Evaluation of Arctic Grayling Enhancement: A Cost Per Survivor Analysis

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EVALUATION OF ARCTIC GRAYLING ENHANCEMENT: A COST PER SURVIVOR ANALYSIS

A

THESIS

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ABSTRACT

Age-0 Arctic grayling *Thymallus arcticus* were stocked as sac fry and fingerlings in lakes in interior and south central Alaska to evaluate cost per survivor at age 1. When sac fry, 4-g, and 6-g fingerlings were stocked in the same lakes in 1986, estimates of the mean rate of survival at age 1 were 0.08, 0.63, and 0.75. The differences were significant. The mean costs per survivor at age 1 were $1.58, $0.24, and $0.21. The differences were significant between sac fry and both sizes of fingerlings. However, the difference was not significant between 4-g and 6-g fingerlings. When sac fry and 4-g fingerlings were stocked in different lakes in 1986 and again in 1987, estimates of the mean rate of survival to age 1 were 0.11 and 0.34. The difference was significant. The mean costs per survivor at age 1 were $0.82 and $0.70. The difference was not significant. I recommend stocking 4-g fingerlings because they require less rearing in a hatchery than 6-g fingerlings and the cost per survivor is usually less than that for sac fry.

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INTRODUCTION

To improve sport fishing opportunities, the Alaska Department of Fish and Game (ADFG) has stocked Arctic grayling *Thymallus arcticus* sac fry into lakes since 1961. As many as 3 million Arctic grayling sac fry are now stocked into Alaskan lakes each year. There are, however, two major disadvantages with stocking sac fry: (1) the few estimates of survival rate that were made indicate that the survival rate of Arctic grayling sac fry during a four to eleven month period is low (1 to 34%), especially when stocked into lakes that have other species (Havens 1986; Holmes 1985; Jennings 1983; Ridder 1981, 1985); and (2) because the survival rate is low, large numbers of Arctic grayling eggs must be taken each year from indigenous stocks. These egg takes are expensive and the number of eggs required for all stocking projects is not always obtained (Jennings 1983).

The ADFG began stocking Arctic grayling fingerlings in 1985 because the survival rate was thought to be higher when fingerlings were stocked (Havens 1986; Holmes 1985; Ridder 1985). Fingerlings, however, cost more to produce than sac fry because they require up to 4 months of rearing in a hatchery. In contrast, the cost per sac fry is low because sac fry are usually stocked within a week of hatching. To justify stocking Arctic grayling fingerlings, the increased survival rate should at least offset the additional cost of producing them.

A comparison of survival rates from past studies (Havens 1986; Holmes 1985, 1986; Jennings 1983; Peckham 1975; Ridder 1985) for Arctic grayling stocked at different sizes (weight) is difficult because: (1) the sizes of the stocked Arctic grayling and the stocking densities were not consistent between experiments; (2) the Arctic grayling brood source was different between some of the studies; and (3) climatic factors may confound any comparisons because the studies were separated by 3 to 10 years.

The purpose of my project was to determine the best size (weight) to stock age-0 (young-of-year) Arctic grayling. I did this by comparing the estimates of the costs per survivor of age-1 Arctic grayling that had been stocked as sac fry and fingerlings in lakes near Fairbanks, Glennallen, and Palmer. Information was also collected to determine if species composition and potential lake productivity influenced the survival rate and growth of stocked Arctic grayling.

