FRED Reports

ENHANCEMENT OF HIDDEN LAKE SOCKEYE SALMON (*ONCORHYNCNUS NERKA*) : SUMMARY OF FISHERIES PRODUCTION (1976-1989)

by
G. B. Kyle, D. S. Litchfield, and G. L. Todd

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P. O. Box 3-2000
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January 1990

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

During 1976-1989, a total of over 17 million sockeye salmon (*Oncorhynchus nerka*) fingerlings was released into Hidden Lake, and contributed an average of 68% to the annual smolt migration. Survival of stocked fingerlings to the smolt stage ranged from 16-28% and averaged 21%. The contribution of hatchery-produced adults returning to the weir during years when hatchery fish returned averaged 50%, and overall smolt-to-adult return to the weir averaged 13.9%. Assuming a 50% commercial fishing exploitation rate, the smolt-to-adult survival rate would average ~28%. Above an escapement of ~10,000 sockeye salmon, wild smolt production levels off, indicating Hidden Lake is spawning-area limited and/or fry survival from potential egg deposition is poor. The enhancement project significantly (Mann Whitney U-test; $p < .01$) and directly increased escapements of sockeye salmon into Hidden Lake. Considering only the years when weir counts of sockeye salmon escapements were conducted (1971-1972; 1976-1989), pre-enhancement escapements averaged 9,492 compared to 27,425 after enhancement.

INTRODUCTION

In 1972, Alaska Senate Resolution No. 27 directed the Alaska Department of Fish and Game (ADF&G) to establish a ..."comprehensive salmon rehabilitation and restoration program in the Cook Inlet watershed"... to expedite the rebuilding of Cook Inlet sockeye salmon stocks. As a result, the Commercial Fisheries Division of ADF&G conducted biological, chemical, and physical inventories of numerous lakes throughout the Cook Inlet basin in 1972 and 1973 (Bill et al. 1972; Barton and Barrett 1973). These investigations revealed that Hidden Lake had the greatest potential for increased production of sockeye salmon. With the formation of the Fisheries Rehabilitation, Enhancement, and Development (FRED) Division of ADF&G in 1973, and the

establishment of a FRED field office in Soldotna in 1975, the sockeye salmon enhancement project at Hidden Lake was initiated in 1976.

In 1976, basic fisheries and some limnological data were collected, and a small number of sockeye salmon eggs were taken to evaluate incubation and fry-rearing procedures (Kyle 1979a). Every year since 1976, smolt and adult enumeration and age-weight-length sampling of sockeye salmon has been conducted, and since 1980 extensive limnological sampling has been conducted. In addition, except for 1979-1981, sockeye salmon eggs have been taken each year for hatchery incubation and fry rearing, and the resultant fingerlings were stocked in Hidden Lake (Kyle 1979b; Kyle 1980; Kyle et al. 1981; Litchfield and Todd 1983; Litchfield 1983; Flagg 1985; Flagg and Litchfield 1987; Litchfield and Flagg 1988).

In 1989, evaluation activities for the Hidden Lake sockeye salmon enhancement project were terminated by the ADF&G after the transfer of Trail Lakes Hatchery (the supporting hatchery for this enhancement project) to the Cook Inlet Aquaculture Association (CIAA) in 1988. Continuation of fisheries evaluation (smolt and adult sampling) activities at Hidden Lake will be done by CIAA. The purpose of this report is to summarize results of the sockeye salmon enhancement project at Hidden Lake during 1976-1989, and provide a comprehensive summary of sockeye salmon smolt and adult production.

Description of Study Area

Hidden Lake (150°15'W, 60°29'N) is located on the Kenai Peninsula 69 km east of Soldotna, Alaska and lies within the boundaries of the Kenai National Wildlife Refuge (KNWR) (Figure 1). The lake outlet, Hidden Creek, flows approximately 5 km into Skilak Lake, which is within the Kenai River watershed. Hidden Lake is steep-sided, with two major basins, a surface area of 6.8 km^2, a mean depth of 20.2 m, and a volume of 138.1 X 10^6 m^3 (Figure 2). The mean annual precipitation of 44 cm over a watershed area of 37.4 km^2, results in an estimated water residence time of 11.7 years for this lake.

