Fishery Data Series No. 91-2

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[1] This investigation was partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777k) under Project F-10-6, Job No. E-3-1C.

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ABSTRACT

Arctic char *Salvelinus alpinus*, Arctic grayling *Thymallus arcticus*, lake trout *Salvelinus namaycush*, rainbow trout *Oncorhynchus mykiss*, and sockeye salmon *Oncorhynchus nerka* were stocked into and subsequently reared in floating net-pens at Harding Lake, Alaska, during the summer of 1990. Fish were reared between five and 11 weeks and were fed a commercially available semi-moist pelletized diet. Fish were sampled every two weeks to estimate mean length and weight. Arctic grayling and sockeye salmon stocked into net-pens as sac fry exhibited the highest growth (18 percent and 15 percent in length per week, respectively), and they also exhibited the lowest survival (less than 10 percent). Arctic grayling and rainbow trout stocked into net-pens as fingerlings grew 11 percent and 10 percent in length per week, respectively, and the survival for these two groups of fish exceeded 99 percent. Rainbow trout stocked into net-pens at an average length of 128 millimeters grew an average of 6 percent in length per week, and exhibited a survival of 99 percent. Rainbow trout stocked into net-pens at an average length of 215 millimeters grew an average of 3 percent in length per week and none died. Arctic char fingerlings grew an average of 5 percent in length per week and survival exceeded 99 percent. Lake trout fingerlings grew 3 percent in length per week and had a survival of almost 98 percent. Conversion factors and average growth increments per temperature unit (degree-day) for pen reared fish were generally similar to such statistics for the same species of fish when reared in Alaskan hatcheries. Lake trout were an exception exhibiting lower growth and less efficient conversion factors. Construction costs for the net-pen facility totaled $26,000. Costs of operating and maintaining the facility totaled $39,000. Assuming a five year amortization rate for construction costs, the cost of the 1990 net-pen rearing project was estimated to be $44,200. A total of 1,231 kilograms of fish were stocked into net-pens and a total of 4,178 kilograms of fish were released from the net-pens. Thus 2,947 kilograms of fish were produced at the facility at an average cost of $15 per kilogram.

KEY WORDS: Floating net-pens, fish rearing, growth rates, survival, enhancement, Harding Lake, Arctic char, Arctic grayling, lake trout, rainbow trout, sockeye salmon, *Salvelinus alpinus*, *Thymallus arcticus*, *Salvelinus namaycush*, *Oncorhynchus mykiss*, *Oncorhynchus nerka*.

INTRODUCTION

Harvest and abundance of many stocks of wild game fish species in interior Alaska have declined in the past 10 years while angling effort has increased. Most angling pressure in Alaska's interior occurs in road-accessible waters of the Tanana drainage. As a result, the wild stocks in these road-accessible waters have been under steadily increasing pressure. Angling pressure on these wild stocks can be reduced by implementing more restrictive regulations, but these measures are generally unpopular with the angling public (Viavant and Clark 1990). Another solution is to redirect angling pressure toward road-accessible stocked fisheries where fishery conservation is not problematic.

Harding Lake is the largest road accessible lake within 300 km of the major population center of interior Alaska (Fairbanks), and is used extensively as a recreational site by area residents. Private recreational cabins are located along three-quarters of the lake shoreline. Located along the north-western shore of the lake is a park and boat launch facility managed by the Alaska Department of Natural Resources. A second public boat launch facility, owned and maintained by the Fairbanks North Star Borough, is located on the west shore of the lake. Because of its size, accessibility, and proximity to the major population center of interior Alaska, Harding Lake has the potential to provide a major sport fishery for anglers of interior Alaska.

Harding Lake is not presently providing the angling recreation that it could. Angler effort in Harding Lake in 1989 was 4,935 angler days or 4.8 angler days per hectare (Mills 1990). In comparison, angler effort at nearby Birch, Chena, and Quartz lakes in 1989 ranged between 29 angler days per hectare at Quartz Lake, 43 angler days per hectare at Birch Lake, and 150 angler days per hectare Chena Lake. It is apparent that Harding Lake is providing angler opportunity but, at a level substantially less than other nearby lakes that are considered as examples of what might be achieved of such waters in the interior of Alaska.

Burbot *Lota lota* and northern pike *Esox lucius* are the only game fish species endemic to Harding Lake. The burbot population is sparse, and regulations imposed in 1987 reduced bag and possession limits and eliminated the use of set-lines for burbot angling. The northern pike population at Harding Lake is also sparse, and the stock has recently received additional regulatory protection (660 mm minimum size limit, closed to fishing during the spawning season, and elimination of both spear and bow and arrow fishing methods and means). Because native game fish stocks are limited, and because Harding Lake has the potential to support a major recreational fishery, the Department of Fish and Game (ADFG) has introduced various species of non-native fish into Harding Lake over the past 20 years. Species stocked include lake trout *Salvelinus namaycush*, coho salmon *Oncorhynchus kisutch*, inconnu *Stenodus leucichthys*, rainbow trout *Oncorhynchus mykiss*, Arctic grayling *Thymallus arcticus*, Arctic char *Salvelinus alpinus*, and sockeye salmon *Oncorhynchus nerka*.

Historically, the success of the introductions of various game fish species into Harding Lake has been relatively poor. The introduction of lake trout established a small reproducing population, and the resulting lake trout stock supports a small fishery. Introductions of coho salmon and inconnu resulted in few fish harvested by sport anglers, reproduction did not occur, and these species have not been found during recent test netting. Recent stockings of rainbow trout and Arctic grayling resulted in some harvest, but the proportions of harvested fish were low. The recent introduction of sockeye salmon (1988-1990) has not yet led to a fishery. Overall, the introduction of these five species over the last 20 years has failed to meet ADFG expectations of providing a major recreational fishery at Harding Lake. Arctic char were first stocked into Harding Lake in 1988 and these fish are supporting a developing fishery.

Most of the previous stocking efforts at Harding Lake have involved stocking small fish (under 5 g). In general, stocking larger fish results in higher survival rates, however, the cost per stocked fish of larger size is also greater. Demand for large fish from Alaskan hatcheries presently exceeds production. An optimal stocking program produces high densities of catchable fish at the lowest possible cost. Since large numbers of small fish can be stocked into net-pens and reared to a larger size prior to release, successful use of net-pen culture could solve much of the problem associated with the current limited space in Alaska's hatcheries. The cost of rearing fish to larger sizes in floating net-pens should be less per fish than if these same fish were reared in a hatchery. This study was initiated in 1990 and was intended to test the feasibility of the use of net-pens to augment the enhancement efforts in Harding Lake.

The objectives of this study were to estimate growth and survival of Arctic char, Arctic grayling, lake trout, rainbow trout, and sockeye salmon while being reared in floating net-pens in Harding Lake. In addition, costs associated with rearing fish in these floating net-pens were documented.

Site Description

Harding Lake is a landlocked, 1,000 ha lake located 54 km south of Fairbanks, Alaska in the Tanana River drainage. The lake has a maximum depth of 43 m, and a surface elevation of 217 m. The lake is essentially bowl shaped, with the littoral zone underlying 33% of the lake surface. Lake sediments consist mostly of sand or sand and gravel in shallow areas with some silty areas near shore, and loose organic and clay sediment in deeper water (Nakao 1980). Productivity of the lake has been characterized as low (LaPerriere 1975, Nakao 1980), and both conductivity and alkalinity levels are lower than in other large lakes of the Tanana drainage.

METHODS

Pen Construction and Fish Rearing Techniques

Fish were stocked into floating net-pens (nylon delta-weave mesh) with mesh sizes ranging from 0.16 cm to 0.63 cm, depending on fish size at time of stocking (Table 1). Net-pens were hung from floating docks constructed of varnished wood and Styrofoam blocks. The docks were arranged in two gangs of

Table 1. Details concerning pen rearing experiments, Harding Lake, Alaska 1990.

