FRED Reports

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by
Tim Zadina and Mike Haddix

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ABSTRACT

Juvenile sockeye salmon (*Oncorhynchus nerka*) were held in replicate net pens suspended within the epilimnion of Hugh Smith Lake. During 12 June to 11 August 1986, the juveniles were fed Alaska Dry Pellet (ADP) at 4.5 to 11.9% of wet body weight per day. Water temperatures during the 60 d experimental period ranged from 12.5 to 18.0°C. Growth rates equalled 0.50 and 0.59 mm/d while sizes increased from 0.13 g (28.7 mm) to near the threshold-size for sockeye smolts of 1.54 g (55.3 mm) and 2.09 g (60.9 mm) depending on stocking density and daily ration. Juveniles were reared in the net pens to a size necessary for coded-wire tagging and for marking with oxytetracycline prior to release into the lake. Survivals ranged from 92% within the pens (with no apparent disease problems) to 55% from mid-summer release into the lake to smolt the following spring. As the overall freshwater survival of the pen-reared juveniles was increased 2-fold over expected survivals of free-ranging juveniles, in-lake pen rearing holds promise as an early intervention tool for the enhancement of severely depressed sockeye stocks.

INTRODUCTION

Strategies for sockeye salmon rehabilitation and enhancement in Southeast Alaska have been directed at maximizing use of under-utilized lacustrine rearing habitat through juvenile sockeye outplants and by improving over-utilized habitat through lake enrichment. Juvenile sockeye salmon are stocked into lakes when insufficient numbers of wild fry cannot utilize existing forage and/or into barriered lakes having no anadromous access.

In several southeast Alaska lakes, juveniles have been stocked into lakes during the spring immediately after emergence from hatchery incubation units. As stocking times and wild stock emergence are synchronized, survival of the stocked juveniles should be similar to that of wild fry. However, since brood-stocks from some of the lakes are limited due to low escapements, techniques to enhance survival of juvenile sockeye planted in nursery lakes were explored. The in-lake rearing of juvenile sockeye in net pens, at the release site, seemed a reasonable alternative to rearing at the incubation facility.

In addition, short term rearing in the nursery lake provided an opportunity to mark the fish prior to release. Juveniles could be reared to a size necessary to be coded-wire tagged; and/or fed an oxytetracycline supplemented diet (Koenings and Lipton 1983, Koenings et al. 1986). Increased growth and circuli formation compared to wild fish might also provide a distinctive scale or otolith pattern.

To determine the feasibility of in-lake, short-term rearing; a small scale pilot project was conducted in 1985 (Appendix). Results indicated that in-lake pen rearing of sockeye salmon fry could be successful. The results from a larger production oriented study conducted in 1986 are the subject of this report.

Study site description--Hugh Smith Lake (50° 06'N, 130° 40'W) is located in mainland Southeast Alaska, about 80 km southeast of the city of Ketchikan (Figure

1). It has a surface area of 309 ha and is surrounded by a mountainous watershed ($49.47\ km^2$) that receives 381 cm of precipitation annually. Sockeye Creek (ADF&G stream identification code 101-30-75) drains into Boca de Quadra and is about 50 m long (from the lake to mean high tide) with an elevation drop of only 6.4 m. The creek is 25 m wide at the lake outlet, and discharges range from 1.4 to $28.3\ m^3/sec$. The water level at the lake outlet fluctuates over a 2-m range, and peak flows occur in late fall.

MATERIALS AND METHODS

In-lake rearing pens--Net pens measuring 2.4 x 1.1 x 1.0 m placed 40 m above the lake outlet were used to rear juvenile sockeye. Pens were of wood frame construction and covered with two types of netting with different mesh sizes. The inner net was fiberglass with eight mesh per cm. This fine screen was used for the first 22 days because the fish were too small to be held by conventional netting. Juveniles were then transferred to a second, similar sized pen having a volume of $2.64\ m^3$ which was equipped with 33-mm mesh vexar plastic netting. Finally, the pens were surrounded on the outside with 5 x 5 cm-mesh rubber coated wire fencing to exclude predators. The control pen was of similar construction, but its dimensions were 0.9 x 0.5 m x 1.0 m with a volume of $0.45\ m^3$. The control pen was located 10 m from the pens holding fed juveniles.

Rearing protocol--Approximately 60,000 fry from eggs taken from Hugh Smith Lake sockeye in the fall of 1985 emerged from R29 incubators at Beaver Falls Hatchery on 11 June 1986. The fish were transported the same day via a DeHavilland Beaver in 50 gallon plastic barrels to Hugh Smith Lake. Ten thousand fry were placed in the control pen (unfed), and 50,000 fry were placed in one large pen (fed).

Beginning on 12 June, the fish were fed ADP-3 (starter mash) for a period of 15 days after which the ration was switched to ADP-3 (1/32 inch pellet) for the remainder of the study. ADP rations were changed when the fish were able to ingest the larger

