.51	3	0.03	1	0.01	90	0.81
5	15	235	9.0	263	1.21	10	0.04	14	0.07	13	0.06	300	1.38
6	7	83	3.2	78	0.99	8	0.10	2	0.02	2	0.03	90	1.14
7	154	1531	58.9	449	0.28	43	0.03	18	0.01	62	0.04	572	0.36
8	16	138	5.3	23	0.15	2	0.02	3	0.02	0	0.00	28	0.19
9	8	91	3.5	182	2.06	1	0.01	10	0.12	33	0.57	226	2.76
Totals	252	2601	100.0	1841		229		61		322		2453	

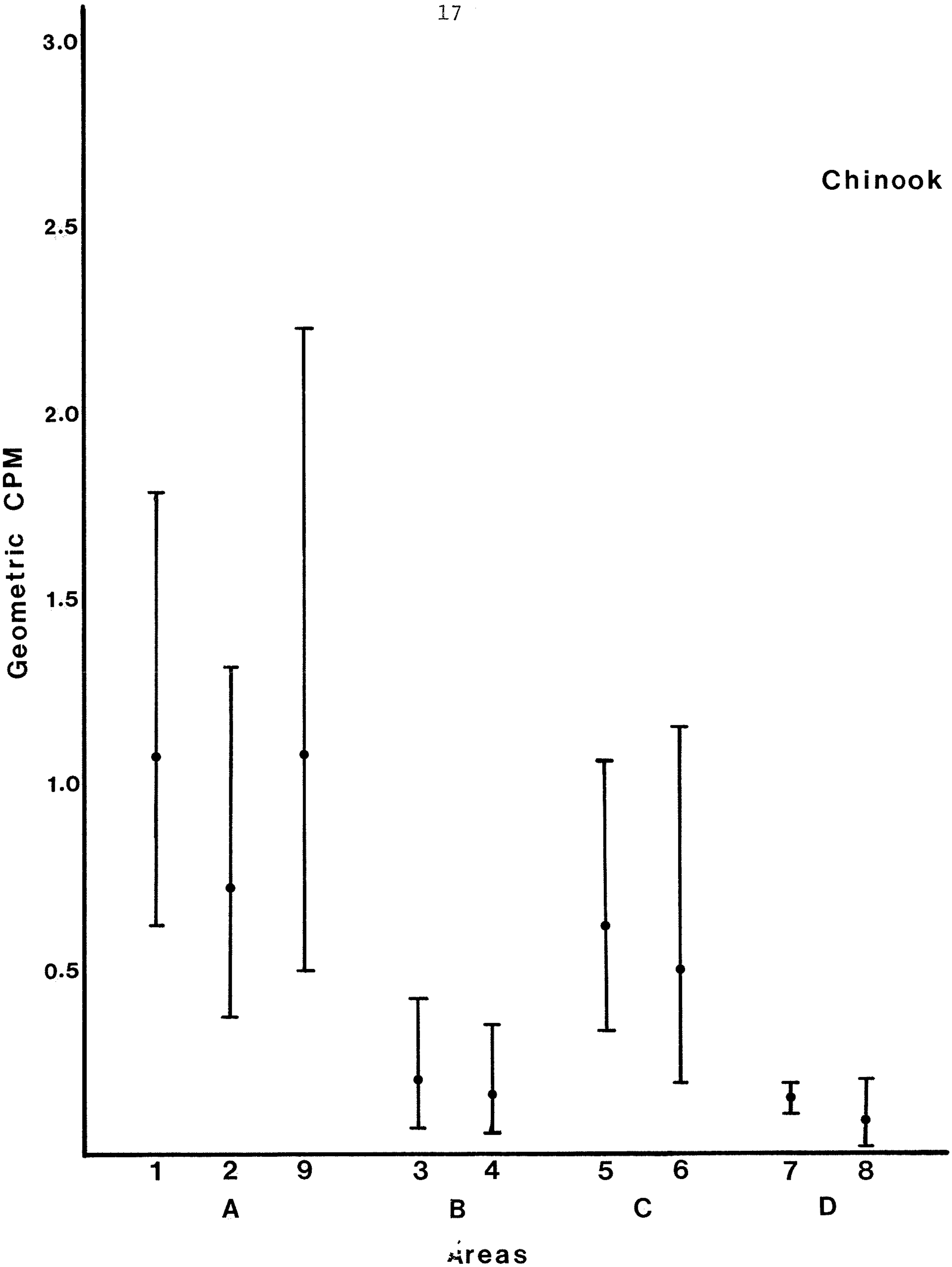

Figure 7. The 95% confidence intervals of the geometric mean catch per minute of juvenile chinook salmon in nine areas of the Priest Rapids Reservoir.

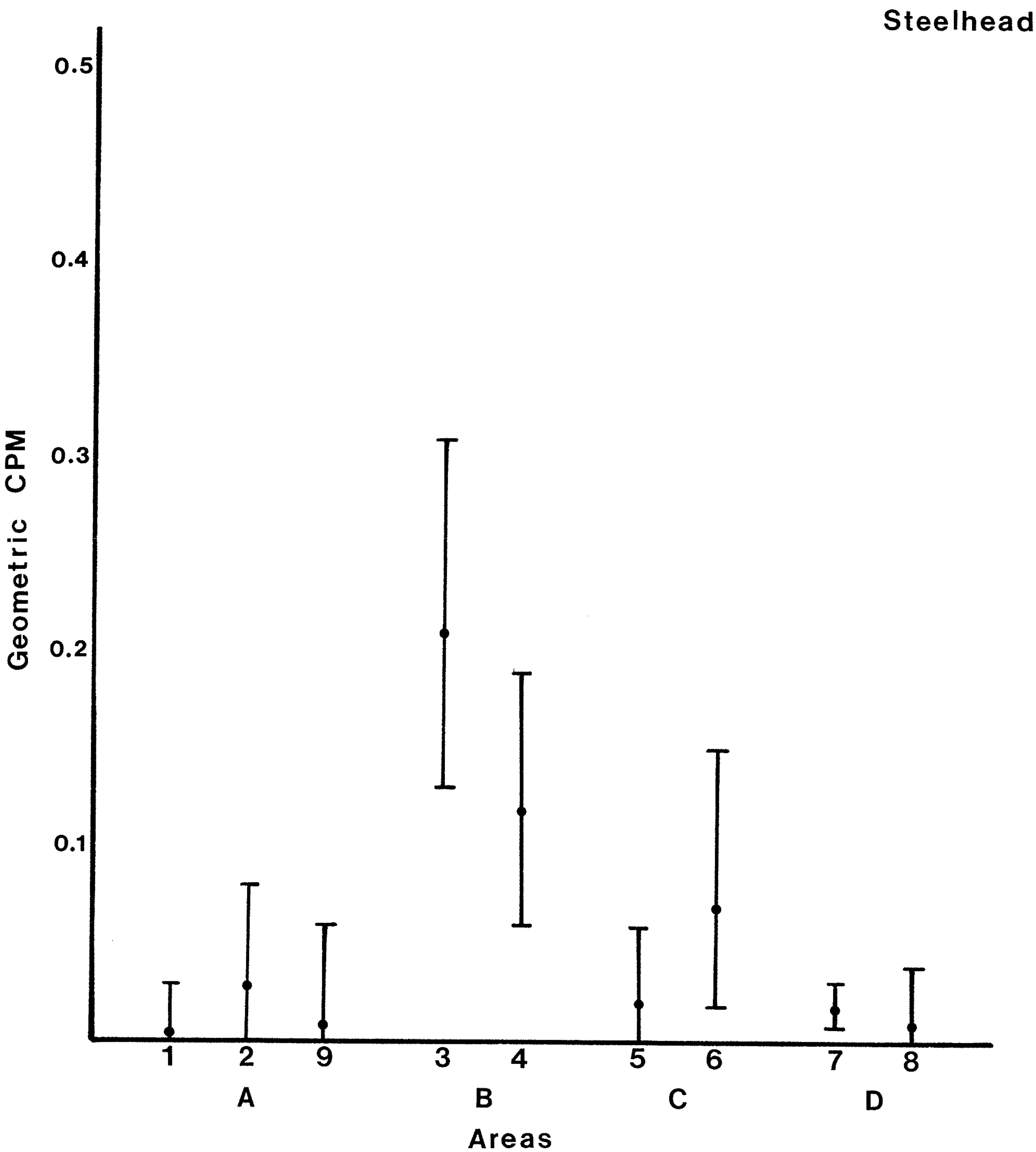

Figure 8. The 95% confidence intervals of the geometric mean catch per minute of juvenile steelhead in nine areas of the Priest Rapids Reservoir.

