DAVID A. VOGEL
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USE OF GROWTH DATA TO DETERMINE THE SPATIAL AND TEMPORTAL DISTRIBUTION OF FOUR RUNS OF JUVENILE CHINOOK SALMON IN THE SACRAMENTO RIVER, CALIFORNIA

U.S. Fish and Wildlife Service
Northern Central Valley Fishery Resource Office
P. O. Box 667
Red Bluff, California 96680

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NATURAL RESOURCE
SCIENTISTS INC.

United States Department of the Interior

FISH AND WILDLIFE SERVICE
NORTHERN CENTRAL VALLEY FISHERY RESOURCE OFFICE
P. O. Box 667
Red Bluff, CA 96080

December 3, 1992

Mr. David Vogel

Dear Mr. Vogel:

Please find attached a corrected copy of our manuscript " *Use of growth data to determine the spatial and temporal distribution of four runs of juvenile chinook salmon in the Sacramento River, California*" mailed to you on November 24. The copy sent to you on the 24th contained an older version of the growth table which has since been revised. The attached copy has an updated version of Table 1 which was used in the actual determination of run in the manuscript—the model now in use was revised on Feburary 2, 1992. Sorry for this inconvience. If you have any questions, please contact me at (916)527-3043.

Sincerely,

Richard R. Johnson

Richard R. Johnson

Attachments:
Manuscript

Table 1.—Growth table developed from fall-run chinook salmon reared naturally in the Tehama-Colusa Fish Facility (Fisher 1992). The table was developed using the linear function Log_e(fork length (mm))=3.516+0.007x*AGE*(days) to estimate the rate of apparent growth.

Emergence	Fall run Oct. 11-Apr. 2			Late-fall run Jan. 1-Jun. 27			Winter run Apr. 16-Oct. 18			Spring run Aug. 16-Dec. 9		
	Early	Peak	Late	Early	Peak	Late	Early	Peak	Late	Early	Peak	Late
Jan.	41		200	200	150	110	110	80	54	54	49	41
mid-month	45		219	219	166	122	122	89	59	59	54	45
Feb.	49	34	244	244	181	136	136	99	65	65	59	49
	54	37	270	270	200	150	150	110	73	73	65	54
Mar.	59	41			219	166	166	122	80	80	73	59
	65	45			244	181	181	136	89	89	80	65
Apr.	73	49	34	34	270	200	200	150	99	99	89	73
	80	54	37	37		219	219	166	110	110	99	80
May	89	59	41	41		244	244	181	122	122	110	89
	99	65	45	45	34	270	270	200	136	136	122	99
Jun.	110	73	49	49	37			219	150	150	136	110
	122	80	54	54	41			244	166	166	150	122
Jul.	136	89	59	59	45	34	34	270	181	181	166	136
	150	99	65	65	49	37	37		200	200	181	150
Aug.	166	110	73	73	54	41	41		219	219	200	166
	181	122	80	80	59	45	45	34	244	244	219	181
Sep.	200	136	89	89	65	49	49	37	270	270	244	200
	219	150	99	99	73	54	54	41			270	219
Oct.	244	166	110	110	80	59	59	45				244
	270	181	122	122	89	65	65	49	34	34		270
Nov.		200	136	136	99	73	73	54	37	37	34	
		219	150	150	110	80	80	59	41	41	37	
Dec.	34	244	166	166	122	89	89	65	45	45	41	34
	37	270	181	181	136	99	99	73	49	49	45	37

USE OF GROWTH DATA TO DETERMINE THE SPATIAL AND TEMPORAL DISTRIBUTION OF FOUR RUNS OF JUVENILE CHINOOK SALMON IN THE SACRAMENTO RIVER, CALIFORNIA

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Abstract.—Juvenile chinook salmon *Oncorhynchus tshawytscha* were captured monthly from 1981 to 1991 using beach seines at 13 sampling sites along a 134 mile stretch of the upper Sacramento River. These salmon were separated into one of four runs using a growth model developed from production records of fall-run chinook salmon reared on natural feed in the Tehama-Colusa Fish Facility from 1972 to 1981. Each of these runs exhibited different rearing strategies which could be explained by the availability of food, river flows, and water temperatures in the upper and lower river and San Francisco-San Joaquin Delta. Generally, fall, winter and spring-run chinook salmon move out of the upper river in one or two months after emergence, and are hypothesized to rear in the lower river or delta. Late-fall-run chinook salmon tend to reside four to six months in the upper river before moving out of the system.

Introduction

The Sacramento River and its tributaries in Northern California support fall, late-fall, winter, and spring runs of chinook salmon (salmon) *Oncorhynchus tshawytscha*. Runs are named according to the time of year adult fish enter San Francisco Bay and begin their migration upriver to spawn (Figure 1). These salmon runs have generally been in decline over the past 25 years (Figure 2). Decline in the threatened[1] winter run has been the most dramatic. Winter run escapement was over 117,000 in 1969, but had deteriorated to 191 in 1991. Fall run has steadily declined in recent years from 140,000 (1988) to 46,000 (1991), and has become increasingly dependent on hatchery production

[1]The winter run was listed as endangered by the California Fish and Game Commission in May 1989 (California Code of Regulations, Title XIV, Section 670.5, Filed 92289) and as threatened by the National Marine Fisheries Service in November 1990 (Federal Register, March 20, 1990, Volume 55, Number 54).

