HIDDEN LAKE SOCKEYE ENHANCEMENT PROJECT TECHNICAL REVIEW

by

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INTRODUCTION

The technical aspects of the sockeye salmon stocking project at Hidden Lake were discussed at the Soldotna ADF&G (Alaska Department of Fish and Game) office December 2, 1998. The evaluation was undertaken to satisfy a condition in the 1998 USF&WS (United States Fish and Wildlife Service) special-use permit. In attendance were Dave Athons, Bruce King and Larry Peltz from Sport Fish Division of ADFG and Jim Seeb, Dan Moore, Ellen Simpson, Steve McGee, Jill Follett, Jim Edmundson, John Edmundson, and Ken Tarbox from the Commercial Fisheries Division of ADFG. The group discussed five aspects of the project, developed recommendations and identified areas that needed more study. Each aspect was addressed by an expert in the field with the entire group participating in subsequent discussion. This report documents the presentations and the ensuing discussion. Recommendations are summarized at the end of the report.

Background

The sockeye salmon stocking project at Hidden Lake is the only enhancement project in the Kenai River drainage. Hidden Lake is 69 km east of Soldotna and lies within the boundaries of the Kenai National Wildlife Refuge (KNWR). A short outlet stream, Hidden Creek, flows approximately 5 km into Skilak Lake (Figure 1). ADF&G initiated the project in 1976 and operated it until 1989, when Cook Inlet Aquaculture Association (CIAA) assumed operations. The Trail Lakes Hatchery, operated by CIAA under contract with the State of Alaska, supports the Hidden Lake project. ADF&G has a cooperative agreement (98010) with CIAA to conduct the Hidden Lake project. Because Hidden Lake is located on the KNWR, a special-use permit from USF&WS is required. ADF&G agreed to obtain the special-use permit in the cooperative agreement because the USF&WS would not issue the permit directly to CIAA.

CIAA has private non-profit hatchery permit #27 and a basic management plan for Trail Lakes Hatchery. ADF&G and CIAA jointly prepare an annual management plan for the facility. The Hidden Lake project is permitted for a 2.3 million egg take and has a 2.0 million fry release goal.

The Hidden Lake project was originally proposed by the Division of Fisheries Rehabilitation, Enhancement and Development (FRED), ADF&G, in the mid-seventies because Hidden Lake was believed to have the greatest potential in Cook Inlet for increased sockeye salmon production (Kyle, 1990). It was thought that the lake was limited by spawning area and that egg to fry survival may be poor; it was considered likely that more sockeye salmon fry could rear in the lake than that produced by natural spawning events. Several different egg take and rearing strategies have been used during the project. Currently, eggs are collected from mature sockeye captured at known natural spawning areas at the west end of the lake. The eggs are incubated in isolation at Trail Lakes Hatchery and the unfed fry are released into Hidden Lake near the egg take location. Fry stocking levels have fluctuated over time from a high of over 6 million in 1988 to a low of less than 10,000 in 1978 (Table 1). In the last 10 years fry releases have ranged between 1 and 2 million.

Smolt outmigration has ranged from under 20,000 to over 700,000. CIAA operates a smolt weir on Hidden Creek to collect age, weight and length data, enumerate the smolt outmigration, and determine the hatchery contribution to the smolt outmigration. Since 1991 the otoliths of all hatchery incubated fry released at Hidden Lake have been thermally marked and this mark has been used to determine the proportion of hatchery reared fry in the smolt outmigration. The proportion of hatchery reared fish in the smolt outmigration has averaged 79% since 1993 (Fandrei 1998).

Adult escapements to Hidden Lake have also fluctuated since the first hatchery reared fish returned in 1980 from a low of 6,000 in 1994 to over 112,000 in 1991. Because large adult escapements and fry stockings common to enhancement projects have the potential to alter the level of primary productivity and the composition of zooplankton species, a 30,000 adult escapement target has been set for Hidden Lake. CIAA operates an adult weir on Hidden Creek to collect age, weight and length data and to enumerate the adult return. Extensive limnological data has also been collected since 1980.

A more detailed project description and further production results can be found in Kyle (1990) and Fandrei (1998).

SUMMARY OF FINDINGS

Genetic Concerns

Concerns over the effect of enhancement projects on the genetic integrity of resident populations are reflected in efforts to minimize straying and to monitor egg take and fry release practices. The ADFG Genetics Section now requires that new projects adhere to the following guidelines prior to approval. These guidelines are based on the Genetic Policy (ADF&G 1985).

1. A project must obtain gametes from at least 60 spawning pairs.
2. Eggs should be taken throughout the duration of the run.
3. Brood fish should not be selected for size or other phenotypic characteristics.
4. Sub-populations, such as shore-spawners, should be maintained separately from outlet, or upstream spawners.
5. Production should be allowed in only a 1:1 ratio of enhanced to wild adult fish.
6. A project is unacceptable if it negatively affects indigenous species.

Straying studies should accompany most project plans. The organization that releases the fish should bear the fiscal responsibility for these studies.

The Hidden Lake project has conformed to most of the above criteria. Relative to egg take and stocking practices, Hidden Lake sockeye are assumed to be all beach spawners, indicating that a single population exists. Large number of eggs have been used to maintain population structure and the fish are released as fry in the area of natural spawning, providing some natural selection. The review team recommends that CIAA continue taking eggs and releasing fry at the west end of Hidden Lake in the historical area of natural spawning.

The Hidden Lake population is genetically different from other stocks in Cook Inlet and even other Kenai River tributaries (Figures 2 and 3). The natural straying rate of this stock would thus be expected to be close to zero. To maintain this distinction, the straying rate of Hidden Lake stock into other systems must be less than 2% of the receiving population. Trail Lakes Hatchery is upstream from Hidden Lake in the Kenai River drainage and uses well water for incubation. The literature indicates that enhanced fish released downstream from their hatchery of origin show a greater homing fidelity than upstream releases. However, the straying rate of Hidden Lake fish is not known. This review team recommends that a straying study be designed and implemented to evaluate whether straying is occurring and, if so, to what extent. This study should include examination of returns to Moose Creek, the stream adjacent to Trail Lakes Hatchery, the confluence of Hidden Creek and Skilak Lake, and other major spawning areas of the Kenai system, especially between Hidden Lake and the hatchery.

The 1:1 ratio (point 5 above) is not a hard and fast rule for supplementation projects, but hatchery fish should not exceed wild fish in the spawning population. Two factors underlie the 1:1 hatchery to wild ratio. First, a 1:1 ratio slows the transfer of undesirable genetic combinations selected in the hatchery environment to the native population (domestication selection). Second, managers avoid the risk of harvesting wild fish at a rate more appropriate to the enhanced portion of the run. Past smolt outmigration data indicate that enhanced fish compose up to 80% of the Hidden Lake escapement (Fandrei, 1998). If this project were to be proposed today, the ADF&G Genetics Section would require no more than a 1:1 production ratio of hatchery to wild fish. or suggest a completely different project. For existing projects with a long history, it has been ADF&G policy to allow variation in the 1:1 goal. In this context, ADF&G will allow the Hidden Lake project to continue; however, the review team recommends that the goal be moved towards a 1:1 ratio of hatchery to wild fish through alterations of egg take numbers over time.

The enhanced contribution to the Hidden Lake escapement is not known but it is assumed to be the same as that found in the smolt outmigration. If there is differential survival between enhanced and wild smolt, the adult return could exceed the 1:1 guideline by an even greater amount. Therefore, the review team recommends that all returning enhanced fish have thermal otolith marks, and adults should be sampled at the existing weir on Hidden Creek to estimate the enhanced proportion within ±5% of the true contribution 95% of the time.