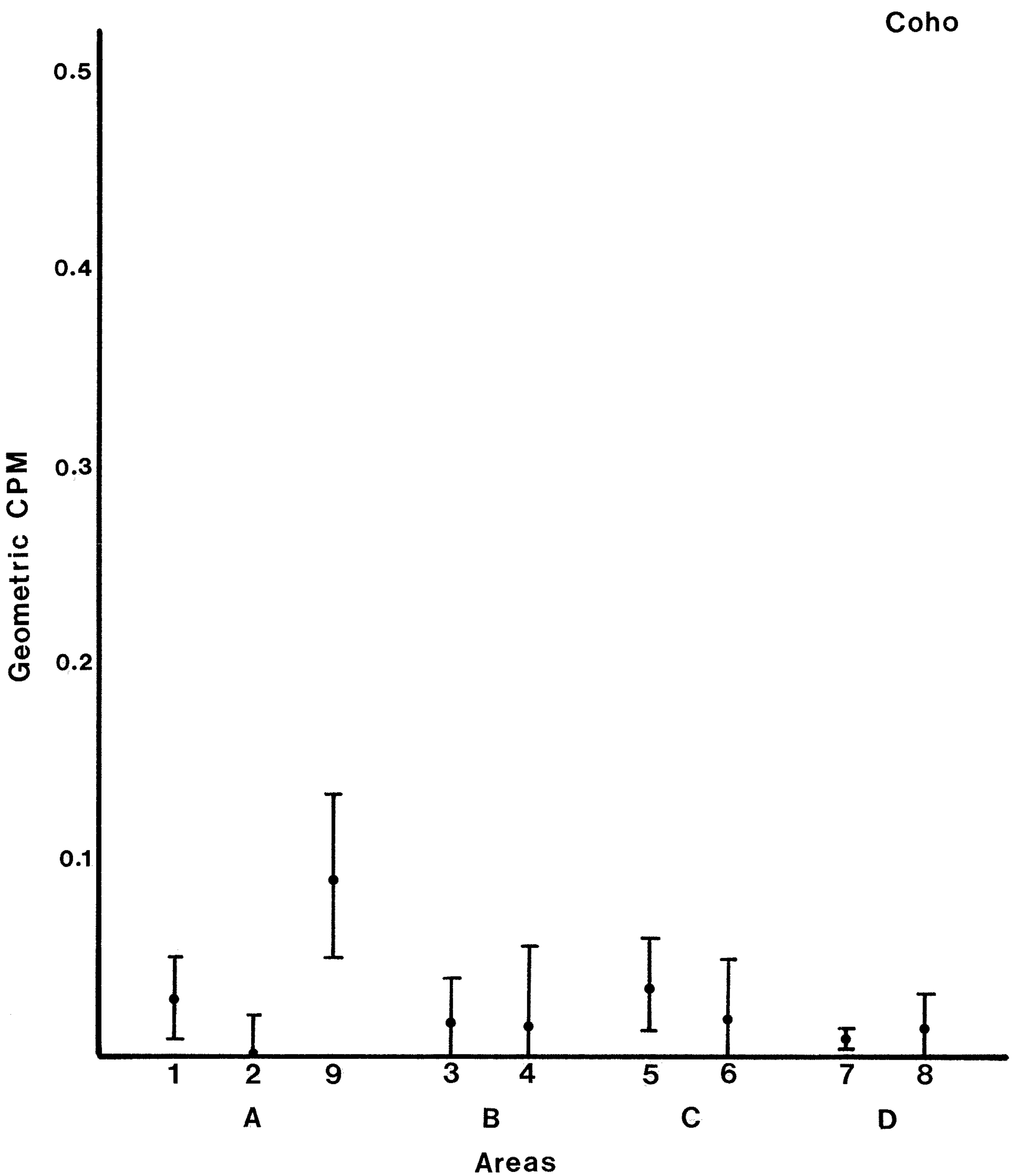

Figure 9. The 95% confidence intervals of the geometric mean catch per minute of juvenile coho salmon in nine areas of the Priest Rapids Reservoir.

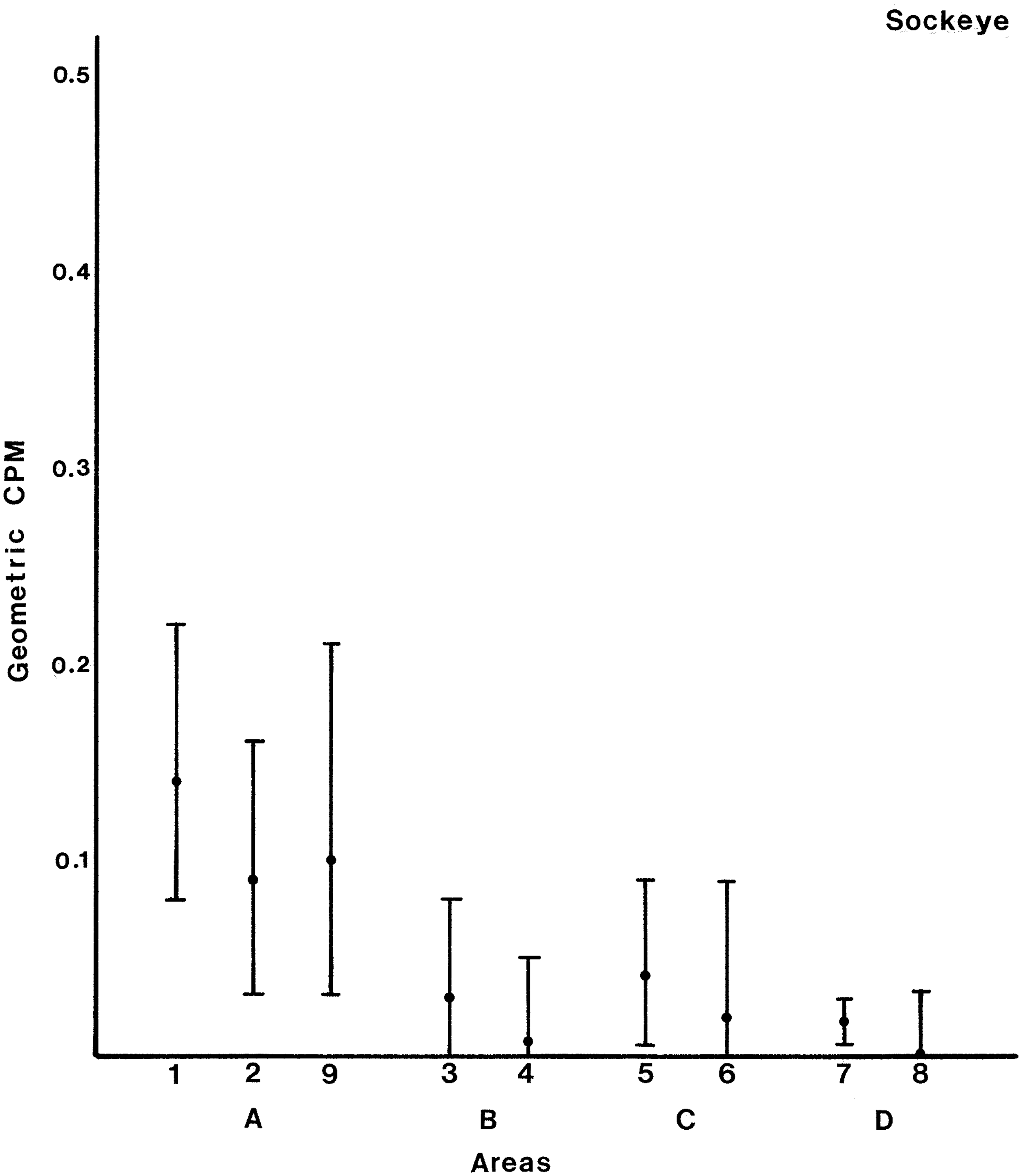

Figure 10. The 95% confidence intervals of the geometric mean catch per minute of juvenile sockeye salmon in nine areas of the Priest Rapids Reservoir.

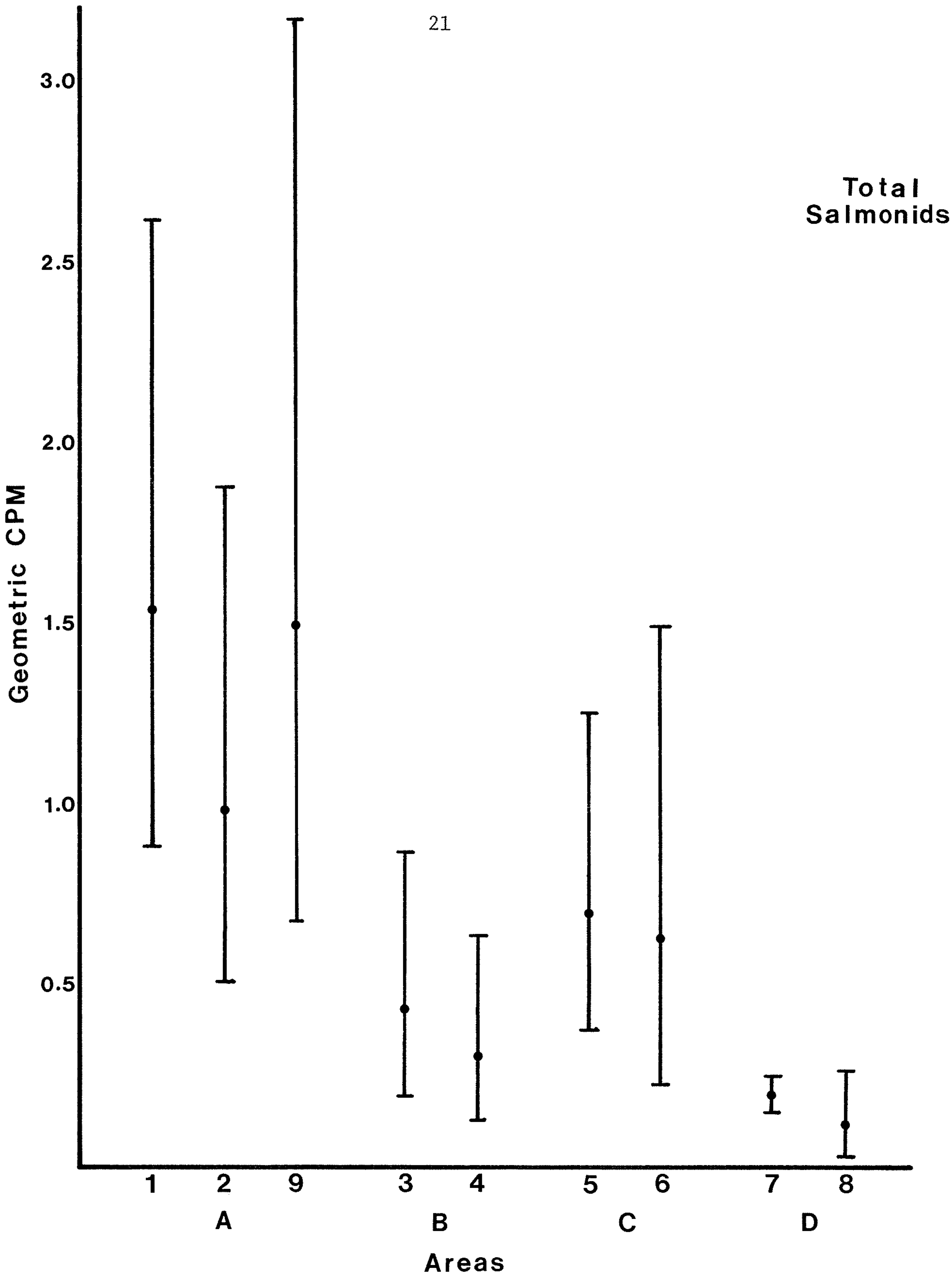

Figure 11. The 95% confidence intervals of the geometric mean catch per minute of juvenile salmonids in nine areas of the Priest Rapids Reservoir.

differences existed among the eight remaining areal mean CPM's for all species groupings except for coho salmon, where $P(F_{7,90} \geq 2.00) > 0.05$.