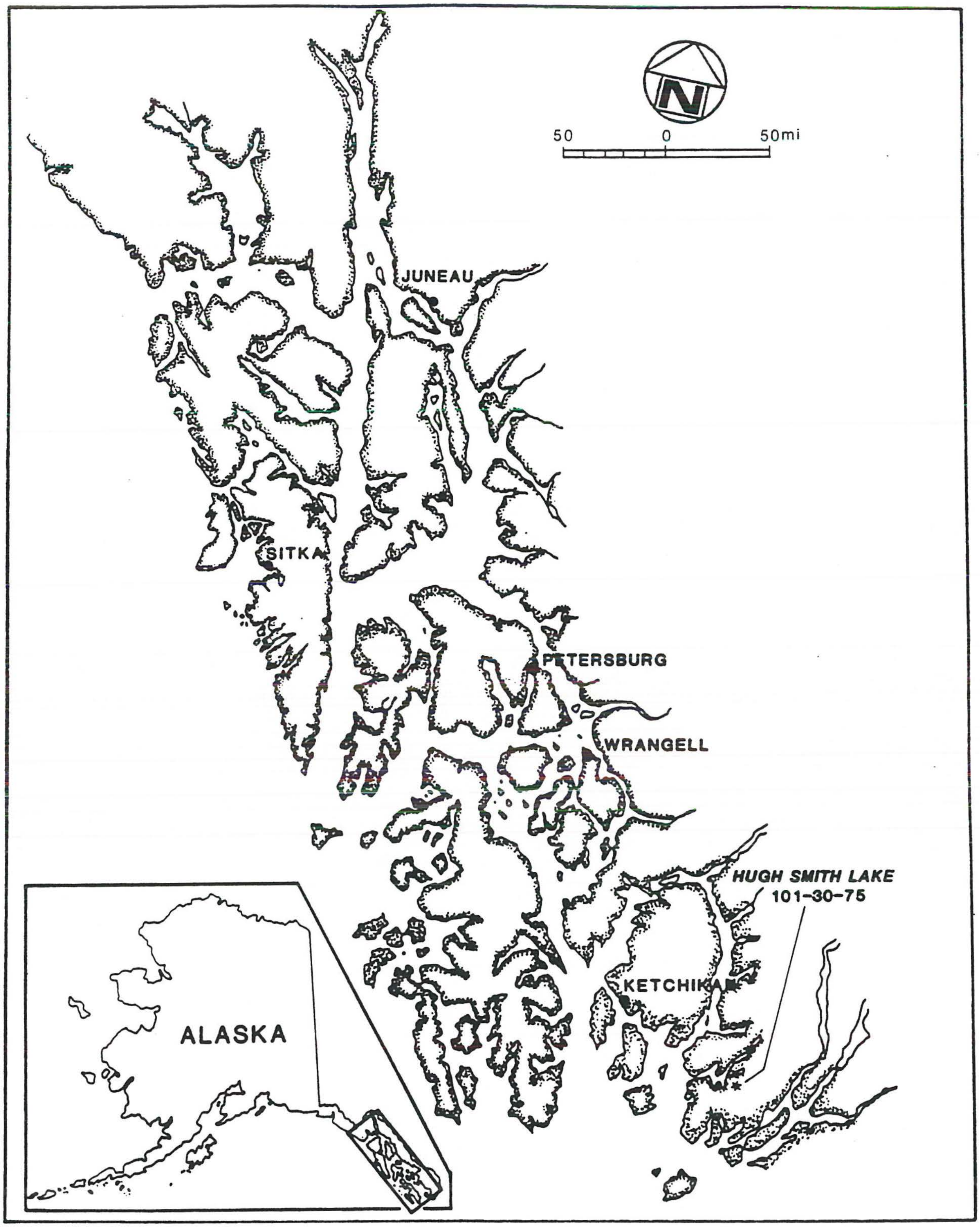

Figure 1. Location of Hugh Smith Lake within southeast Alaska and relative to the Cith of Ketchikan.

pellets. ADP was broadcast over the surface of the pens thirteen times per day from 0800 to 2000 hr. at a rate of five percent of mean total body weight per day (Brett and Shelbourn 1975) adjusted at five day intervals.

Temperatures and temperature units--Temperatures were taken daily at 0800 and 2000 hr. using a hand held thermometer with 1°C gradations from -10 to +40°C. The thermometer was attached to a 1 m line suspended from the surface. Temperatures were measured to the nearest 0.5°C. Temperature units (T.U.) were calculated from the mean of the two recordings. One temperature unit equals one degree Celsius above freezing (0°C) for a period of 24 hours. For example, if the mean temperature for day 1 is 15°C then 15 T.U.'s have accumulated for that day.

Oxytetracycline marking--Juvenile sockeye salmon were fed an oxytetracycline (OTC) medicated diet in order mark the fish (Koenings and Lipton 1983). The medicated diet was used for fourteen days starting on 17 July when fish reached a mean length of 43 mm. The OTC medicated ADP was fed at the rate of 1.0 g per 10 kg of fish per day. Juvenile sockeye were subsampled for analysis of residualized OTC just prior to lake release. Samples were immediately frozen, and sent to the FRED Limnology Lab in Soldotna for later analysis. When combined with adult return information, the results of the OTC marking will be published in a later report.

Lengths, weights, and condition factor--Juvenile sockeye were sampled for wet weight every five days prior to feeding. Initially, fifty fish were blind dipped from each of the control and treated pens, anesthetized with MS-222, placed in a small aquarium net, and all excess water removed. The group of fish was then weighed to the nearest 0.1 g on an Ohaus Port-O-Gram digital scale. Individual sockeye were measured from tip of snout to fork of tail. The fed group was split equally on 1 July into two pens to reduce densities with subsequent sample sizes accordingly reduced by 50% to 25 fish per pen. The condition factor (K) was calculated as:

$$K = \frac{W * 10^5}{L^3}$$

Where: W = weight (g) and L = length (mm).

Growth rates and survival of pen-reared sockeye--The growth rates of the pen-reared juvenile sockeye were derived from regressions of both the log of fish weight (g) and weight (mm) against time (d) for each pen. The significance of the regressions was determined by F-test, and differences between growth rates of sockeye within the two pens were tested using analysis of covariance (ANCOVA). There was no difference between growth rate estimates based on changes in fish length using either an linear or log model; however, a log model increased the fit (coefficient of determination) of growth rate estimates based on changes in fish weight.

Losses of pen-reared sockeye include the observed mortalities (daily) as well as live fish that escaped undetected through a hole in the netting. The non-mortality loss was estimated as the difference between the number of fish sorted during coded-wire tagging at the end of the rearing period and the initial number of sockeye in the starter pen minus the observed mortalities. The corrected starter pen count divided by the number of sockeye counted out of the pens during coded-wire tagging equalled the proportion that survived pen rearing.

Coded-wire tagging and in-lake release--All fed fish were coded wire tagged (CWT) with full length tags (1 mm) after reaching a mean length of 50 mm during the period 31 July to 4 August. Juvenile sockeye receiving CWT were dipped from the pens in groups of 30-50 fish and placed in a fin-clipping tray holding a 80-135 mg/L solution of MS-222. In the tagging shed, the adipose fins were clipped, the juveniles tagged (Peltz and Haddix 1989); and then passed through a quality control device to check for tag retention. If tagged, the fish went directly into another pen via a 4" plastic pipe while fish without a tag were shunted off into an aerated recovery bucket to be retagged. Juveniles within each pen had a unique tag code, and all tagged fish were held for ten days prior to release to assess short term mortality.

The pen-reared juvenile sockeye were released into the lake on 13 August from 6-30 gallon plastic barrels transported with a 17 foot boat. Fish were distributed over the upper two-thirds of the lake to allow mixing with wild sockeye. During release, 20 live fish were retained, transported back to Ketchikan, and the following day autopsied for general health.