Disease History of Hidden Lake Sockeye

The primary disease concern at Hidden Lake is infectious hematopoietic necrosis (IHN). The IHN virus has been detected in every assessed wild population of anadromous sockeye salmon in Alaska; it is not restricted to those populations exposed to enhancement. One concern with enhancement programs is that a high density of sexually mature adults might result in increased IHN prevalence as a result of horizontal transmission on spawning beds (Mulcahy et al. 1983; Mulcahy and Pascho 1986). However there is no evidence that the Hidden Lake stocking program has increased viral prevalence in the returning sockeye salmon adults or in smolt outmigrants. Analyses indicated that IHN prevalence was not significant ($\alpha = 0.05$) when compared to escapements to Hidden Lake (P-value = 0.071 for ripe fish and 0.96 for postspawners). Analyses of prevalence versus outmigration the following year were also not significant (P=0.15). There were very high prevalences of IHNV from adult fish in the first 5 years of data when few hatchery produced fish were present and outmigration still continued to increase.

Chinook salmon are known to be susceptible to the IHN virus, but it has been only rarely detected in chinook salmon in Alaska. Chinook salmon coexist with sockeye salmon in other parts of the Kenai River drainage but there are no known chinook salmon spawning populations in Hidden Lake. There is, therefore, little chance of chinook salmon intermingling with sexually-mature Hidden Lake sockeye salmon adults in Hidden Lake.

For this project, there is a KNWR requirement for a prerelease inspection of fry and there has been no evidence that fish are being released with IHN. The eggs are taken from Hidden Lake, incubated in isolation from other sockeye stocks and then released back into Hidden Lake as unfed fry. These fry are therefore not exposed to any pathogens that are not already a part of the Kenai River watershed. In summary, the cyclical occurrence of IHNV in these fish will occur with or without hatchery manipulation. High and low years of virus will depend on environmental variables beyond human control.

Hidden Lake Limnology

There are two major limnological issues of concern relative to the Hidden Lake Sockeye Salmon Enhancement Program; 1) the potential impact of increased carcass-derived nutrients (phosphorus) on water quality, and 2) the impact of increased fry densities on the trophic structure (plankton and indigenous fish) of the lake ecosystem. In particular, a large increase in carcass nutrient loading, as a result of sockeye enhancement, might produce an increase in lake phosphorus. Because phytoplankton (algae) require only small amounts of phosphate, excessive amounts (e.g., from successive high escapements) could cause extensive algal growth or nuisance algal blooms and decrease water clarity (aesthetics). Although, potential productivity is set by nutrient supply, consumers acting at the top of the food web can regulate the biomass of lower tropic levels. Thus, high densities of rearing sockeye juveniles might negatively affect the trophic structure of the lake by substantially decreasing macrozooplankton biomass, reducing the species diversity of the forage base, and altering competitive regimes among other resident fish species. To address the above concerns, limnological evaluation of the Hidden Lake Sockeye Salmon Enhancement Program was conducted to assess parameters from all trophic levels so that the effect of stocking and increased production could be ascertained.

With respect to the nutrient issue, phosphorus (P) in Hidden Lake originates primarily from the surrounding watershed (i.e., terrigenous loading) and to a lesser extent, from the decomposition of salmon carcasses (Figure 4). Carcass nutrient loading is only a subcomponent of the total annual P input. Prior to stocking (1976), adult escapements represented <10% of the total P loading (watershed + fish). However, based on the 22-year average escapement, carcasses may now contribute as much as 40% of the total annual P input. Nevertheless, terrigenous and carcass-P loadings can vary independently. For example, less precipitation and soil run off and a subsequent decrease in terrigenous-P loading can compensate carcass P loading from higher escapements. Normally, less runoff produces lower P concentrations. In addition, phosphorus is exported from the lake via the outlet discharge and through fish biomass as smolt. The question that is being asked is, "What is the rate of carcass-P loading that will threaten the stability of the natural trophic state?" That is, what is the carcass-P loading that will lead from oligotrophy to mesotrophy? It should be noted that excessive P loading creates only the potential for the appearance of mesotrophic or eutrophic conditions.

Several models are used to determine the critical-P loading value. Using P-loading equations, which incorporate both sedimentation rate and hydraulic residence time, the estimated specific loading rate for Hidden Lake is 50 mg P m^{-2} yr^{-1}; the critical P-loading rate is 76 mg P m^{-2} yr^{-1}. Thus, annual carcass-P loadings (supplemental P) should not exceed about 26 mg P m^{-2} yr^{-1} (76 minus 50). Based on the average sockeye escapement (29,621), and using a value of 8 g P per adult sockeye, the annual contribution of carcass nutrients to the annual total P input for Hidden Lake is about 34 mg P m^{-2} yr^{-1} which is similar to the calculated supplemental P loading. Although a change in P-loading to a lake results in a change in water column total P (TP) concentration, the change is not instantaneous. According to mass balance models for P, some time interval is required for the lake to equilibrate to the new P loading. Assuming all other P inputs and outputs remain unchanged, we estimate that the contribution of nutrient loadings from constant escapements of 30,000 sockeye would yield a final steady-state TP concentration of about 10 $\mu g\ L^{-1}$ within about 12 years.

Criteria exist to describe the water quality and trophic state of a lake. Most often, summer or seasonal mean TP and chlorophyll *a* (chl *a*) concentrations are used to define trophic state and water quality. These criteria are used to track changes in a lake regarding increases or decreases in P loading. Oligotrophic lakes are usually associated with TP values $<10\ \mu g\ L^{-1}$ and chl *a* levels $<3\ \mu g\ L^{-1}$. Since 1980 either ADFG or CIAA has conducted monthly limnological surveys to monitor general water chemistry, nutrients, and plankton in Hidden Lake. Over the past 19 years, the seasonal mean epilimnetic (1 m) TP concentration in Hidden Lake varied from 5.6-8.6 $\mu g\ L^{-1}$ and averaged 7 $\mu g\ L^{-1}$ (Figure 5). As pointed out earlier, the estimated time required for Hidden Lake to respond to a change (i.e., higher escapements) in P loading is quite long (7-12 yr), but still is less than the number of years sampled; we do not detect any significant change in TP concentration. Although steady-state models have been validated for sets of temperate lakes, there can be considerable error in predicting TP for any given lake. For example, an error may exist in the sedimentation coefficient used in the model and in estimates of water residence time or the lake may not be in equilibrium with its external P loading. In addition, although escapements have been higher in recent years, exceeding 50,000 in each of the past three years, escapements and thus the nutrient contribution of carcasses over the past two decades have been quite variable. Nonetheless, since sockeye enhancement began, the oligotrophic status (TP $<10\ \mu g\ L^{-1}$) of Hidden Lake remains unaltered.

The phenomenon of size-selective predation by planktivorous fish (fry) warns of the potential impact of enhancement programs on zooplankton composition and ultimately on the state of lower trophic levels. If top-down forces are regulating lower trophic level biomass, then its effect(s) can sometimes be described as an inverse relationship between consumer or predator and producer or prey. In particular, when rearing sockeye juveniles are the top consumers, increased planktivory (e.g. from high escapements, high stocking levels or both) decreases macrozooplankton biomass and increases the biomass of phytoplankton. The extreme condition is the introduction of sockeye fry into barren (non-anadromous) lakes. Under severe predation, some components of the zooplankton can be completely eliminated. For instance, under intense predation there tends to be an exchange of larger-sized herbivores for smaller ones after fry introductions.