Sample sizes increase when all the catch data for salmonids, including that from area 7, are placed among the four reservoir areas defined in Figure 5, which are the east and west bank, the zone immediately in front of the dam, and the offshore region of the forebay. Table 4 presents the catch, mean catch per minute ($\overline{CPM}$), as well as the percent catch by species and for total salmonids for these four areas. One-way analysis of variance of the log-transformed data indicates that there are significant differences among the mean CPM of chinook, steelhead, coho, sockeye and total salmonids in areas A, B, C and D (Table 5). The results of Scheffe's multiple contrasts (S test) testing for differences among pairs of ANOVA generated geometric mean CPM's for areas A, B, C and D at the $\alpha = 0.05$ level of significance are presented in Table 6. Scheffe's test indicates significantly more juvenile chinook salmon were netted along the east and west banks of the reservoir (areas A and C) than in front of the dam or out in the forebay (areas B and D). Table 4 indicates 70.6 percent of the chinook were netted in areas A and C, where townetting took place only 28.2 percent of the time. Conversely, more steelhead (69.4 percent) were netted in area B in front of the dam than anywhere else. ANOVA indicated that there were small differences in the coho catch among areas A, B, C and D (Table 5), due to the small variance of the large sample from area 7. However, Scheffe's test was unable to detect the difference at $\alpha = 0.05$ because of variations in sample size among the four areas. Some ambiguity remains with regard to the significance of the differences in the mean catch per minute ($\overline{CPM}$) of sockeye and total salmonids in

Table 4. Salmonid catch by species, for total salmonids, percent of catch, and average catch per minute ($\overline{CPM}$) in four areas of the Priest Rapids Reservoir, May 7 through May 30, 1980 (see Figure 5).

	Tows	Time		Chinook			Steelhead			Coho			Sockeye			Total Salmonids		
Area	No.	Min.	%	No.	%	$\overline{CPM}$	No.	%	$\overline{CPM}$	No.	%	$\overline{CPM}$	No.	%	$\overline{CPM}$	No.	%	$\overline{CPM}$
A	36	416	16.0	959	52.1	2.24	7	3.1	0.03	19	31.2	0.04	239	74.2	0.53	1224	49.9	2.84
B	24	198	7.6	69	3.8	0.34	159	69.4	0.75	5	8.2	0.03	6	1.9	0.02	239	9.7	1.14
C	22	318	12.2	341	18.5	1.14	18	7.9	0.06	16	26.2	0.06	15	4.7	0.05	390	15.9	1.31
D	170	1669	64.2	472	25.6	0.27	45	19.6	0.02	21	34.4	0.01	62	19.2	0.04	600	24.5	0.34
Totals		2601	100.0	1841	100.0		229	100.0		61	100.0		322	100.0		2453	100.0	

Table 5. Analysis of variance to detect significant differences ($\alpha = 0.05$) among the mean catch per minute ($\overline{CPM}$) of chinook, steelhead, coho, sockeye and total salmonids in areas A, B, C and D.

H_0: $\overline{CPM}_A = \overline{CPM}_B = \overline{CPM}_C = \overline{CPM}_D$

H_A: Not all means are equal.

	Degrees of Freedom
Between groups (k-1)	3
Within groups (N-k)	248
Total (N-1)	251

$F(0.05, 3, 248) = 2.60$

Species	Sum of squares		Mean squares		F ratio	F prob.
	Between	Within	Between	Within		
Chinook	76.08	236.92	25.36	0.96	26.55	0.0000
Steelhead	13.98	67.85	4.66	0.27	17.04	0.0000
Coho	1.27	26.42	0.42	0.11	3.98	0.0085
Sockeye	11.42	89.17	3.81	0.36	10.59	0.0000
Total salmonids	86.86	263.05	28.95	1.06	27.30	0.0000

Table 6. Homogeneous subsets of geometric mean catch per minute $(\overline{CPM})$ for chinook, steelhead, coho, sockeye and total salmonids in areas A, B, C and D of the Priest Rapids Reservoir. Homogeneity was tested with Scheffe's multiple contrasts at $\alpha = 0.05$. Means do not differ by more than the shortest significant range for a subset of that size.

Species	Ranked areal geometric mean CPM			
Chinook salmon	A 2.34	C 1.91	B 1.02	D 0.88
	—	—	—	—
Steelhead	B 0.95	C 0.30	D 0.15	A 0.14
	—	—	—	—
Coho salmon	C 0.25	A 0.25	B 0.14	D 0.08
	—	—	—	—
Sockeye salmon	A 0.75	C 0.30	B 0.15	D 0.14
	—	—		
		—	—	—
All salmonids	A 2.66	C 2.06	B 1.55	D 1.06
	—	—		
		—	—	
			—	—

areas A, B, C and D. This confusion can only be resolved through more evenly distributed and larger sample sizes taken in the four areas. In general, 78.9 percent of the sockeye and 65.8 percent of the total salmonid catch was collected along the east and west banks of the Priest Rapids Reservoir, where only 28.2 percent of the time was spent trawling (Table 4).

5.2 Length-frequency Analysis

Figure 12 depicts the length-frequency distribution and the relative numbers of the four species of salmonids which were caught by townet and measured in May 1980 at Priest Rapids. The length-frequency distribution of steelhead, coho and sockeye indicates one year-class normally distributed in size. The steelhead were the largest and averaged 179 mm in fork length and the sockeye the smallest, grouped tightly around 101 mm. The chinook salmon length-frequency distribution was distinctly bimodal and probably composed of hatchery-reared fish and smaller naturally propagated wild stock. The length-frequency distributions for chinook, steelhead, coho and sockeye are presented by week and for areas A, B, C and D in Figures 13-20. Table 7 presents the results of four one-way analyses of variance tests used to detect differences among the weekly mean fork lengths of the four salmonid species. Table 8 presents four analyses of variance used to detect real differences in the mean fork length of the four species.

A cohort of small chinook salmon was caught in the latter half of May (Figure 13) and principally in area A, along the east bank of the reservoir (Figure 14). The small chinook were probably wild stock which emigrated later than the hatchery component. The fact that two distinct size groups

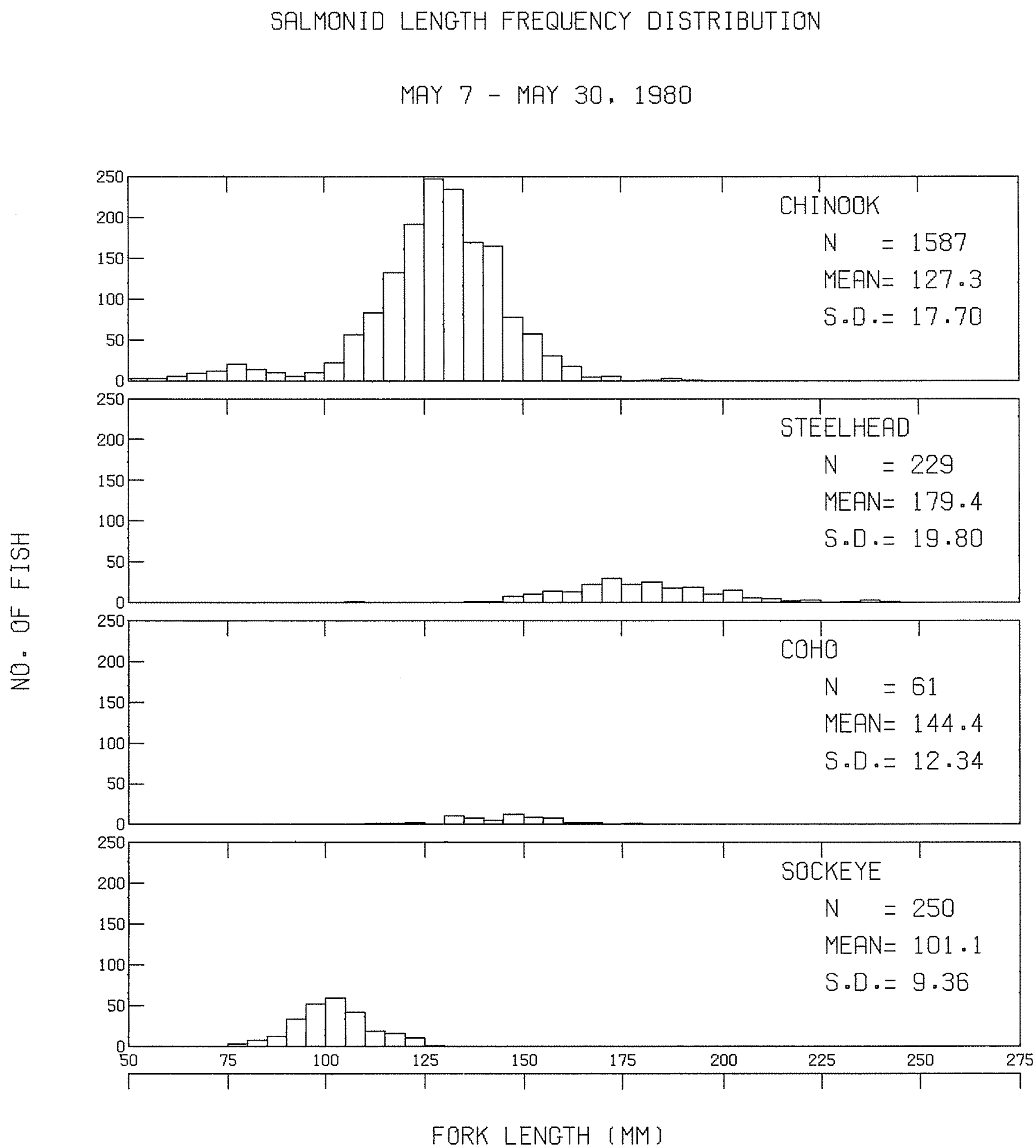

Figure 12. Length-frequency distribution for all salmonids by species caught and measured at the Priest Rapids Reservoir between May 7 and May 30, 1980.