Estimates of body-size and growth rates of free-ranging sockeye--The lengths and weights of juvenile sockeye rearing in Hugh Smith Lake and in nearby Badger and McDonald Lakes were from 80 to 225 fish captured in 1986 mid-water trawl surveys. The in-lake surveys were done in mid-July and again in mid-September as part of the ongoing evaluation of either sockeye outplant or lake enrichment projects, and were conducted as part of the population abundance surveys using hydroacoustic techniques. Growth rates of the rearing fish were made from the changes in fish length between the July and September surveys assuming linear changes in length.

Hydroacoustic estimate of sockeye smolt abundance--Numbers of outmigrant sockeye smolt (both wild and pen-reared), in the spring of 1987, were based on hydroacoustic estimates and midwater trawl catches on 20 March and on 14 July. Juvenile sockeye age classes were estimated as described by Peltz (1985); and the 14 July survey revealed a 25% holdover component for juveniles enumerated as pre-smolts in the 20 March survey. During the coded-wire tagging of the wild smolts in the spring of 1987, pen-reared sockeye smolts were separated from wild smolts by the presence or absence of an adipose fin and the presence of a coded-wire tag.

RESULTS AND DISCUSSION

In-lake water temperatures and temperature units--Water temperatures during the feeding study ranged from 12.5 to 18.0°C (Figure 2). Although in the high range for sockeye tolerance, temperatures did not adversely affect the juvenile sockeye during the study. Past studies on sockeye salmon rearing involved similar temperature ranges (Brett et al. 1969; Brett, 1971; Brett and Shelbourn, 1975; Biette and Geen, 1980). In addition, the 1 m water temperatures in Hugh Smith Lake during 1986 were similar in magnitude and range to temperatures in the past six years (Table 1).

Juvenile sockeye biomass--Changes in juvenile sockeye biomass over the study period are presented in Figure 3. The initial biomass of 2.42 kg/m^3 stocked into a single fine mesh pen on 12 June (Table 2) was divided into two equal groups when the sockeye biomass reached 3.35 kg/m^3 on 21 June because mortalities increased. The loss of 251 fish (0.5%) early in the experiment is attributed to stress related to overcrowding in the fine mesh pens as once fish were placed in less crowded conditions in the new coarse meshed pens, mortalities ceased. By 11 August, the juvenile sockeye biomass in large mesh pens reached 9.62 kg/m^3 in pen 1 and 7.88 kg/m^3 in pen 2 (Table 2).

A rip in one fine mesh pen during fry transfer allowed 19,924 fish to escape into the lake between 21 June and 2 July. This hole was discovered on 2 July during final transfer to the large mesh pens. The exact number lost was not known until the fish were counted for tagging. This loss explains why an attempted feeding rate of 5% of sockeye body weight actually ranged between approximately 8% and 12% in pen 2 (Table 2).

Juvenile sockeye biomass in the control pen of 2.84 kg/m^3 was slightly higher than the starter pen at 2.42 kg/m^3; however, while the fish biomass increased within the pen(s) receiving food, the fish biomass within the control pen declined (Table 3). Although we did not sample the control pen for sockeye forage e.g., zooplankton, we

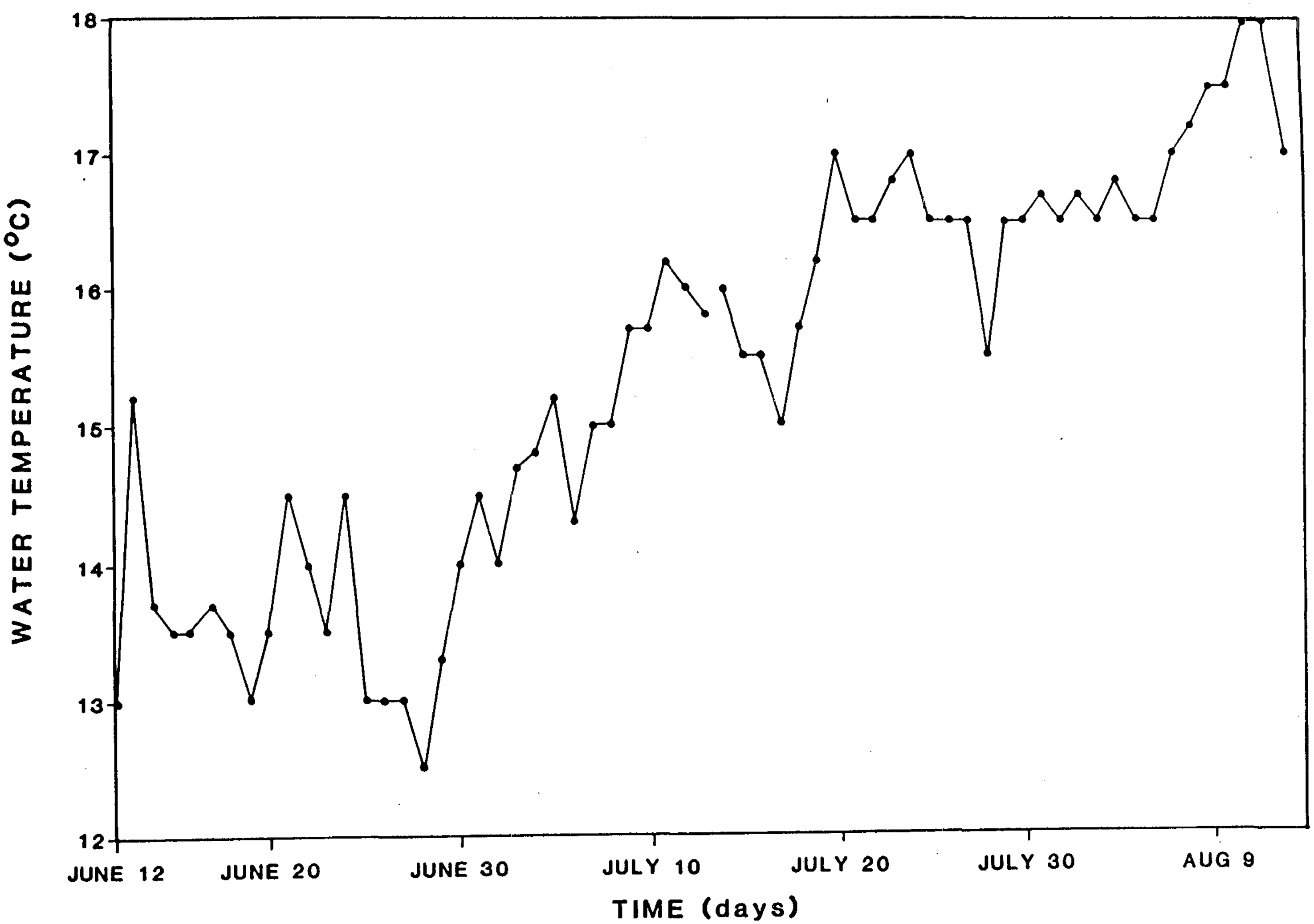

Figure 2. Daily mean water temperatures at 1 m in Hugh Smith Lake during the pen-rearing of juvenile sockeye salmon from 12 June to 11 August 1986.