Species	Brood Source	Number Of Fish	Average Weight At Start (g)	Date Fish Were Placed In Pens	Pen Size (m) (Length x Width x Depth)	Fish Density At Time Of Stocking (kg/cubic m)	Mesh Of Pens (cm)	Number Of Pens	Feeding Bouts Per Day
Arctic char	AleknagiK Lake	50,000	5.66	6/18	3.66 x 3.66 x 6.10	0.69	0.48	5	4
Arctic grayling	Moose Lake	30,000	0.25	7/03	1.83 x 1.83 x 1.83	1.22	0.32	1	12
Arctic grayling	Moose Lake	30,000	1.78	8/01	3.66 x 3.66 x 3.66	0.54	0.16	2	12
Lake trout	Paxson Lake	72,000	4.60	6/14	3.66 x 3.66 x 6.10	1.35	0.48	3	4
Rainbow trout	Swanson River	100,000	1.18	6/27	3.66 x 3.66 x 3.66	2.41	0.32	1	8
Rainbow trout	Swanson River	50,000	1.70	7/24	3.66 x 3.66 x 3.66	0.87	0.32	2	8
Rainbow trout	Swanson River	10,061	22.00	6/07	3.66 x 3.66 x 3.66	1.50	0.63	3	2
Rainbow trout	Swanson River	1,000	110.00	7/19	3.66 x 3.66 x 3.66	2.24	0.32	1	2
Sockeye salmon	Gulkana River	100,000	0.16	6/07	1.83 x 1.83 x 1.83	1.30	0.16	2	12

nine pens each, with a center dock running between the gangs of pens. The structure was anchored over 12 m of water in the north-east quadrant of the lake with one large concrete anchor at each end of the structure and 24 smaller concrete anchors along the perimeter of the structure.

Fish were stocked at various sizes and at various dates as dictated by fish availability from several hatcheries. Stocking densities were low (Table 1) due to initial concerns about potential high water temperatures and low dissolved oxygen levels. Fish were fed from 2 to 12 times per day between 09:00 and 19:00 hours. Number of feeding bouts per day varied based on size and species of fish. Daily rations were calculated using standard ADFG methods (F.R.E.D. staff 1983), based on a combination of total kg of fish present in the pen, average water temperature, and anticipated growth rates, condition factors, and conversion factors of the different lots of fish. Fish were fed Biodiet grower feed (Bioproducts Inc.[1]), or Moore-Clark Diet 825 (Moore-Clark Co.[2]). Optimal pellet size of food fed to each lot of fish was determined from a standardized table (FRED staff 1983).

All fish reared in the net-pens were released into Harding Lake during August. Some of the pen reared fish were marked before release. Marking was implemented for the purpose of identifying cohorts for post-release determination of survival, growth, and contribution to the creel. All catchable rainbow trout were tagged with Floy anchor tags and adipose fins were removed prior to release. Two thousand sub-catchable rainbow trout were tagged and left ventral fins were removed prior to release. Right ventral fins were removed from 15,000 fingerling rainbow trout prior to release.

Physical and Chemical Measurements

Temperature was measured and recorded continuously at depths of 0.1 m, 1.5 m, 3.0 m, and 6.0 m from the surface using Ryan model J-90 thermographs[3]. Degree-days were calculated using the 24 hour daily average temperature. For the purpose of calculating growth per temperature unit (degree-day), the stocking date for each experimental group of fish was used as the starting point (zero degree-days) for that group of fish. For 1.8 m deep pens, degree-days were calculated using the mean of the average daily temperature of water at depths of 0.1 m and 1.5 m. For 3.7 m deep pens, degree-days were calculated using the mean of the average daily water temperature at depths of 0.1 m, 1.5 m, and 3.0 m. For 6.0 m deep pens, degree-days were calculated using the mean of the average daily water temperatures at depths of 1.5 m, 3.0 m, and 6.0 m.

Dissolved oxygen (D.O.) profiles were taken daily (except during a period when the instrument failed to function properly) using a Y.S.I.[4] model 51-D dissolved oxygen meter. Dissolved oxygen readings were not checked against

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[1] Bioproducts, Inc. Fish Feeds Division. 1990. P.O. Box 429, Warrenton, Oregon 97146.

[2] Moore-Clark Co. 1990. P.O. Box M, LaConner, Washington 98257.

[3] Peabody/Ryan. 1990. 402 - 6th Street South, P.O. Box 599, Kirkland, Washington.

[4] Yellow Springs Instrument Co. 1990. Yellow Springs, Ohio.

chemical calibration. These measurements were only used as a relative measure of dissolved oxygen content of the water in the pens versus water outside the pens in order to identify potential low dissolved oxygen problems. It was decided at the beginning of the experiment that fish in a pen would not be fed while the measured D.O. level in that pen was substantially below that of the lake.

Growth

Average lengths and weights of fish introduced into the net-pens were estimated at the hatcheries using standard ADFG hatchery methods (F.R.E.D. staff 1983) prior to the transport of the fish to the net-pen rearing station. Total number of fish was estimated by dividing the total weight of fish stocked into the pens (measured prior to fish transport) by the average weight.

At each pen and on an every other week schedule, a sample of fish was collected by dip-net and the entire sample was weighed. Number of fish in the sample was enumerated and the average weight of fish in the sample was calculated. This procedure was repeated three times for fish in each pen.

For all fish except rainbow trout stocked into the pens at an average size of 22 or 110 g, three samples of 50 fish each were measured individually (to the nearest mm of fork length) and total weight of each sample was measured (as described above). For 22 g rainbow trout (sub-catchables), individual weights and lengths were taken from three samples of 50 fish each. For 110 g rainbow trout (catchables), individual weights and lengths were taken for three samples of 25 fish each. Measured weights of individual fish were accurate to ± 0.5 g. All fish sampled were anesthetized with CO_2 prior to being measured or weighed.

Mean length and mean weight of fish was calculated as the simple arithmetic average of individual measurements. The variance for average fish length was calculated as follows:

$$V_1 = (1-f_1)\frac{S_1^2}{n} + f_1(1-f_2)\sum_{i=1}^{n}\frac{S_{2i}^2}{n^2m} + f_1f_2\sum_{i=1}^{n}\sum_{j=1}^{m}(1-f_{3ij})\frac{S_{3ij}^2}{n^2m^2k_{ij}}; \quad (1)$$

$$S_1 = \frac{\sum_{i=1}^{n}(\bar{\bar{y}}_{ij} - \bar{\bar{\bar{y}}})^2}{n-1}; \quad (2)$$

$$S_{2i}^2 = \frac{\sum_{j=1}^{m}(\bar{y}_{ij} - \bar{\bar{y}}_i)^2}{m-1}; \quad (3)$$

$$S_{3ij}^2 = \frac{\sum_{t=1}^{k} (y_{ijt} - \bar{y}_{ij})}{k - 1} \text{ ; and,} \tag{4}$$

where:

i = pen;
n = number of pens;
t = a fish measured for length;
k = number of fish measured for length in a sample;
j = a sample;
m = number of samples;
y_{ijt} = length of fish t from sample j from pen i;
f_1 = fraction of pens sampled;
f_2 = fraction of fish in pen represented by sample;
f_3 = fraction of fish in sample measured for length;

$\bar{\bar{y}}_i$ = average length of fish in pen i; and,

$\bar{y}_{ij}$ = mean length of fish in pen i from sample j.

The variance for average fish weight was calculated as follows:

$$V_1 = (1-f_1)\frac{S_1^2}{n} + f_1(1-f_2)\sum_{i=1}^{n}\frac{S_{2i}^2}{n^2 m}\left[\frac{1}{h}\right]^2 ; \tag{5}$$

$$S_1 = \frac{\sum_{i=1}^{n} (\bar{\bar{y}}_{ij} - \bar{\bar{\bar{y}}})^2}{n - 1} \text{; and,} \tag{6}$$

$$S_{2i}^2 = \frac{\sum_{j=1}^{m} (\bar{y}_{ij} - \bar{\bar{y}}_i)^2}{m - 1} ; \tag{7}$$

where:

h = number of fish weighed in a single sample;

$\bar{y}_{ij}$ = mean weight of fish in a sample; and,

$\bar{\bar{y}}_i$ = mean weight of fish in pen i.

Conversion factors (the rate of conversion of fish food into fish flesh) and condition factors (relative measure of robustness) were calculated using standard ADFG F.R.E.D. Division procedures (F.R.E.D. staff 1983). Conversion factors were calculated as follows:

$$\text{Conversion factor} = \frac{\text{Weight of feed (g)}}{\text{Weight gain of fish (g)}} . \qquad (8)$$

Condition factors were calculated as follows:

$$\text{Condition factor} = \frac{W}{L^3}(1{,}000); \qquad (9)$$

where: W = weight of fish in grams; and,
L = length of fish in mm.

Conversion and condition factors presented in the results section are arithmetic averages from all sampling dates.

Survival

Mortality and hence survival of individual lots of pen reared fish were monitored by removing and enumerating the dead fish from each pen at the beginning of each day. The mortalities from large die-offs were not enumerated directly. In these cases, the total mass of dead fish was measured, and an average weight per fish calculated from a sub-sample of 50 fish. Total mortality was then estimated from the total mass of dead fish. Survival of pen reared fish was calculated by dividing the number of fish alive at the end of rearing regime by the number of fish stocked into the pen at the beginning of the rearing regime.