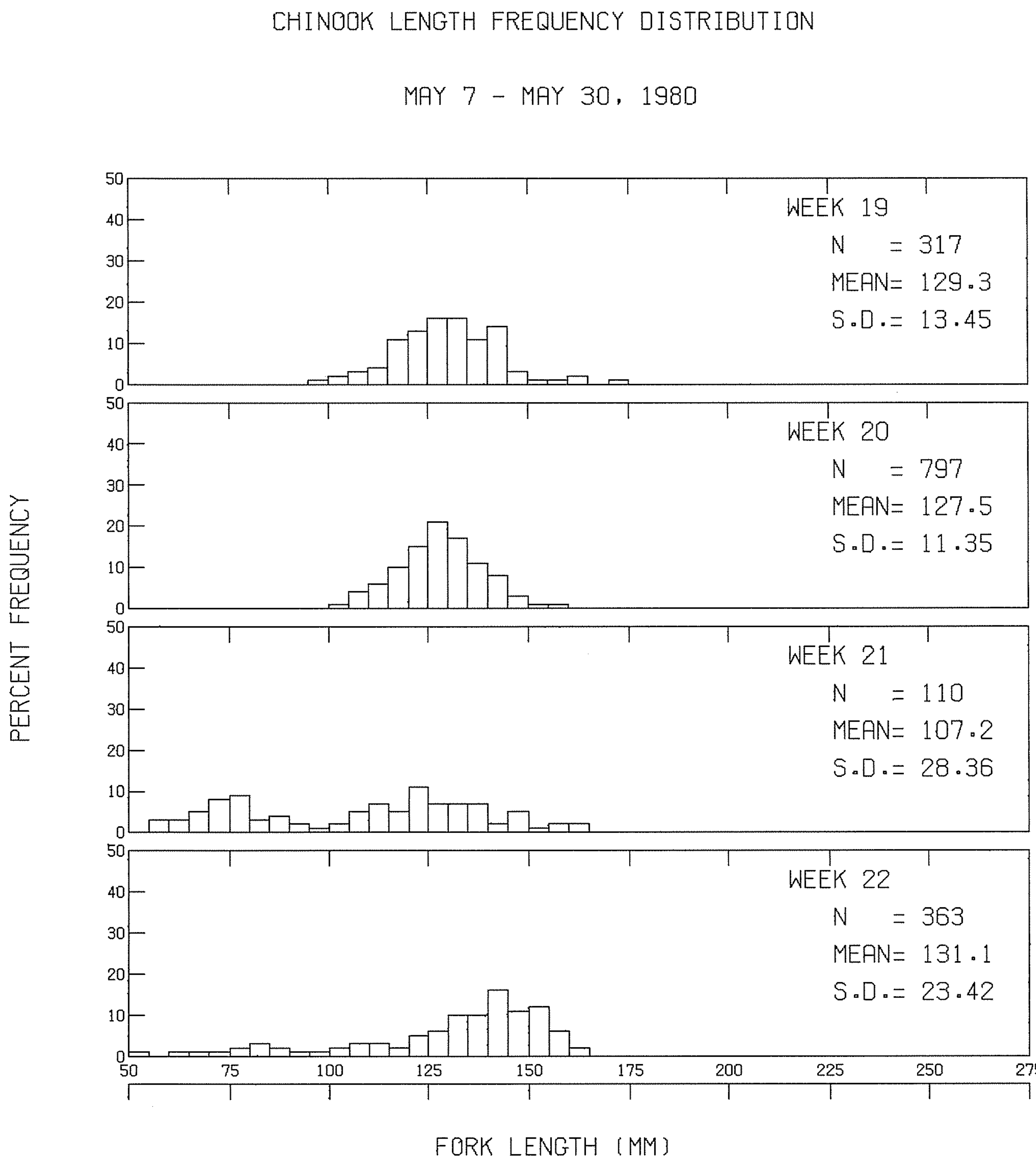

Figure 13. Chinook salmon length-frequency distribution by week in Priest Rapids Reservoir.

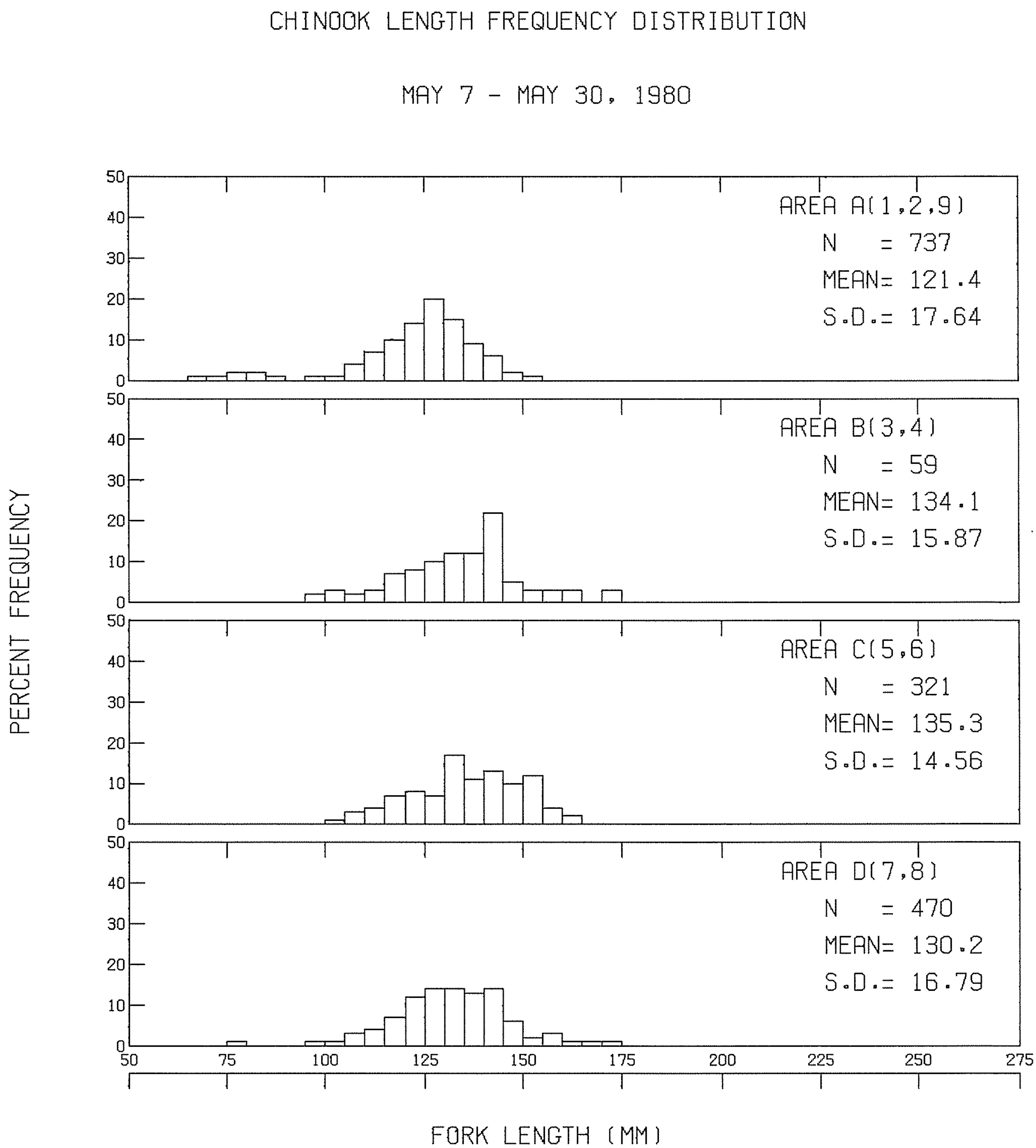

Figure 14. Chinook salmon length-frequency distribution by area in Priest Rapids Reservoir.