Table 1. The mean temperatures at 1 m in Hugh Smith Lake for ten day periods from 21 May to 10 August 1986 and the six year (1980-1985) mean temperatures and ranges for the same time periods.

	Mean temperatures (°C)		
Date	Study temperatures	1980-1985	1980-1985 Range
5/21-31	9.9	10.0	5.7-11.1
6/01-10	10.4	11.7	8.8-14.2
6/11-20	13.6	13.4	11.9-14.8
6/21-30	13.5	14.4	12.2-16.2
7/01-10	14.9	15.1	13.2-16.5
7/11-20	15.9	15.6	13.4-17.1
7/21-31	16.5	17.0	15.5-18.8
8/01-20	16.9	16.6	15.8-18.3

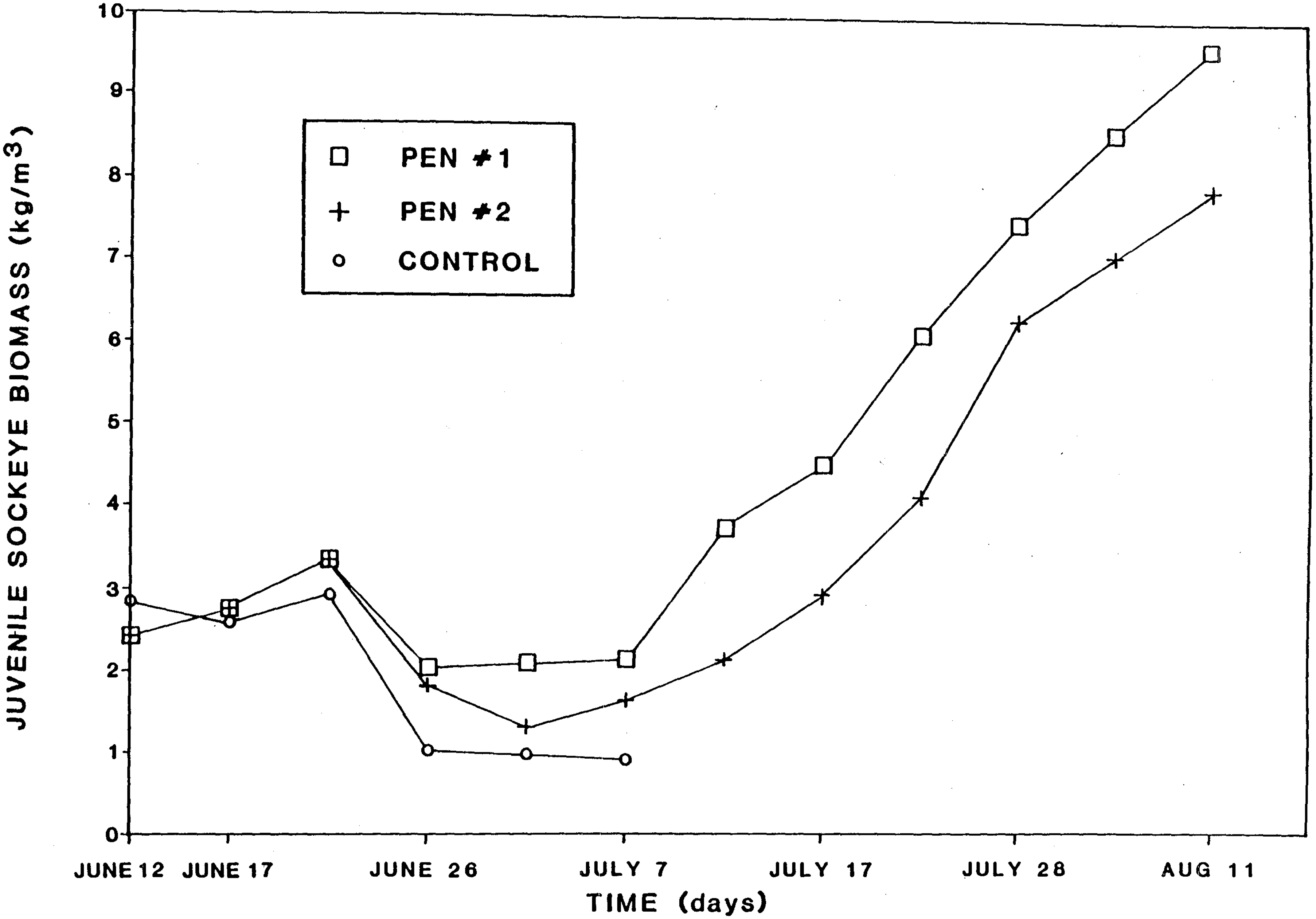

Figure 3. Changes in the biomass (kg/m^3) of pen-reared (fed) and non-fed (control) juvenile sockeye salmon during 12 June to 11 August 1986 at Hugh Smith Lake.

feel the fine screen of the pen probably excluded zooplankton resulting in the fish starving.

Juvenile sockeye growth--The lengths and weights for juvenile sockeye in the treated pens are shown in Table 2 while those for the control or unfed group are presented in Table 3. The mean weight of 0.13 g for juveniles stocked in the one fine meshed pen compares to the ending mean sockeye weights in pen 1 of 1.54 g and in pen 2 of 2.09 g. The growth rate for sockeye juveniles equalled 0.030 g/d in pen 1 and 0.041 g/d in pen 2 (Figure 4A); however, the overall growth rates were not significantly different (ANCOVA; P=.077).

From a pre-feeding mean length of 28.7 mm, the juvenile sockeye grew to post-feeding mean lengths of 55.3 mm in pen 1 and 60.9 mm in pen 2. The growth rates of the feeding sockeye were 0.502 mm/d in pen 1 and 0.592 mm/d in pen 2 (Figure 4B); however, the overall growth rates were not significantly different (ANCOVA; P=.076). Finally, the growth rates of the two groups of juvenile sockeye, formed after transfer to the less crowded conditions in the two net pens, were not significantly different (ANCOVA; P=.16). Thus, the higher level of ration (8-12% of sockeye body weight) for pen 2 sockeye did not produce a significant increase in growth rate compared to pen 1 sockeye fed at 5% of body weight. However, the body-size of the pen 2 sockeye did consistently exceed those of the pen 1 sockeye in mid-July indicating that if the study period had been extended the increased ration may have significantly elevated growth rates.