Costs

Costs associated with these experiments were documented as capital costs (associated with construction of the facility) versus operating costs. Because personnel working on the experiment were also working on other activities, personnel costs, both for the capital and operating phases of the experiment were estimated. These fiscal estimates were based upon the project supervisor's judgement of time spent by staff on pen rearing activities. Other costs were taken directly from accounting ledgers maintained by regional administrative staff.

RESULTS

Physical and Chemical Measurements

Thermal stratification of Harding Lake occurred within the water column utilized by the pens. Water temperatures in the pens varied from 5°C to over 20°C depending on the time of year and water depth. Stratification began to break down in mid-August (Figure 1). Water temperatures remained above 14°C from July 1 through the end of the season, even at a depth of 6 m.

Cumulative degree-days for the 3.7 m deep pens reached 1,264 from the date the pens were first put in the water until the date that the last fish were released (Figure 2). Cumulative degree-days totaled 1,116 as calculated for the 6 m deep pens; a difference of 148 degree-days, or 12% less than for the 3.7 m deep pens. Cumulative degree-days for the 1.8 m deep pens total 1,317, 53 degree-days (4%) higher than for the 3.7 m deep pens, and 201 degree-days (18%) higher than for the 6 m deep pens.

Dissolved oxygen levels (as measured) for lake water outside of the net-pens ranged from 9.2 parts per million (ppm) at 18°C to 8.4 ppm at 19°C. Dissolved oxygen levels in the net-pens ranged from 9.5 ppm at 20.5°C to 5.2 ppm at 18°C.

Growth

Sockeye salmon from the Gulkana Incubation Facility were stocked into Harding Lake pens at an average size of 24 mm and 0.16 g on 7 June. They were released on 2 August and had grown to an average size of 52 mm and 1.64 g over the intervening eight week period (Table 2). Growth as measured by length was relatively linear across this entire time period; whereas, growth as measured by weight increased sharply by early July (Figure 3). Average weekly growth was 14.6% in length and 115.6% in weight for sockeye salmon (Table 2). Average lengths and weights of fish on each of the sampling dates with associated variances are provided in Appendix A.

Two lots of Arctic grayling provided by Clear Hatchery were reared in floating net pens at Harding Lake. The first lot was stocked as sac-fry on 3 July at an average size of 29 mm and 0.25 g and they grew to an average size of 72 mm and 3.88 g by 29 August. Growth for this lot of fish decreased after mid-August (Figure 3). Average weekly growth was 18.2% in length and 178.3% in weight for Arctic grayling sac-fry over the eight week period (Table 2). The second lot of Arctic grayling was stocked into Harding lake pens as fingerlings on 1 August at an average size of 54 mm and 1.78 g. Over a four week period they grew to an average size of 78 mm and 5.22 g (Table 2). Growth of fingerling Arctic grayling was linear (Figure 3). Average weekly growth was 11.1% in length and 48.3% in weight for Arctic grayling fingerlings over the four week period (Table 2). From early July through early August, Arctic grayling stocked as sac-fry into Harding Lake pens grew more rapidly than Arctic grayling sac-fry that were held at Clear Hatchery and subsequently stocked into Harding Lake pens as fingerlings (average size of 1.7 g). After these fish reached fingerling size at the hatchery and were stocked, they grew faster than did the Arctic grayling originally stocked into pens as sac-fry (Figures 3 and 4) and, they reached a larger size at release (Table 2).

Four groups of rainbow trout from the Fort Richardson Hatchery were reared in pens at Harding Lake. Fingerling rainbow trout stocked into pens at an average size of 47 mm and 1.2 g on 27 June grew to an average size of 88 mm and 6.9 g by 29 August (Table 2). Growth appeared to be linear across this eight week period (Figure 3). Average weekly growth was 9.7% in length and

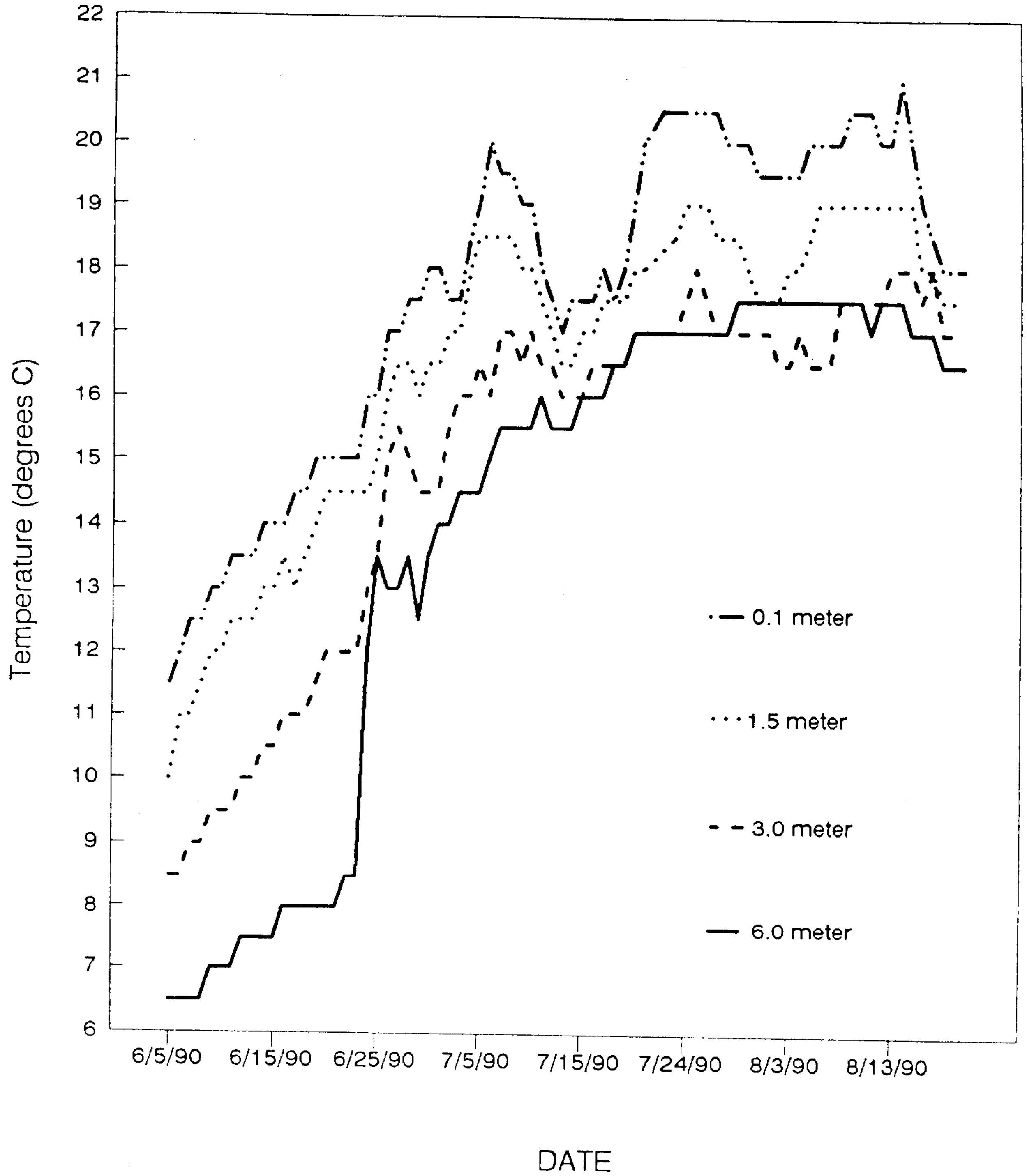


Figure 1. Water temperatures at various depths within a 6.0 m deep pen at the experimental fish rearing facility, Harding Lake, Alaska, 1990.