The macrozooplankton community of Hidden Lake is primarily composed of two species of cladocera (*Daphnia sp.* and *Bosmina longirostris*) and two species of copepoda (*Epischura sp.* and *Cyclops sp.*). *Cyclops* is the dominant taxon both numerically and in terms of biomass, followed by *Bosmina*, *Daphnia*, and *Epischura*. Over the past two decades, there has been little change in the species composition of the macrozooplankton community despite changes in planktivorous fish abundance from variable escapements and level of stocking (Figure 6). Moreover, plots of seasonal (May-October) mean total zooplankton densities against escapement and stocking levels show no significant relationship, suggesting that stocking and higher escapements, as a result of the enhancement project, have not yet negatively altered the macrozooplankton in Hidden Lake (Figure 7). However, a lowess smoother does reveal a slight inverse tendency in that some (not all) of the lowest densities are associated with escapements >50,000 and stocking levels >2 million. Escapement variations also complicate assessment of changes in lake trophic structure from fry stocking as both top-down predation from increased fry loading is coupled with positive effects (increased fertility) of carcass additions to the system. Thus, robust indices of trophic response such as mean total macrozooplankon density may not be appropriate to detect changes in lower trophic level structure.

The Limnology Section also considered several other 'finer' zooplankton variables to test for significant differences between years of high (>30,000) and low escapement (<30,000) and between years of high (>300,000) and low (<300,000) fry stocking levels (Table 2). The results of analysis-of-variance suggest there has been no significant effect ($P>0.05$) of larger escapements or higher stocking levels on individual zooplankton species densities. However, combined cladocera densities, number of cladoceran eggs per animal, and percentage of ovigerous cyclopoids were lower ($P<0.05$) under years of high escapements and stocking, which indicates a foraging preference for ovigerous animals. However, such statistical differences are not a major concern. This kind of response has been seen under varying forage pressure in other sockeye lakes. Moreover, Hidden Lake ranks as one of the most productive systems in Alaska in terms of zooplankton biomass and it produces some of the largest sized smolt suggesting that stocking has not overgrazed the zooplankton forage base.

Based on these findings, the current sockeye escapement target of 30,000 is appropriate for maintaining water quality and the lake's oligotrophic condition. However, higher escapements (e.g. >50,000) such as occurred in the last three years, should be avoided at least on a sustained basis. Although current TP and chl *a* levels indicate good water quality, given the lake's long response time, caution is necessary before allowing increased P loading from higher (>30,000) escapements. Fry recruitment from some high escapements (assuming no spawning area limitation) as occurred in 1991 (112,792 adults) or high stocking rates as occurred in 1988 (6 million fry) do coincide with the lowest zooplankton densities. However, there is no immediate adverse nor any lag effect on the zooplankton community in subsequent years that can be discerned in terms of density, body size, biomass, or species composition. Thus, the current stocking levels (2 million fry) do not and have not adversely altered the macrozooplankton community in Hidden Lake.

Impacts of Fry Stocking on Hidden Lake Resident Fish Species

Concerns in the past have focused on enhanced sockeye competition with resident fish species. The species composition of Hidden Lake before stocking is unknown. Lake trout were found to eat some species that sockeye also eat (i.e., amphipods and caddis fly larvae). Because no data is available to either support or refute the view that stocked sockeye are competing with indigenous species in the lake, the review team cannot technically evaluate this question.

Adult Return and Escapements

Concerns about the Hidden Lake project from the perspective of commercial-fishery management are twofold: the effect on inseason management decisions relating to escapement goals and the impact on the sockeye salmon wild stock database.

The Board of Fisheries has set the Kenai River inriver escapement goal at 550,000 to 850,000 sockeye salmon. The biological escapement goal (BEG) is 330,000 to 600,000 sockeye salmon. The Hidden Lake hatchery component is not known in the escapement when management decisions are made relative to wild stock escapement goals. ADF&G felt that management decisions would not be influenced when escapements to Hidden Lake are less than 30,000, even though this can be 10 percent of the minimum BEG. However recent escapements to Hidden Lake in the 60,000 fish range have become problematic when trying to meet a minimum escapement goal. In 1998 the ADF&G faced this problem during the season. The major age class returning to Hidden Lake is age 1.2 with a large freshwater scale growth. By late July ADF&G could estimate the proportion of age 1.2 fish with a large freshwater scale growth from the fish wheel sample at river mile 19. The estimation model used is still under development and is biased towards over estimating the age 1.2 with a large freshwater scale growth component (Hidden Lake return) in the total fish wheel sample (Figure 5). Management actions using estimates from the model are consequently conservative. ADF&G does not estimate the enhanced component of the Hidden Lake return in season. A technique to more accurately identify the Hidden Lake fish so that they can be subtracted from the escapement needs to be developed. Increased precision in estimating the number of age 1.2 fish in fish wheel samples may be accomplished relatively easily.

Using the inseason estimates to project the final Hidden Lake escapement has resulted in considerable overestimation in 4 of the last 6 years (Figure 6). In these years ADF&G estimated almost twice as many Hidden Lake fish than actually passed the Hidden Lake weir. Potential explanations of the overestimation include: 1) The fish wheel catch is biased towards smaller fish (age 1.2) thus ADF&G is over-estimating the number of age 1.2 fish in the river; 2) the sonar counters are over counting which appears unlikely; 3) Hidden Lake fish are being removed by humans or predators from the river in substantial numbers after the sonar counter but before the Hidden Lake weir; and/or 4) Hidden Lake fish are straying to other locations in the Kenai River system in high numbers.

The Hidden Lake contribution to the Kenai River escapement has been significant in some years and has influenced the return/spawner (R/S) database to some degree. Age 1.2 sockeye make up from 10 to 20 percent of the Kenai River return. ADF&G has no way of estimating and removing the Hidden Lake contribution from the commercial catch other than by assuming an exploitation rate similar to other Kenai River wild stocks, which may not be accurate. But ADF&G could subtract the Hidden Lake return from the total escapement and estimate the wild production from the weir counts. Currently ADF&G has no formal mechanism to do this. However at the last BEG committee meeting, the committee recommended that the Hidden Lake enhanced escapement be removed from the total Kenai River escapement goal and that the Department bring this recommendation to the Board of Fisheries this winter. In addition, a program to identify the ratio of enhanced to wild spawning fish in the Hidden Lake escapement needs to be developed by otolith examination at the Hidden Lake weir.

Since this technical review occurred, the Board of Fisheries established an inriver goal of 600,000 to 1,100,000 sockeye salmon. They also removed the Hidden Lake enhanced sockeye component from the Kenai River sockeye escapement goal.

TASKS AND RECOMMENDATIONS

The completion of proposed tasks and the adoption of the following recommendations will bring the Hidden Lake sockeye stocking project more in line with current Alaska Department of Fish and Game expectations regarding enhancement projects The recommendations should be incorporated into the Trail Lakes Hatchery annual management plan.

Tasks

1. ADF&G in conjunction with CIAA should examine the fry to smolt and smolt to adult survival rates, in conjunction with harvest rate assumptions, to determine if 2.3 million green eggs is the appropriate egg take to yield an average 30,000 escapement (wild + enhanced).
2. ADF&G in conjunction with CIAA should review water quality models to ensure the best model is being used.
3. ADF&G in conjunction with CIAA should review egg take and fry release procedures.
4. ADF&G should review fish wheel sampling procedures to improve the precision of estimating the abundance of Hidden Lake stock in the escapement.
5. ADF&G should remove the Hidden Lake enhanced fish from the R/S database and obtain approval from the Board of Fisheries to remove the enhanced component of the Hidden Lake stock from the BEG.