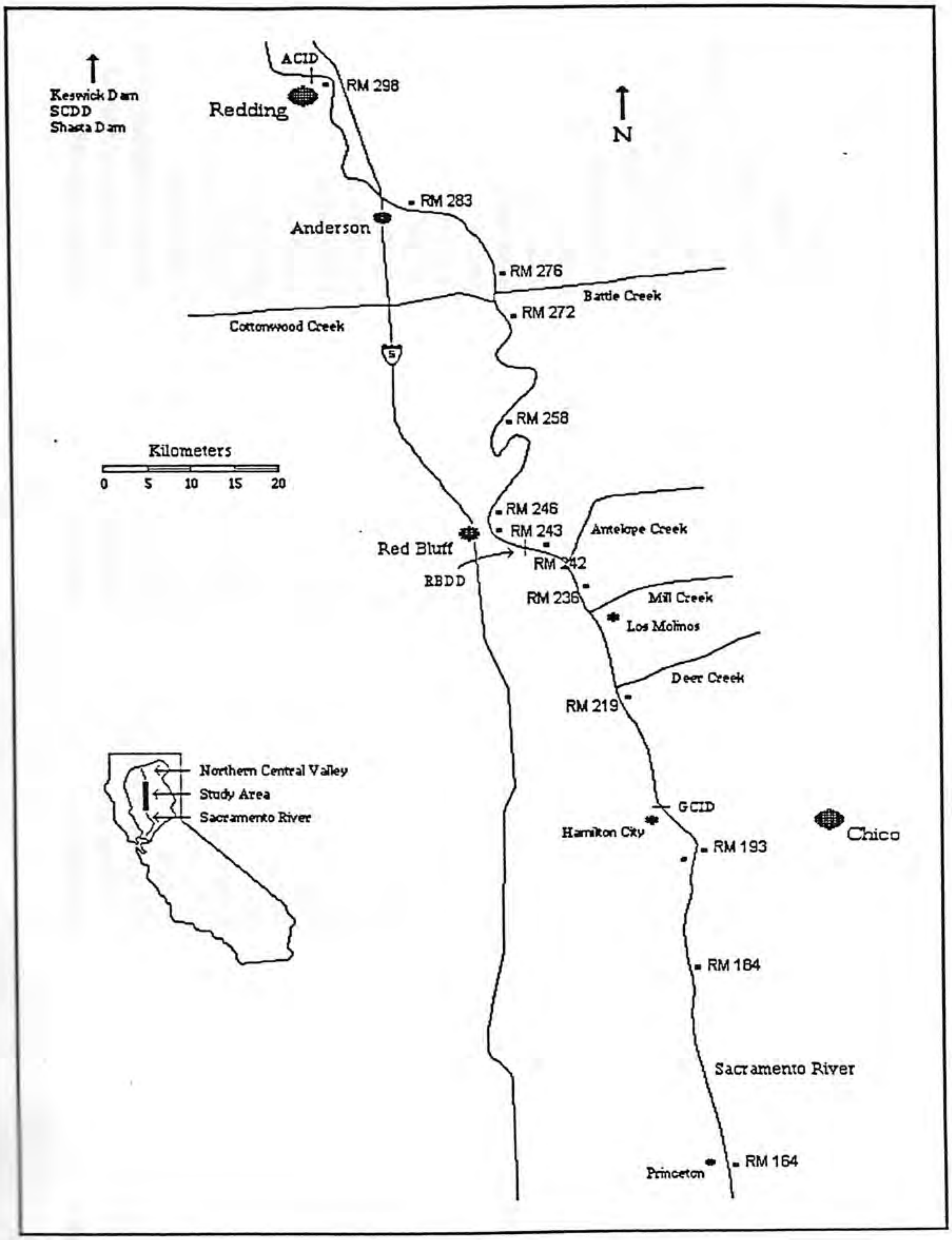

Figure 1.-Location of 13 sampling sites on the Sacramento River from river mile 164 to 298, and with respect to Redding, Red Bluff, Chico, Anderson-Cottonwood Irrigation District Dam (ACID), and the Red Bluff Diversion Dam (RBDD), California.