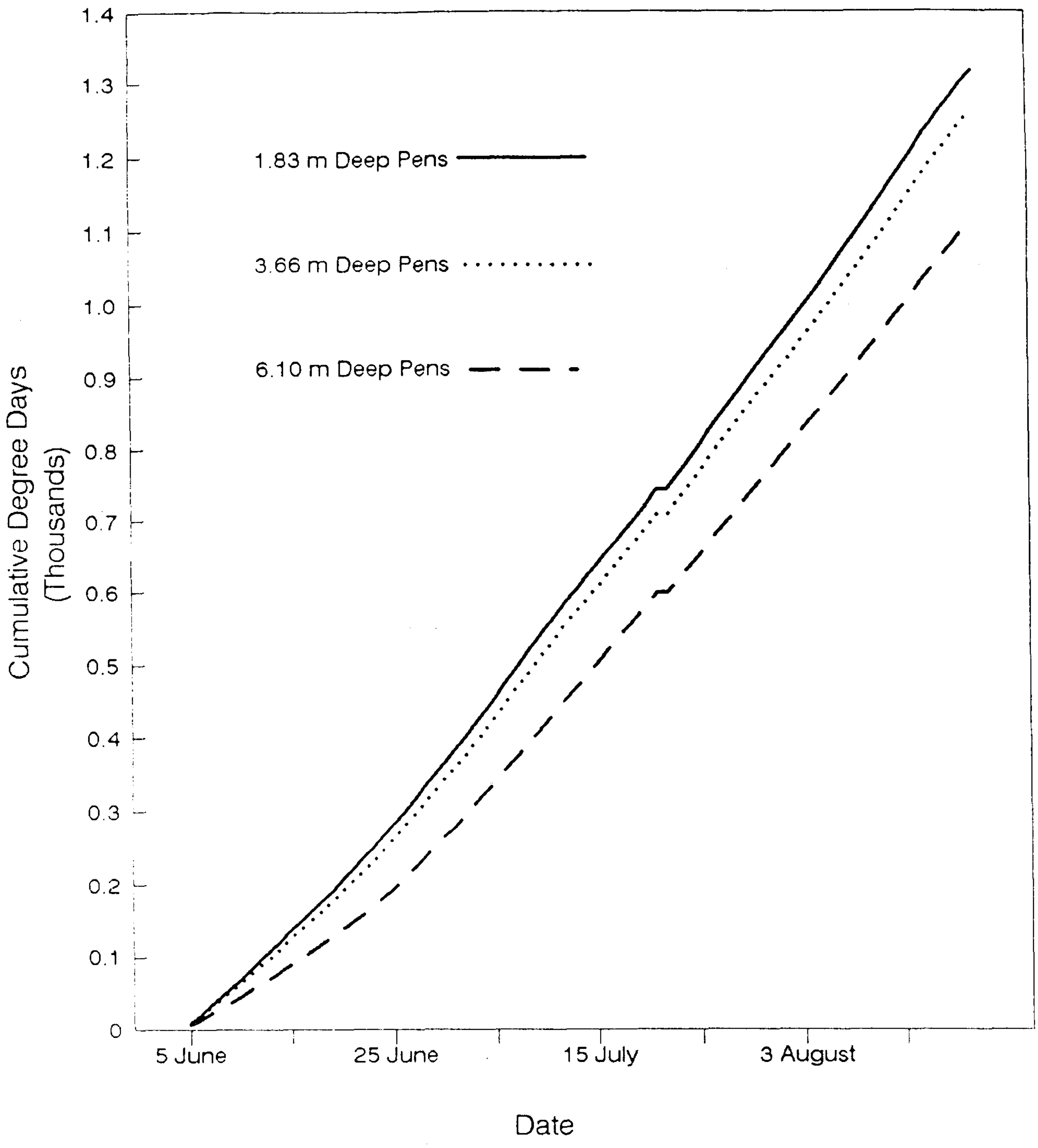


Figure 2. Cumulative degree-days calculated for three pen designs used at the experimental fish rearing facility, Harding Lake, Alaska, 1990.

Table 2. Growth and survival of fish reared in net-pens, Harding Lake, Alaska, 1990.

Species And Category Of Fish Placed In Pens	Number Of Fish Stocked	Number Of Fish Released	Date Of Stocking	Date Of Release	Length Of Rearing (days)	Percent Survival	Weight: Average (g) Stocked	Weight: Average (g) Released	Weight: Percent Gain	Weight: Percent Growth Per Week	Weight: Growth g/Day	Length: Average (mm) Stocked	Length: Average (mm) Released	Length: Percent Gain	Length: Percent Growth Per Week	Length: Growth mm/day
Rainbow trout																
catchables	1,000	1,000	7/19	8/26	38	100.0	110.0	177.0	60.9	11.2	1.76	215	245	14.0	2.6	0.79
subcatchables	10,061	9,970	6/07	8/25	79	99.1	22.0	125.5	470.5	41.7	1.31	128	212	65.6	5.8	1.06
fingerlings	100,000	99,907	6/27	8/29	63	99.9	1.2	6.9	475.0	52.8	0.09	47	88	87.2	9.7	0.65
fingerlings	50,000	49,912	7/24	8/28	35	99.8	1.7	3.2	88.2	17.6	0.04	51	63	23.5	4.7	0.34
Sockeye salmon	100,000	289	6/07	8/02	56	0.3	0.16	1.64	925.0	115.6	0.03	24	52	116.7	14.6	0.50
Arctic grayling	30,000	2,400	7/03	8/29	57	8.0	0.25	3.88	1452.0	178.3	0.06	29	72	148.3	18.2	0.75
Arctic grayling	30,000	29,972	8/01	8/29	28	99.9	1.78	5.22	193.3	48.3	0.12	54	78	44.4	11.1	0.86
Arctic char	50,000	49,887	6/18	8/27	70	99.8	5.66	20.07	254.6	25.5	0.21	79	121	53.2	5.3	0.60
Lake trout	73,000	71,446	6/14	8/27	74	97.9	4.6	10.27	123.3	11.7	0.08	78	100	28.2	2.7	0.30

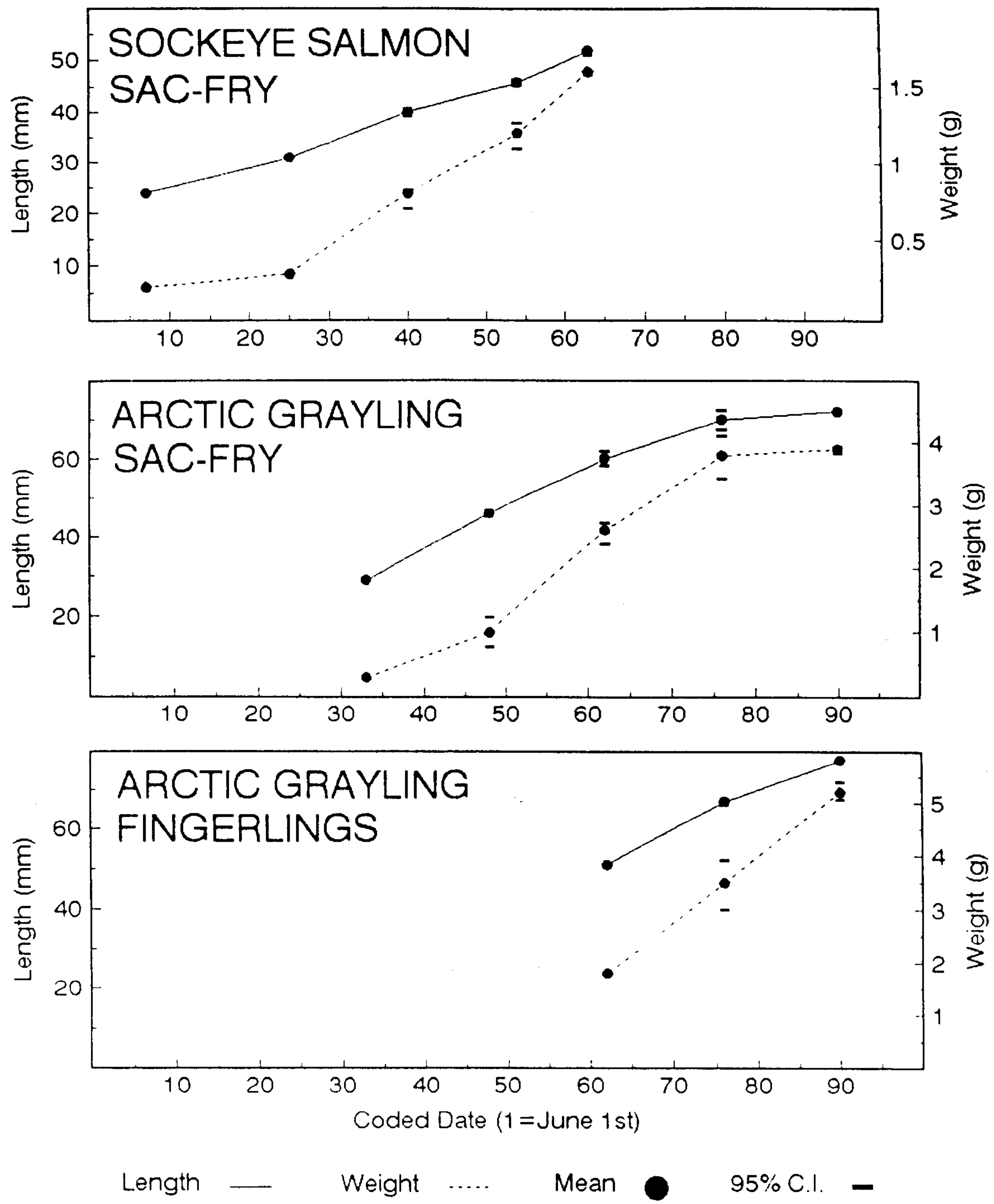


Figure 3. Mean length and weight of fish reared in net-pens, Harding Lake, Alaska, 1990.