METHODS

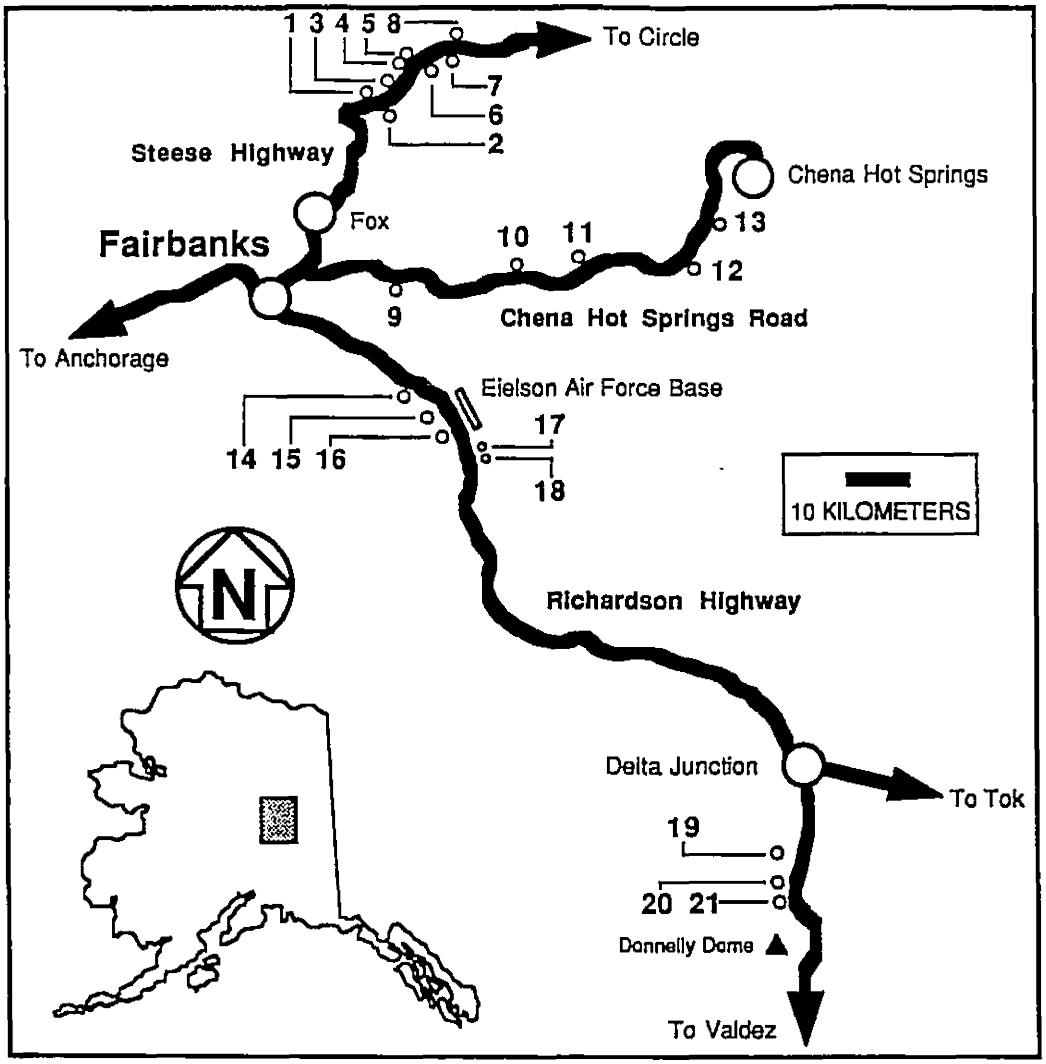
The lakes used for this research are located near Fairbanks, Glennallen, and Palmer (Figures 1, 2, and 3). These three areas have on-going Arctic grayling stocking programs. The lakes are small (most are less than 12 ha), have easy access, and are easy to sample. They have a mix of physical and biological environments and include barren lakes (no fish present), lakes with previously stocked Arctic grayling, and lakes with other predator and competitor species such as rainbow trout *Oncorhynchus mykiss*, threespine stickleback *Gasterosteus aculeatus*, lake trout *Salvelinus namaycush*, burbot *Lota lota*, and northern pike *Esox lucius* (Appendix 1).

Stocking Costs

The ADFG hatchery at Clear Air Force Station, near Anderson, Alaska, produced sac fry, 4-g, and 6-g Arctic grayling for my study. The cost of producing sac fry, 4-g, and 6-g fingerlings at Clear Hatchery was calculated by the hatchery manager from hatchery records. The cost per fish when stocked was calculated as the total cost of producing and stocking a size group divided by the number of fish in that size group.

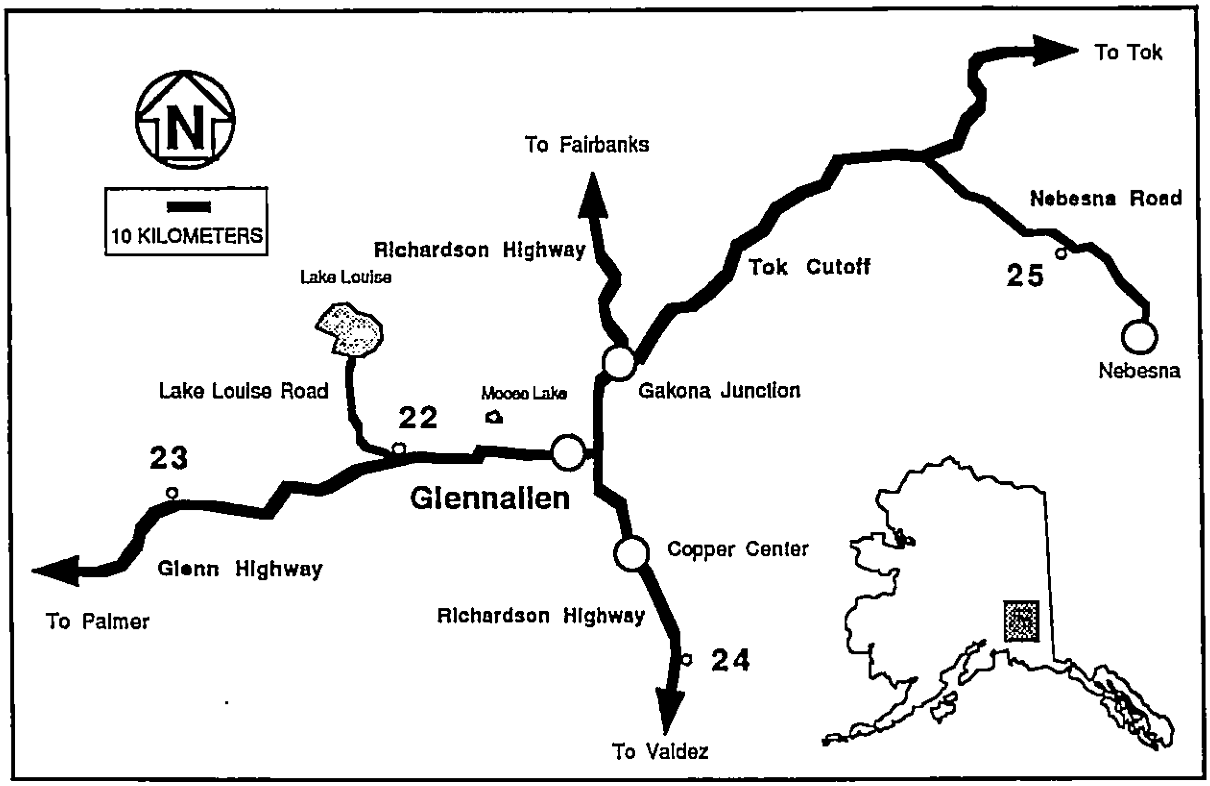
Estimates of Abundance, Survival Rate, and Cost per Survivor