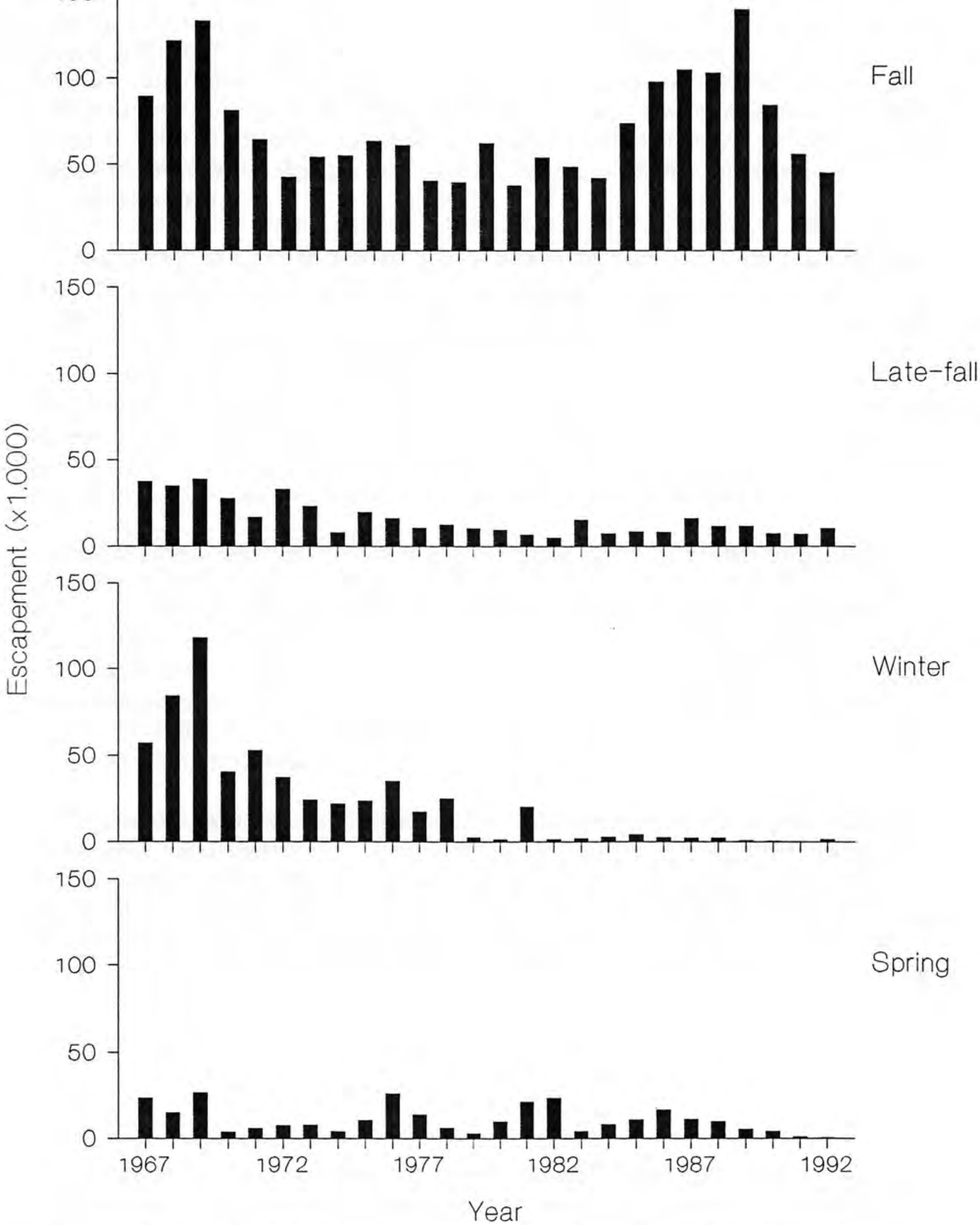

Figure 2.-Estimates of escapement for fall, late-fall, winter, and spring runs of chinook salmon past Red Bluff Diversion Dam, 1967-1992. (California Department of Fish and Game, Red Bluff, California).

(Cramer 1991). Escapements of late-fall (7,089) and spring (773) run are substantially lower in 1991 than their 1969 highs of 37,000 and 26,000. The outmigration of juvenile salmon in the Sacramento River is possibly the least understood stage of their life histories. Information on spatial and temporal distribution of each of the four runs is critical to management, particularly in regard to operation of water diversions and other facilities. Also, it would enable resource managers to make informed decisions regarding release of hatchery fish that will maximize survival and minimize interference with natural production.

Using growth as a tool to separate salmon runs in the Sacramento-San Joaquin Delta was first proposed by Stevens[2] (1989). He recognized that the four salmon runs of the Sacramento River spawn at different times and should therefore exhibit different lengths at a given date. However, he assumed empirical growth in hatcheries, in which weight doubled each month, was an unbiased estimator of length in naturally occurring salmon. This method overestimated real growth in these stocks. Kjelson et al. (1982) conducted a tag and recapture experiment using fall-run from Coleman National Fish Hatchery to evaluate growth in the Sacramento River and Delta. His results underestimated apparent growth in the river, and drastically underestimated growth in the delta.

Natural growth rates are difficult to obtain. Broad spawning periods coupled with juvenile immigration and emigration confuse apparent with real growth (Healey 1980). Bias associated with sampling gear and changes in preferred habitat at different life history stages add further complexity to growth determination. Hatchery and laboratory studies give some insight into growth; however, they artificially provide food, manipulate water temperatures, and regulate density of test fish. All of these factors influence growth. Tag and recapture experiments provide estimates of growth but assumes tagging causes no interference with growth.

The goal of this study was to understand the outmigration patterns of juvenile salmon in the upper Sacramento River. Specific objectives were to: (1) Determine spatial and temporal distribution of four runs of naturally growing salmon using a growth model developed from juvenile fish rearing on natural feed in the Tehama-Colusa Fish Facility; and, (2) verify the growth model using theorized life history strategies and historical records of the four chinook salmon runs in the upper Sacramento River.

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[2]Memorandum, June 19, 1989, To: H. K. Chadwick, Program Manager Bay-Delta Project, From: D. E. Stevens, California Department of Fish and Game, Subject: When do winter-run chinook salmon migrate through the Sacramento-San Joaquin Delta? California Department of Fish and Game, Red Bluff, California.

Study Area

The Sacramento River is located in the Central Valley of Northern California (Figure 1). Originating on Mt. Shasta near Mt. Shasta City, California, it flows south-southwest to San Francisco Bay. The river may be divided into 2 sections: the upper Sacramento River and the lower Sacramento River (California Resource Agency 1989). The lower section extends 80 river miles (RM) from San Francisco Bay to the mouth of the Feather River near Verona, California to. The banks are riprapped and flow is uniform throughout much of the lower river. The upper Sacramento River extends 232 RMs from the mouth of the Feather River to Shasta Dam. Despite much agricultural and urban development and several man-made obstacles, the upper river remains a more natural state than the lower river.

Methods

Sampling.—Thirteen sampling sites were selected along a 134 mile reach of the upper Sacramento River from RM 164 to 298 - six sites below the Red Bluff Diversion Dam (RBDD) and seven sites above RBDD. Sites were selected empirically on the basis of current, substrate composition, accessibility, and relative separation from one another. Sites were either gravel bars or boat ramps. Gravel bars were shallow with high water velocities; while boat ramps were deep with low water velocities. Sites below RBDD were gravel bars (except RM 242); while boat ramps predominated above RBDD (except RMs 246 and 272). Sampling was conducted approximately once a month from 1981 to 1991. An 1/8 in mesh beach seine (4 x 75 ft) was used to capture juvenile fish. Fish were immediately removed from the bag of the seine and held in fresh water. Tricaine methanesulfonate (MS 222) was added to anesthetize the fish if salmon were present. Fork lengths (mm) were measured from 50 randomly selected salmon; additional salmon (if present) were counted. A second haul was conducted at gravel bars if less than 50 juvenile salmon were captured on the first. Second hauls were upriver of the first to minimize the chance of recapturing fish. All fish were released back into the river.

Run Determination.—An estimate of apparent growth rate to establish run was made from 1972 through 1981 production records of fall-run chinook salmon < 90 mm fork length reared naturally (without artificial feed) at the Tehama-Colusa Fish Facility (Fisher 1992). A growth curve was fitted to fork length at age (days) using a linear function:

$$Log_e(Fork\ Length\ [mm]) = a + b(age)$$

where a and b are constants derived by regressing the logarithm (base e) of fork length and age. A table to predict run from length and capture date was developed and extrapolated to account for fish ≥ 90 to 270 mm (Table 1). The same model was used for late-fall, winter, and spring runs with adjustments made for spawning and incubation periods. Because minimum and maximum lengths of successive runs are the same, it was subjectively determined that these ambiguous fish be placed in the later spawning run.