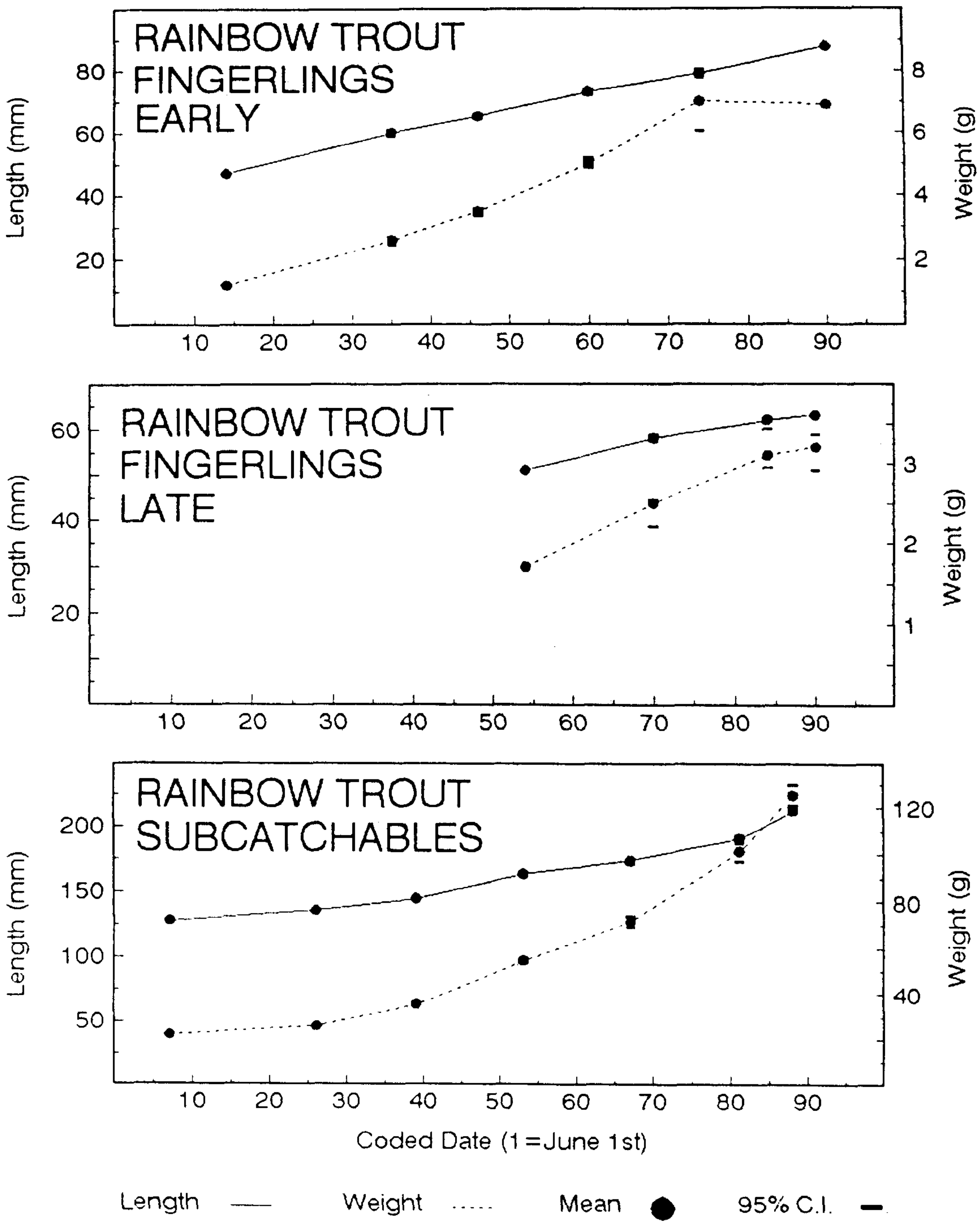


Figure 3. (2 of 3)

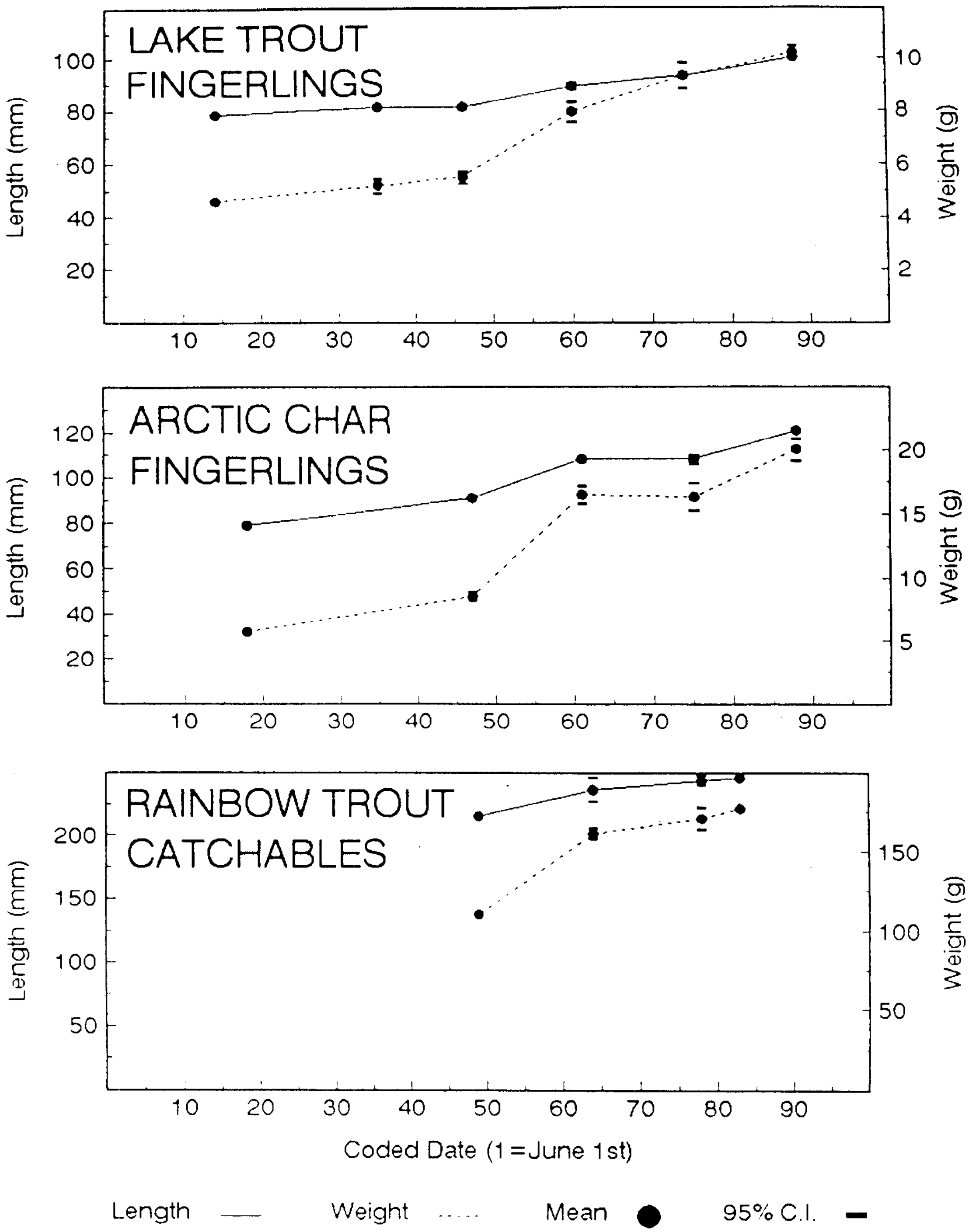
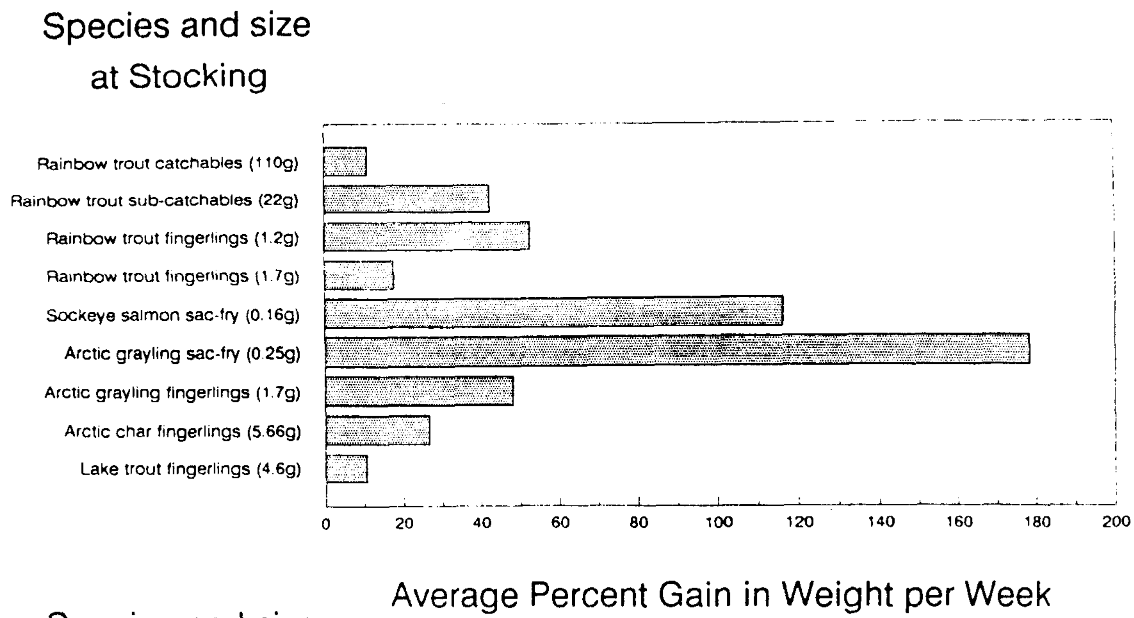