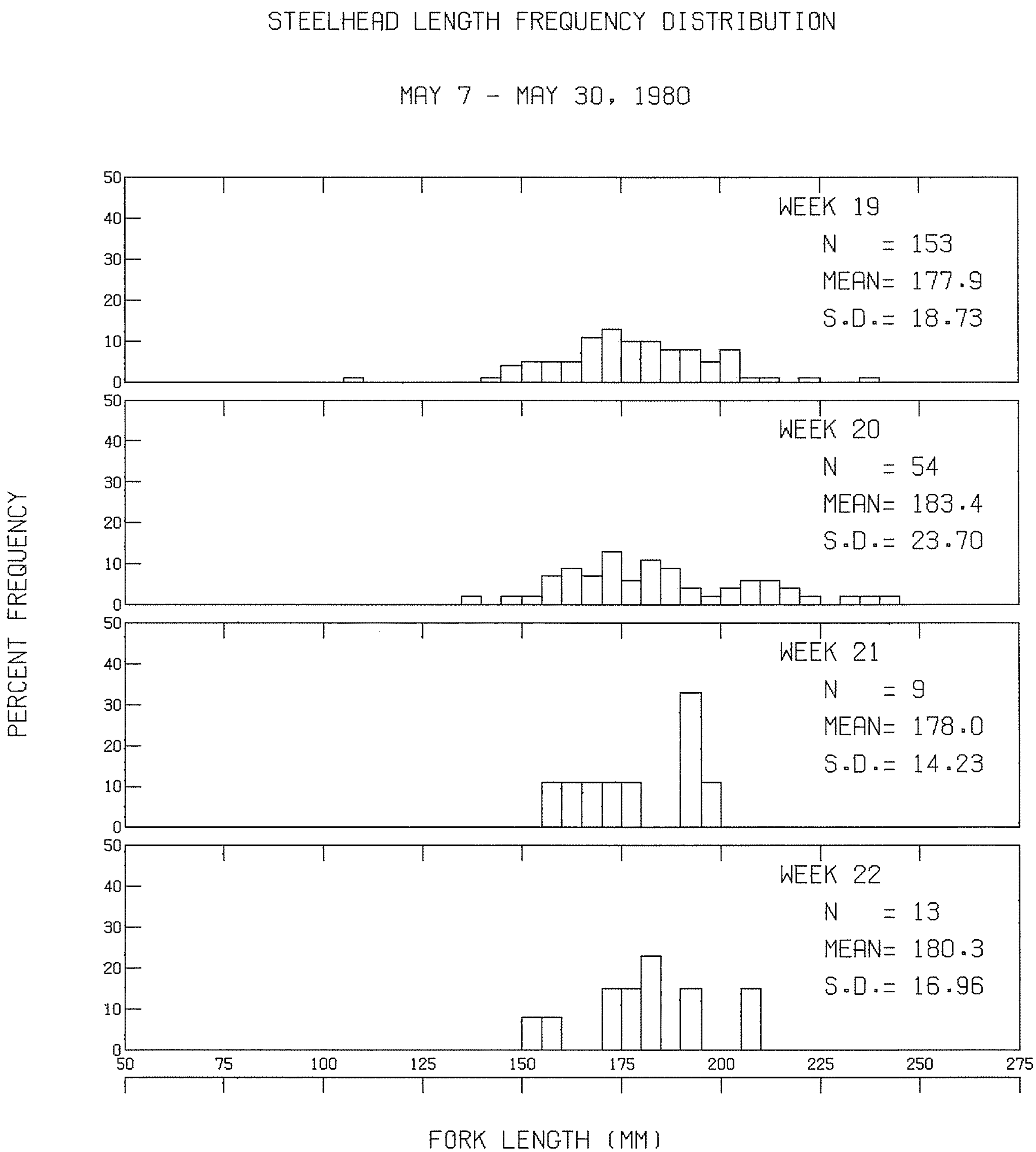

Figure 15. Steelhead length-frequency distribution by week in Priest Rapids Reservoir.

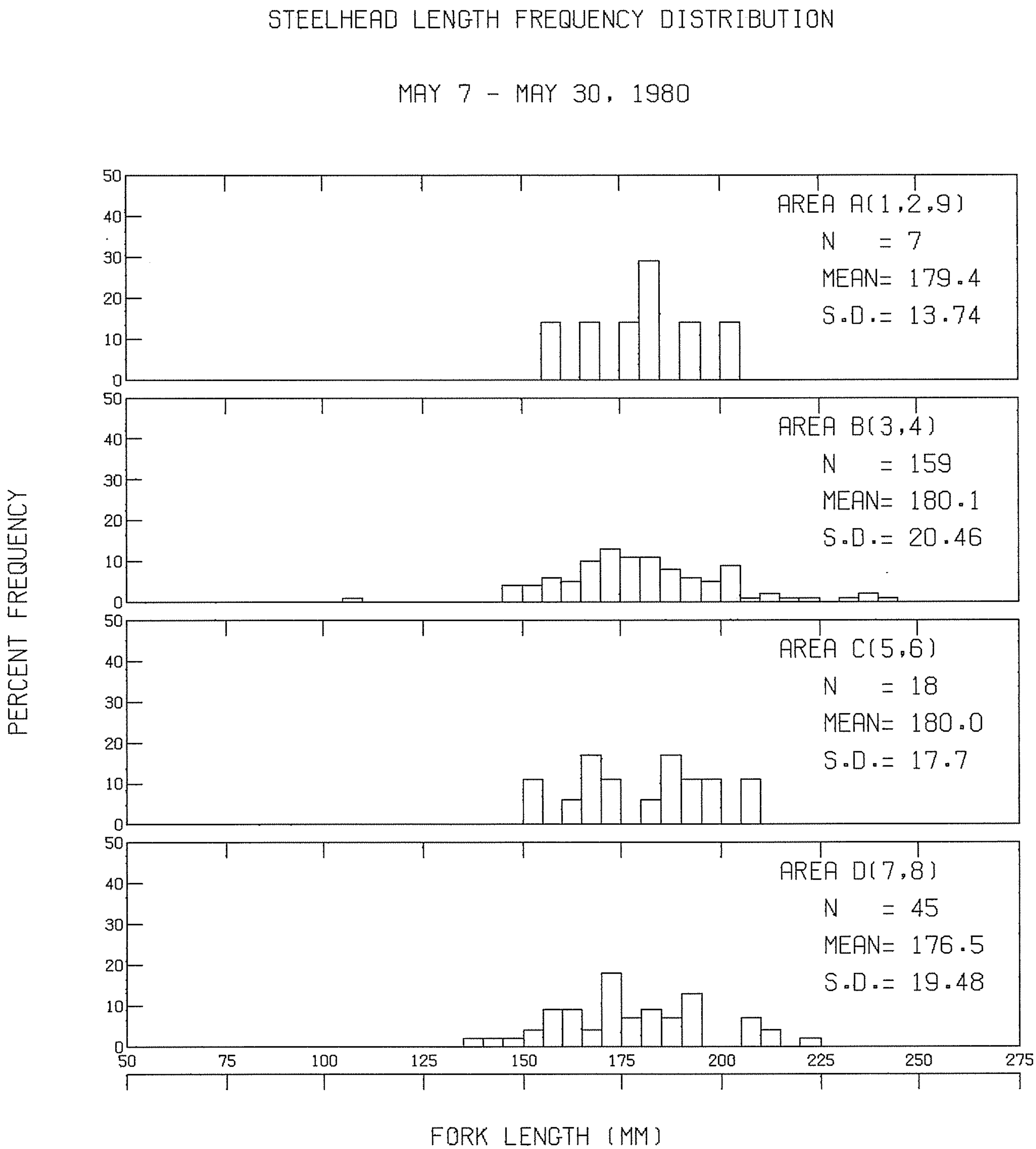

Figure 16. Steelhead length-frequency distribution by area in Priest Rapids Reservoir.

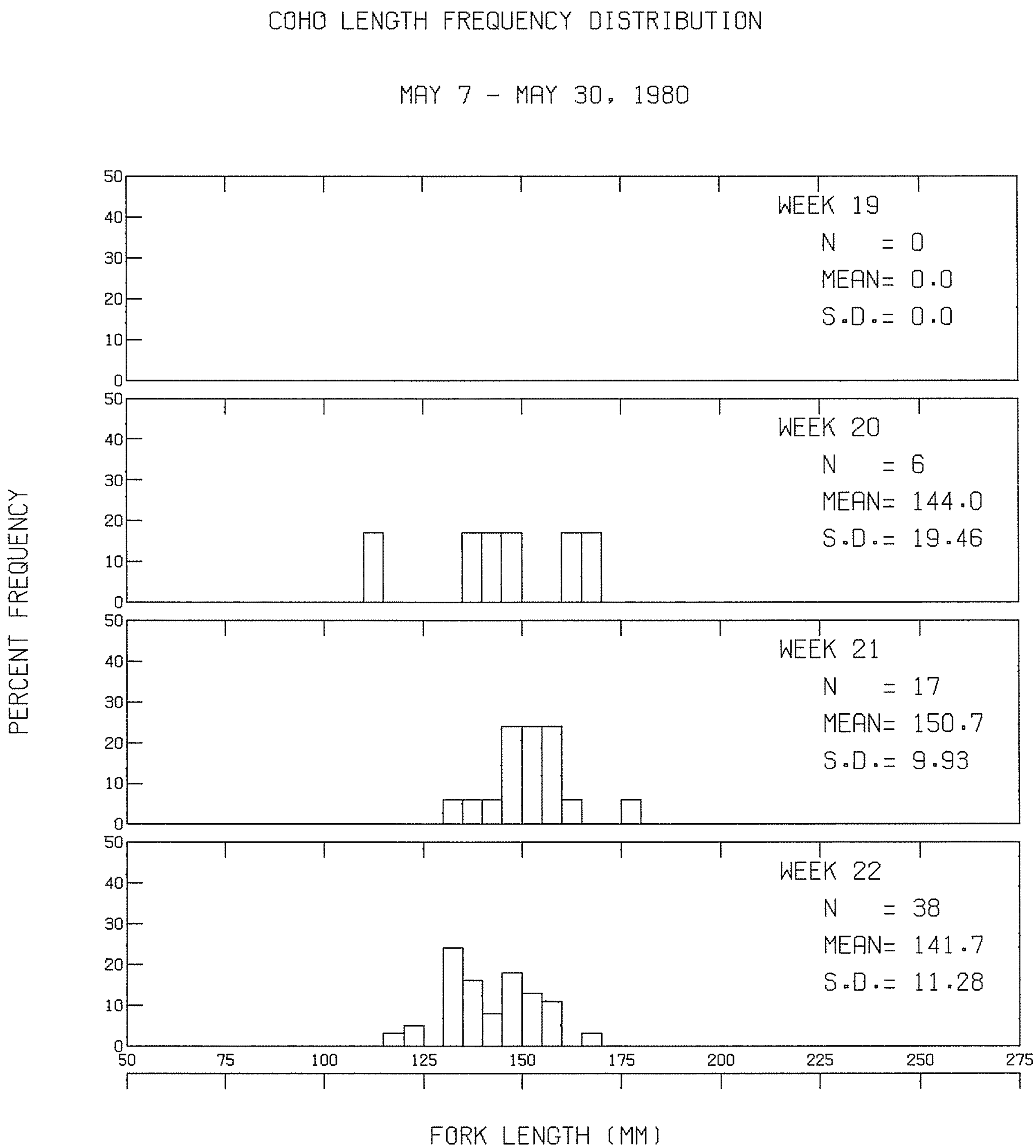

Figure 17. Coho salmon length-frequency distribution by week in Priest Rapids Reservoir.