Table 1.—Growth table developed from fall-run chinook salmon reared naturally in the Tehama-Colusa Fish Facility (Fisher 1992). The table was developed using the linear function $\mathrm{Log_e}$(fork length (mm))=3.516+0.007x*AGE*(days) to estimate the rate of apparent growth.

Emergence	Fall run Oct. 11-Apr. 2			Late-fall run Jan. 1-Jun. 27			Winter run Apr. 16-Oct. 18			Spring run Aug. 16-Dec. 9		
	Early	Peak	Late	Early	Peak	Late	Early	Peak	Late	Early	Peak	Late
Jan. mid-month	30			181	150	110	110	73	49	49	41	34
	34			200	166	122	122	80	54	54	45	37
Feb.	37	30		219	181	136	136	89	59	59	49	41
	41	34		244	200	150	150	99	65	65	54	45
Mar.	45	37		270	219	166	166	110	73	73	59	49
	49	41			244	181	181	122	80	80	65	54
Apr.	54	45	30	30	270	200	200	136	89	89	73	59
	59	49	34	34		219	219	150	99	99	80	65
May	65	54	37	37	30	244	244	166	110	110	89	73
	73	59	41	41	34	270	270	181	122	122	99	80
Jun.	80	65	45	45	37			200	136	136	110	89
	89	73	49	49	41	30	30	219	150	150	122	99
Jul.	99	80	54	54	45	34	34	244	166	166	136	110
	100	89	59	59	49	37	37	270	181	181	150	122
Aug.	122	99	65	65	54	41	41		200	200	166	136
	136	110	73	73	59	45	45	30	219	219	181	150
Sep.	150	122	80	80	65	49	49	34	244	244	200	166
	166	136	89	89	73	54	54	37	270	270	219	181
Oct.	181	150	99	99	80	59	59	41			244	200
	200	166	110	110	89	65	65	45	30	30	270	219
Nov.	219	181	122	122	99	73	73	49	34	34		244
	244	200	136	136	110	80	80	54	37	37	30	270
Dec.	270	219	150	150	122	89	89	59	41	41	34	
		244	166	166	136	99	99	65	45	45	37	30

Table 2.—Mean number of fall-run chinook salmon captured per month at the 13 sites between January 1981 and January 1991 (N=60,728). Means were rounded to the nearest whole number. Blanks indicate zero catches and dashes no sampling.

	River mile												
Month	298	283	276	272	258	246	243	242	236	219	193	184	164
December	17	<1	2	12	4	48	1	15	18	1	1	1	1
January	113	238	68	174	113	74	30	28	46	64	101	49	39
February	128	224	158	183	40	103	103	51	40	64	103	38	44
March	118	135	596	151	30	39	30	38	67	26	129	63	116
April	75	30	30	152	43	—	9	10	90	31	65	56	63
May	7	1	10	123	51	124	7	18	86	35	50	68	49
June			11	24	<1	—	<1	8	38	3	6	5	3
July		<1	6	9	<1	—		1	3	1	2	<1	1
August			<1	9		—		<1		<1	<1	1	<1
September		<1	<1	4		—		<1	<1	<1	<1	<1	
October				1		—	<1		<1		<1	<1	<1
November				<1		—					<1		<1