Figure 3. (3 of 3)



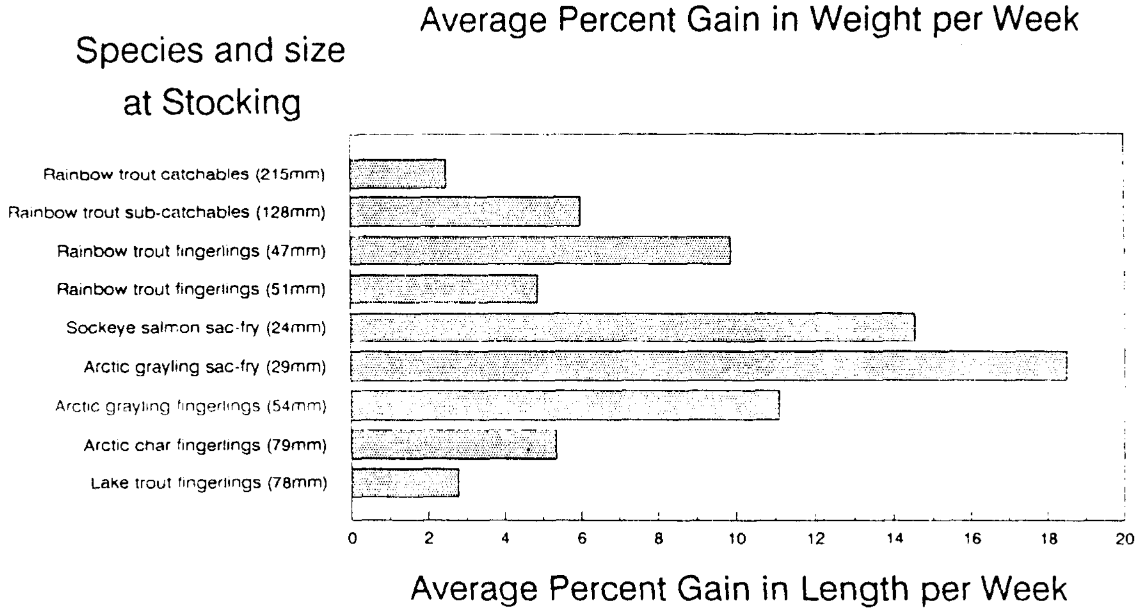


Figure 4. Average weekly percent gain in weight and length for fish reared in net-pens, Harding Lake, Alaska, 1990.

52.8% in weight for this lot of fish (Table 2). A second lot of fingerling rainbow trout stocked into the pens on 24 July at an average size of 51 mm and 1.7 g grew to an average size of 63 mm and 3.2 g by 28 August. Growth of the second lot of fingerling rainbow trout was substantively slower than was the case for the lot stocked into the pens on 27 June (Figure 4). Sub-catchable rainbow trout were stocked into the pens on 7 June at an average size of 128 mm and 22 g. This lot of fish grew to an average size of 212 mm and 125.5 g by the time they were released on 25 August (Table 2). Growth as measured by length was relatively linear across these 11 weeks, but was exponentially increasing as measured by weight (Figure 3). Average weekly growth of sub-catchable rainbow trout was 5.8% in length and 41.7% in weight (Table 2). Catchable rainbow trout were reared in Harding Lake pens over a five week period from 19 July through 26 August. They averaged 215 mm and 110 g when stocked and had grown to an average size of 245 mm and 177 g by the time they were released (Table 2). Average weekly growth of catchable rainbow trout was 2.6% in length and 11.7% in weight (Figure 4).

Lake trout from Clear Hatchery were stocked into the Harding Lake pens at an average size of 78 mm and 4.6 g on 14 June. They were released 11 weeks later on 27 August and had grown to an average size of 100 mm and 10.27 g (Table 2). Growth as measured by length was relatively linear across this entire time period; whereas, growth as measured by weight increased somewhat in mid-July (Figure 3). Average weekly growth of lake trout was 2.7% in length and 11.7% in weight (Table 2).

Arctic char from Clear Hatchery were stocked into the net-pens at an average size of 79 mm and 5.66 g on 18 June. They were released on 27 August. By the time of release, Arctic char had grown to an average size of 121 mm and 20.07 g (Table 2). Growth as measured by length and by weight varied across the intervening 10 week period (Figure 3). Average weekly growth of Arctic char was 5.3% in length and 25.5% in weight (Table 2).

Growth adjusted for cumulative degree-days differed somewhat from growth expressed as percent gain per week. Average length gain per degree-day was highest for sub-catchable rainbow trout, followed by Arctic grayling sac-fry and fingerlings and Arctic char fingerlings (Table 3). Sockeye salmon sac-fry and rainbow trout fingerlings demonstrated relatively low average growth per degree-day; whereas, these lots of fish demonstrated higher average weekly percent growth than most other lots of fish. This inconsistency has to do with the differences between growth expressed as percent gain versus absolute gain. Because very small fish gain both length and weight rapidly compared to larger fish, growth of small fish expressed as a percentage gain will almost always be higher than will be the case for larger fish. Lake trout were consistent in having the lowest average growth per degree day and the lowest average percent weekly growth.

Condition factors were relatively similar for all lots of pen-reared fish. Lake trout and sockeye salmon demonstrated slightly smaller average condition factors and fingerling and sub-catchable rainbow trout demonstrated slightly larger average condition factors (Table 3). Conversion factors (the metabolic conversion of fish food into fish biomass) were generally best (lowest) for rainbow trout, except that catchable rainbow trout demonstrated the highest

Table 3. Average growth per degree-day, average condition factors, and average conversion factors for fish reared in net-pens at Harding Lake, 1990.