Recommendations

1. The long-term project goal should be a 1:1 ratio of F_1 hatchery fish to the other sockeye in the lake.

2. The straying rate must be less than 2% of the receiving population. CIAA or ADF&G should plan and implement a study, beginning in 1999, to determine if enhanced fish from Hidden Lake are straying into other spawning populations in the Kenai River system.
3. CIAA should continue to release fry at the original location of spawners.
4. CIAA should continue to take eggs from adults in the original location of spawners.
5. In the absence of new limnological data or a new phosphorous loading model, escapement should be limited to an annual average of 30,000 fish.
6. CIAA should determine the enhanced contribution to the escapement by otolith examination at the Hidden Lake weir beginning in 1999.

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Table 1. Summary of egg takes, fry release, smolt outmigrations and adult returns for Hidden Lake, 1976-1998. Data from 1976 to 1989 are from Kyle (1990). Data from 1990 to 1998 are from Fandrei (1998).

Brood Year	Egg take (GE numbers in millions)	Release Year	Fry Release (in millions)	Life Stage at release	Smolt Year	Number of Smolts			% Hatchery	Return Year	Escapement	% by Age Class		
						Wild	Hatchery	Total				1.2	1.3	2.2
										1976	4,860	79	1	20
										1977	1,055	64	2	34
					1976	29,639	0	29,639	0	1978	4,647	88	10	2
					1977	17,670	0	17,670	0	1979	5,762	90	4	6
1976	.833	1977	.330	fingerling	1978	52,745	58,721	111,466	53	1980	27,488	92	1	1
1977	.407	1978	.301	fed fry	1979	46,828	47,519	94,347	50	1981	15,939	78	15	7
1978	.312	1979	.008	fingerling	1980	79,458	2,290	81,748	3	1982	9,790	70	23	4
1979	0		0		1981	161,522	0	161,522	0	1983	11,297	87	11	2
1980	0		0		1982	222,673	0	222,673	0	1984	27,784	92	3	5
1981	0		0		1983	235,233	0	235,233	0	1985	24,784	77	13	9
1982	1.579	1983	1.085	fed fry	1984	175,876	246,500	422,376	58	1986	17,530	85	9	6
1983	1.928	1984	1.237	fingerling	1985	98,000	298,000	396,000	75	1987	43,487	96	3	0
1984	3.766	1985	1.806	fingerling	1986	140,965	510,924	651,889	78	1988	50,907	94	4	2
1985	7.019	1986	0		1987	68,980	0	68,980	0	1989	7,770	44	41	15
1986	4.740	1987	3.718	fed fry	1988			471,625		1990	77,959	86	2	12
1987	7.000	1988	6.085	fed fry	1989			719,527		1991	112,792	90	7	3
1988	2.719	1989	2.470	emer/fed fry	1990			231,300		1992	32,912	82	13	5
1989	2.220	1990	1.748	emer fry	1991			208,500		1993	11,582	80	9	11
1990	2.189	1991	1.600	emer fry	1992			191,900		1994	6,086	60	31	6
1991	2.652	1992	1.716	emer fry	1993[a]	62,200	326,300	388,500	84	1995	7,542	63	12	21
1992	2.293	1993	1.901	emer fry	1994	53,900	360,800	414,700	87	1996	55,526	83	7	9
1993	2.200	1994	1.800	emer fry	1995	79,300	214,400	293,700	73	1997	56,053	77	18	3
1994	2.156	1995	1.700	emer fry	1996	94,200	333,900	428,100	78	1998	67,727	83	14	3
1995	1.893	1996	1.600	emer fry	1997	65,000	163,000	228,000	71					
1996	2.048	1997	1.501	emer fry	1998	85,600	299,700	385,300	78					
1997	2.166	1998	1.035	emer fry										
1998	2.303	1999												

[a]Prior to 1993, estimates of smolts originating from hatchery fry releases were based on CWT studies. Since 1993, estimates are based on otolith thermal marks.

Table 2. Results of ANOVA using a randomized block design to test for significant differences of mean values for selected zooplankton variables between years of high (HS) and low stocking (LS) and between years of high (HE) and low sockeye escapement (LE). Approximate probabilities (P-values) <0.05 are significant.

Dependent Variable	Treatment Mean		Approximate Probabilities	Treatment Mean		Approximate Probabilities
	HS	LS	HS vs LS	HE	LE	HE vs LE
Total Density	667.8	574.30	0.226	711.20	613.30	0.252
Epischura Density	18.1	22.80	0.534	15.30	21.00	0.494
Cyclops Density	501.3	385.40	0.117	517.20	445.70	0.372
Bosmina Density	109.2	120.80	0.331	142.70	103.80	0.007
Daphnia Density	39.2	45.20	0.262	36.00	42.80	0.256
Cladocera Density	148.4	166.00	0.178	178.70	146.60	0.033
Number Cladocera Eggs	27.9	40.90	0.007	19.40	36.30	0.002
Percent Cladocera Eggs	0.214	0.25	0.361	0.13	0.26	0.003
Ovigerous Cyclops Density	3.1	6.10	0.093	1.90	4.80	0.140
Percent Ovigerous Cyclops	0.572	1.63	0.001	0.29	1.12	0.010