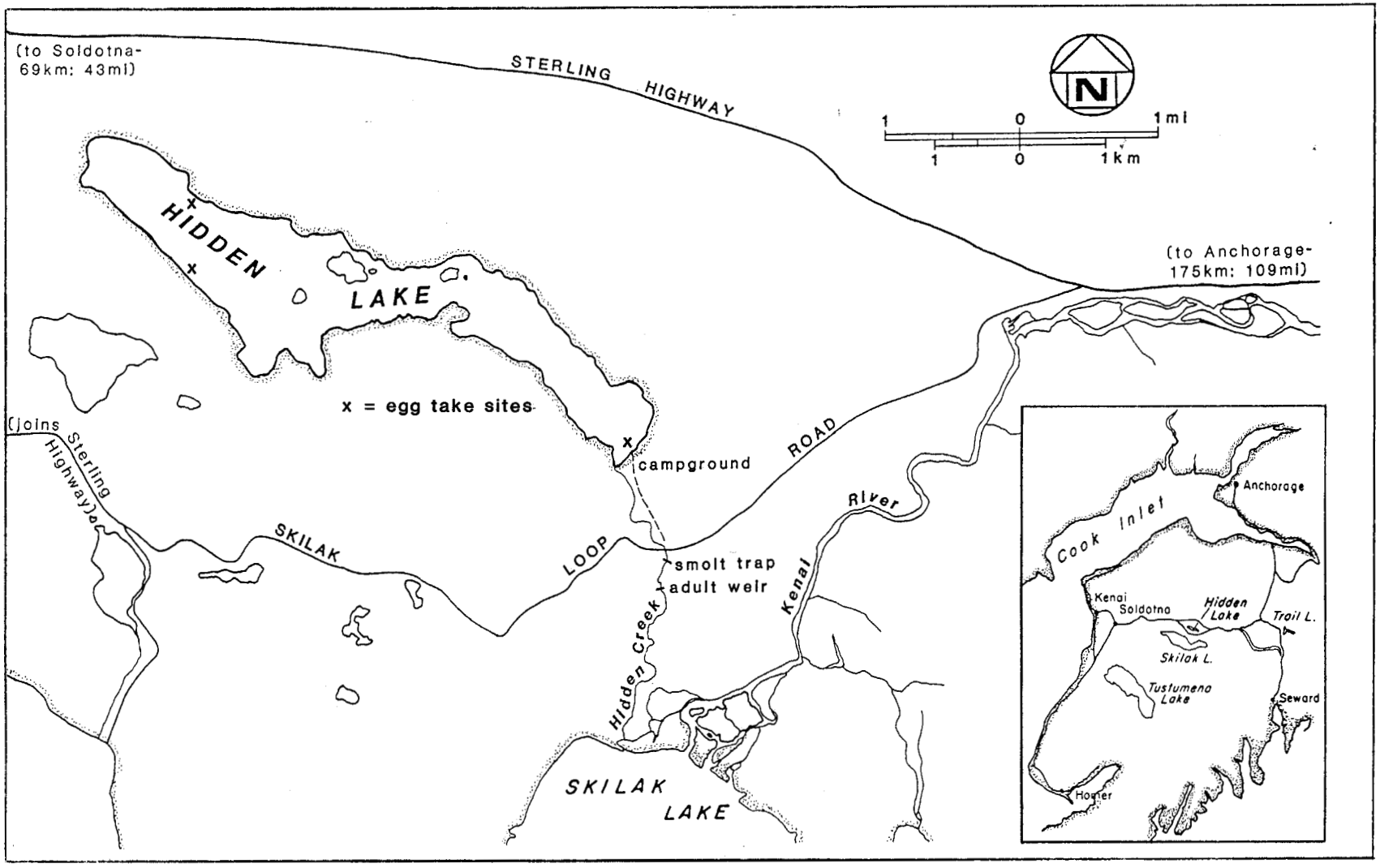
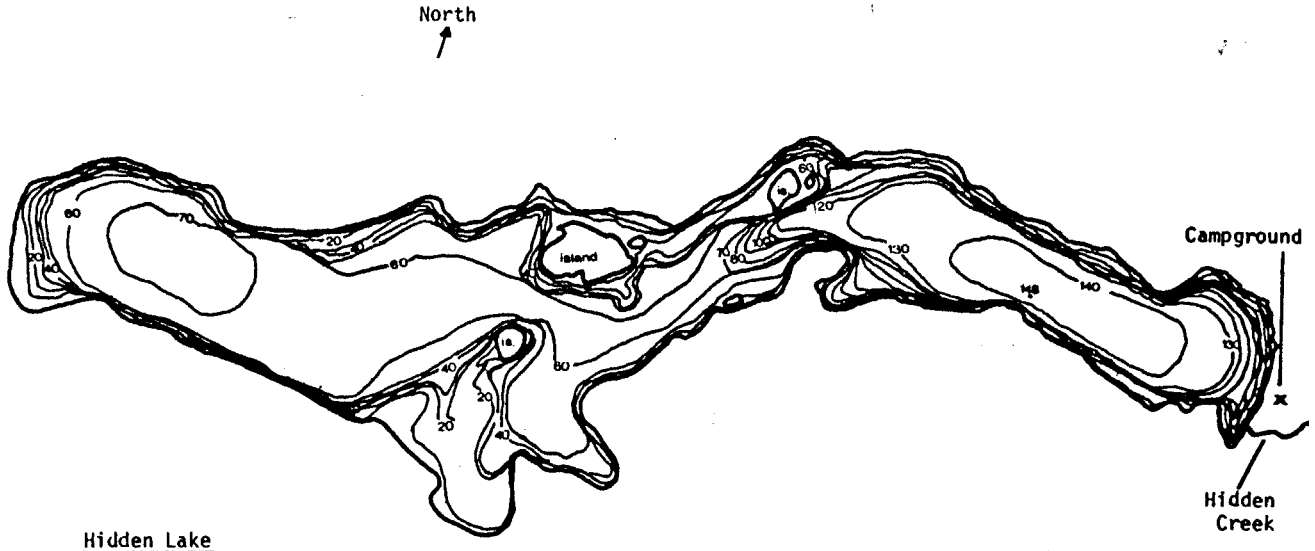


Figure 1. Area map of Hidden Lake in southcentral Alaska showing locations of the smolt and adult weirs, and egg take sites.



Hidden Lake

Elevation	86.0 m
Volume	138.1 x 10^6 m^3
Surface Area	682.7 x 10^4 m^2
Maximum Depth	45.1 m
Mean Depth	20.1 m
Shoreline Length	22.5 km
Shoreline Development	2.4

Scale: 2.6 cm = 1.0 km
Bottom contours in feet

Figure 2. Morphometric map of Hidden Lake showing the two major lake basins.

Hidden Lake is a oligotrophic-mesotrophic system, with a mean (May-October) total phosphorus concentration of 7 μg/L, a total nitrogen concentration of 178 μg/L, a TN:TP ratio of 60:1, and a seasonal mean chlorophyll a concentration of 0.6 μg/L. The lake has a mean euphotic zone depth of 20 m and an euphotic volume of 135 X 10^6 m^3. The zooplankton community is composed mainly of two cladocerans (*Bosmina longirostris*) and (*Daphnia longiremus*), three copepods (*Diaptomus pribilofensis*), (*Epishura navadensis*) and (*Cyclops columbianus*), and numerous species of rotifers.

With the exception of chum salmon (*Oncorhynchus keta*), four of the five species of Pacific salmon in one lifestage or another have been observed in the Hidden Lake system; however, mainly sockeye salmon utilize the nursery area of the lake. All of the sockeye salmon in Hidden Lake spawn along the shoreline. Other resident fish species include lake trout (*Salvelinus namaycush*), rainbow trout (*Oncorhynchus mykiss*), Dolly Varden char (*Salvelinus malma*), threespine stickleback (*Gasterosteus aculeatus*), and coastrange sculpin (*Cottus aleuticus*).

METHODS

Egg Takes and Fingerling Releases

Sockeye salmon eggs taken at Hidden Lake were incubated and fry were short-term reared (2-4 weeks) at three different hatcheries. The Crooked Creek Hatchery (on the Kenai Peninsula) was used for broodyears 1976 and 1978, the Big Lake Hatchery (near Wasilla) was used for broodyear 1977, and the Trail Lakes Hatchery (on the Kenai Peninsula) has been used since 1982. No sockeye salmon eggs were taken during 1979-1981 because of the unavailablity of a hatchery for egg incubation and fry rearing.

In general, the Hidden Lake sockeye salmon egg takes, fecundity sampling, hatchery incubation, and fry rearing protocol followed the ADF&G Fish Culture Manual (FRED

Staff 1983). Near-spawning adults were captured by seine and placed in a large holding area until they were spawned (Kyle 1979a) (Figure 1). From 1976 through 1982 eggs were fertilized on site in a spawning bucket containing eggs from more than one adult pair. However, because of disease considerations for infectious hematopoietic necrosis virus (IHNV) (Burke and Grischkowsky 1984; Grischkowsky et al. 1986), since 1983, eggs and milt were collected from individual fish and stored until each female was individually fertilized at the hatchery (Litchfield and Flagg 1988). In addition, since 1987, unfed fry were released instead of fingerlings (0.2-0.3 g) in an attempt to minimize risks associated with IHNV.

Approximately 2-17% of the sockeye salmon fingerlings released each year in Hidden Lake were marked by either a ventral clip or an adipose fin clip. Fingerlings were transported to Hidden Lake by either fixed-wing aircraft (1977), or hatchery tanker truck (all other years), and released at the spawning sites located at the western end of the lake by boat. In addition, after 1983, a portion of the fingerlings were released each year at the boat ramp located in the KNWR campground at the eastern end of the lake (Figure 1). Fingerlings were released at the boat ramp to simplify the capture of returning adults for egg takes.