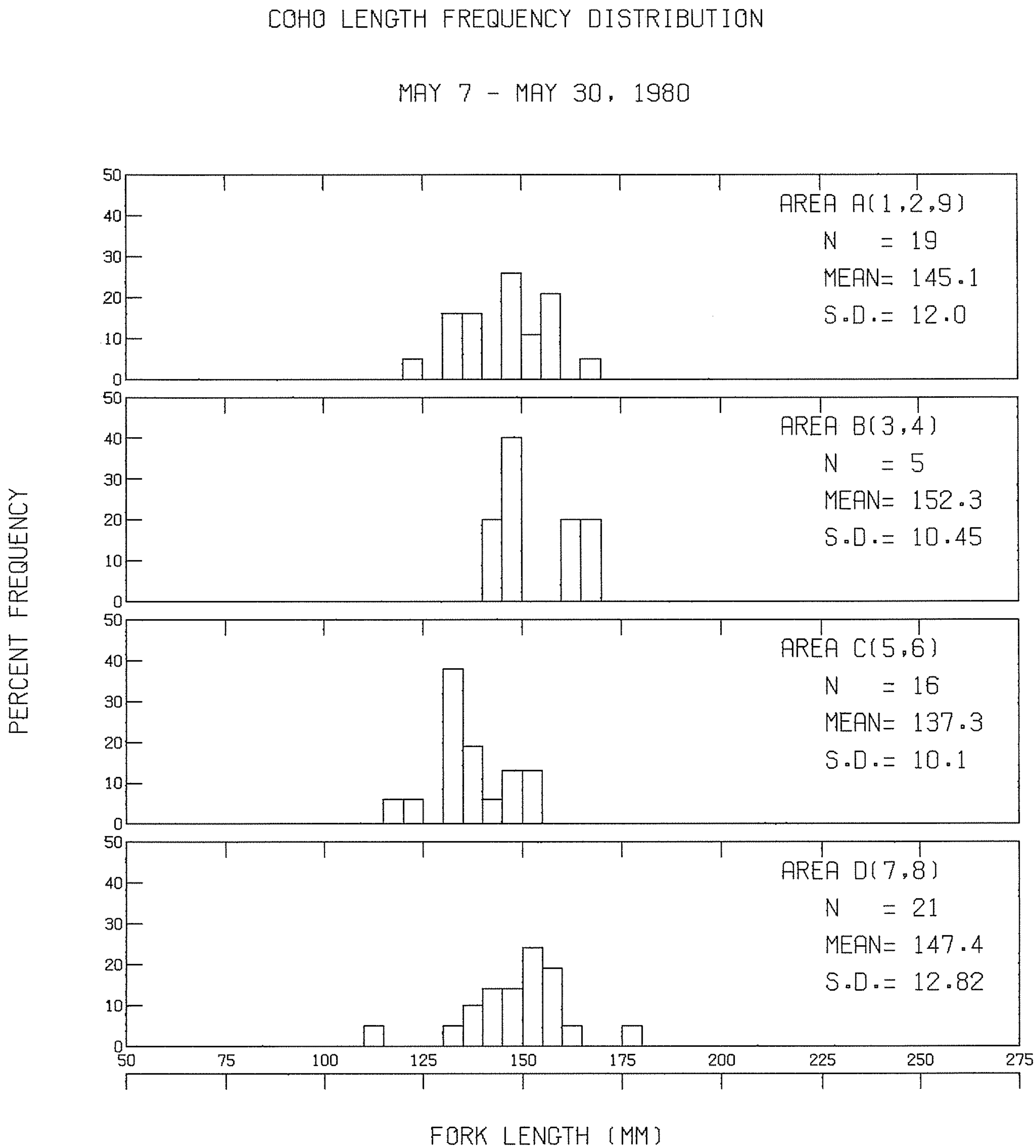

Figure 18. Coho salmon length-frequency distribution by area in Priest Rapids Reservoir.

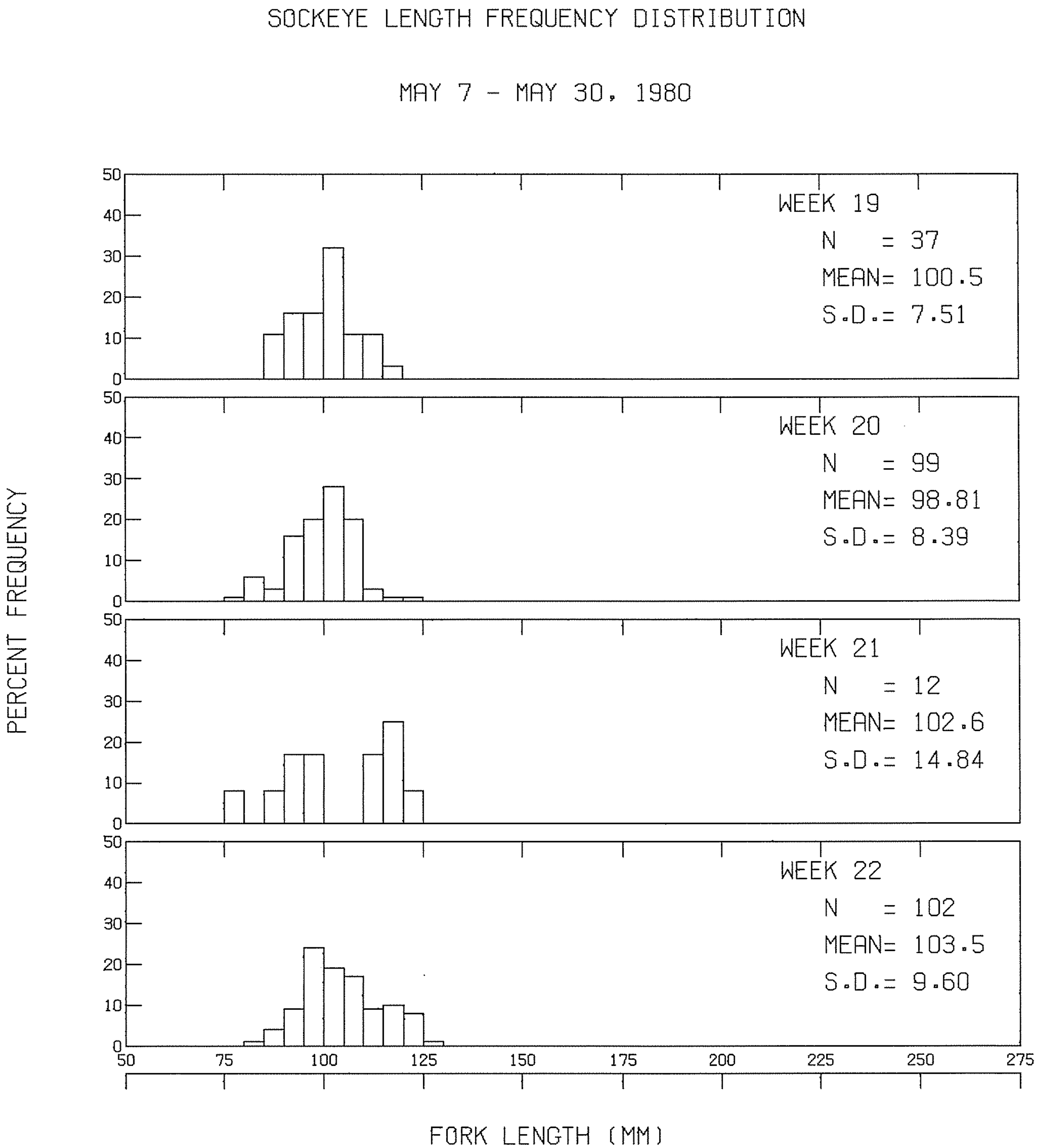

Figure 19. Sockeye salmon length-frequency distribution by week in Priest Rapids Reservoir.

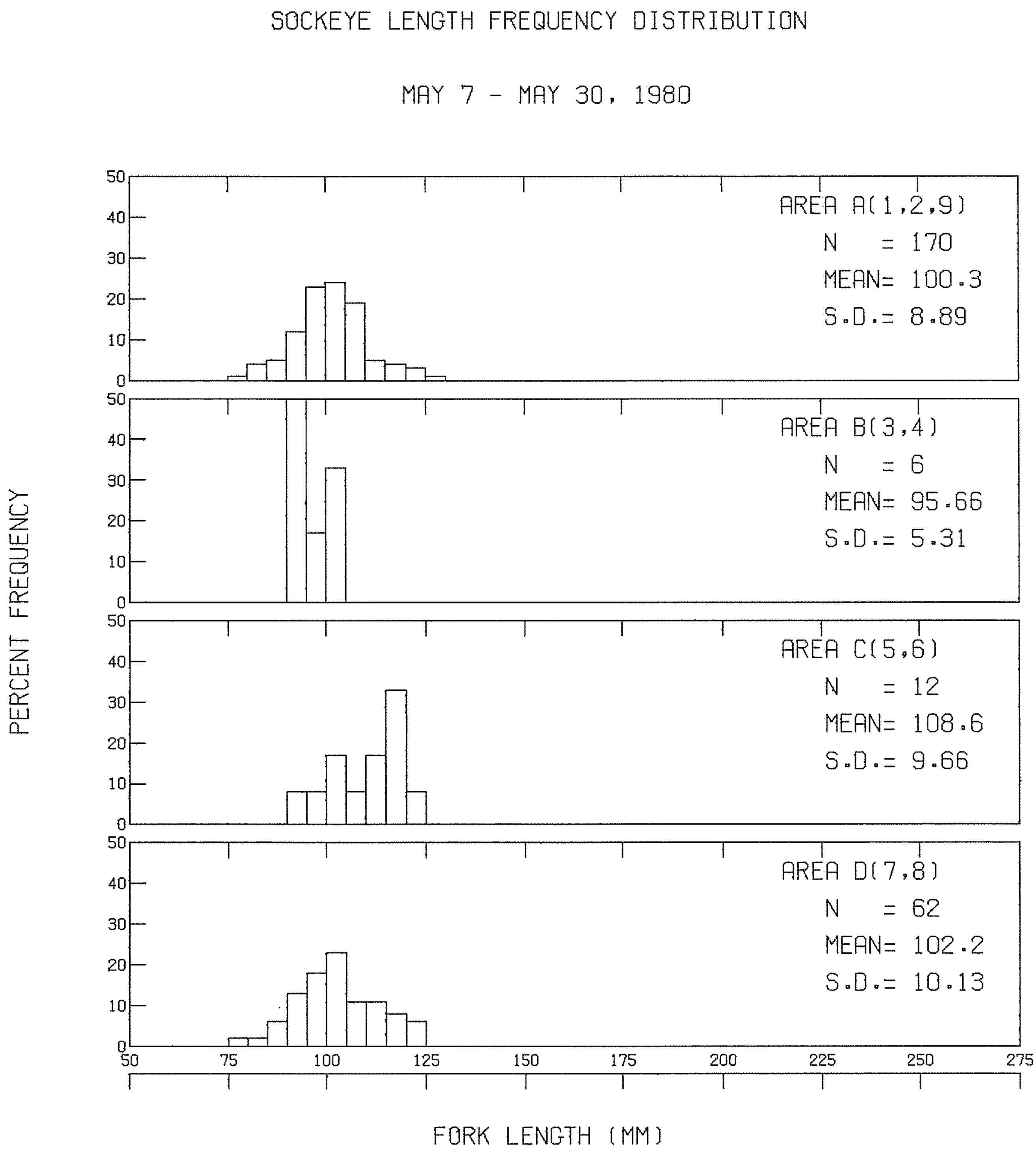

Figure 20. Sockeye salmon length-frequency distribution by area in Priest Rapids Reservoir.