The cost per survivor was estimated using multiple and single size group stocking experiments. In the multiple size group stocking experiment, Arctic



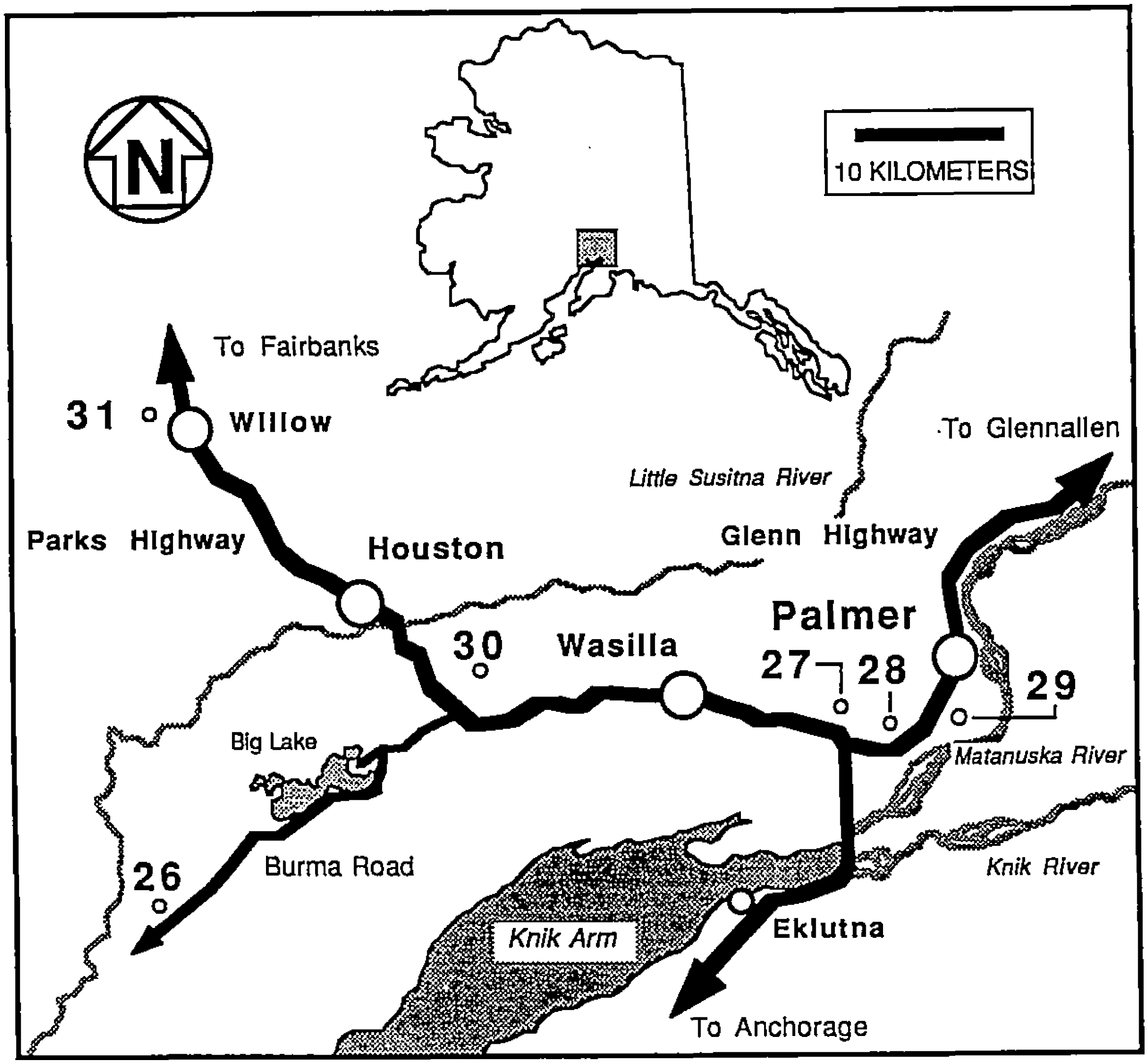
Code	Lake Name	Code	Lake Name
1	Steese Highway 29.5 Mile	12	Chena Hot Springs Road 45.5 Mile
2	Steese Highway 30.6 Mile	13	Chena Hot Springs Road 47.9 Mile
3	Steese Highway 31.6 Mile	14	Bathing Beauty
4	Steese Highway 33.0 Mile	15	Hidden Lake
5	Steese Highway 33.5 Mile	16	Grayling Lake
6	Steese Highway 34.6 Mile	17	Johnson Road Pit #1
7	Steese Highway 35.8 Mile	18	Johnson Road Pit #2
8	Steese Highway 36.6 Mile	19	Sheefish Lake
9	Walden Pond	20	Luke Lake
10	Chena Hot Springs Road 32.9 Mile	21	Unnamed Lake
11	Chena Hot Springs Road 42.8 Mile		

Figure 1. Location of the lakes in the Fairbanks area that were stocked with age-0 Arctic grayling in 1986 and 1987.