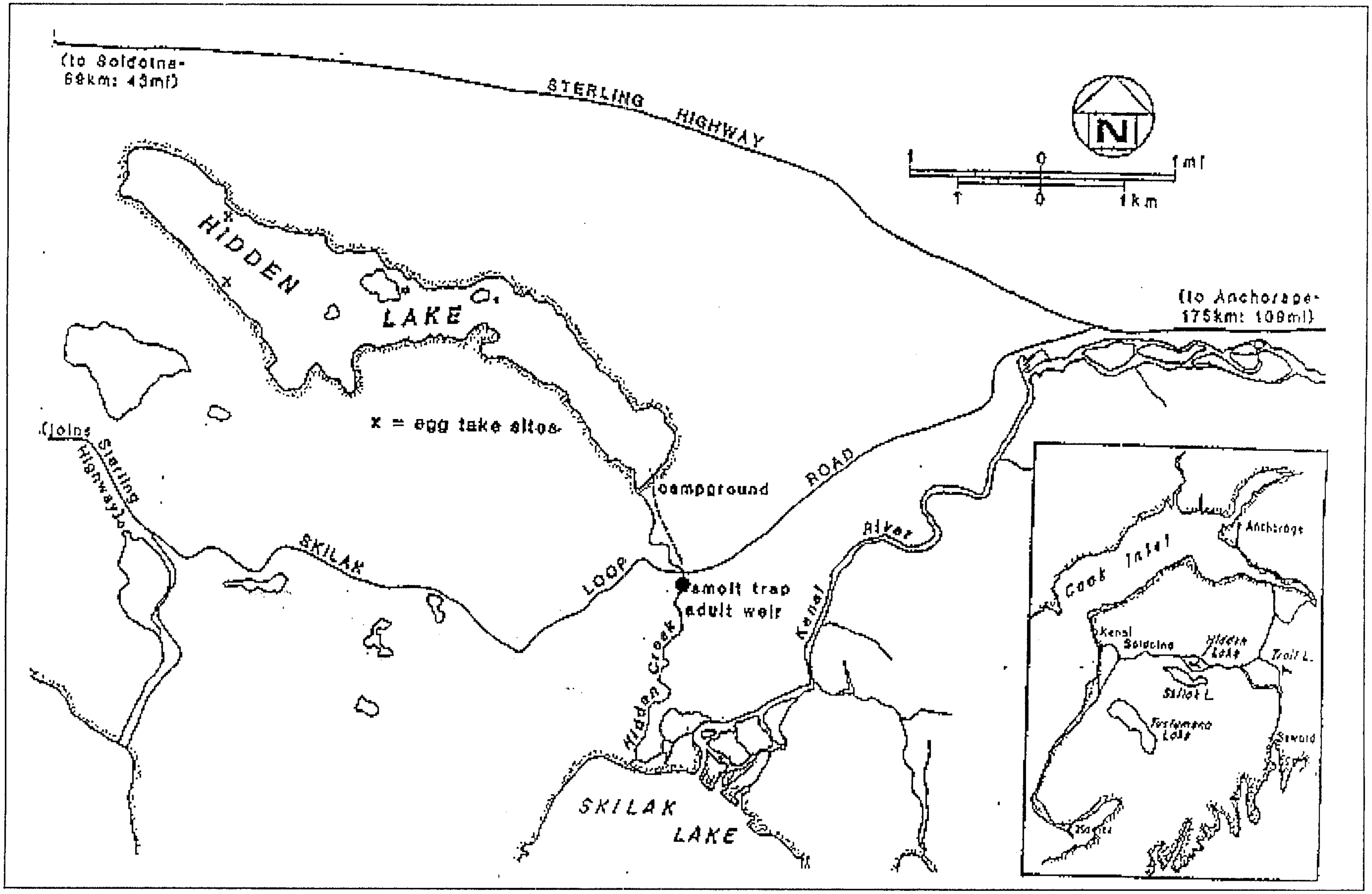

Figure 1. Location of smolt trap, adult weir, and egg take sites at Hidden Lake.

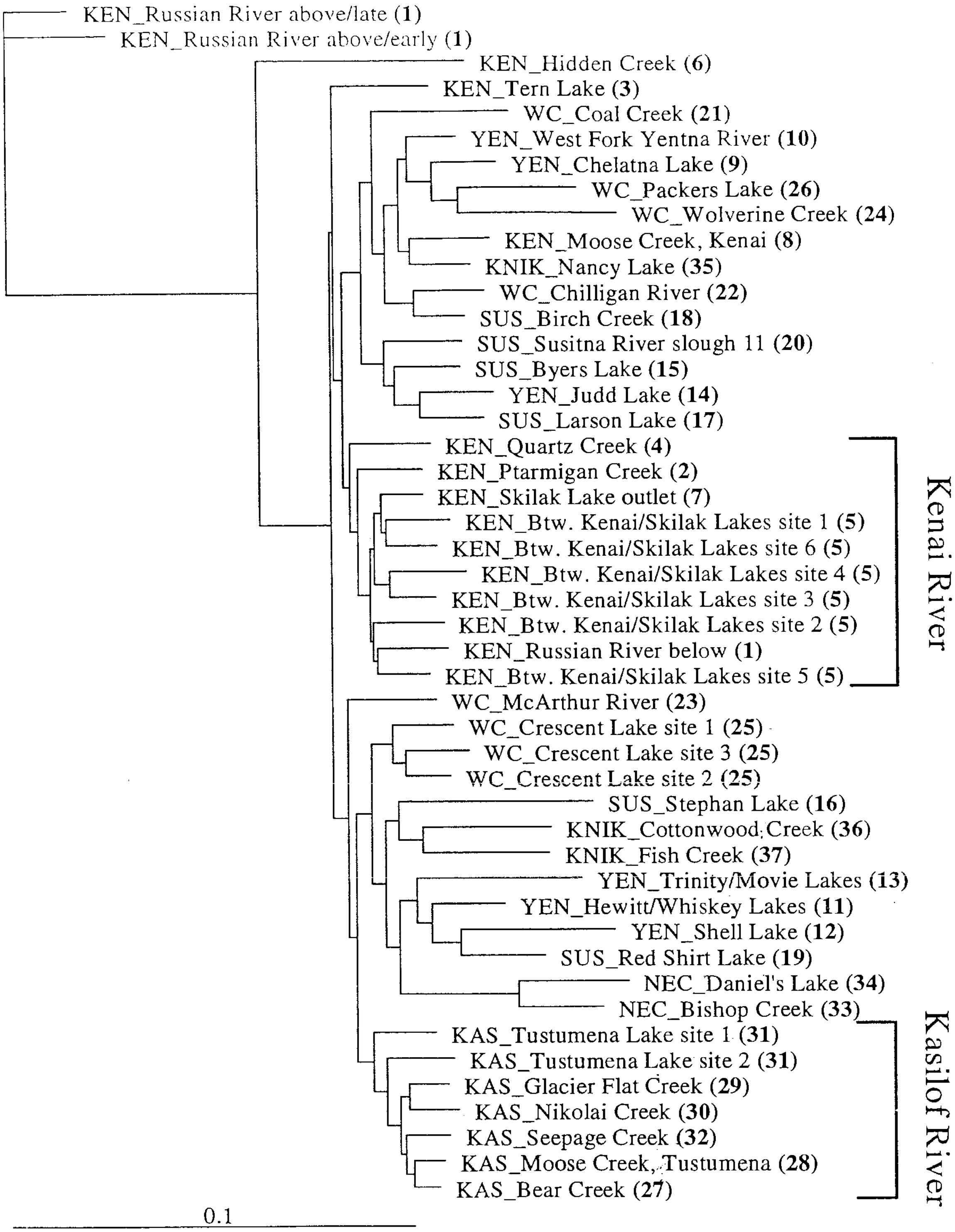

Figure 2. Neighboring-joining tree for Upper Cook Inlet sockeye salmon using Cavalli-Sforza and Edwards (1967) chord measure of genetic distance. Numbers in parenthesis refer to sampling locations in Figure 3. Figure taken from Seeb et al. (*in press*).