Enumeration and Sampling of Sockeye Salmon Smolts

Total counts or estimates of the number of migrating smolts were made utilizing a smolt trap placed in Hidden Creek (Figure 1), usually from the third week of May until mid-July (Kyle 1979b). During peak migration periods (>5,000 smolts/hr), subsampling by time was employed to estimate numbers of migrating smolts (Litchfield and Flagg 1988). Each day, 30 smolts were anesthetized in a tricaine methanesulfonate (MS-222) solution, measured to the nearest millimeter (snout-to-fork of tail), and weighed to the nearest 0.1 g. In addition, a scale smear was taken from each measured fish, placed on a glass slide, and ages were determined using a microfiche projector. Lengths, weights, and age-class compositions were weighted over the migration period by five-day intervals (Cochran 1963).

Enumeration and Sampling of Sockeye Salmon Adults

A double-V-shaped weir was installed in Hidden Creek (Figure 1) usually by mid-July to until early September to enumerate migrating adult sockeye salmon. Adult sockeye salmon were passed through the weir a least twice each day of the migration. Thirty adults were measured daily for mideye-to-fork lengths (nearest centimeter) and individual weights (nearest 0.1 kg). A scale smear was taken from each measured fish and ages were determined using a microfische projector.

Contribution of Hatchery-Produced Sockeye Salmon to the Weir

The number of hatchery-produced fish contributing to the Hidden Lake sockeye salmon escapement was estimated from the ratio of marked (finclipped) to unmarked fish recovered at the Hidden Creek weir. Ages of all marked fish were determined so that respective expansion factors representing the proportion of fingerlings marked at time of release were incorporated. For each week of the migration, the number of hatchery-produced fish contributing to the escapement was calculated in the following manner:

$$H_i = \Sigma \left[\frac{n_c \cdot n_p / n_e}{\Theta_m} \right]$$

where

H_i = number of hatchery-produced fish in week *i*

n_c = number of finclipped fish observed for each age class in week *i*

n_e = number of adults examined for finclips in week *i*

n_p = number of adults passed in week *i*

Θ_m = proportion of fingerlings marked (clipped) at time of release.

The estimated number of hatchery-produced fish for each age class was summed to estimate the total number of hatchery-produced fish in the weekly escapements. Finally, the weekly estimates of the number of hatchery-produced fish in the return were

summed to estimate the total number of hatchery-produced sockeye salmon in the escapement.

RESULTS

Egg Takes and Fingerling Releases

During 1976-1989, over 32.5 million eggs have been taken from nearly 11,000 sockeye salmon (mean fecundity = 3,063) for the enhancement project at Hidden Lake (Table 1). A total of 17,049,512 fingerlings have been stocked of which 0.9% were marked with either an adipose or ventral fin clip. Excluding the 1978 broodyear, (when hatchery fry suffered high mortality due to problems with hatchery source water), the overall mean egg-to-fingerling survival was 70.4%. Emergent fry from the 1985 broodyear that were incubated at the Trail Lakes Hatchery became infected with IHN virus and were destroyed. Thus, no stocking occurred from the year (1985) when the greatest number of eggs (7,019,000) were taken.

Production of Wild and Hatchery Sockeye Salmon Smolts

The number of sockeye salmon smolts migrating from Hidden Lake during 1976-1989 varied annually from approximately 18,000-720,000, and averaged 263,000 (Table 2). The age composition of smolts varied slightly each year, ranging from 80-99% age-1, and averaging 91% age-1. Age-1 smolts ranged in mean size from 126-145 mm and 17.6-30.7 g, while age-2 smolts ranged in size from 163-200 mm and 43.5-83.9 g. The overall mean size of age-1 smolts was 138 mm and 24.9 g, and for age-2 smolts was 180 mm and 62.4 g. The mean size of neither age-1 or age-2 smolts changed substantially during 1976-1989 as the coefficients of variation were <0.20 (Table 2). Moreover, in 1989, the sizes of both age-1 and age-2 smolts were the smallest ever recorded, but they were not significantly (Mann Whitney U-test; $p>.05$) smaller than the average.

Table 1. Summary of sockeye salmon egg takes and fingerling releases at Hidden Lake, 1976-1989.

Brood year		No. eggs taken	No. females used for egg take	Fecundity	Receiving hatchery	No. fingerlings released	Egg-to-fingerling survival (%)	Type of mark	No. fry marked	Percent marked
1976		832,880	274	3,091	Crooked Cr.	330,228	39.6	Adipose	18,665	5.7
1977*	(A)	299,128	84	3,515	Big L.	218,957	73.2	L. ventral	29,053	13.3
	(R)	107,750	116	929	Big L.	89,747	83.3	R. ventral	15,046	16.8
1978		311,808	100	3,118	Crooked Cr.	8,258**	2.7	None	0	
1979		0				0			0	
1980		0				0			0	
1981		0				0			0	
1982		1,579,188	576	2,741	Trail L.	1,086,000	68.8	L. ventral	15,045	1.4
1983		1,928,000	639	3,017	Trail L.	1,236,900	64.2	L. ventral	25,384	2.1
1984		3,766,000	1,310	2,875	Trail L.	1,805,792	47.9	L. ventral	22,293	1.2
								Adipose	22,050	1.2
1985		7,019,000	2,330	3,012	Trail L.	0***				
1986		4,740,000	1,580	3,000	Trail L.	3,718,311	78.5	None	0	
1987		7,000,184	2,434	2,876	Trail L.	6,085,307	86.9	None	0	
1988		2,718,853	891	3,046	Trail L.	2,470,012	91.0	None	0	
1989		2,209,447	647	3,400	Trail L.	NA				
Total		32,512,238	10,981			17,049,512			147,536	
Mean				3,063			70.4			0.9

* In 1977 sockeye salmon eggs were taken from the anadromous (A) and residual (R) stock.

** The 1978 hatchery broodstock (eggs) suffered high mortality due to complications with hatchery source water.

*** The 1985 hatchery broodstock (fry) became infected with IHN virus and were destroyed.

Table 2. Summary of Hidden Lake sockeye salmon smolt migrations, hatchery contributions, ages, and sizes during 1976-1989.

Smolt year	Number of smolts			Hatchery contribution (%)	Age class composition (%)		Mean length (mm)		Mean weight (g)	
	Wild	Hatchery	Total		Age-1	Age-2	Age-1	Age-2	Age-1	Age-2
1976	29,639	0	29,639	0	80	20	130	146	NA	NA
1977	17,670	0	17,670	0	83	17	144	199	NA	NA
1978	52,745	58,721	111,466	53	88	12	133	190	22.4	79.3
1979	46,828	47,519	94,347	50	85	15	145	177	30.7	57.2
1980	79,458	2,290*	81,748	3*	90	10	143	200	27.3	83.9
1981	161,522	0	161,522	0	98	2	144	198	28.5	81.4
1982	222,673	0	222,673	0	99	1	145	174	27.3	55.3
1983	235,233	0	235,233	0	94	6	132	186	21.3	66.1
1984	175,876	243,500	419,376	58	95	5	144	170	28.7	49.2
1985	98,000	298,000	396,000	75	97	3	141	185	26.3	63.7
1986	140,965	510,924	651,889	78	96	4	134	180	22.4	55.6
1987	68,980	0	68,980	0	81	19	143	175	28.0	54.3
1988	110,000	361,625**	471,625	77	94	6	128	179	18.7	59.1
1989	110,000	609,527**	719,527	85	94	6	126	163	17.6	43.5
						c.v.***	0.05	0.07	0.16	0.19
Mean	110,685	152,293	262,978	68****	91	9	138	180	24.9	62.4

* A relatively small number of hatchery smolts were produced due to the small number of fingerlings stocked in 1979. The 1978 hatchery broodyear suffered high mortality due to hatchery water problems.