Code	Lake Name
22	Junction Lake
23	Buffalo Lake
24	Squirrel Creek Pit
25	Kettle Lake

Figure 2. Location of the lakes in the Glennallen area that were stocked with age-0 Arctic grayling in 1986.



Code	Lake Name
26	Farmer Lake
27	Sliver Lake
28	Meirs Lake
29	Canoe Lake
30	Bruce Lake
31	Willow Lake

Figure 3. Location of the lakes in the Palmer area that were stocked with age-0 Arctic grayling in 1986 and 1987.

grayling sac fry, 4-g, and 6-g fingerlings were stocked together in 14 lakes in 1986. In the single size group stocking experiment, sac fry and 4-g fingerlings were not stocked together. Sac fry and 4-g fingerlings were stocked in 12 lakes in 1986 and 24 lakes in 1987. The multiple size group experiment has the advantage of identical environmental conditions for each treatment and the disadvantages of possible intraspecific competition and treatments that are unlike standard stocking procedures. The single size group stocking experiment uses standard stocking procedures and results in no intraspecific competition, however, treatments will be exposed to different environmental conditions between years.

Multiple Size Group Experiment

In 1986, three size groups of Arctic grayling were stocked at different times of the year in 14 lakes: (1) 1-4 day old sac fry were stocked in June; (2) 4-g fingerlings were stocked in August; and (3) 6-g fingerlings were stocked in September. The Arctic grayling brood source for all size groups was from Moose Lake near Glennallen (Figure 2). The 4-g and 6-g fingerlings were marked at Clear Hatchery at the same time with left or right pelvic fin clips, respectively. The time of stocking and the sizes of fingerlings were based on the space and time constraints of Clear Hatchery. The sac fry were stocked at about 4,940/ha (2,000/acre). The 4-g and 6-g fingerlings were each stocked at about 250/ha (100/acre). The stocking density for the sac fry was based on an average of prior survival rates for Arctic grayling stocked in summer rearing ponds (Holmes 1985; Ridder 1985). The stocking density for the fingerlings was based on survival rates estimated for coho salmon *Oncorhynchus kisutch* and rainbow trout fingerlings (Mike Doxey, ADFG, Fairbanks, personal communication).

Fyke nets were used to capture Arctic grayling during May and June 1987. All captured Arctic grayling were examined for fin clips, measured to the nearest millimeter, marked by removing the adipose fin, and released. This process was repeated until the desired accuracy and precision of the abundance estimate was reached (95% confidence intervals within ± 10% of the estimated abundance). If the desired level of precision and accuracy was not reached by the seventh sampling event, sampling was stopped. In the ponds near Fairbanks, a late sampling event was conducted during September and October. The size of each sample was random; they were not fixed in advance.

The lakes under investigation were considered to be a simple random sample from all possible lakes where Arctic grayling might be stocked and two-stage sampling (Cochran 1977, p. 278-279; Hankin 1984) was used to estimate the mean survival rate, mean cost per survivor, and mean length for each size group. The total abundance of Arctic grayling in a lake was estimated by pooling the data for all size groups. The total abundance was then apportioned into estimates of abundance for each size group. This method was used because it usually gives smaller variances than those obtained from individually estimating the abundance of each size group (Seber 1982, p. 100-101).

For each lake that was sampled using multiple-event mark-recapture experiments during May and June, the abundance of age-1 Arctic grayling was estimated using Chapman's (1952) modification of Schnabel's (1938) estimator (Seber 1982, p. 139):

(1)
$$\hat{N}_k = \frac{\lambda_k}{1+\sum_{i=2}^{s} m_{ik}}$$

(2)
$$V(\hat{N}_k) \approx N_k^2 \left[\frac{N_k}{\lambda_k} + 2\frac{N_k^2}{\lambda_k^2} + 6\frac{N_k^3}{\lambda_k^3} \right]$$

where:

$\hat{N}_k$ = abundance estimate in the k^{th} lake;

$V(\hat{N}_k)$ = variance of $\hat{N}_k$;

λ_k = $\sum_{i=2}^{s} n_{ik} M_{ik}$;

s = number of lakes where estimates were made;

n_{ik} = sample size of the i^{th} sample in the k^{th} lake;

m_{ik} = number of marked individuals in n_{ik}; and,

M_{ik} = number of marked individuals in the lake just before the i^{th} sample was taken.