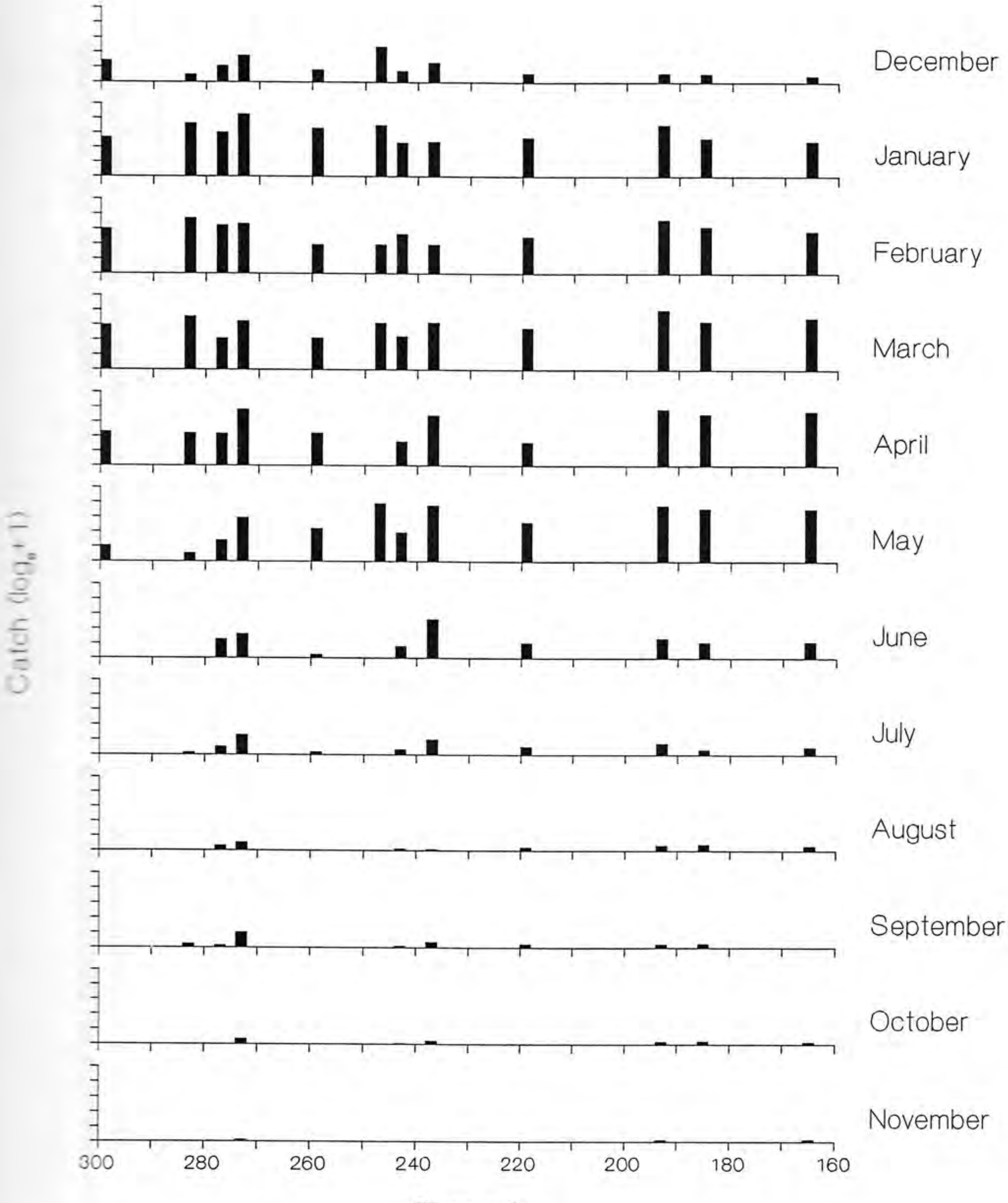

Figure 3.-Spacial and temporal distribution of fall-run chinook salmon captured during beach seine sampling from 1981 to 1991. Because of the large range, total catch has been rescaled using the transformation $\log_e$(catch+1), so that values range from 1 to 5.

Table 3.—Mean numbers of late-fall-run chinook salmon captured per month at the 13 sites between January 1981 and January 1991 (N=6,284). Means were rounded to the nearest whole number. Blanks indicate zero catches and dashes no sampling.

	River mile												
Month	298	283	276	272	258	246	243	242	236	219	193	184	164
April	16	17	7	7	5	—	<1	2	<1	<1		<1	
May	49	39	16	72	16	5	6	13	7	1		<1	
June	49	6	39	8		—	<1	2	9	<1		<1	<1
July	7	1	5	6	1	—		<1	<1				
August	4	1	3	42	1	—	<1	<1	1	<1	<1	<1	<1
September	26	4	2	46	11	—	<1	<1	4		<1	<1	<1
October	9	<1	2	18	1	—	<1	1	3	<1	3	<1	1
November	<1		<1	12	2	—		<1	<1	<1	6	<1	1
December	1			9	1	10	5	<1	4	1	8	1	3
January			<1	4	<1			1	<1	<1	2	<1	1
February													
March													

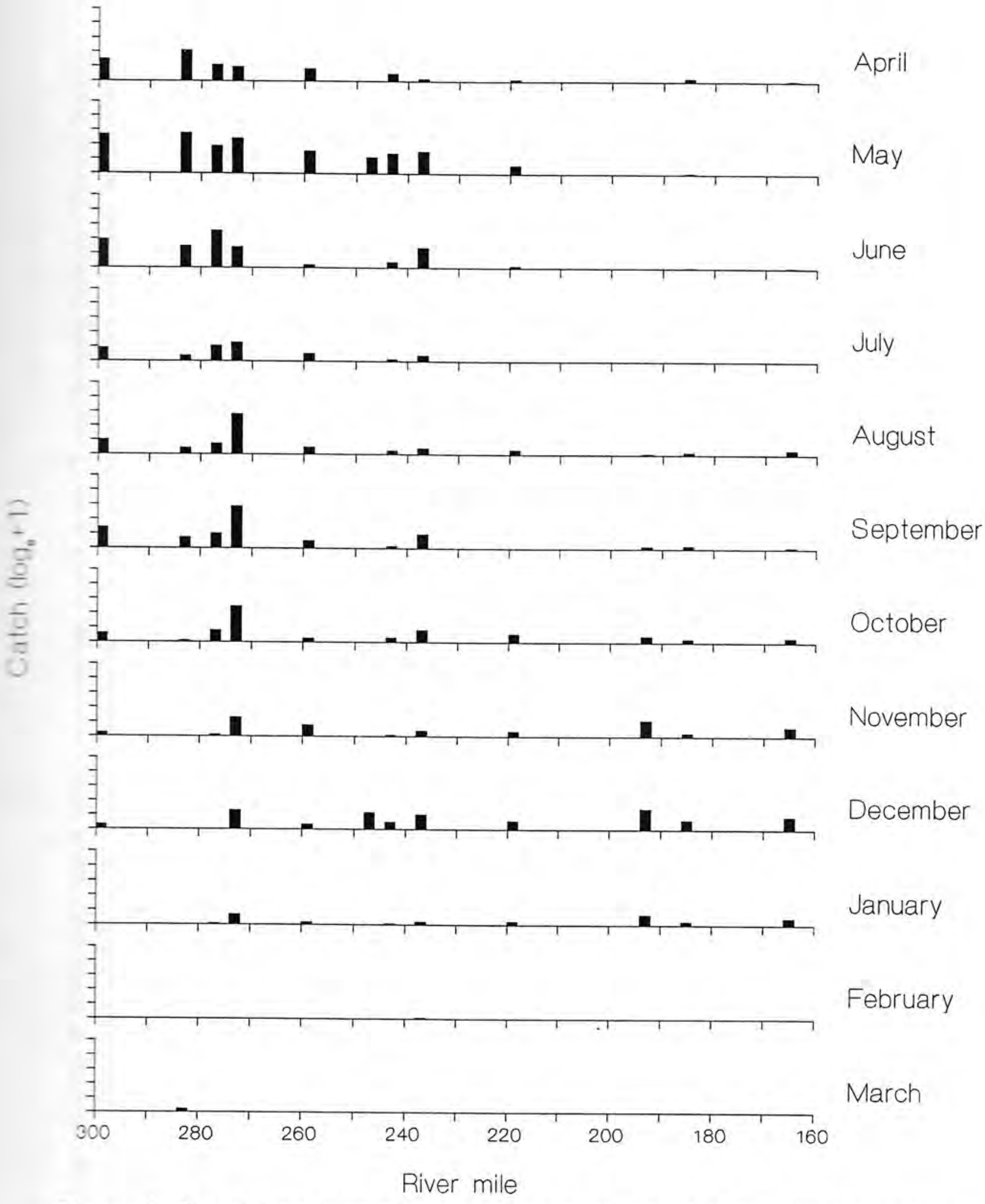

Figure 4.-Spacial and temporal distribution of late-fall-run chinook salmon captured during beach seine sampling from 1981 to 1991. Because of the large range, total catch has been rescaled using the transformation $\log_e$(catch+1), so that values range from 1 to 5.