The lengths of the juvenile sockeye in the control pen did not change (P=.11); but weights steadily decreased (P=.02) over the 25 d study (Table 3). Not only did the fish simply not grow, they lost weight presumably because of a lack of sufficient autochthonous forage entering the pens.

The body-size of the pen-reared sockeye were generally larger than the free-ranging juvenile sockeye in Hugh Smith Lake as well as juvenile sockeye captured in nearby

Table 2. A summary of the rearing protocol by time period, changes in rearing pens, and changes in juvenile sockeye density and growth responses during 12 June to 11 August 1986 for in-lake pen-reared (fed) sockeye salmon at Hugh Smith Lake.

Date	Mean period water temperature (°C)	Fish condition (means)			Sockeye density		Rearing protocol by period		
		Weight (g)	Length (mm)	Condition factor (K)	Number/ pen	Biomass (kg/m^3)	Temperature units	Ration (g)	Percent of wet body-weight
Starter Pen (fine mesh)									
6/12	13.3	0.128	28.7	0.540	50,000	2.42	0.0	0	--
6/17	13.7	0.146	29.6	0.563	49,978	2.76	82.2	1,440	4.5
6/21	13.6	0.178	30.3	0.640	49,749	3.35	68.2	1,825	5.0
Pen One (coarse mesh)									
6/26	13.9	0.224	31.8	0.697	24,000	2.04	68.0	1,155	5.4
7/02	13.6	0.316	34.8	0.750	17,571	2.10	94.3	1,325	5.6
7/07	14.8	0.321	33.8	0.831	17,571	2.14	74.0	1,975	7.1
7/12	15.7	0.562	40.7	0.834	17,571	3.74	78.6	1,925	6.8
7/17	15.6	0.678	42.8	0.865	17,571	4.51	77.8	2,389	4.8
7/23	16.5	0.920	46.6	0.909	17,571	6.12	98.7	3,456	4.8
7/28	16.4	1.126	50.1	0.895	17,568	7.49	82.0	3,910	4.8
8/02	16.6	--	53.3	--	16,538	--	82.9	--*	--*
8/11	17.1	1.536	55.3	0.908	16,538	9.62	153.5	--*	--*
Pen Two (coarse mesh)									
6/26	13.9	0.200	31.7	0.628	24,000	1.82	68.0	1,155	5.4
7/02	13.6	0.328	35.2	0.752	10,505	1.31	94.3	1,325	10.5
7/07	14.8	0.412	37.8	0.763	10,505	1.64	74.0	2,050	11.9
7/12	15.7	0.538	40.8	0.792	10,505	2.14	78.6	2,575	11.9
7/17	15.6	0.738	44.1	0.860	10,505	2.94	77.8	2,287	8.1
7/23	16.5	1.035	49.6	0.848	10,505	4.12	98.7	3,762	8.1
7/28	16.4	1.578	54.1	0.997	10,501	6.28	82.0	4,575	8.4
8/02	16.6	--	56.4	--	9,949	--	82.9	--*	--*
8/11	17.1	2.092	60.9	0.926	9,949	7.88	153.5	--*	--*

*Ration was estimated by volume.

Table 3. A summary of the rearing protocol by time period, and changes in juvenile sockeye density and growth responses during 12 June to 7 July 1986 for in-lake, pen-reared (non-fed) sockeye salmon at Hugh Smith Lake.

Date	Mean period water temperature (°C)	Fish condition (means)			Sockeye density		Rearing protocol by period	
		Weight (g)	Length (mm)	Condition factor (K)	Number/ pen	Biomass (kg/m^3)	Temperature units	Ration (g)
6/12	13.3	0.128	28.7	0.540	10,000	2.84	0.0	0
6/17	13.7	0.116	28.7	0.491	10,000	2.58	82.2	0
6/21	13.6	0.132	28.9	0.547	10,000	2.93	68.2	0
6/26	13.9	0.092	29.0	0.377	5,000	1.02	68.0	0
7/02	13.6	0.088	28.3	0.388	5,000	0.98	94.3	0
7/07	14.8	0.082	26.8	0.426	5,000	0.91	74.0	0