Species and Mean Weight (g) at Stocking	Average Condition Factor	Average Conversion Factor: Pen Reared	Average Conversion Factor: Clear Hatchery[b]	Average Growth Per Temperature Unit (mm/degree-day): Pen Reared	Average Growth Per Temperature Unit (mm/degree-day): Clear Hatchery[b]
Arctic char (5.7)	0.012	1.57	1.30	0.048	0.037
Arctic grayling (0.25)	0.011	1.74	1.65	0.049	0.055
Arctic grayling (1.7)	0.012	1.54	NA	0.049	NA
Lake trout (4.6)	0.011	2.43	1.14	0.019	0.042
Rainbow trout:					
Fingerling (1.2)	0.013	0.81	1.50	0.030	0.042
Fingerling (1.7)	0.013	1.48	NA	0.019	NA
Sub-catchable (22)	0.013	1.32	NA	0.054	NA
Catchable (110)	0.012	3.89	NA	0.041	NA
Sockeye salmon (0.16)	0.011	NA[a]	NA	0.030	NA

[a] Conversion factors were not calculated for sockeye salmon.
[b] These values represent averages for all sizes of fish from 1986 through 1988.

conversion factor (least efficient) of all lots of fish that were pen-reared (Table 3). Lake trout had a high (least efficient) conversion factor compared with most other groups of pen-reared fish.

<u>Survival</u>

Survival was high for all but two lots of pen-reared fish (Table 2). Arctic char, all rainbow trout, and Arctic grayling fingerlings survived at levels in excess of 99%. Survival of lake trout was almost 98%. All of the mortalities associated with Arctic char, lake trout, rainbow trout (of all sizes), and fingerling Arctic grayling occurred as deaths of one or two fish at a time, spread out over the entire season. Most mortalities of lake trout occurred during the last several weeks of their pen rearing period, when groups of 10 to 20 fish were dying daily in each of three pens.

Survival of sockeye salmon stocked as sac-fry was 0.3% (Table 2). Sockeye salmon mortality occurred largely during the first three weeks of their rearing period. However, smaller numbers of sockeye salmon continued to die throughout the entire period that the fish were reared. Survival of Arctic grayling stocked as sac-fry was 8.0% (Table 2). Almost all of the Arctic grayling sac-fry deaths were the result of a mass mortality that occurred six days after the fish were stocked into the net-pens. This die-off occurred concurrent with the accidental feeding of a large amount of food to this lot of fish by a young visitor.

<u>Costs</u>

Capital costs associated with the project totaled $26,088. Most capital costs were directly related to the purchase of commodities needed for initial construction of the net-pen facility. Operating costs over the time that fish were reared totaled $38,914 and most were labor costs associated with feeding of fish and routine facility maintenance. A listing of costs associated with the project is provided in Appendix B.

<u>Public Visitation</u>

Public visitation to the net-pen facility was much higher than expected. While the net-pen facility was operating at Harding Lake (82 days), 2,494 visitors toured the facility. Some of these visitors had previously visited the facility (individuals numbered over 1,000 but less than 2,000). The majority of these visitors came to the pens during weekends when the weather was good. Comments concerning the project were almost entirely positive and members of the public who toured the facility supported ADFG's efforts to enhance the Harding Lake sport fishery. Visitation was so high on several weekends early in the season that the staff at the facility had difficulty conducting research activities. It became necessary to have a staff member present at the facility on weekends to accommodate visitors (giving tours and answering questions) so that the regular staff could maintain feeding schedules.

DISCUSSION

Physical and Chemical Measurements

Water temperatures in the net-pens were fairly warm, particularly after late June. Water temperatures did not reach lethal levels for the five species of fish reared in the pens, although surface water temperature approached lethal levels for Arctic char and lake trout (Martin and Olver 1980). Arctic char and lake trout were reared in 6.10 m deep pens rather than standard 3.66 m deep pens because of their intolerance to high temperatures. Water temperatures in the lower, cooler portions of these 6.10 m deep pens did not approach the lethal maximum for those two fish species.

Water temperatures in the Harding Lake pens were generally higher and more variable than water temperatures used in hatcheries. Water temperatures at Clear Hatchery (the source for Arctic grayling, Arctic char, and lake trout) and at Fort Richardson Hatchery (the source for rainbow trout) average less than 13°C. Despite the more variable and lower water temperatures the Harding Lake pens during the early portion of the rearing season, cumulative degree days over the entire rearing season were higher than at Clear and Fort Richardson Hatcheries for the same length of time. These higher water temperatures led to increased metabolic rates, and in some cases, to more rapid growth.

Dissolved oxygen levels in the net-pens became low enough to be of concern only on one day. Low levels of dissolved oxygen were probably related to attached algae clogging the mesh of the rearing pens. This problem was largely avoided by frequent cleaning of the mesh using a high pressure water pump. Use of larger mesh pens would lessen the cost of maintaining the Harding Lake pen rearing facility.

Growth

Fish stocked into the Harding Lake pens at smaller sizes generally demonstrated faster growth (expressed as average percent gain per week) than did fish stocked at larger sizes. This result is primarily due to the size of the fish, and the method of expressing growth. Growth expressed in another manner, grams gained per day, was highest for rainbow trout catchables. Fish that were stocked into the pens earlier in the season tended to grow faster than those fish stocked later, even when both cohorts were of similar size (Table 2, Figure 3). Rainbow trout fingerlings stocked at an average size of 47 mm and 1.2 g in late June grew faster than rainbow trout fingerlings of the same stock that had been held at Fort Richardson Hatchery and subsequently stocked in late July at an average size of 51 mm and 1.7 g. The rainbow trout fingerlings stocked in late June had a higher weekly growth and reached a larger size at release. Sub-catchable rainbow trout stocked at an average size of 128 mm and 22 g grew faster than catchable rainbow trout stocked at an average size of 215 mm and 110 g when growth was expressed as average percent gain in length or weight per week or expressed as average gain in mm per day but grew slower when growth was expressed as average gain in g per day.

While the lot of Arctic grayling stocked in early July at an average size of 29 mm and 0.25 g demonstrated a higher weekly percent growth, the lot of Arctic grayling held at Clear Hatchery and subsequently stocked in early August at an average size of 54 mm and 1.78 g reached a larger size at release (Table 2). It is possible that the Arctic grayling stocked at an average size of 29 mm and 0.25 g reached a smaller release size because they were held in 1.8 m deep pens. There were more problems with net fouling in these shallow pens than in the larger pens. Also, shallow pens prevented fish from descending into cooler, deeper water that may have been more optimal for growth.

Arctic grayling and sockeye salmon stocked as sac-fry demonstrated the highest average percent weekly growth, but they also exhibited low survival. Sub-catchable rainbow trout grew faster than rainbow trout stocked as fingerlings in late July, but slower than rainbow trout fingerlings stocked in late June. Rainbow trout stocked into the net-pens at subcatchable size combined rapid growth and high survival prior to release with large size at release and high potential return to the creel. These factors made them the cohort reared in 1990 most likely to provide minimum cost to the creel.

Growth adjusted for water temperatures in the pens (mm/degree-day) was highest for rainbow trout sub-catchables. Average growth expressed as mm per degree-day for Arctic char was faster than that reported for Arctic char reared at Clear Hatchery (Table 3). The opposite was the case for Arctic grayling, lake trout, and rainbow trout (Table 3). However, growth based on thermal units in the pens are only approximations due to the heterogeneity of the water column and the difficulty of determining how many temperature units the fish were exposed to.

Conversion factors were least (most efficient) for rainbow trout fingerlings stocked in late June and for sub-catchable rainbow trout (Table 3). The best rate of conversion was demonstrated by rainbow trout fingerlings stocked in late June at an average size of 47 mm and 1.2 g. It is unclear why this group of rainbow trout fingerlings had a conversion rate so much better than the rainbow trout fingerlings stocked in late July. Possibly there was an extensive acclimation period (perhaps several weeks) before fish stocked into pens began feeding efficiently.

The average conversion factor for rainbow trout catchables was very high (less-efficient conversion). This was likely due to several factors. For a period of several weeks, catchable rainbow trout were fed food of a size that was much smaller than optimal. During the last two weeks of their rearing regime, the quantity of food provided to catchable rainbow trout was increased substantially, but it was discovered just prior to release that not all of the food was being consumed.

Lake trout demonstrated a high average conversion factor. Lake trout grew more slowly than anticipated. Due to the difficulty of observing feeding behavior at depth, lake trout may not have been consuming all of the food that was provided to them. Lake trout may also simply be less efficient at converting food into biomass than other species reared in the net-pens.

Conversion factors were lower (more efficient conversion) for Arctic char and rainbow trout reared in the net-pens than for the same species reared at Clear Hatchery (Table 3). Average conversion factor for Arctic grayling stocked as sac-fry in the net-pens was higher than the rate documented for Arctic grayling sacfry at Clear Hatchery, but was lower for Arctic grayling stocked as fingerlings in the net-pens than for Arctic grayling fingerling reared at Clear Hatchery. Average conversion factor for lake trout reared in floating net-pens was substantially higher (less efficient conversion) than the rate reported for lake trout reared at Clear hatchery.