Table 4.—Mean numbers of winter-run chinook salmon captured per month at the 13 sites between January 1981 and January 1991 (N=10,778). Means were rounded to the nearest whole number. Blanks indicate zero catches and dashes no sampling.

	River mile												
Month	298	283	276	272	258	246	243	242	236	219	193	184	164
July	<1	<1	<1			—			<1				
August	23	<1	4	4	9	—	<1	1	3	<1			
September	264	3	43	193	67	—	7	9	57	<1		1	<1
October	76	1	28	59	29	—	9	8	11	3	6	<1	1
November	8	1	8	132	10	—	2	<1	2	1	2	<1	<1
December	4		1	15	1	4	6	1	11	<1	3	<1	4
January	1		<1	25		<1	1	24	2	2	16	4	9
February	<1	<1	<1	<1		4	<1	<1	1	3	11	<1	3
March	<1	<1	<1	<1		<1	<1	<1	1	<1	<1	2	3
April				<1	<1	—		<1					
May													
June						—							

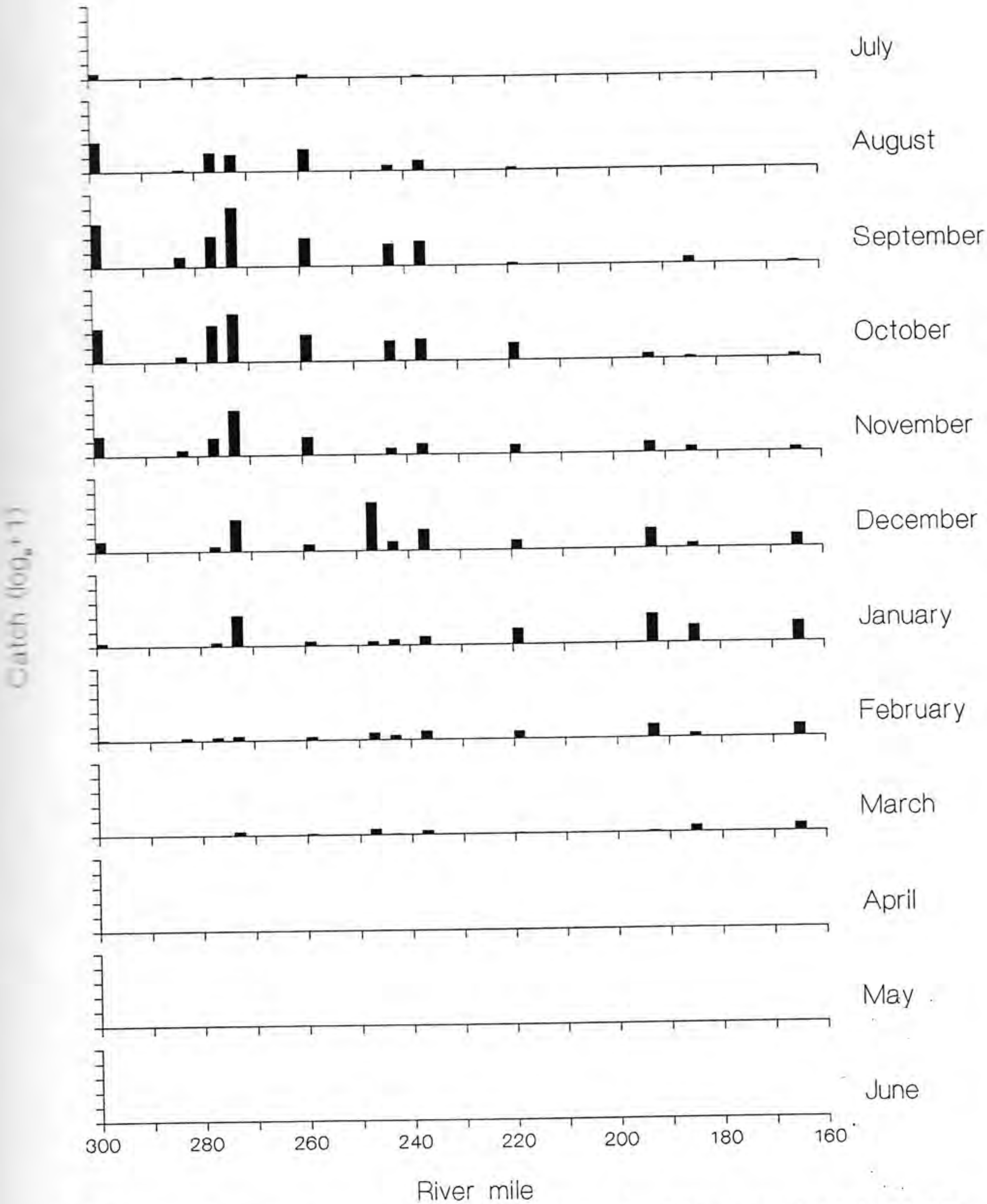

Figure 5.-Spacial and temporal distribution of winter-run chinook salmon captured during beach seine sampling from 1981 to 1991. Because of the large range, total catch has been rescaled using the transformation $\log_e$(catch+1), so that values range from 1 to 5.