When there was a late recapture event in the fall, Arctic grayling that were marked in the spring were treated as a multiple marking event. The abundance of age-1 Arctic grayling for each lake was then estimated using Chapman's modification of the Petersen estimator (Seber 1982, p. 60):

(3) $$\hat{N}_k = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1$$

(4) $$V(\hat{N}_k) = \frac{(n_{k1} + 1)(n_{k2} + 1)(n_{k1} - m_{k2})(n_{k2} - m_{k2})}{(m_{k2} + 1)^2(m_{k2} + 2)}$$

where:

$\hat{N}_k$ = estimated abundance of age 1 Arctic grayling in the k^{th} lake;

$V(\hat{N}_k)$ = variance of $\hat{N}_k$;

n_{k1} = number of Arctic grayling captured and marked during the multiple marking events;

n_{k2} = number of Arctic grayling captured in the recapture event; and,

m_{k2} = number of marked Arctic grayling captured in the recapture event.

The abundance for each size group in a lake was calculated using the formulae (Seber 1982, p. 100):

(5)
$$\hat{q}_{jk} = \frac{\sum_{i=1}^{s}(n_{ijk} - m_{ijk})}{\sum_{i=1}^{s}\sum_{j=1}^{g}(n_{ijk} - m_{ijk})}$$

(6)
$$V(\hat{q}_{jk}) = \frac{\hat{q}_{jk}\ (1 - \hat{q}_{jk})}{\sum_{i=1}^{s}\sum_{j=1}^{g}(n_{ijk} - m_{ijk}) - 1}$$

(7)
$$\hat{N}_{jk} = \hat{N}_k\ \hat{q}_{jk}$$

and from Goodman (1960):

(8)
$$V(\hat{N}_{jk}) = V(\hat{N}_k)\ \hat{q}_{jk}^2 + V(\hat{q}_{jk})\ \hat{N}_k^2 - V(\hat{q}_{jk})\ V(\hat{N}_k)$$

where:

$\hat{q}_{jk}$ = estimated fraction of age-1 Arctic grayling in the j^{th} group in the k^{th} lake;

$V(\hat{q}_{jk})$ = variance of $\hat{q}_{jk}$;

n_{ijk} = size of the i^{th} sample in the j^{th} group in the k^{th} lake;

m_{ijk} = number of marked individuals in n_{ijk} (note: $m_{1jk} = 0$);

s = number of samples;

g = number of size groups in the k^{th} lake;

$\hat{N}_{jk}$ = abundance estimate for the j^{th} group in the k^{th} lake; and,

$V(\hat{N}_{jk})$ = variance of $\hat{N}_{jk}$.

For two-stage sampling, the mean survival rate for each size group for all lakes was calculated as follows:

(9)
$$\bar{S} = \frac{\sum_{j=1}^{n} \hat{S}_j}{n}$$

(10)
$$V(\bar{S}_j) = \frac{\sum_{j=1}^{n} V[\hat{S}_j]}{n^2} + \frac{\sum_{j=1}^{n} [\hat{S}_j - \bar{S}]^2}{n\ (n - 1)}$$

(11)
$$\hat{S}_j = \frac{\hat{N}_{jk}}{N_{jko}}$$

(12)
$$V(\hat{S}_j) = \frac{V(\hat{N}_{jk})}{N_{jko}^2}$$

where:

$\bar{S}$ = mean survival rate of the j^{th} group;

$V[\bar{S}_j]$ = variance of the mean survival rate of the j^{th} group;

$\hat{S}_j$ = estimated rate of survival of the j^{th} group in the k^{th} lake;

$V(\hat{S}_j)$ = variance of the mean survival rate of the j^{th} group in the k^{th} lake;

N_{jko} = number of Arctic grayling of the j^{th} group stocked in the k^{th} lake; and,

n = number of lakes where estimates of cost per survivor were made for the j^{th} size group.

The estimate of cost per survivor was calculated using the formulae:

(13)
$$\bar{C} = \frac{\sum_{j=1}^{n} \hat{C}_j}{n}$$

(14)
$$V(\bar{C}) = \frac{\sum_{j=1}^{n} V[\hat{C}_j]}{n^2} + \frac{\sum_{j=1}^{n} [\hat{C}_j - \bar{C}]^2}{n\ (n - 1)}$$

(15)
$$\hat{C}_j = \frac{N_{jko} C_{jh}}{\hat{N}_{jk}}$$

where:

$\bar{C}$ = mean cost per survivor of the j^{th} group;

$V[\bar{C}]$ = variance of the mean cost per survivor of the j^{th} group;

$\hat{C}_j$ = estimated cost per survivor of the j^{th} group in the k^{th} lake;

C_{jh} = hatchery cost of producing a single fish for the j^{th} group;

N_{jko} = number of Arctic grayling of the j^{th} group stocked in the k^{th} lake; and,

n = number of lakes where estimates of cost per survivor were made for the j^{th} size group.

The variance of $\hat{C}_j$ was estimated through resampling techniques on the original data (Efron 1981, 1982; Bickel and Freedman 1981; Efron and Gong 1983). A computer program was written (Appendix 2) that creates a table of the capture history, resamples from the table, and estimates the variance of $\hat{C}_j$ using the method described by Buckland (unpublished).