** These smolts were released as unfed and unmarked hatchery fry; smolt survival is based on an average production of 110,000 wild smolts.

*** Coefficient of variation.

**** Excludes 1980 smolt year.

The percentage contribution of hatchery-produced sockeye smolts averaged 68%, with a high of 83% in 1989 (Table 2). An average of 111,000 wild smolts and 152,000 hatchery-produced smolts were produced during 1976-1989. In addition, the lowest hatchery fingerling-to-smolt survival rate was 16.0% from the 1978 release, while the highest survival rate was 28.3% from the 1985 release (Table 3). The average fingerling-to-smolt survival for the six release years with complete hatchery contribution information was 21.2%. The estimated smolt survival of 10% for the unfed (and unmarked) hatchery fry released in 1987 and 1988 was based on a wild smolt production of 110,000.

Returns of Wild and Hatchery Sockeye Salmon Adults to the Weir

During 1976-1989, a mean of 10,789 wild sockeye salmon adults returned to Hidden Lake, and for the six years when hatchery-produced fish returned (1980-1982 and 1986-1988), a mean of 17,002 hatchery-produced sockeye salmon returned (Table 4). The mean number of both wild and hatchery sockeye salmon returning to Hidden Lake during 1976-1989 was 18,076, and the hatchery contribution rate (for the six years when hatchery fish returned) was 50%.

Adult sockeye salmon returning to the weir during 1976-1989 were dominated by three major age classes (Table 4). Age-1.2 fish averaged 81% of the composition, followed by age-2.2 (8%), and age-1.3 (7%). In most years, there were small percentages (<5%) of other age classes e.g., age-1.1 and age-2.3 (not listed in Table 4); however, in 1989, there were larger percentages of the minor age classes and a smaller percentage of the dominant age-1.2. The mean sizes of the three major adult age classes varied slightly each year, and averaged 2.1 kg for age-1.2, 2.5 kg for age-1.3, and 2.3 kg for age-2.2. The percentage of smolts that returned as adult sockeye salmon to the Hidden Creek weir for the three major age classes from respective smolt years ranged from 4.4-32.8%, and averaged 13.9% for the smolt years with complete adult return data (Table 5).

Table 3. Numbers of wild and hatchery sockeye salmon smolts produced from parent-year escapements (minus fish used for egg takes) and hatchery fingerling releases in Hidden Lake during 1976-1989.

Parent year	Escapement	Release year	No. of hatchery fingerlings released	Smolt production (numbers)					Hatchery fingerling-to-smolt survival (%)
				Smolt years	Wild		Hatchery		
					Age-1	Age-2	Age-1	Age-2	
1976	4,312	1977	330,228	1978	52,745		58,721		17.8
				1979		14,529		0	
1977	882	1978	301,104	1979	32,299		47,519		15.8
				1980		7,127		721	0.2
1978	4,447	1979	8,258	1980	72,331		1,569		19.0
				1981		2,903		0	
1979	5,762	1980	0	1981	158,619		0		
				1982		3,321		0	
1980	27,448	1981	0	1982	219,352		0		
				1983		15,525		0	
1981	15,939	1982	0	1983	219,708		0		
				1984		20,989		0	
1982	8,608	1983	1,085,300	1984	154,887		243,500		22.4
				1985		13,860		0	
1983	10,019	1984	1,236,900	1985	84,140		298,000		24.1
				1986		23,186		0	
1984	25,212	1985	1,806,000	1986	117,779		510,924		28.3
				1987		13,175		0	
1985	20,124	1986	0	1987	55,805		0		
				1988		6,600		0	
1986	14,968	1987	3,718,311	1988	103,400		361,600*		9.7*
				1989		6,600		0	
1987	38,619	1988	6,085,307	1989	103,400		609,500*		10.0*
1988	50,907	1989	2,470,012						
1989	7,770								
								Mean	21.2**

* Hatchery smolt production based on an average wild smolt production of 110,000.

** Excludes the unfed fry-to-smolt survival estimates for release years 1987 and 1988.

Table 4. Summary of Hidden Lake adult sockeye salmon weir returns, hatchery contributions, ages, and sizes during 1976-1989.

Return year	Number of adults			Hatchery contribution	Age class composition (%)			Mean length (cm)			Mean weight (kg)		
	Wild	Hatchery	Total	(%)	Age-1.2	Age-1.3	Age-2.2	Age-1.2	Age-1.3	Age-2.2	Age-1.2	Age-1.3	Age-2.2
1976	4,860	0	4,860	0	79	1	20	54	53	55	2.4	2.2	2.5
1977	1,055	0	1,055	0	64	2	34	55	60	57	2.4	3.2	2.6
1978	4,647	0	4,647	0	88	10	2	53	54	54	2.1	2.3	2.1
1979	5,762	0	5,762	0	90	4	6	54	56	55	2.2	2.5	2.4
1980	16,191	11,257	27,448	41	92	1	1	53	56	53	2.0	2.1	2.1
1981	11,620	4,319	15,939	27	78	15	7	53	56	55	2.0	2.5	2.2
1982	8,506	1,284	9,790	13	70	23	4	52	56	52	2.0	2.5	2.0
1983	11,297	0	11,297	0	87	11	2	53	55	53	2.0	2.3	2.0
1984	27,784	0	27,784	0	92	3	5	52	57	55	2.0	2.7	2.4
1985	24,784	0	24,784	0	77	13	9	52	57	58	2.0	2.6	2.0
1986	7,475	10,055	17,530	57	85	9	6	53	57	54	2.0	2.7	2.2
1987	8,947	34,540	43,487	79	96	3	0	53	54	54	2.0	2.1	2.2
1988	10,347	40,560	50,907	80	94	4	2	54	57	57	2.2	2.8	2.6
1989	7,770	0	7,770	0	44	4	15	55	58	54	2.3	2.6	2.2
Mean	10,789	17,002*	18,076	50*	81	7	8	53	56	55	2.1	2.5	2.3

* Mean for years when hatchery fish returned (1980-1982 and 1986-1988).

Table 5. Wild and hatchery adult sockeye salmon returns by age group to the Hidden Creek weir from smolt years 1976-1989.