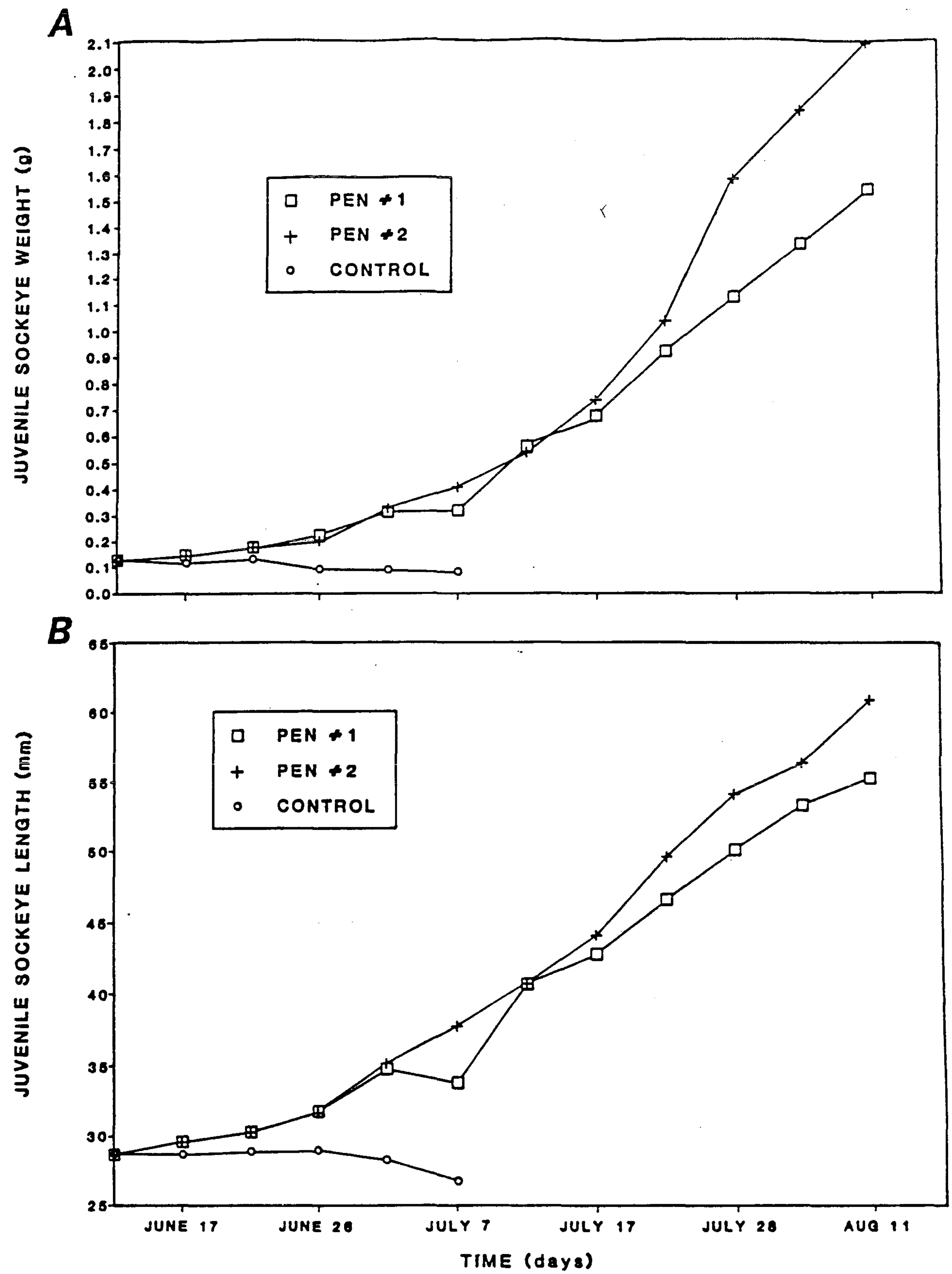

Figure 4. Changes in (A) mean lengths (mm) and (B) in mean weights (g) of pen-reared (fed) and non-fed (control) juvenile sockeye salmon during 12 June to 11 August 1986 at Hugh Smith Lake.

McDonald and Badger Lakes (Table 4). During July, the pen-reared sockeye were about 41 mm in length and weighed about 0.55 g whereas free-ranging sockeye were between 34 and 35 mm in length, and between 0.27 and 0.38 g in weight. By August, the pen-reared sockeye had grown to a mean size of 58 mm and 1.82 g compared to the free-ranging sockeye in Hugh Smith and Badger Lakes which had only reached 43 to 49 mm and 0.62 and 1.13 g by mid-September. The only free-ranging sockeye of comparable size (56 mm and 1.65 g) to the pen-reared sockeye of Hugh Smith Lake were sockeye rearing in McDonald Lake which was undergoing nutrient enrichment to increase sockeye forage. Finally, the mean growth rate of free-ranging sockeye in Hugh Smith Lake during the mid-July to mid-September period (about 60 d) equalled 0.263 mm/d over a six year (1980-1985) period; and 0.19 mm/d in 1986. Thus, the growth rates for the pen-reared sockeye were 2 to 3 fold those achieved by the free-ranging fish.

Juvenile sockeye condition factor--The length and weight of the pen-reared sockeye did increase throughout the study period, and so did the condition factor (K) (Table 2). In both pens, the condition of the rearing sockeye consistently (P=.0001) increased from 0.543 on 12 June to 0.908 in pen 1 and 0.926 in pen 2. Thus, as the juvenile sockeye grew in the pens, they put on more weight per unit change in length.

In contrast to the increase in condition as the fed sockeye grew, the fish in the control pen lost condition (Table 3) as they utilized body reserves in order to survive without food.

Coded-wire tagging of pen-reared sockeye--Coded-wire tagging occurred between 31 July and 4 August when 27,778 juveniles were sorted. There were 1,283 undersized fish (35-42 mm) which were untaggable because of a lack of nose-cartilage and were released into the lake. As the undersized juveniles were close to the threshold size of about 40 mm necessary for OTC residualization (Koenings et al. 1986), they may not be marked. The CWT fed-fish were returned to the net pens and held for nine to twelve days prior to release into the lake. During this time period, rations were cut

Table 4. A comparison between the lengths and weights of pen-reared juvenile sockeye salmon at Hugh Smith Lake, and wild juvenile sockeye from Hugh Smith Lake and nearby Badger and McDonald Lakes. Also shown are the sampling dates in 1986 for all lakes.

Lake	Stock	Date	Length (mm)	Weight (g)
Hugh Smith	Fed pen #1	7/12	40.7	0.56[a]
Hugh Smith	Fed pen #2	7/12	40.8	0.54[a]
Badger	Wild	7/10	33.6	0.29[b]
Hugh Smith	Wild	7/11	35.2	0.38[b]
McDonald	Wild	7/13	33.6	0.27[b]
Hugh Smith	Fed pen #1	8/11	55.3	1.54[a]
Hugh Smith	Fed pen #2	8/11	60.9	2.09[a]
Badger	Wild	9/16	42.5	0.62[b]
Hugh Smith	Wild	9/17	48.5	1.13[b]
McDonald[c]	Wild	9/15	55.7	1.65[b]

[a]Weights are taken from live fish.

[b]Fish were preserved in 10% formalin for 60 days prior to measurements. Length was multiplied by 1.042 and weight multiplied by 1.021 to give equivalent live fish measurements (Rogers 1964).

[c]McDonald Lake fish are subjected to a lake enrichment program.

to three percent of wet body weight per day. Finally, since 22,604 of the juvenile sockeye released during mid-August had valid tags, and 3,871 had no tags but were adipose clipped; tag retention was estimated at 85.4%.

Upon release into Hugh Smith Lake, the juvenile sockeye appeared very healthy which was confirmed by fish autopsies performed on 20 live fish. For example, hematocrit counts averaged 41.8% with a range of 37.5-50.0%, and serum refraction averaged 6.9 with a range of 6.0-8.2. The hematocrit counts fall in the normal range of other salmonid species (Miller et al. 1983).

In-lake survivals after release--A total of 41,619 sockeye smolts were examined of which 1,181 were tagged and an additional 511 clipped smolt without tags, assumed to be part of the fed groups, were counted. A total of 1,692 fed fish were counted for a ratio of 24.6 to 1. Of an estimated 360,470 total smolt leaving the lake in 1987, fed fish accounted for 14,655 of the total smolt population. Juvenile survival from the August release into the lake to smolt the following spring was estimated at 55.3%.