When calculating the mean survival rate and cost per survivor I did not include any estimates that were made when the estimate of abundance was less than 50, the cost per survivor was more than $5, or when fewer than 7 fish were recaptured. When the abundance is less than 50 there are too few survivors to justify continued stocking. I set the maximum cost of a catchable size Arctic grayling (about 160 mm) at $10; the cost of an Alaskan resident sport fishing license. Most of the stocked Arctic grayling reach catchable size in two years and I estimated that at least 50% of the survivors at age 1 would be alive at age 2. This would make the maximum cost per survivor of age-1 Arctic grayling about $5. I did not include estimates of cost per survivor when fewer than 7 fish were recaptured because the estimate may not be reliable (Chapman 1951; Seber 1982, p. 60).

Single Size Group Experiment

In 1986, 10 lakes were stocked with sac fry and 2 lakes were stocked with 4-g fingerlings from Clear Hatchery. These 12 lakes, about 2 ha each, are near Fairbanks and are the majority of small lakes traditionally stocked with Arctic grayling in the Tanana River drainage.

In 1987, 6 lakes were stocked with sac fry and 18 lakes were stocked with 4-g fingerlings. These lakes are near Fairbanks and Palmer and include most of the lakes that had been stocked in 1986. Most of the lakes that were stocked with sac fry in 1986 were stocked with fingerlings in 1987. Hidden Lake and Unnamed Lake were stocked with 4-g fingerlings in 1986 but were not stocked in 1987. Sac fry were stocked in June and 4-g fingerlings were stocked in August. The sac fry were stocked at 4,940/ha (2,000/acre). The 4-g fingerlings were stocked at 500/ha (200/acre), except for Luke Lake where 4-g fingerlings were stocked at 250/ha (100/acre). All fish came from the same stock as those used in the multiple size group stocking experiment. The fingerlings stocked in the Fairbanks area were marked at Clear Hatchery with double pelvic fin clips. The fingerlings that were stocked near Palmer were not marked. In 1987 and 1988, the abundance of age-1 Arctic grayling was estimated in each lake using the same methods described for the multiple size group experiment.

Breakeven Analysis

A breakeven analysis was used to determine when the cost per survivor was less for sac fry or 4-g fingerlings. The analysis requires that enough sac fry and 4-g fingerlings were stocked so that the number of survivors at age 1 were equal. The cost per fish was calculated using the estimates of survival and the number of fish stocked. Under these constraints the ratio of the costs per sac fry and 4-g fingerlings when stocked was equal to the ratio of the respective rates of survival. To make comparisons easier I arbitrarily set the cost per sac fry when stocked to 1.

This was compared to the ratio of the costs per sac fry and 4-g fingerlings that was calculated using expected hatchery costs and the estimates of survival rate. The estimates of the survival rate used in this analysis were the average of the estimates for sac fry and 4-g fingerlings from the multiple and single size group experiments. When the ratio of the expected costs was less than the breakeven ratio, then the cost per survivor at age 1 was less for Arctic grayling that were stocked as 4-g fingerlings. However, when the ratio of the expected costs was more than the breakeven ratio then sac fry should be stocked.

Length

The mean lengths at age 1 for sac fry, 4-g, and 6-g fingerlings were calculated using two-stage sampling with variance among and within populations in which units are of equal size (Cochran 1977, p. 292-294):

(16) $$\bar{\bar{x}} = \frac{1}{n}\sum_{i=1}^{n}\frac{\sum_{j=1}^{m} x_{ij}}{m_i}$$

(17) $$V(\bar{\bar{x}}) = \frac{\sum_{i=1}^{n}(\bar{x}_i - \bar{\bar{x}})^2}{n(n-1)} + \frac{1}{n^2}\sum_{i=1}^{n}\left(1 - \frac{m_i}{\hat{N}_i}\right)\sum_{j=1}^{n}\frac{(x_{ij} - \bar{x}_i)^2}{m_i(m_i - 1)}$$

(18) $$\bar{x}_i = \frac{\sum x_{ij}}{m_i}$$

(19) $$V(\bar{x}_i) = \frac{\sum (x_{ij} - \bar{x}_i)^2}{m_i(m_i - 1)}(1 - f)$$

where:

$\bar{\bar{x}}_i$ = mean length for all populations of a size group;

$V(\bar{\bar{x}})$ = variance of mean length for all populations of a size group;

$\bar{x}_i$ = mean length of the i^{th} population;

$V(\bar{x}_i)$ = variance of the mean length of the i^{th} population;

m_i = sample size of the i^{th} population;

n = number of populations; and,

f = finite population correction factor.