Smolt year	Number of smolts					Number of adults returning to weir							Smolt-to-adult return to weir (%)
	Wild		Hatchery			Wild			Hatchery				
	Age-1	Age-2	Age-1	Age-2	Total	Age-1.2	Age-1.3	Age-2.2	Age-1.2	Age-1.3	Age-2.2	Total	
1976	23,711	5,928	0	0	29,639	4,089	230	93	0	0	0	4,412	14.9
1977	14,666	3,004	0	0	17,670	5,185	273	345	0	0	0	5,803	32.8
1978	46,416	6,329	58,721	0	111,466	13,635	2,176	359	11,257	300	0	27,727	24.9
1979	32,299	14,529	47,519	0	94,347	7,881	1,299	1,263	4,319	1,072	0	15,834	16.8
1980	72,331	7,127	1,569	721	81,748	5,761	1,231	374	1,284	0	0	8,650	10.6
1981	158,619	2,903	0	0	161,522	9,922	633	144	0	0	0	10,699	6.6
1982	219,352	3,321	0	0	222,673	25,974	3,172	1,177	0	0	0	30,323	13.6
1983	219,708	15,525	0	0	235,233	19,329	1,466	283	0	0	0	21,078	9.0
1984	154,887	20,989	243,500	0	419,376	4,917	2,435	1,092	10,055	0	0	18,499	4.4
1985	84,140	13,860	298,000	0	396,000	6,251	0	0	34,354	2,143	0	42,748	10.8
1986	117,779	23,186	510,924	0	651,889	9,436	0	1,018	38,417	3,167	0	52,038	8.0
1987	55,805	13,175	0	0	68,980	3,378	NA	1,126	0	NA	0	4,506+	6.5+
1988	103,400	6,600	361,625*	0	471,625	NA	NA	NA	NA	NA	NA	NA	NA
1989	103,400	6,600	609,500*	0	719,527	NA	NA	NA	NA	NA	NA	NA	NA
Mean	100,465	10,220	152,293	52	262,978	9,647	1,174	606	16,614**	1,670**	0	19,818	13.9

* Based on an average production of 110,000 wild smolts.

** Mean for years when hatchery fish returned.

Before the return of hatchery fish (1947-1979), sockeye salmon escapements into Hidden Lake averaged 2,003, while afterwards (1980-1989), when six out of the ten years had returns of hatchery fish, the escapement averaged 23,624 (Table 6). Moreover, considering only the years when weir counts of sockeye salmon escapements were conducted (1971-1972; 1976-1989), significantly (Mann Whitney U-test; $p<.01$) greater escapements occurred after enhancement (average of 9,492 sockeye before enhancement compared to 27,425 after enhancement). In addition, the number of wild adults returning to the weir was significantly (Spearman's Rho = .71; $p<.05$) correlated to the respective number of migrating wild smolts (Figure 3A), as was the number of hatchery adults returning from the respective number of migrating hatchery smolts (Spearman's Rho = .91; $p<.05$) (Figure 3B).

Finally, despite increasing escapements of adult sockeye salmon into Hidden Lake, a nonsignificant (Spearman's Rho = .58; $p>.05$) relationship was found between increased parental escapements and the number of wild smolts produced (Figure 4A). However, a significant (Spearman's Rho = .96; $p<.01$) positive correlation was found between the number of hatchery fingerlings released and the number of respective hatchery smolts produced (Figure 4B).

DISCUSSION

Since 1976, a total of over 17 million sockeye salmon fingerlings were released into Hidden Lake (Table 1), and on average contributed 68% to the total smolt migration (Table 2). Survival of stocked fingerlings to the smolt stage ranged from 16-28% and averaged 21% (Table 3). The contribution of hatchery-produced adults returning to the weir in years when hatchery fish returned averaged 50% (Table 4), and overall smolt-to-adult return to the weir averaged 13.9% (Table 5).

Table 6. Summary of sockeye salmon escapements into Hidden Lake, 1947-1989.

Return year	Escapement Count	
1947	1,200	
1948	1,000	
1949	--	
1950	800	
1951	--	
1952	2,500	
1953	2,328	
1954	1,500	
1955	1,543	
1956	1,522	
1957	1,737	
1958	200	
1959	2,486	
1960	2,006	
1961	3,568	
1962	820	
1963	3,700	
1964	2,494	
1965	792	
1966	--	
1967	--	
1968	601	
1969	500	
1970	323	
1971	1,958 *	
1972	4,956 *	
1973	690	
1974	1,150	
1975	1,375	
1976	4,860 *	
1977	1,055 *	
1978	4,647 *	
1979	5,762 *	
Mean	2,003	
1980	27,448 *	HR
1981	15,393 *	HR
1982	9,790 *	HR
1983	11,297 *	
1984	27,832 *	
1985	24,784 *	
1986	17,530 *	HR
1987	43,487 *	HR
1988	50,907 *	HR
1989	7,770 *	
Mean	23,624	

* Weir counts.

HR Years when hatchery fish contributed to the escapement.