EVALUATION

Temperature ranges within the net-pens held in the epilimnion of Hugh Smith Lake were suitable for sockeye salmon rearing (Biette and Geen 1980; Brett 1971; Brett and Shelbourn 1975; Brett et al. 1969); however, crowding of the juvenile sockeye appeared to be a problem with the fine mesh pen. Apparently, the fine screen restricts water exchange and excludes zooplankton which led to an increase in fish mortality. Fish densities should be kept very low (<2.80 kg/m^3) until the larger mesh pens can be used.

Finally, the use of regular nylon net pens with aluminum or plastic frames would ease both pen cleaning and fish handling. A starting mesh size of 0.16 cm is sufficient, but a finer screen was used because the 0.16 cm netting made in plastic was not available.

The feeding rates of ADP at 5% to 8% percent of wet body weight per day for 60 days was sufficient to rear juvenile sockeye to threshold-size (60 mm) for smolting (Koenings and Burkett 1987) by mid-August. The survival of the pen-reared sockeye was excellent as 92% of the juvenile fish introduced into the starter pen (corrected for non-mortality losses) were successfully released into the lake. By the end of the study period, the size of the pen-reared sockeye was marginal for tagging with full length CWT. We would suggest the use of a half-length CWT in future work which may increase the 85.4% tag retention achieved with the full length tags.

The survival of pen-reared sockeye released in mid-August to smolt the following spring was estimated to be 55.3%, and the survival of juvenile sockeye from mid-June to smolt was estimated (0.92 x 0.553) to be about 50% (Figure 5A). In comparison, juvenile sockeye, released directly into lakes in mid-June and grow to threshold size before smolting the following spring, generally survive at a rate of 22% (Koenings et al. 1989), and have an over-winter (fall to spring) survival of 65% (Figure 5B). Thus, most of the increase in freshwater survival from about 22% for spring released juveniles to the 50% of pen-reared juveniles apparently occurred during the pen-rearing period of mid-June to mid-August. During this period, pen-reared sockeye survivals were estimated at 92% compared to in-lake survival estimates of 34%.

Consequently, we feel pen rearing, when used to enhance the survival and growth of juvenile sockeye, holds considerable promise for the rehabilitation of severely depressed sockeye stocks in nursery lakes with either a low natural forage production or extremely low escapements.

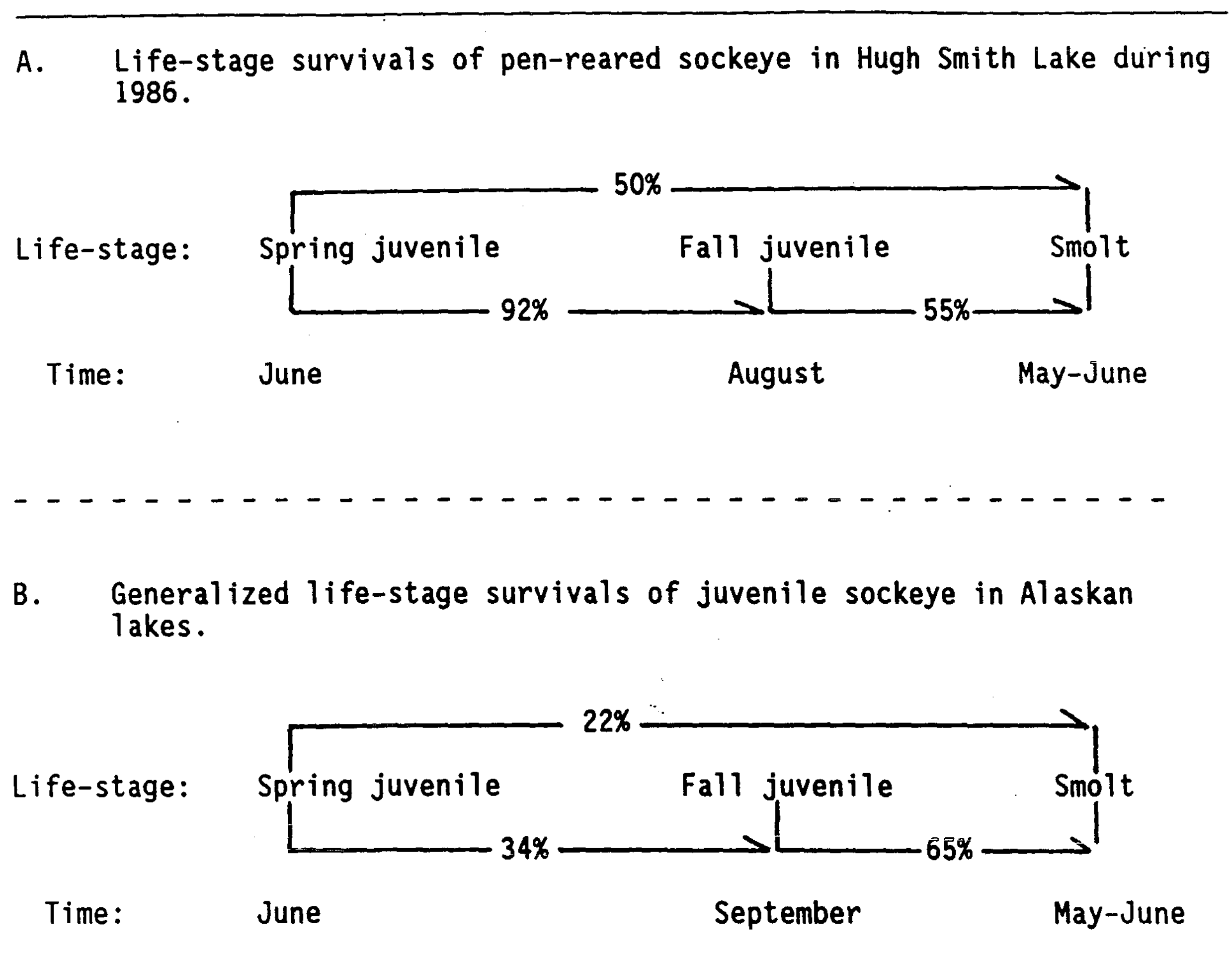

Figure 5. Life-stage survivals of juvenile sockeye salmon rearing in floating net pens (A) until release into Hugh Smith Lake in August compared to generalized life-stage survivals (B) of juvenile sockeye in Alaskan lakes.

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REFERENCES

Biett, R. M. and G. H. Geen. 1980. Growth of underyearling salmon (*Oncorhynchus nerka*) under constant and cyclic temperatures in relation to live zooplankton ration size. Can. J. Fish. Aquat. Sci. 37:203-210.