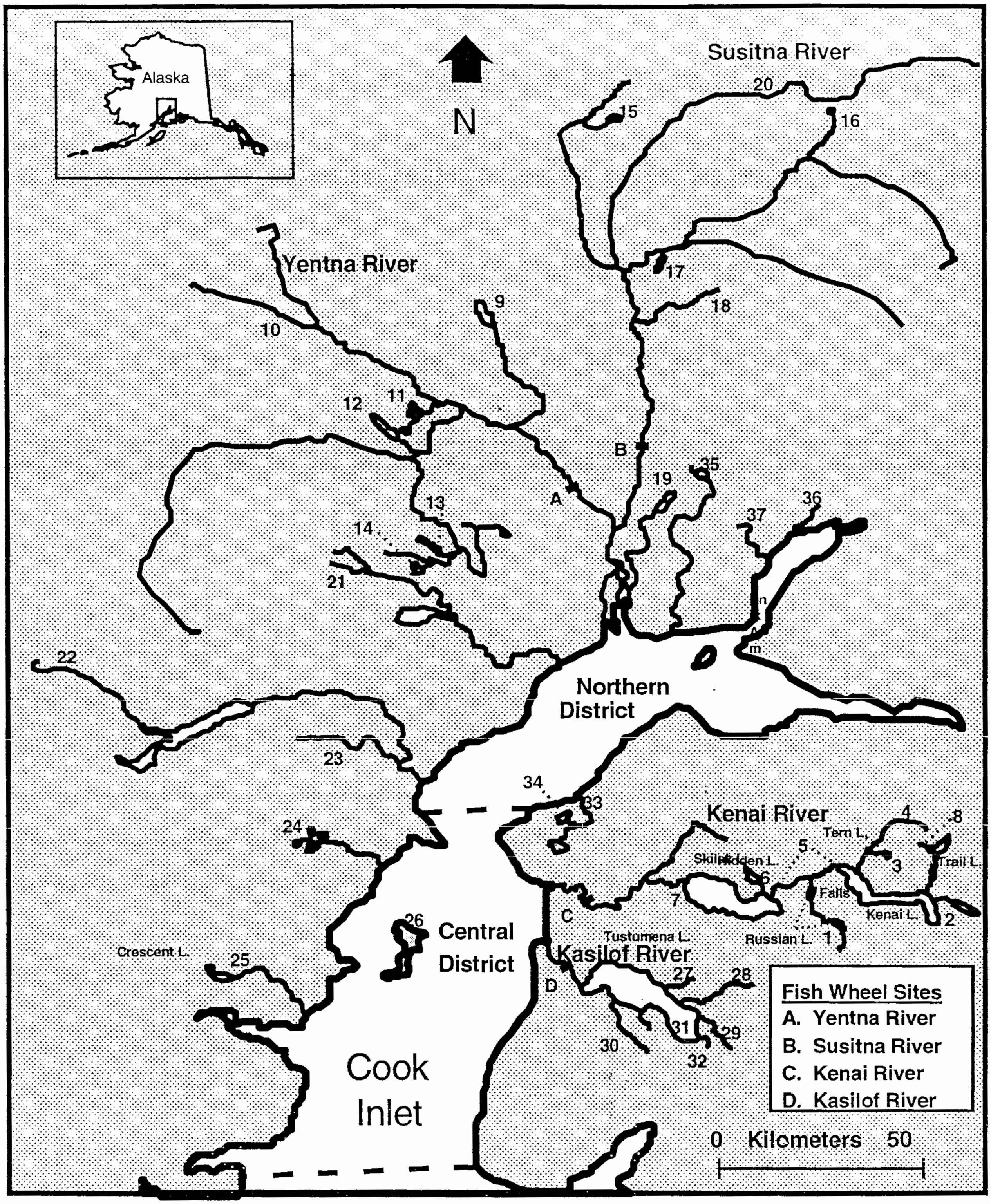

Figure 3. Sampling locations for sockeye salmon used in determination of genetic distances among populations originating from Upper Cook Inlet, 1992 - 1995 (Seeb et al., *in press*).

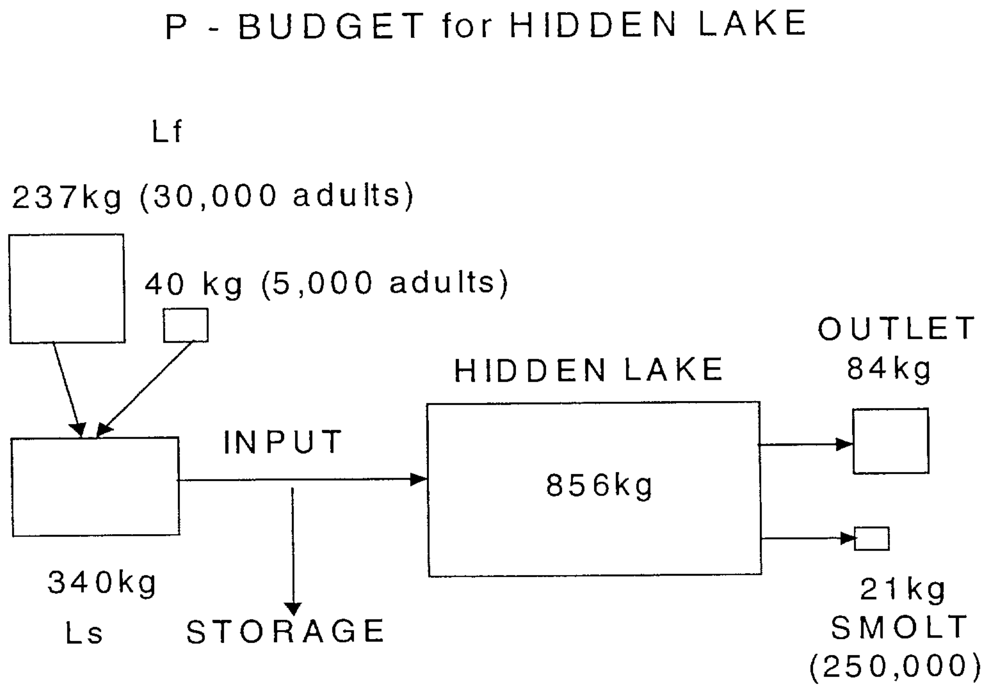

Figure 4. Annual phosphorus (P) budget for Hidden Lake comparing the magnitude of P inputs from terrigenous sources (Ls) and fish carcasses (Lf) based on low escapements (5,000) and the 22 year mean escapement (30,000) compared to lake P content and P export via outlet discharge and by smolt.

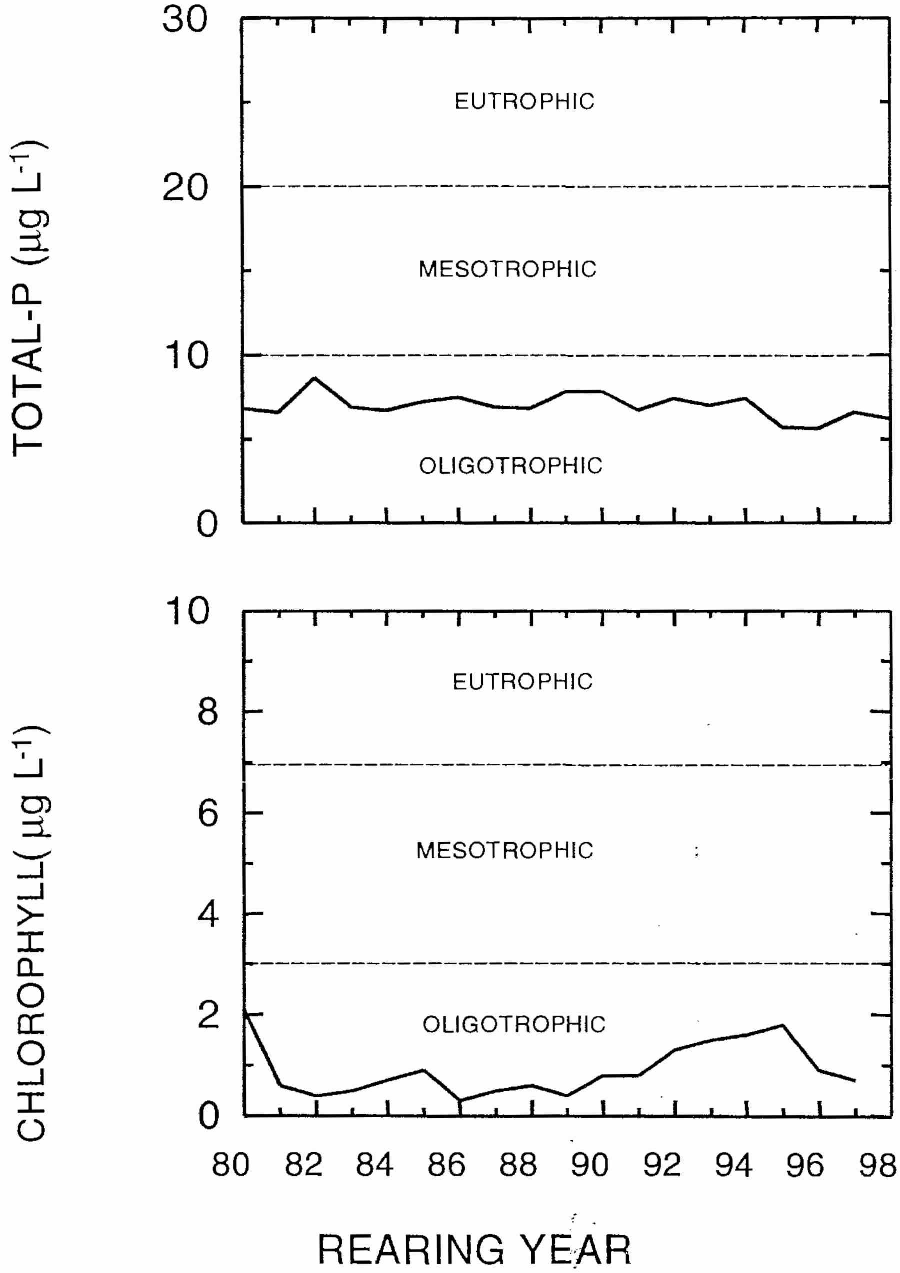

Figure 5. Seasonal (May-October) mean total phosphorus and chlorophyll concentration for the 1-m stratum relative to trophic state criteria in Hidden Lake, 1980-1998.