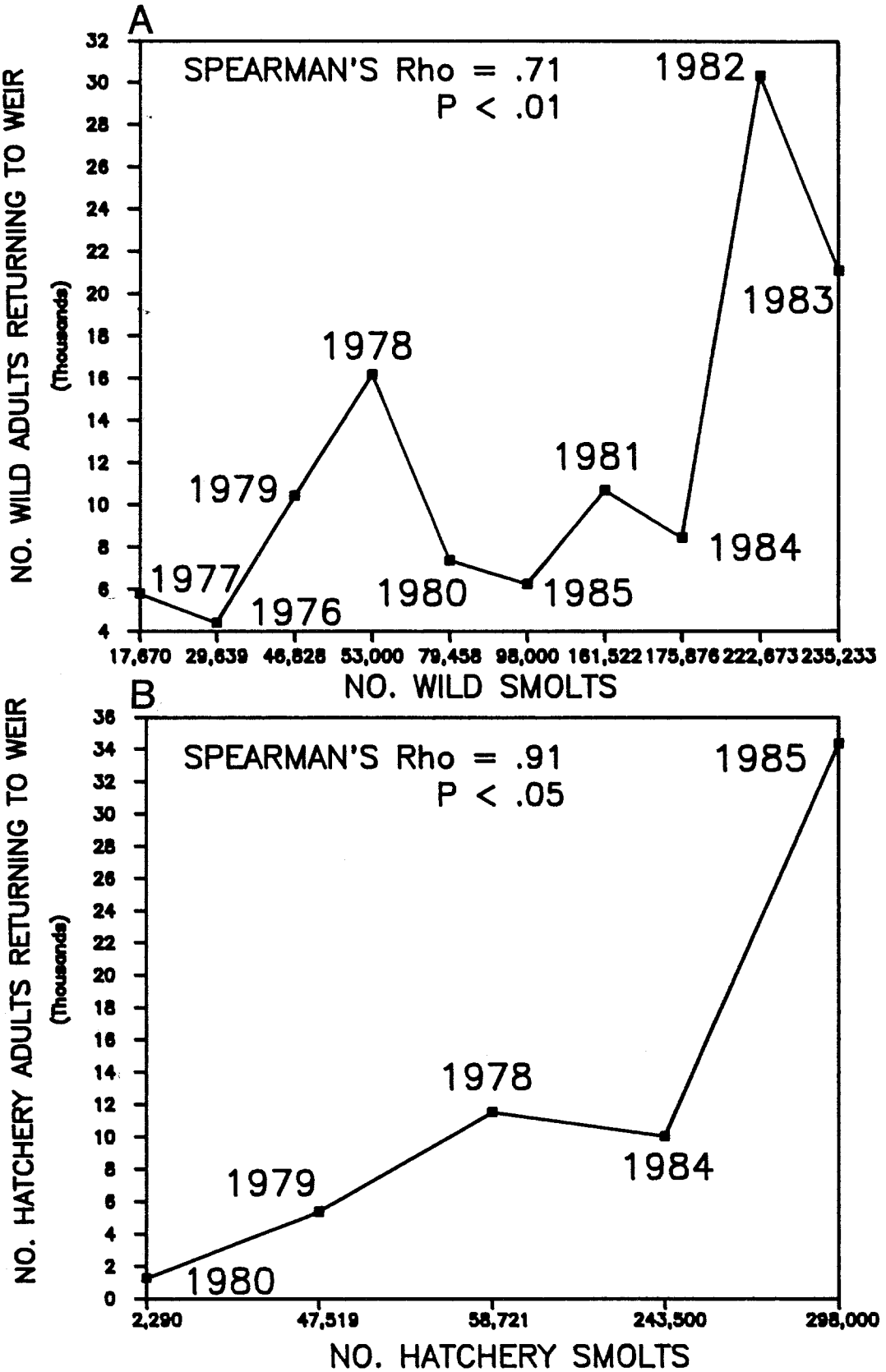


Figure 3. Relationship between wild (A) and hatchery (B) smolt production and respective adult returns to the weir for Hidden Lake sockeye salmon.

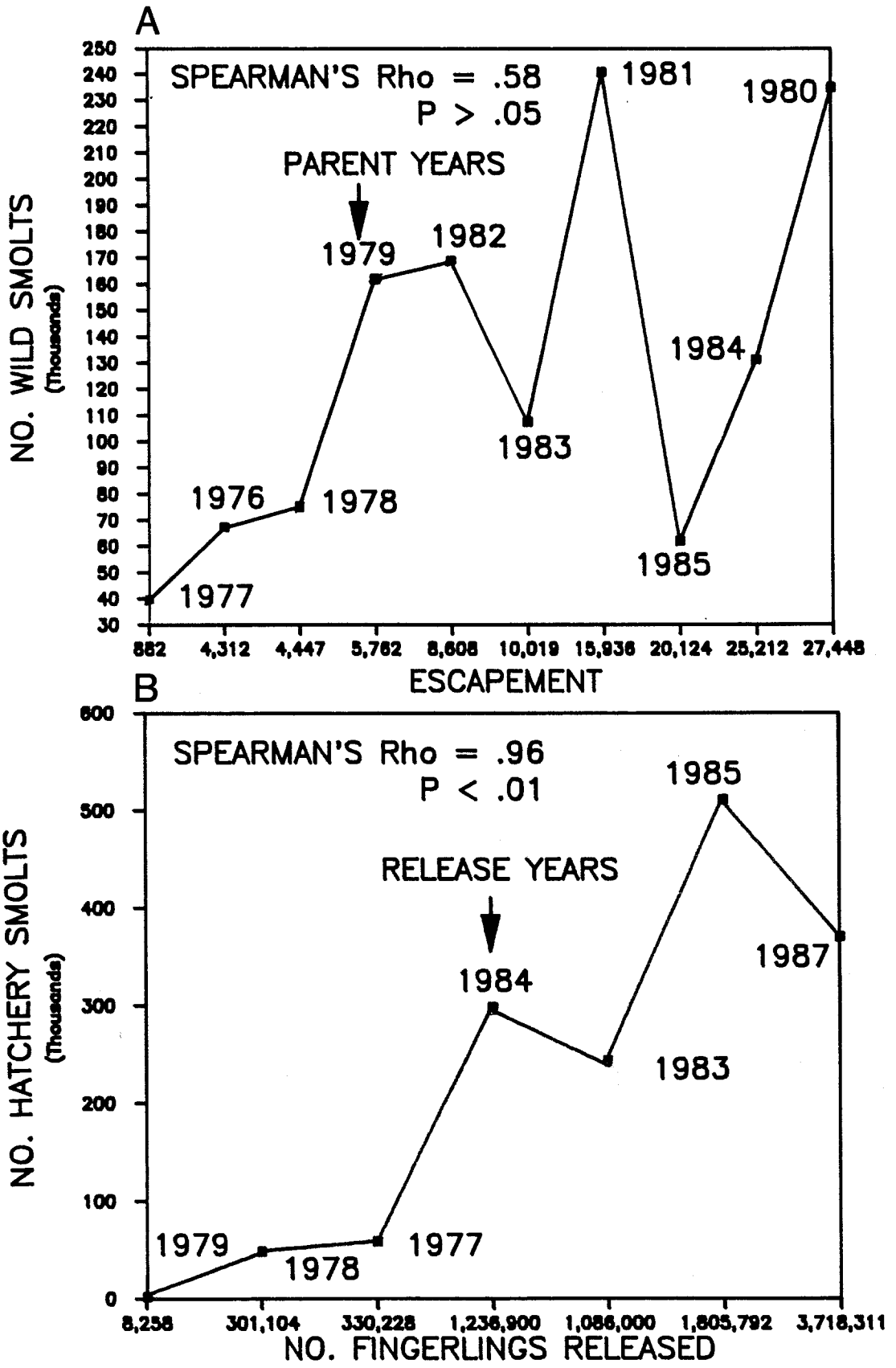


Figure 4. Relationship between escapement and wild smolt production (A), and between the number of hatchery fingerlings released and hatchery smolt production (B) for Hidden Lake sockeye salmon.

The ability to estimate the commercial harvest, the hatchery contribution to the commercial harvest, the total adult return, and smolt-to-adult survival rates for Hidden Lake sockeye salmon is obscured by an unknown commercial fishing exploitation rate. The exploitation rate for all sockeye bound for the Kenai River has averaged 75% (D. Waltemyer[1], personal communication). However, application of this rate to Hidden Lake adult weir returns, results in smolt-to-adult survivals greater than 75% in some years, and an average of 42%. If a 50% exploitation rate is assumed, the smolt-to-adult survivals observed at the weir (Table 5) would double, and result in a more realistic average smolt-to-adult survival of ~28%.