Table 7. Analysis of variance to detect significant differences ($\alpha = 0.05$) among the mean fork lengths ($\overline{Fl}$) of chinook, steelhead, coho and sockeye collected from the Priest Rapids Reservoir during weeks 19, 20, 21 and 22 in May 1980. No coho were collected in week 19 (Table 2).

$$H_0: \overline{Fl}_{19} = \overline{Fl}_{20} = \overline{Fl}_{21} = \overline{Fl}_{22}$$

H_A: not all means are equal

Species	Degrees of Freedom Between	Degrees of Freedom Within	Sum of squares Between	Sum of squares Within	Mean squares Between	Mean squares Within	F ratio	F prob.
Chinook	3	1583	50916.42	446127.33	16972.14	281.82	60.22	0.0000
Steelhead	3	225	1202.95	88232.09	400.98	392.14	1.02	0.3834
Coho	2	58	953.32	8187.93	476.66	141.17	3.38	0.0410
Sockeye	3	246	1182.55	20674.74	394.18	84.04	4.69	0.0033

Table 8. Analysis of variance to detect significant differences ($\alpha = 0.05$) among the mean fork lengths ($\overline{Fl}$) of chinook, steelhead, coho and sockeye collected in areas A, B, C and D of the Priest Rapids Reservoir

$$H_0: \overline{Fl}_A = \overline{Fl}_B = \overline{Fl}_C = \overline{Fl}_D$$

H_A: not all means are equal

Species	Degrees of Freedom Between	Degrees of Freedom Within	Sum of squares Between	Sum of squares Within	Mean squares Between	Mean squares Within	F ratio	F prob.
Chinook	3	1583	53104.22	443939.52	17701.41	280.44	63.12	0.0000
Steelhead	3	225	471.70	88963.34	157.23	395.39	0.398	0.7548
Coho	3	57	1312.63	7828.62	437.54	137.34	3.186	0.0305
Sockeye	3	246	1052.97	20804.33	350.99	84.57	4.15	0.0068

contributed to the mean fork length determination explains the large F ratios in Tables 7 and 8 and renders the analyses of variance and subsequent multiple contrast tests (Tables 9 and 10) meaningless for chinook salmon. There was no significant difference at $\alpha = 0.05$ in the size of steelhead caught by week or in areas A, B, C or D of the Priest Rapids Reservoir (Figures 15 and 16, Tables 7 and 8). Although few juvenile coho were caught in May and none in week 19 (Figure 17), one-way ANOVA at $\alpha = 0.05$ did show differences existed among the three mean weekly fork lengths that were obtained (Table 7). Differences were also significant among the mean coho fork lengths for areas A, B, C and D (Figure 18, Table 8). Scheffe's multiple contrasts at $\alpha = 0.05$ were unable to detect the difference in areal mean coho fork lengths (Table 10).

The sockeye, which were composed only of wild fish, were caught during all four weeks in areas A, B, C and D and averaged about 100 mm (Figures 19 and 20), but weekly and areal mean fork lengths tested as significantly different at $\alpha = 0.05$ (Tables 7 and 8). Scheffe's multiple contrasts test was able to detect these differences among the mean sockeye fork lengths, but the results were ambiguous because samples were small and differences slight (Tables 9 and 10).

Table 9. Homogeneous subsets of mean fork lengths ($\overline{Fl}$) of chinook, steelhead, coho and sockeye collected from Priest Rapids Reservoir during weeks 19, 20, 21 and 22 in May 1980. Homogeneity was tested with Scheffe's multiple contrasts at $\alpha = 0.05$. Means do not differ by more than the shortest significant range for a subset of that size.

Species	Ranked weekly mean fork length (mm)			
	22	19	20	21
Chinook	121.12	129.33	127.56	107.24
	————	————		
		————	————	————
	20	22	21	19
Steelhead	183.41	180.38	178.00	177.99
	————	————	————	————
		21	20	22
Coho		150.76	144.00	141.76
		————	————	
			————	————
	22	21	19	20
Sockeye	103.52	102.66	100.05	98.82
	————	————	————	
		————	————	————

Table 10. Homogeneous subsets of mean fork lengths $(\overline{Fl})$ of chinook, steelhead, coho and sockeye from areas A, B, C and D in Priest Rapids Reservoir. Homogeneity was tested with Scheffe's multiple contrasts at $\alpha = 0.05$. Means do not differ by more than the shortest significant range for a subset of that size.

Species	Ranked areal mean fork lengths (mm)			
	C	B	D	A
Chinook	135.40	134.02	130.21	121.43
	B	C	A	D
Steelhead	180.15	180.00	179.43	176.51
	B	D	A	C
Coho	152.40	147.43	145.16	137.88
	C	D	A	B
Sockeye	108.66	102.29	100.33	95.66

6.0 DISCUSSION

The catch data obtained by townet sampling in the forebay of the Priest Rapids Dam during May 1980 indicate that the majority of emigrant juvenile salmonids approach the upstream face of the dam by closely following the shores of the reservoir (Figure 11, Table 6). This was certainly the case for chinook and sockeye salmon juveniles, which comprised 88 percent of the total salmonid catch (Table 1). These species were caught principally along the east and west shores of the reservoir (Tables 3 and 4). Though 57 percent of the coho juveniles were also caught along the east and west shores (Tables 3 and 4), little significance could be attached to this figure, since too few coho were caught with the townet. It is not known whether the townet was ineffective in sampling juvenile coho salmon. While coho were not present in the reservoir until halfway into May, by the end of May thousands of coho salmon had been collected with dipnets from the gatewells of the Priest Rapids Dam, representing 34 to 48 percent of the daily dipnet catch (CH_2-M-Hill, unpublished data). Since juvenile coho did not make up more than a small percentage of the townet catch, even late in May, we suspect that this species may be distributed at greater depth in the water column.

The juvenile steelhead provide an interesting exception because this species was found to be most abundant near the upstream face of the dam and least abundant in the shoreline areas. Steelhead were caught primarily in early May (Table 2). A significant majority of the steelhead was sampled immediately in front of the dam (Tables 3, 4 and 6). Those that were not were often taken in two's or three's in the middle of the forebay (area D), suggesting steelhead move through the middle of the reservoir. This finding indicates a fundamental difference in the migratory approach to the dam between steelhead and salmon which will require specific systems in order to bypass these fishes. Fish diversion systems must focus on both shorelines of the reservoir as well as the upstream face of the dam.

There appears to have been little relationship between mean fork length and date or catch location in the Priest Rapids Reservior for steelhead, coho and sockeye. The weekly and areal differences in mean fork length of coho and sockeye detected by ANOVA and Scheffe's test (Tables 7, 8, 9 and 10) were slight. Visual examination of the length-frequency histograms in Figures 17-20 lead us to conclude that those differences were probably a result of random effects, small sample sizes, and of no real consequence.

Examination of the chinook salmon length-frequency histograms (Figures 12, 13 and 14) have led us to conclude that some wild chinook salmon were passing downstream, or at least in residence, nearshore in area A late in May. These fish were probably the same age as the hatchery-reared fish passing downstream. Their smaller size was probably due to a less certain natural food supply in conjunction with cooler river water temperatures. Townet sampling, which ended May 30, missed much of the downstream migration of these wild chinook salmon, which appears to have started near the middle of May (Figure 13) and probably extended into June.

7.0 CONCLUSIONS

There is no evidence which suggests that naturally propagated salmon or steelhead can be sustained indefinitely in the face of any excess, or long-term mortality beyond that which these fish normally experience in an unaltered river system and at sea. Death due to natural causes prior to reaching maturity was the norm for greater than 95 percent of all downstream salmonid migrants on the Columbia River before the first dam was built. Now that the character of this river is unalterably changed, it is not likely that the runs can continue into the next century unless dam-related mortality is drastically reduced along with final development of the maximum hydroelectric capacity.

It is our opinion that some scheme must be devised for safely passing most downstream migrants past dams. The policy of the regulatory and fisheries management agencies to spill water during the migration is laudable, but whether a significant portion of the run is past by this practice is becoming increasingly doubtful. Spill may in fact be "wasted" water in the sense that no power is derived from it and few fish use it to pass safely downstream (Carlson et al. 1980).