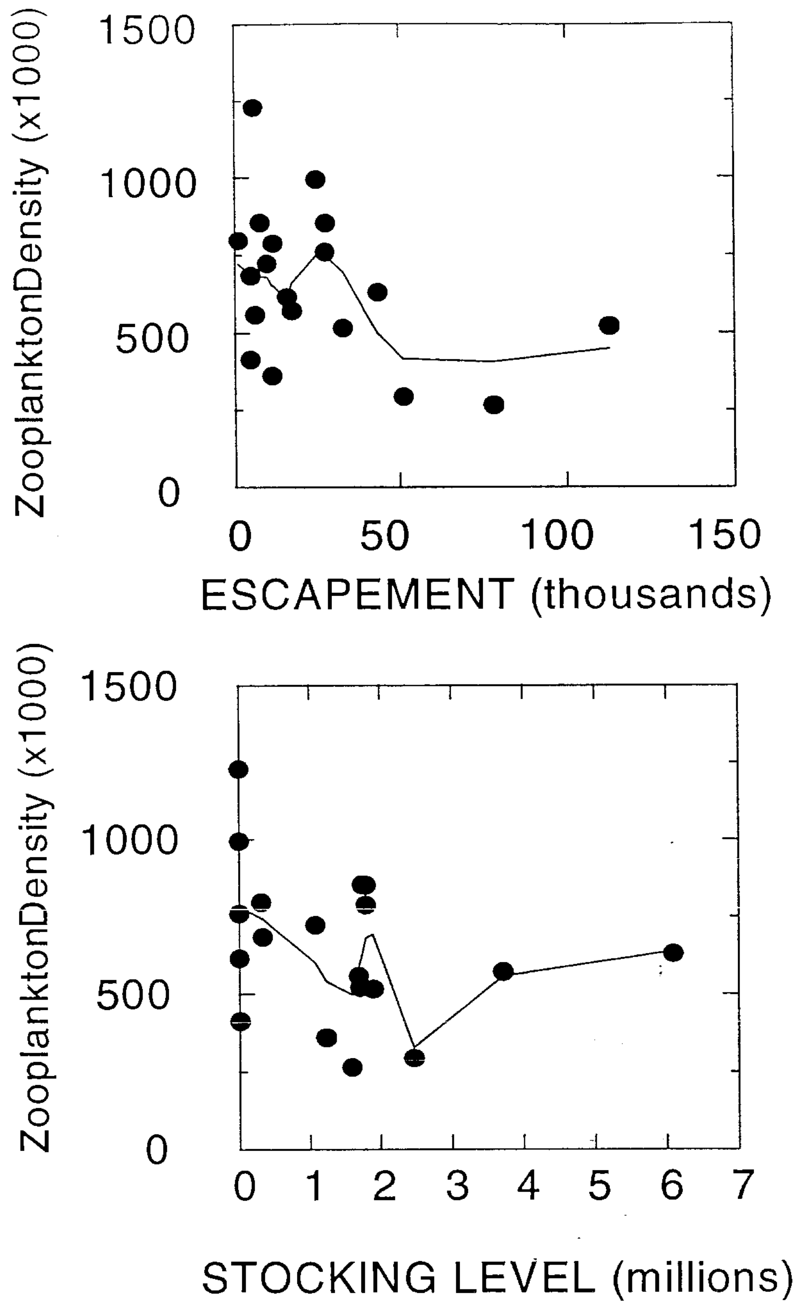

Figure 6. Regression plots of mean total macrozooplankton density (number m^{-2}) against sockeye escapement and fry stocking levels in Hidden Lake. Regression lines derived by Lowess smoothing.

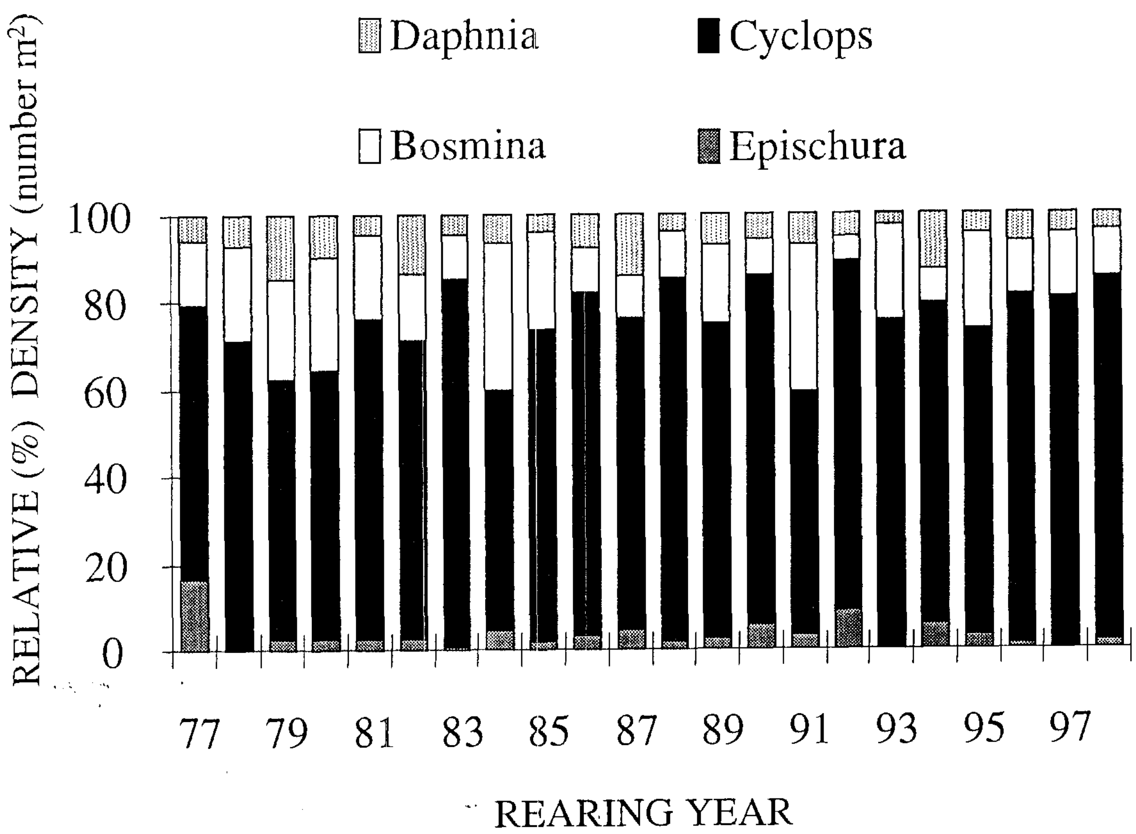

Figure 7. The percentage areal density as seasonal (May-October) means for the major zooplankton species in Hidden Lake, 1977-1998.