Although there was not a significant correlation between escapement and the number of wild smolts produced in Hidden Lake (Figure 4A); conditional smoothing of these data using a locally weighted robust regression (LOWESS) procedure illustrates a functional relationship (Figure 5). That is, above an escapement level of ~10,000 sockeye salmon, wild smolt production levels off and approximates 140,000 smolts. This level of sockeye salmon production is similar to the average number of wild smolts and adults observed during 1976-1989 (Tables 2 and 4). Limited sockeye salmon smolt production in a lake suggests poor quanity or quality of forage base, poor spatial or temporal concurrence of fry and forage, unfavorable environmental conditions e.g., cool rearing temperature or short growing season, or a combination of these or other factors. Because increase numbers of hatchery fingerlings released into Hidden Lake resulted in significantly more hatchery-produced smolts (Figure 4B); the rearing environment does not appear to limit smolt numbers from larger escapements. Moreover, sockeye salmon production in Hidden Lake appears to operate in a density-dependent manner as there is a significant ($p = .02$), but poor-fit ($r^2 = .41$) relationship between smolt numbers and smolt sizes (Figure 6). Thus, wild smolt production must be limited by poor quanity and/or quality of spawning area and/or poor fry survival from potential egg deposition. Considering the variable effect of weather on the spawning success of sockeye salmon confined to

[1] ADF&G, Division of Commercial Fisheries, 34828 Kalifornsky Beach Road, Suite B, Soldotna, AK. 99669.

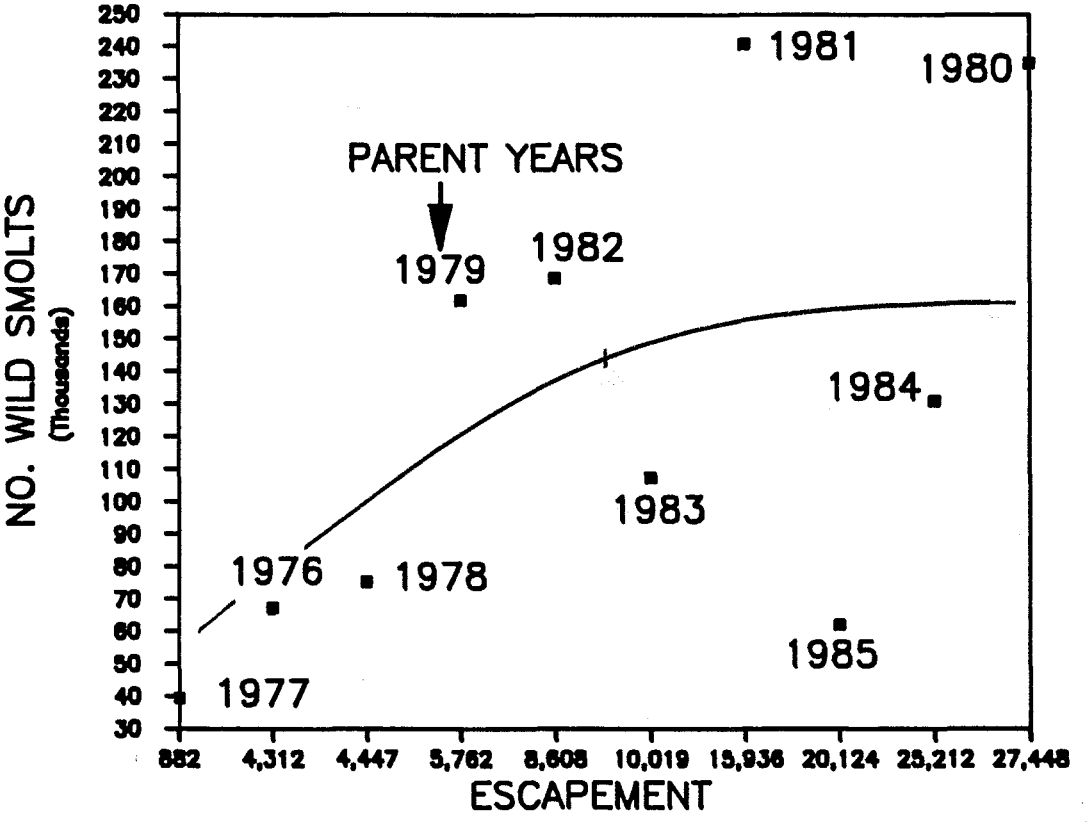


Figure 5. Functional relationship between escapement and wild smolt production showing the levelling of smolt production above an escapement of approximately 10,000 sockeye salmon in Hidden Lake.

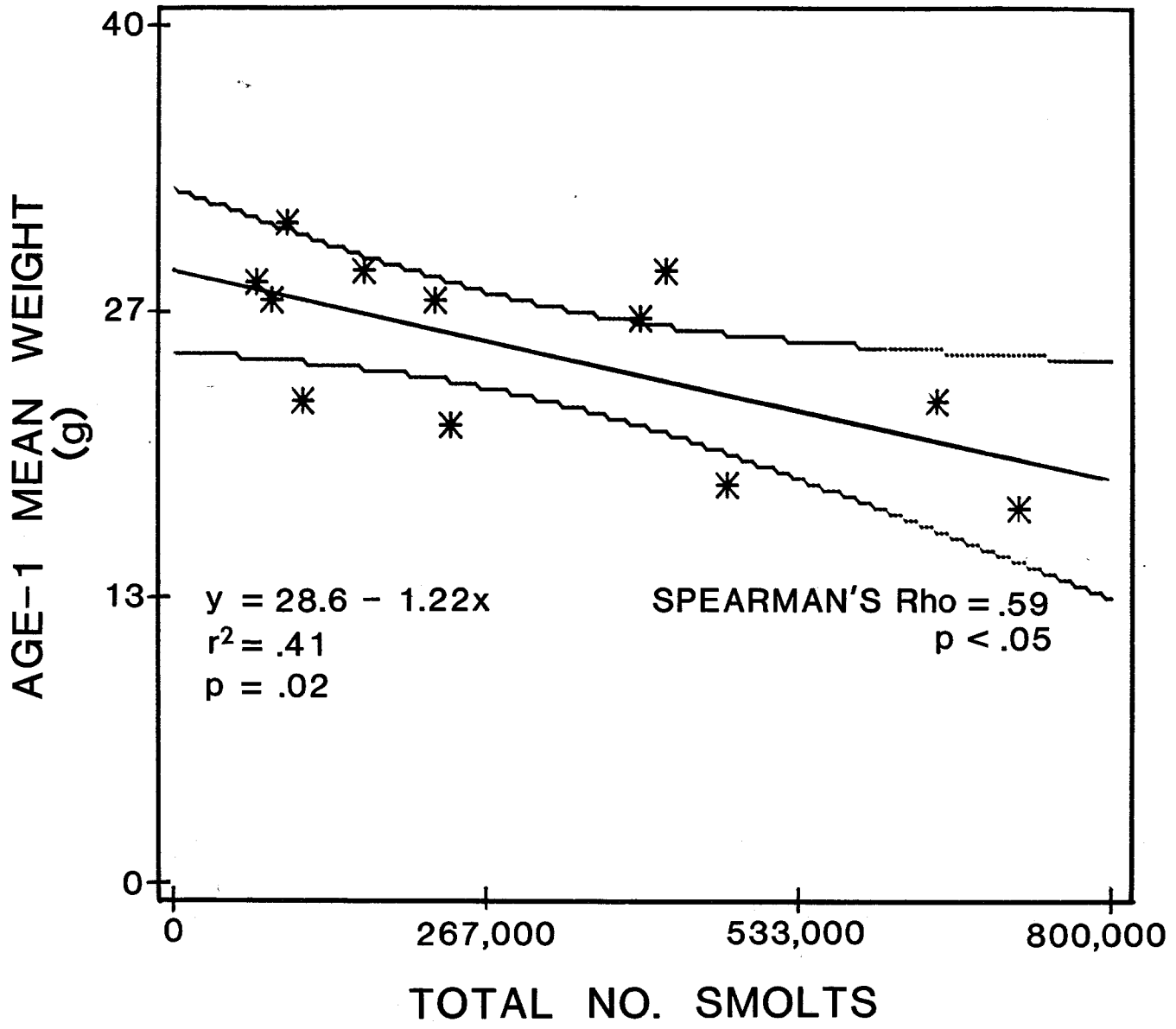


Figure 6. Relationship between the total number of smolts produced and mean weight of age-1 smolts for Hidden Lake sockeye salmon, 1978-1989.