Survival

Survival was high for all lots of pen reared fish with the exception of sockeye salmon and Arctic grayling stocked as sac-fry. Survival of all lots of rainbow trout, Arctic char, lake trout, and for fingerling Arctic grayling exceeded expectations developed as the fish rearing facility was planned.

Survival of sockeye salmon was almost zero. Sockeye salmon deaths occurred primarily within the first three weeks after the fish were stocked into the pens, but smaller numbers of fish continued to die through the remaining rearing period. The high mortality exhibited by sockeye salmon soon after stocking may have been due to the relatively poor condition of the fish at the time they were stocked into the Harding Lake rearing pens. Sockeye salmon were fed a maintenance diet for several weeks prior to arriving at the Harding Lake facility rather than being fed a diet intended to allow substantive growth. The relative stunting of growth at such a small size, the shock associated with transport, and the adjustment to much warmer water temperatures at the Harding Lake rearing facility probably contributed to the high mortality rate.

Survival of Arctic grayling stocked as sac-fry was low (8%). Arctic grayling sac-fry deaths occurred primarily as a single massive die-off soon after the fish were stocked. Just prior to this mortality event, the entire amount of food scheduled to be given to Arctic grayling sac-fry was spilled into the pen. Many of the dead fish removed from the pen had ruptured abdomens, and it may be that these fish died as a result of overfeeding. The spilled food was starter mash, and it could not be adequately removed from the pen after the accidental spill occurred. As this spilled starter mash decomposed, biological oxygen demand may have depressed dissolved oxygen levels to a degree that was lethal to the Arctic grayling sac-fry in the small (1.8 m x 1.8 m x 1.8 m) pens.

Small pens with small sized mesh were used to rear both Arctic grayling and sockeye salmon sac-fry. These are the same cohorts that demonstrated low survival. Water temperatures within these pens were typically higher than in the larger and deeper net-pens. The small mesh was more difficult to clean during routine maintenance and net fouling occurred more often. Considering these difficulties, it will likely be more difficult and challenging to develop successful fish culture techniques for the rearing of sac-fry in the floating net-pens of Harding Lake.

Costs

Costs associated with construction of the floating net-pen fish rearing facility should be considered to be one-time costs to be amortized over a five year period.

Costs of rearing fish at the net-pen facility in 1990 are estimated to have totaled $44,200 (20% of construction costs plus all operational costs). A total of 1,231 kg of fish (all cohorts of all five species) were stocked into net-pens. A total of 4,178 kg of live fish were released. Thus, 2,947 kg of fish were produced at the rearing facility at an average cost of about $15 per kilogram. Operating costs would have been substantially less if the objective of the project were simply to rear fish to a larger release size. Because of the research goals of this project, staffing levels were higher than would be needed if the project were conducted with the sole objective of rearing fish for release.

Recommendations

Based upon the results of rearing fish in floating net-pens at Harding Lake in the summer of 1990, several recommendations can be made. The project was adequately successful to be continued. Small mesh netting should be avoided to the extent practical. Fish should be stocked into pens constructed with mesh just small enough to contain average sized fish, even if this means that the smaller fish in the rearing lot will potentially escape through the mesh. The use of 1.8 m deep pens should be minimized due to high surface water temperatures that occur in mid-summer. Because of high water temperatures with corresponding high growth, sampling of penned fish every week rather than every two weeks should lead to better calculations of the appropriate quantity of food to be provided, in turn leading to improved growth and conversion rates. Rainbow trout fingerlings should be stocked into floating pens soon after reaching one gram rather than being held at the Fort Richardson Hatchery until later in the summer. Arctic grayling, on the other hand, will likely survive at a higher rate and grow faster if they are held at Clear Hatchery until reaching an average size of one gram before introduction into the net-pens. Sub-catchable rainbow trout stocked into the Harding Lake net-pens in early June and reared to catchable size prior to release will likely provide the most cost effective option for enhancing the sport fishery of Harding Lake

ACKNOWLEDGEMENTS

Thanks to Mike Doxey of Sport Fish Division and to Dave Parks, Terry Ellison, and other staff of the Fisheries Rehabilitation, Enhancement, and Development Division for advice and support. Thanks to the property owners and the general public users of Harding Lake, whose comments while visiting the facility were almost entirely positive. Fred Andersen, Mike Doxey, Pat Hansen, and Peggy Merritt provided constructive criticisms of an earlier draft of the report. Thanks to Sara Case and Saree Timmons for word processing support and development of the figures. This research was made possible by partial funding provided by the U.S. Fish and Wildlife Service through the

Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under project F-10-6, Job Number E-3-1C.

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APPENDIX A

Appendix A. Average lengths and weights with associated variances at stocking, at various sampling dates, and at release for fish reared in net-pens, Harding Lake, 1990.

	Length (mm)		Weight (grams)	
Date	Average	Variance	Average	Variance
Sockeye Salmon Sac-Fry:				
6/7 (stocking)	24	NA	0.16	NA
6/25	31	0.014	0.28	0.000
7/10	40	0.118	0.76	0.001
7/24	46	0.095	1.18	0.002
8/2 (release)	52	0.029	1.64	0.001
Arctic Char Fingerlings:				
6/18 (stocking)	79	NA	5.66	NA
7/17	91	0.253	8.47	0.032
7/31	108	0.291	16.51	0.122
8/14	108	1.064	16.34	0.293
8/27 (release)	121	NA	20.07	0.197
Arctic Grayling Sac-Fry:				
7/3 (stocking)	29	NA	0.25	NA
7/18	46	0.217	1.01	0.013
8/1	60	0.822	2.55	0.008
8/15	70	1.614	3.77	0.029
8/29 (release)	72	NA	3.88	0.0008
Arctic Grayling Fingerlings:				
8/1 (stocking)	51	NA	1.78	NA
8/15	67	0.185	3.46	0.054
8/29 (release)	77	NA	5.22	0.007
Lake Trout Fingerlings:				
6/14 (stocking)	78	NA	4.60	NA
7/5	81	0.269	5.17	0.020
7/16	81	0.171	5.48	0.013
7/30	89	0.372	7.90	0.038
8/13	93	0.503	9.31	0.066
8/27 (release)	100	NA	10.21	0.020

- continued -

Appendix A. (page 2 of 2).

Date	Length (mm)		Weight (grams)	
	Average	Variance	Average	Variance
Rainbow Trout Fingerlings Stocked in June:				
6/27 (stocking)	47	NA	1.18	NA
7/12	60	0.272	2.59	0.004
7/26	65	0.125	3.47	0.004
8/9	73	0.207	5.01	0.007
8/23	79	0.407	7.01	0.258
8/29 (release)	88	NA	6.89	0.002
Rainbow Trout Fingerlings Stocked in July:				
7/24 (stocking)	51	NA	1.7	NA
8/9	58	0.134	2.54	0.029
8/23	62	0.029	3.10	0.006
8/29 (release)	63	NA	3.21	0.022
Rainbow Trout Sub-catchables:				
6/7 (stocking)	128	NA	22.0	NA
7/9	145	0.021	35.3	0.004
7/23	164	0.112	54.7	0.317
8/6	174	0.760	71.6	1.607
8/20	191	1.433	101.3	3.941
8/27 (release)	212	NA	125.5	5.604
Rainbow Trout Catchables:				
7/19 (stocking)	215	NA	110.0	NA
8/3	236	21.658	161.1	3.175
8/17	243	4.261	170.5	12.285
8/22 (release)	245	NA	177.0	NA

APPENDIX B

Appendix B. Capital and operating costs associated with the Harding Lake experimental fish rearing facility, 1990.

Expense Item			Cost
Capital Costs:			
Net-pens			$ 8,426
Dip-nets			140
Floating Docks			
Lumber			3,744
Styrofoam floats			849
Hardware			1,070
PVC frames			900
Rope, Paint, Misc			864
Labor (to construct docks)			8,200
Sampling equipment			295
Pump (to clean netting)			600
Signs			1,000
Total Capital Expenses			$26,088
Operating Costs:			
Labor			
Student Assistant	3 mo.	@ $1,044.00/mo	$ 3,432
Student Assistant	3 mo.	@ $1,044.00/mo	3,432
Graduate Student	4 mo.	@ $800.00/mo	3,200
Fishery Biologist II	4 mo.	@ $4,200.00/mo	16,800
Fish food			6,202
Transportation			1,575
Employee housing			4,273
Total			38,914
Total Operating Expenses			$38,914