Brett, J. R. 1971. Satiation time, appetite, and maximum food intake of sockeye salmon (*Oncorhynchus nerka*). J. Fish. Res. Board Can. 23:409-415.

Brett, J. R. and J. E. Shelbourn. 1975. Growth rate of young sockeye salmon (*Oncorhynchus nerka*), in relation to fish size and ration level. J. Fish. Res. Board Can. 32:2110-2130.

Brett, J. R., J. E. Shelbourn, and C. T. Shoop. 1969. Growth rate and body composition of fingerling sockeye salmon, (*Oncorhynchus nerka*), in relation to temperature and ration size. J. Fish Res. Board Can. 26:2363-2394.

Koenings, J. P. and J. Lipton. 1983. The flourometric determination of the uptake and retention of the antibiotic oxytetracycline in sockeye salmon (*Oncorhynchus nerka*) fry: A quantitative approach to tetracycline marking. Alaska Department of Fish and Game, FRED Division Report Series No. 19:22 p.

Koenings, J. P., J. Lipton, and P. McKay. 1986. Quantitative determination of oxytetracycline uptake and release by juvenile sockeye salmon. Trans. Amer. Fish. Soc. 115:621-629.

Koenings, J. P. and R. D. Burkett. 1987. Population characteristics of sockeye salmon (*Oncorhynchus nerka*) smolts relative to temperature regimes, euphotic volume, fry density, and forage base within Alaskan lakes. p. 216-234. *In* H. D. Smith, L. Margolis, and C. C. Woods [ed.] Sockeye salmon (*Oncorhynchus* *nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.

Koenings, J. P., R. D. Burkett, M. Haddix, G. B. Kyle, and D. L. Barto. 1989. Experimental manipulation of lakes for sockeye salmon (*Oncorhynchus nerka*) rehabilitation and enhancement. Alaska Department of Fish and Game, FRED Division Report Series No. 96:18p.

Miller, W. R. III, A. C. Hendricks, and J. Cairns Jr. 1983. Normal ranges for diagnostically important hematological and blood chemistry characteristics of rainbow trout (*Salmo gairdneri*). Can. J. Fish. Aquat. Sci. 40:420-425.

Peltz, L. 1985. Evaluation of hydroacoustics as an estimator of sockeye salmon presmolt numbers in two Southeast Alaska Lakes. Alaska Department of Fish and Game, FRED Division, 2030 Sea Level Drive, Ketchikan, Alaska. Unpublished.

Peltz, L., M. Haddix, and G. Downey 1983. Hugh Smith Lake juvenile sockeye salmon studies, 1981-1983. Alaska Department of Fish and Game, FRED Division, 2030 Sea Level Drive, Ketchikan, Alaska. Unpublished. 10 p.

Peltz, L., M. Haddix, and G. Downey. 1984. Hugh Smith Lake sockeye salmon smolt and fry studies, 1982-1983. Alaska Department of Fish and Game, FRED Division, 2030 Sea Level Drive, Ketchikan, Alaska. Unpublished. 26 p.

Peltz, L., and M. Haddix. 1989. Coded-wire tagging of wild sockeye salmon smolts at Hugh Smith Lake, Alaska. Alaska Department of Fish and Game, FRED Division Report Series No. 90:26p.

Rogers, D. E. 1964. Variability in measurement of length and weight of juvenile sockeye salmon and threespine stickleback. University of Washington, Fisheries Research Institute, Circular No. 224:34 p.

APPENDIX

Sockeye Salmon Fry Feeding Pilot Study of 1985.

On 24 May 1985, newly emerged sockeye fry from Beaver Falls Hatchery were transported in 5 gallon buckets via float plane to Hugh Smith Lake. There were no apparent mortalities due to the transport. The estimated 2,600 fry were divided in three approximately equal lots and placed in 1 x 1 x 1 m pens made of wooden frames and covered with wire screens. The pens were entirely within the epilimnion and were located near the lake outlet. Prior to the first feeding, 30 fish were removed from each pen, bulk weighed, individually measured to the nearest mm, and discarded. This procedure was repeated every 5 days to monitor growth. Juvenile sockeye in pen 1 were not fed while sockeye in pens 2 and 3 were initially fed Oregon Moist Pellet (OMP) #4 and after 15 days switched to OMP soft-moist, fry fine. Juvenile sockeye rations in pens 2 and 3 were approximately 8 grams of OMP per pen. Feeding took place 8 times per day beginning at 1400 hr and ending at 2100 hr. Although sockeye in pen 1 were not fed, some of the OMP ration floated from pen 2 into pen 1.

The growth results are as follows:

	Unfed		Fed			
	Pen 1		Pen 2		Pen 3	
Date	Mean length (mm)	Mean weight (mm)	Mean length (mm)	Mean weight (mm)	Mean length (mm)	Mean weight (mm)
5/15	28.3	0.16	28.0	0.15	28.1	0.15
5/30	28.0	0.16	28.6	0.15	28.5	0.15
6/04	28.0	0.19	29.1	0.24	28.7	0.18
6/09	29.3	0.18	29.2	0.19	29.3	0.21
6/14	29.4	0.19	30.4	0.25	31.0	0.24
6/19	31.0	0.24	32.3	0.27	32.0	0.26
6/24	32.5	0.29	34.8	0.37	34.9	0.38
6/29	35.3	0.38	38.2	0.48	38.5	0.50
7/04	34.8	0.35	39.8	0.59	38.3	0.51
7/09	37.9	0.50	45.3	0.88	44.4	0.80
7/14	37.4	0.47	47.4	1.03	47.6	1.05

All fish in each pen were counted and discarded on 14 July. The pilot study results are summarized as follows:

	Pen 1	Pen 2	Pen 3
Fish removed for growth data	300	302	329
Fish counted at end of experiment	389	412	677
Mortalities from 5/15 to 7/14	70	28	42
Total number in each pen	759	742	1,048
Percent mortalities	9.2	3.8	4.0

Mean water temperatures from daily records.

Date	Mean temperatures
5/21-31	10.4
6/01-10	11.5
6/11-20	11.9
6/21-30	12.2
7/01-10	14.9
7/11-20	15.9

The purpose of this pilot study was to see if juvenile sockeye could be safely held and reared in a lake environment prior to release. The results are encouraging and we feel that the growth rate can be improved. Following a personnel change and a change in the feeding procedure in early July, the sockeye doubled their weight in 10 days.