spawning along shore (as is the case at Hidden Lake); in years with mild weather, potential egg deposition to spring fry survival would be greater, resulting in more wild smolts than in other years such as 1982 and 1983 (Table 2).

Sockeye salmon escapements into Hidden Lake significantly increased after returns of hatchery-produced fish (1980). Comparison of Kenai River sockeye salmon escapement (Ruesch and Browning 1989) during Hidden Lake pre-enhancement years (1976-1979) with post-enhancement years (1980-1986), before record returns to the Kenai River (1987-1989) (Figure 7); indicated no significant difference (Mann Whitney U-test; $p < .025$) between pre- and post-enhancement periods. Moreover, during pre-enhancement years 1976-1979, Hidden Lake sockeye salmon contributed an average of 1.1% to the Kenai River sockeye salmon escapement, while during post-enhancement years (1980-1986), the contribution of Hidden Lake sockeye salmon increased nearly 4-fold (Figure 7). Thus, an increasing trend in sockeye salmon escapements in the Kenai River during 1976-1986 was not evident, indicating that the increased sockeye salmon escapements into Hidden Lake resulted directly from the enhancement project.

The enhancement project also indirectly increased the return of wild adult sockeye salmon to Hidden Lake. That is, the record high returns of wild adults in 1984 and 1985 resulted mainly from the parental escapements of 1980 and 1981, the first two years of hatchery returns (Table 4). Thus, production from natural spawning in 1980 and 1981, when hatchery-produced adult sockeye salmon first returned and spawned, evidently augmented natural fry recruitment and resulted in increased adult production (returns) to Hidden Lake in 1984 and 1985.

ACKNOWLEDGEMENTS

We acknowledge the support of staff at the Crooked Creek, Big Lake, and Trail Lake Hatcheries for the production of Hidden Lake sockeye salmon fingerlings. In addition,

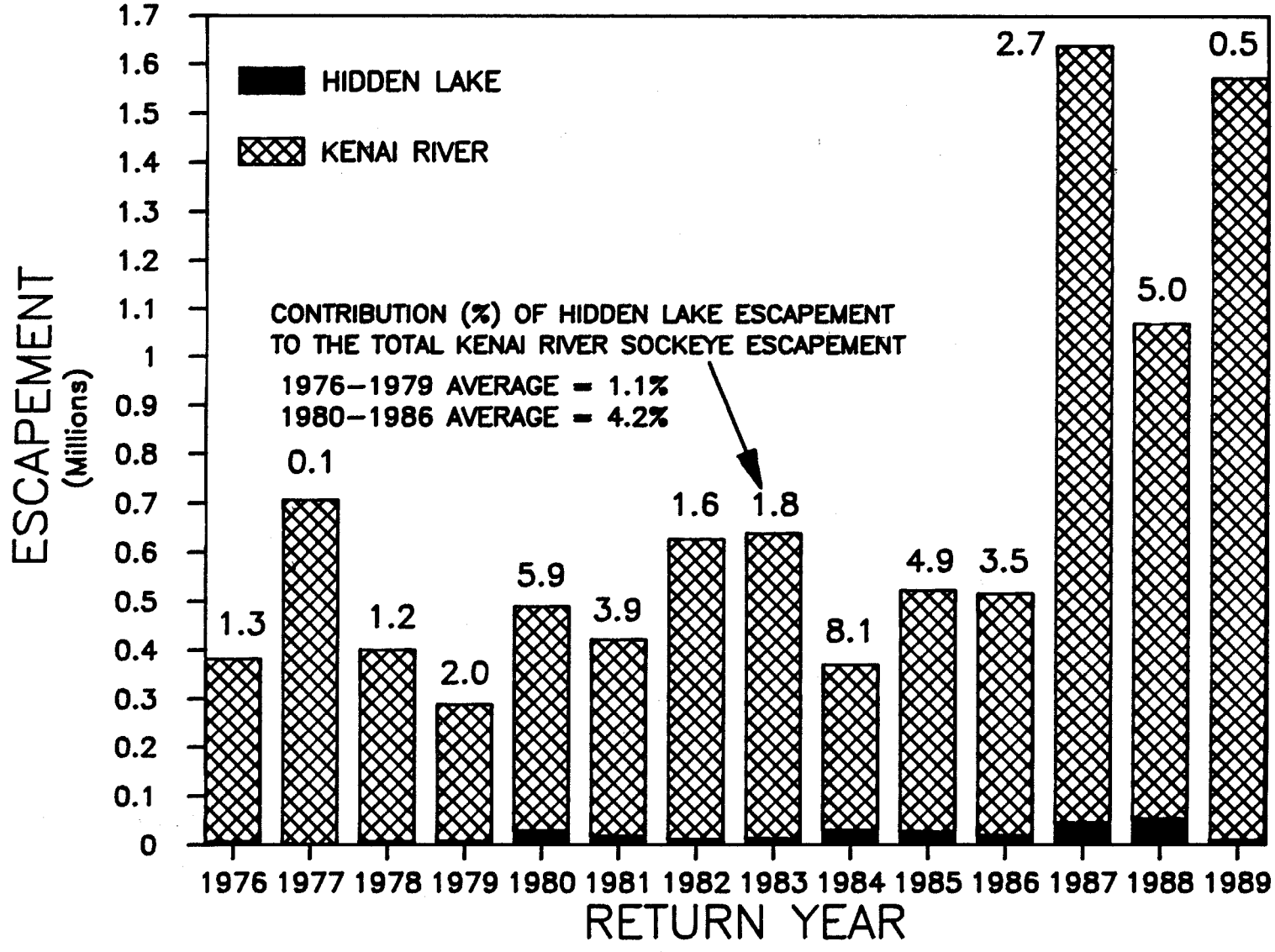


Figure 7. Comparison of the sockeye salmon escapement into Hidden Lake and the Kenai River, 1976-1989.

we recognize the many ADF&G fisheries technicians that worked on this project over the last 14 years. Finally, Jeff Koenings provided helpful comments to the early version of this report.

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