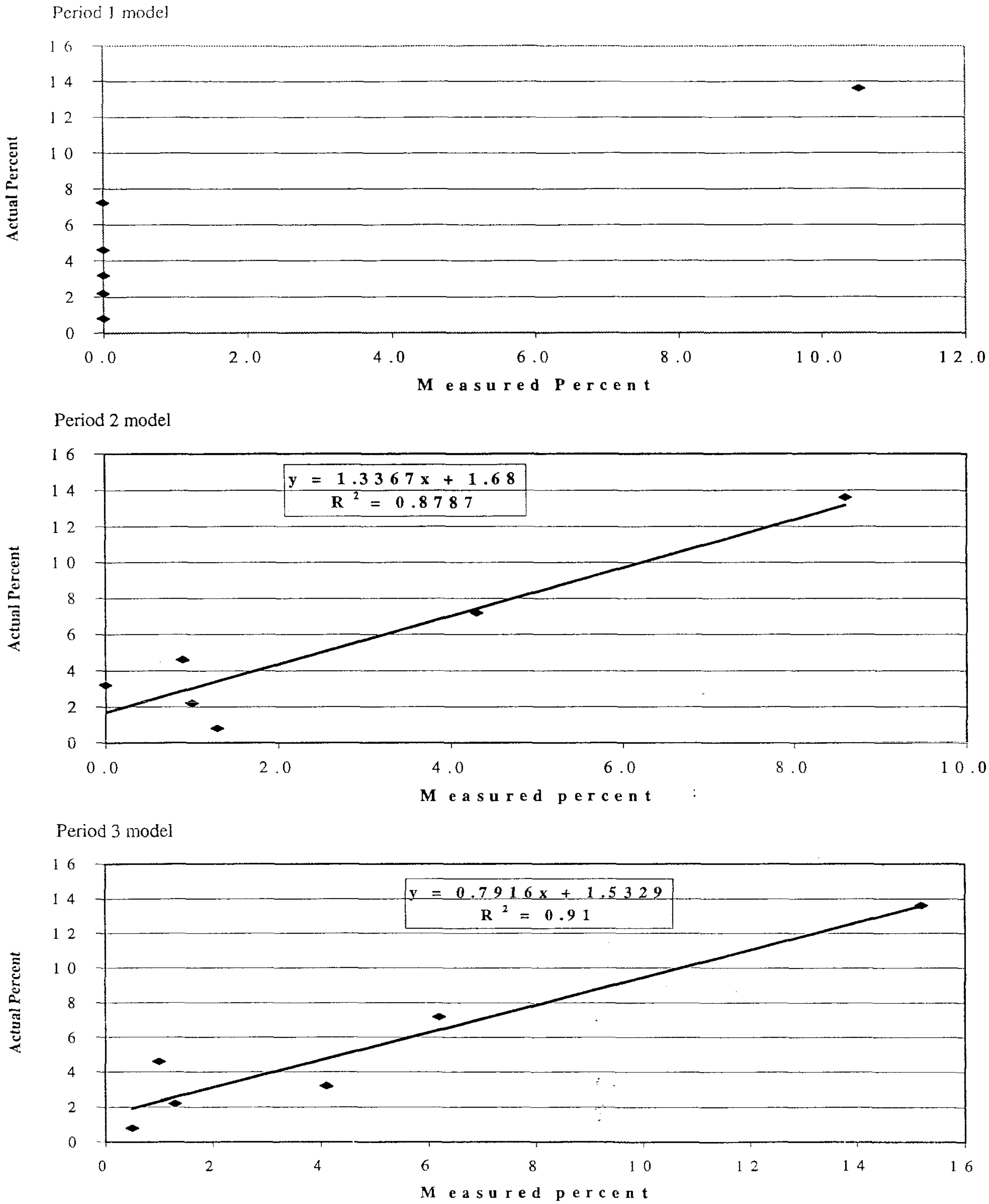

Figure 8. Percent of sockeye salmon with large fresh water scale pattern in Kenai River fish wheel sample used to estimate actual Hidden Lake percent.

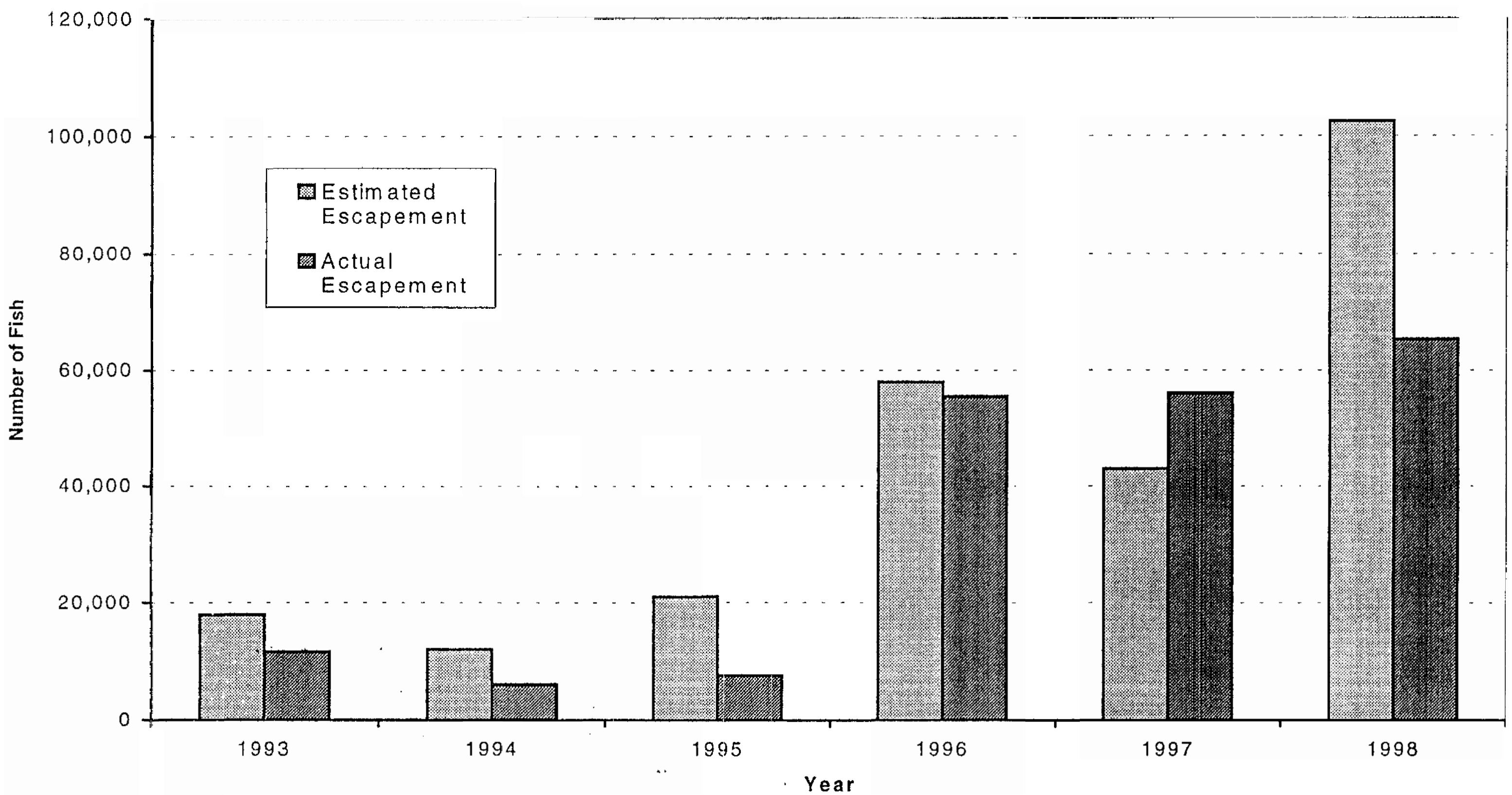

Figure 9. Estimated versus actual adult sockeye salmon escapement to Hidden Lake by year.