Relationship between Production and Morphoedaphic Index

Spearman's formula for rank correlation (Zar 1984, p. 318-320) was used to estimate the relationship between the morphoedaphic index (a fish yield estimator, Ryder et al. 1974) and the production (increase in weight) of sac fry, 4-g, and 6-g fingerlings from stocking to age 1. The production for Arctic grayling stocked as sac fry, 4-g, and 6-g fingerlings was calculated from the time of stocking to age 1 using the procedures of Ricker (1975, p. 16-18):

(20) $$\hat{P}_{jk} = \bar{B}_{jk}\hat{G}_{jk}$$

(21) $$\bar{B}_{jk} = \frac{B_{jko}\left(e^{(\hat{G}_{jk}-\hat{Z}_{jk})} - 1\right)}{\hat{G}_{jk} - \hat{Z}_{jk}}$$

(22) $$\hat{G}_{jk} = \ln\left(\frac{\bar{\omega}_{jk}}{\bar{\omega}_{jk0}}\right)$$

(23) $$\hat{Z}_{jk} = -\ln\left(\frac{\hat{N}_{jk}}{N_{jk0}}\right)$$

(24) $$B_{jk0} = N_{jk0}\,\bar{\omega}_{jk0}$$

(25) $$\bar{\omega}_{jk} = a\bar{l}_{jk}^{b}$$

where:

$\hat{P}_{jk}$ = production, or total growth in weight of the j^{th} group in the k^{th} lake;

$\overline{B}_{jk}$ = mean biomass of the j^{th} group in the k^{th} lake;

B_{jk0} = biomass of the j^{th} group when stocked in the k^{th} lake;

$\hat{Z}$ = instantaneous rate of mortality;

$\hat{G}$ = instantaneous rate of growth;

$\bar{\omega}_{jk}$ = mean weight of individuals in the j^{th} group in the k^{th} lake at age 1;

$\bar{\omega}_{jk0}$ = mean weight of individuals in the j^{th} group when stocked in the k^{th} lake at age 0;

$\hat{N}_{jk}$ = abundance estimate for size group j in the k^{th} lake;

N_{jk0} = number of Arctic grayling in the j^{th} group stocked in the k^{th} lake; and,

$\bar{l}_{jk}^{b}$ = average length of the j^{th} group in the k^{th} lake at age 1.

Six hundred eighty-six Arctic grayling were measured to the nearest millimeter and weighed to the nearest 0.01 g in 1986 at age 0 prior to stocking and in 1987 at age 1 during the mark-recapture experiments. For most of the fish captured during the mark-recapture experiments, when weight was not measured it was estimated using the following relationship between weight and length:

(26) $$\omega = al^{b}$$

where:

ω = weight;

l = length;

a = y-intercept; and,

b = slope.

The coefficients a and b were estimated with a computer statistics program, Statgraphics (version 2.6, published by STSC, Incorporated), that uses an algorithm for least-squares estimation of nonlinear parameters (Marquardt 1963).

The morphoedaphic index for each lake was estimated using the relationship described by Ryder et al. (1974):

(27) $$MEI_k = \frac{A_k}{\bar{z}_k}$$

where:

MEI_k = the morphoedaphic index of the k^{th} lake;

A_k = the total alkalinity (mg/L as $CaCO_3$) of the k^{th} lake; and,

$\bar{z}_k$ = the mean depth of the k^{th} lake.

The total alkalinity of the lakes near Fairbanks and Palmer was measured in 1988 using the Hach digital titrator method. After the lake surface had frozen, a transit was used to estimate the distance and bearing to the shore and other points on the lake surface where the depth was estimated with a portable sonar unit. The sonar transducer was placed on the ice in a puddle of propylene glycol. The surface area and volume was then calculated using Topography 200/300, a computer program published by PacSoft Incorporated, Kirkland, Washington. To calculate the surface area, the distance and bearing measurements were converted to rectangular coordinates; the area of the resulting polygon was then calculated (Selby 1971, p. 353). The volume was calculated by first creating a rectangular grid of equally spaced points (Davis 1973), and then calculating the volume of the two prisms that were formed within each rectangle. Mean depth of each lake was calculated by dividing the volume by the surface area.

RESULTS

Stocking Costs

In 1986, the costs of producing and stocking Arctic grayling sac fry, 4-g, and 6-g fingerlings were about $0.02, $0.12, and $0.14 per fish, respectively (Table 1). In 1987, the costs of producing and stocking sac fry and 4-g fingerlings were about $0.07 and $0.18 per fish, respectively (Table 1).

Multiple Size Group Experiment

In 1987, Arctic grayling were captured in 13 of the 14 lakes that were stocked with sac fry, 4-g, and 6-g fingerlings in 1986 (Tables 2 and 3). No Arctic grayling were captured in Kettle Lake. In 11 of the 13 lakes, Arctic grayling stocked as either 4-g or 6-g fingerlings were more abundant than Arctic grayling that were stocked as sac fry. Arctic grayling stocked as sac fry were more abundant in Steese 31.6 Mile and Luke Lake. Age-1 fish stocked as sac fry were not captured in Farmer and Sliver lakes which have populations of threespine stickleback.

Survival Rate

The rate of survival to age 1 increased when larger Arctic grayling were stocked (Figure 4). The rates of survival for Arctic grayling stocked as sac fry, 4-g, and 6-g fingerlings ranged from 0.01 to 1 (Table 4). The mean rates of

Table 1. Costs of producing Arctic grayling sac fry, 4-g, and 6-g fingerlings at Clear Hatchery in 1986 and 1987.