Table 5.—Mean numbers of spring-run chinook salmon captured per month at the 13 sites between January 1981 and January 1991 (N=4,768). Means were rounded to the nearest whole number. Blanks indicate zero catches and dashes no sampling.

Month	River mile												
	298	283	276	272	258	246	243	242	236	219	193	184	164
October	1	<1	1		<1	—	<1		<1				
November	3	5	1	7	<1	—	2	<1					<1
December	14	<1	15	37	6	53	2	19	40	1	4	2	2
January	15	8	4	45	6	29	1	2	1	2	13	8	9
February	1		1	10	<1	2	<1	<1	1	3	10	3	13
March		<1	<1	2	<1	4	<1	2	2	1	11	3	19
April			<1	1	1	—	<1	<1	2	<1	6	4	10
May			<1	<1		50	<1	<1	<1	1		1	2
June						—							<1
July						—							
August						—							
September						—							

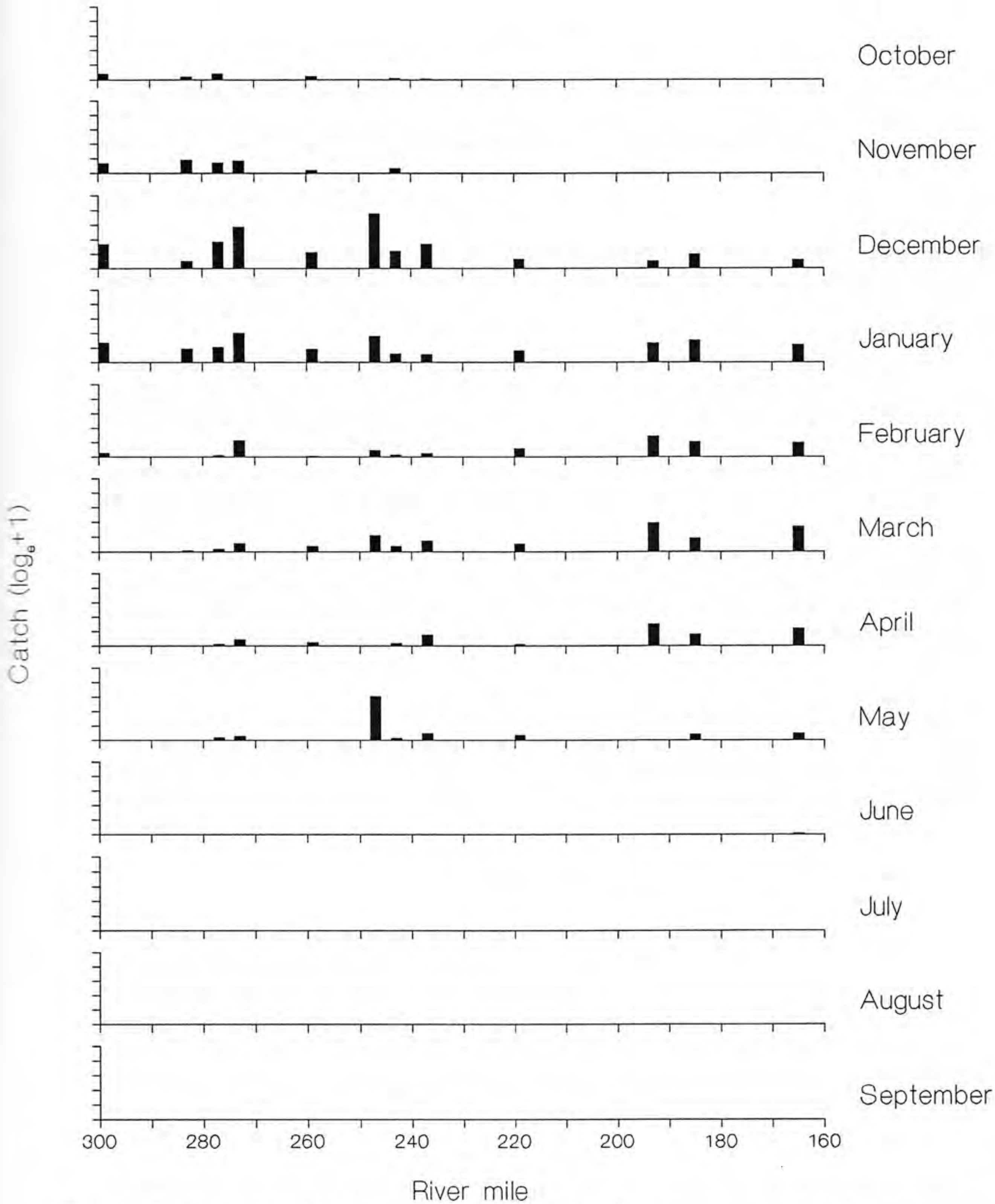

Figure 6.-Spacial and temporal distribution of spring-run chinook salmon captured during beach seine sampling from 1981 to 1991. Because of the large range, total catch has been rescaled using the transformation $\log_e$(catch+1), so that values range from 1 to 5.

Results

Run Composition.—Thirteen brood years of salmon (1980 - 1992) were represented over 10 sampling years. Fall run comprised the largest part of total catch (74%); followed by winter run (13%), late-fall run (7%), and spring run (6%).

Spatial and Temporal Distribution

Fall Run.—Although present year-round fall run were captured primarily between December and May (Table 2; Figure 3). They exhibited a fairly evenly distribution. By June, most had left the study area.

Late-Fall Run.—Late-fall run were also captured year-round but predominately between April and January (Table 3; Figure 4). They tended to remain in the upper reach between April and September. None were captured below RM 219 between April and September but slowly spread to the lower reach (below RBDD) after October. There appears to be a dramatic movement downstream of late-fall juveniles in December, and were largely gone from the study area by February.

Winter Run.—Winter run were captured between July and March (Table 4; Figure 5). They largely confined themselves to the upper reach of the study area from July through September and slowly spread to the lower reach from October through March. By April they had completely left the study area. No winter run were captured in April through June.