The results of this townet study in the forebay of Priest Rapids Dam suggest a significant majority of the downstream salmonid migrants approach the dam by following the shores of the reservoir. Only upon reaching the earthen retaining walls that lead to the dam do the fish approach the turbine units. This finding suggests engineering efforts to direct fish past the dam could be reasonably made on both sides of the dam where the earthen retaining walls merge with the boundaries of the reservoir. It is possible that large numbers of chinook and sockeye salmon could be diverted into a small quantity of water which is then spilled past the dam before the fish approach the turbines. Since turbines inflict an average 10 percent mortality (Bell et al. 1976) on downstream-migrant salmonids it is most desirable to reduce this loss by reducing the number passing through the turbines. Engineering efforts to reduce the mortality experienced by smolts passing downstream through turbines by modificaton of blade and intake structures, while commendable, can only be expected to result in small reductions in turbine-caused mortality. Such design modifications are negated in the operating phase if the turbines are frequently run at less than peak efficiency. Turbine modification will only enhance the four new units while the 10 original units will operate as usual. We do not think that it is possible to prevent all salmonid smolts from entering the turbines. However, the concentration of most of the salmonids along both shorelines in the reservoir presents the potential for collection and diversion. An attempt to minimize downstream fish passage mortality must develop a means to take advantage of this natural behavioral distribution to prevent at least a majority of the population from passing through the turbines. A multi-faceted fish diversion system as well as turbine design modification are required in order to effectively minimize the dam-related mortality for all juvenile salmonid species.

A fish by-pass system should make special efforts insofar as the welfare of remaining wild stocks of salmon is concerned. The importance of the genetic pools of the remaining wild stocks of salmonids cannot be overemphasized in this era of artificial fish propagation and reduction of genetic variability. The fact that both the wild sockeye and the wild component of chinook migrants appear to prefer the reservoir shorelines should make diversion located in these areas most attractive. Solutions to the diversion of steelhead, which seem to follow the movement of the main body of reservoir water through the turbines, require separate by-pass facilities located on the face of the dam.

Additional data are needed in order to draw conclusions regarding coho salmon smolts. Coho appear to be distributed at greater depths in the forebay, judging from the low abundance in the surface trawl samples. It may be that turbine design modifications are the only means of reducing the mortality of this species because they may be the most difficult to divert. However, additional sampling at greater depth intervals is needed for verification.

8.0 RECOMMENDATIONS

8.1 A second season of townet and midwater sampling over a longer duration is needed to verify these results in the forebay of Priest Rapids Dam. Sampling should begin by early April, intensify during May and continue on a reduced basis through the summer to adequately assess the status of the numerous hatchery and wild stocks of salmonids in the river. Little was learned regarding whether residualization occurs to any significant degree in Priest Rapids Reservoir during the brief sampling period to which the present study was confined.

8.2 Research and development studies should be initiated immediately to explore methods for the collection and diversion of juvenile salmonids along both shores of the reservoir. This effort could be conducted with the use of special barrier nets and pumps designed to collect and divert fish which could be constructed of more durable materials once the system was developed. Simultaneous hydroacoustic monitoring of the turbine intakes and spill openings on the dam as well as the net diversion structures would be highly desirable along with simultaneous townet sampling in the development of an effective fish collection and bypass system.

8.3 Research and development of a skimmer wall fish collection and diversion system for steelhead across a large part of the upstream face of the dam should be conducted with net gear. Such a system should operate on a basis which would minimize sounding by the fish while at the same time create high-velocity currents through diversion routes to stimulate the movement of fish to collective bypass facilities. Hydroacoustic monitoring would be very desirable in testing such a system.

8.4 Modification of the turbines to minimize fish passage mortality should be done because all salmonids cannot be diverted from turbine passage; however, to rely on these modifications as the principal means of reducing fish passage mortality is inadequate.

8.5 The abundance and distribution of fish predators in the Priest Rapids forebay and tailrace should be determined from the standpoint of potential predator control around the engineered bypass facilities.

8.6 The fisheries studies being conducted for FERC as well as these conducted under new construction should be integrated and summarized in order to maximize the results of the entire effort.

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10.0 APPENDIX

Table 1. Marked salmonids collected with a townet in Priest Rapids Reservoir between May 7 and May 30, 1980. L = left, R = right, D = dorsal, A = anterior, Fl = fork length (in mm).

Date	Chinook Fl	Chinook Marks	Steelhead Fl	Steelhead Marks	Coho Fl	Coho Marks
5/07	113	≍LA	151	-<LD		
	116	⊨LA	152	RD		
	123	πLA	179	λLD		
	127	πLA				
	136	πLA				
	142	⊨LD				
	143	≍LA				
5/08			155	πLD		
	119	⊨LA	163	⫤LD		
	124	≍LA	172	YRD		
			191	YLD		
			193	-<LD		
5/09	113	πLA				
	115	πLA	146	λRD		
	115	πLA	147	πLD		
	121	⫤LA	148	λLD		
	126	⫤LA	151	⊨LD		
	127	⫤LA	156	⫤RD, ⊨LD		
	130	λRD	157	πRD, ⊨RD		
	162	≍LA	163	πRD, ⊨LD, ⊨LD		
			165	⊨RD, λLD, λRD		
			166	YLD, ⫤LD, ⊨RD		
			167	⊨LD		
			168	λRD		
			169	πRD, ⊨RD		

Table 1 (cont.)

Date	Chinook Fl	Chinook Marks	Steelhead Fl	Steelhead Marks	Coho Fl	Coho Marks
5/09			171	⫣LD, πRD, ⫣RD		
			172	⫣RD		
			173	⫣LD, ⤙RD, ⫣LD. ⫢RD		
			174	⫣RD		
			175	⫢RD, ⫣LD		
			176	⫢RD, ⅄LD		
			177	⫢RD, YRD, ⤙RD		
			179	πLD		
			180	πLD		
			181	⫢RD, ⅄LD, πRD		
			183	⫣RD, πRD, πRD, ⫣LD, ⫢RD, ⫢LD		
			184	⤙RD		
			186	πRD, YRD		
			187	πLD		
			188	πLD, ⅄RD, ⫢LD		
			190	⫣RD		
			191	πLD		
			193	⤙RD		
			194	πRD		
			195	⅄RD, ⤙RD		
			196	⫢RD, VRD, ⫣LD		
			198	⫢LD		
			200	⫢RD		
			201	⫢LD		
			202	⫢LD, ⅄LD		
			203	YRD		
			204	⫣LD		
			205	⅄LD		

Table 1 (cont.)

Date	Chinook Fl	Chinook Marks	Steelhead Fl	Steelhead Marks	Coho Fl	Coho Marks
5/09			211	πRD		
			222	λRD		
			238	⊨RD		
5/13	125	≍LA	170	|JRD		
	135	⊨LA	180	V RD		
	143	⫣LA				
	144	⫣LA				
5/14	105	⊨LA	178	ᑎ|LD		
	111	≍LA	182	⊨RD		
	116	≍LA	198	|JLD		
	117	πLA	200	ᑎ|LD		
	124	≍LA	202	λLD		
	125	≍LA	206	|JLD		
	129	πLA	207	ᑎ|RD		
	132	πLA	209	|JLD		
	134	⫣LA	232	λLD		
	136	πLA				
	137	≍LA				
	142	≍LA				
	145	πLA				
5/15	127	⊨LA	159	ᑎ|RD		
	134	⊨RA	165	πLD		
	135	⫣LA	174	ᑎ|LD		
	137	≍LA	219	ᑕ LD		
	144	⫣LA				
	–	≍LA, ≍LA, ≍LA				
	–	πLA, πLA				

Table 1 (cont.)

Date	Chinook Fl	Chinook Marks	Steelhead Fl	Steelhead Marks	Coho Fl	Coho Marks
5/15	—	⊨LA, ⊨LA				
	—	⫤LA, ⫤LA, ⫤LA, ⫤LA				
5/16	111	⊨LA, ≍LA	184	Y LD		
	114	⫤LA	185	⊂̄ RD		
	115	⫤LA	223	⊂̄ LD		
	116	≍LA				
	118	≍LA, ⊨LA				
	119	≍LA				
	121	≍LA				
	122	≍LA, ≍LA				
	123	⫤LA				
	124	≍LA, ≍LA				
	125	≍LA, ⊨LA				
	127	⫤LA, ≍LA				
	128	≍LA, ≍LA				
	129	⊨LA				
	130	πLA				
	133	≍LA				
	134	≍LA				
	135	πLA				
	136	⫤LA				
	137	πLA, πLA				
	139	⫤LA				
	140	⫤LA				
	143	⫤LA				
5/23	119	≍LA			135	X| LD
	122	⫤LA			150	X̄ LD

Table 1 (cont.)

Date	Chinook Fl	Chinook Marks	Steelhead Fl	Steelhead Marks	Coho Fl	Coho Marks
5/23	130	⊨LA			151	X|LD
	135	⊨LA			154	|XRD
	147	πLA			155	王RD
					156	X|RD
					159	H|LD
					160	X|LD
5/24	130	≍LA			134	X|LD
					140	王RD
					149	王LD
					150	H|RD
					158	52LD
5/26	122	πLA			145	H|LD
					175	H|RD
5/27	133	πLA			116	王RD
					153	H|RD
					154	王RD
5/28	122	≍LD			130	X|RD
	128	≍LD, ≍LD			138	H|LD
	130	╒RD			140	王LD
	133	≍LA			149	52RD
	138	╒RD			154	王LD
	142	⫣LA, πLA			158	X|RD
	149	╒RD				
5/29	116	⫣LA			120	王RD
	124	52LD			132	X|LD

Table 1 (cont.)

Date	Chinook		Steelhead		Coho	
	Fl	Marks	Fl	Marks	Fl	Marks
5/29	125	≍LA			133	H|LD
	131	≍LA			134	H|RD, X̄LD, 52RD
	133	|λRD			137	Ī LD
	135	πLA,			138	Ī RD, H|LD, H|LD
	136	≍LA, |λLD			139	X̄ LD
	137	πLA, |YLD, ⌐ RD			145	H|LD, X̄ LD
	138	⌐LD, ⌐RD, πLA			146	H|RD
	143	∃LA			147	ĪRD
	145	⌐LD, λ|LD, ⋶LA			149	52RD, X̄RD
	153	λ|LD			150	52RD
	156	⌐LD			152	H|RD
	159	⌐LD			155	X|RD
					165	H|LD
5/30	134	⌐LD			132	H|RD
	143	⌐LD				
	148	⌐RD				
	151	⌐LD				
	163	⌐LD				