Spring Run.—Spring run were captured between October and May (Table 5; Figure 6). They were confined to the upper reach until December when they began to distribute themselves downstream. They became less abundant from January through May, and had completely left the study area by July. No spring run were captured in the study area in July through September.

Discussion

Fall run spawn throughout the study area. Recently emerged (≤ 40 mm) fall run at sites above and below RBDD between December and March support this conclusion. Numbers of fall run captured above and below RBDD between December and March suggests 28% of the parental fish spawned in the lower reach of the study area. This estimate is high since a large number of small fish outmigrate almost immediately upon emergence (Frank Fisher, California Department of Fish and Game (CDFG), unpublished data, 1991). However, it is similar to the 30% estimated to have spawned in the lower reach in 1979 (Vogel et al. 1988).

Vogel et al. (1988) concluded that most fall run outmigrate past RBDD during winter in normal precipitaion years and spring in dry years. Results of our study support this conclusion. During the dry years 1989 to 1991, outmigration past RBDD did not occur until spring (April — June). In fact, in those years fall run were captured at RM 298 and 283 until May and above RBDD until October.

Late-fall run spawn mainly in the upper reach of the study area. Most recently emerged late-fall run were captured in the upper reach between April and June. Conversely, very few small late-falls were captured in the lower reach or even at lower sites of the upper reach (RMs 243, 246, and 258). It is further supported results from a 1985 redd distribution study in which 25% of the late-fall run spawned in a 3 ½ mile reach between RM 298 and Keswick Dam (RM 302; Hallock 1987).

Fisher (CDFG, unpublished data, 1991) identified two distinct outmigrant groups of late-fall run from capture data collected at RBDD between 1978 and 1989. One group outmigrated as fry in April and May and the second as smolts in October and November. A similar trend was observed in our study — one group in May and a second in October. Outmigration of two distinct groups may be related to precipitation. It is hypothesized that early outmigrants move with spring rains while late outmigrants move with fall rains. Precipitation in April and May in the years 1989 to 1991 was less than normal; consequently, a relatively large number of late-fall run reared in the upper river over the summer and outmigrated in the fall.

Large number of winter run begin to outmigrate almost immediately upon emergence. A substantial number of newly emerged winter run were captured in the lower reach of the study area in August and September. Since most winter run spawn in the upper reach of the study area (above RM 298; Vogel et al. 1988), these small fish are believed to have emerged above RBDD. This is supported by capture data collected at RBDD between 1978 and 1989 which demonstrates most winter run pass RBDD between August and October (Frank Fisher, CDFG, unpublished data, 1991). Early outmigrants are believed to rear somewhere in the system between RBDD and the Sacramento-San Joaquin Delta since water temperatures in the Delta during the summer are not suitable for juvenile salmon.

Although a large number of winter run outmigrate almost immediately upon emergence, a substantial number rear in upper reaches of the study area for several months. Almost half of the winter run captured between November and March were captured in this area. It is hypothesized that winter run rearing in the upper river over the fall await winter rains to begin their outmigration. As an example, 49 winter run were sampled using a backpack electrofisher (41 minutes of fishing effort) in a side channel riffle at RM 289 near Redding in January 1992 (Richard Johnson, USFWS, unpublished data, 1992). The same riffle was sampled after heavy rains and increased river flows in February 1992 and no winter run were captured, suggesting winter run rearing in this location moved out with the increased river flows.

Spring run spawn in the upper reach of the study area. The capture of most recently emerged spring run in the upper reach between October and January support this conclusion. Historic spawning areas occurred at higher elevations above Shasta and Keswick dams (Reynolds et al. 1990).

Although some spring run rear in the upper reach for several months, most outmigrate almost immediately upon emergence. Our study indicates peak outmigration past RBDD in January. Seventy-one percent of the spring run were captured in the upper reach between October and January while only 23% were captured there in February and March. Capture data collected at RBDD between [illegible] and 1989 indicated most spring run pass RBDD in January (Frank Fisher, CDFG, unpublished data, 1991). It is hypothesized that spring run move with increased river flows after winter rains that occur during peak emergence.

Using the growth table to identify run of juvenile salmon captured in the study area appears to work well, and as such, is a valuable tool for resource managers. However, the model lacks measurable statistical veracity. It was developed from fall run reared in an artificial environment and harbors unknown biases when applied to wild fish and other runs. Also, it was extrapolated for fish with fork lengths ≥ 90 mm and; therefore, is hypothetical when predicting growth for larger fish.

We recommended the growth model be verified (or amended) to provide statistically valid estimates for all four runs of naturally rearing fish up to 250 mm fork length. Growth of hatchery fish or fish reared in an artificial stream (such as the Tehama-Colusa Fish Facility) can be estimated with measurable accuracy and precision. Perhaps adjustments to such an estimate could be made using scale or otolith pattern differences between hatchery/artificial stream and wild fish. Tag and recapture methods could also be used, but we reiterate, biases in growth rates could be significant in smaller fish.

Daily capture rates and length frequency information gathered strategically along the river would facilitate an understanding of the relative movements of the four runs. Beach seining, although valuable, is a biased technique for obtaining estimates of abundance of the four runs of juvenile salmon. Efficiency varies with changes in current, substrate composition, amount of debris, and distance of haul. Permanently based screw or fyke traps are a less biased technique for obtaining reliable estimates of abundance. We recommend the use of screw or fyke traps to expand juvenile salmon outmigration studies to better estimates juvenile abundance.

Summary

1. A model was produced that described the spatial and temporal distribution of four runs of chinook salmon in the Sacramento River using a prototype growth table developed from juvenile fish rearing on natural feed in the Tehama-Colusa Fish Facility.

2. The model provided reasonable results based on theorized life history strategies and historical records.

3. We recommend the growth model be rigorously verified (or amended) to provide statistically valid estimates of length by date by run, for all four runs of naturally rearing fish up to 250 mm fork length.

3. Daily capture rates and length frequency information gathered from screw traps strategically located along the river would facilitate a more complete understanding of the relative movements of the four runs.

Acknowledgements

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