	1986			1987	
	Sac fry	4-g fish	6-g fish	Sac fry	4-g fish
Operations	$1,090			$46,090	$24,150
Maintenance	440			2,680	632
Eggtake	11,730			8,010	2,000
Incubation	220			55	13
Rearing		5,850	9,890		5,650
Marking					1,650
Stocking	3,070	3,710	3,710	2,340	2,240
Pathology				160	670
Total Cost	$16,550	$23,040[1]	$27,080[1]	$59,340	$37,000
Number released	835,300	200,000	200,000	900,000	210,000
Cost per fish	$0.02	$0.12	$0.14	$0.07	$0.18

[1] The operation, maintenance, eggtake, and incubation costs were not estimated separately.

Table 2. Number of age-1 Arctic grayling captured, marked, and released during the first sampling event and the number of marked and unmarked Arctic grayling captured during the second sampling event, 1987.[1]

Area and Lake	Stocking Size	Event 1 Date	Event 1 Captured	Event 1 Marked and Released	Event 2 Date	Event 2 Total Captured	Event 2 Recaptured
Fairbanks							
Steese 31.6 Mile	Sac fry	26 May	127	127	5 Aug	43	1
	4-g		1	1		1	1
	6-g		0	0		0	0
Steese 34.6 Mile	Sac fry	26 May	35	35	5 Aug	0	0
	4-g		258	257		112	78
	6-g		279	277		204	68
CHSR[2] 32.9 Mile	Sac fry	1 Jun	3	3	9 Oct	4	3
	4-g		178	175		123	83
	6-g		262	257		212	144
Luke Lake	Sac fry	6 Jun	954	950	2 Oct	1,462	295
	4-g		21	21		49	3
	6-g		31	31		75	4
Sheefish Lake	Sac fry	6 Jun	60	60	2 Oct	34	9
	4-g		122	122		59	18
	6-g		97	96		73	14

[1] The Arctic grayling were stocked in 1986.

[2] Chena Hot Springs Road.

Table 3. Number of age-1 Arctic grayling captured, recaptured, and removed during the multiple mark-recapture events, 1987.[1]

Area and Lake	Stocking Size	Date	Captured	Recaptured	Mortalities
Glennallen					
Junction Lake	Sac fry	17 Jun	121		
	4-g		108		
	6-g		184		
	Sac fry	18 Jun	111	53	
	4-g		129	34	
	6-g		197	87	
	Sac fry	19 Jun	411	92	
	4-g		368	81	
	6-g		420	130	
Buffalo Lake	Sac fry	17 Jun	30		
	6-g		162		
	Sac fry	18 Jun	8	5	
	4-g				
	6-g		44	12	
	Sac fry	19 Jun	26	12	
	4-g				
	6-g		72	45	
Squirrel Ck. Pit	Sac fry	17 Jun	5		2
	4-g		7		
	6-g		46		
	Sac fry	18 Jun	2	0	
	4-g		3	0	
	6-g		15	1	1
	Sac fry	19 Jun	9	0	2
	4-g		15	0	
	6-g		84	4	1
Kettle Lake	Sac fry	30 Sep	0		
	4-g		0		
	6-g		0		

-Continued-

Table 3. Number of age-1 Arctic grayling captured, recaptured, and removed during the multiple mark-recapture events, 1987. (Continued).

Area and Lake	Stocking Size	Date	Captured	Recaptured	Mortalities
Palmer					
Farmer Lake	Sac fry	12 May	0		
	4-g		398		2
	6-g		719		1
	Sac fry	13 May	0		
	4-g		364	171	
	6-g		532	270	
	Sac fry	14 May	0		
	4-g		328	246	
	6-g		581	420	
Sliver Lake	Sac fry	5 May	0		
	4-g		25		
	6-g		74		
	Sac fry	6 May	0		
	4-g		33	2	
	6-g		130	21	
	Sac fry	7 May	0		
	4-g		74	19	
	6-g		196	72	
	Sac fry	8 May	0		
	4-g		40	13	
	6-g		82	54	
	Sac fry	22 May	0		
	4-g		100	51	
	6-g		200	124	

-Continued-

Table 3. Number of age-1 Arctic grayling captured, recaptured, and removed during the multiple mark-recapture events, 1987. (Continued).

Area and Lake	Stocking Size	Date	Captured	Recaptured	Mortalities
Palmer					
Canoe Lake	Sac fry	12 May	16		
	4-g		51		
	6-g		87		
	Sac fry	13 May	10		
	4-g		29	0	
	6-g		41	1	
	Sac fry	14 May	2		
	4-g		15	0	
	6-g		11	0	
	Sac fry	15 May	10		
	4-g		59	4	
	6-g		145	8	
	Sac fry	20 May	8		
	4-g		60	12	
	6-g		119	25	
	Sac fry	21 May	4		
	4-g		49	6	
	6-g		93	14	
Meirs Lake	Sac fry	5 May	29		
	4-g		21		
	6-g		30		
	Sac fry	6 May	119	2	
	4-g		251	2	
	6-g		331	4	
	Sac fry	7 May	52	7	
	4-g		87	11	
	6-g		136	18	
	Sac fry	8 May	59	21	
	4-g		167	34	
	6-g		212	37	
	Sac fry	19 May	64	27	
	4-g		294	107	
	6-g		350	145	

[1] The Arctic grayling were stocked in 1986.

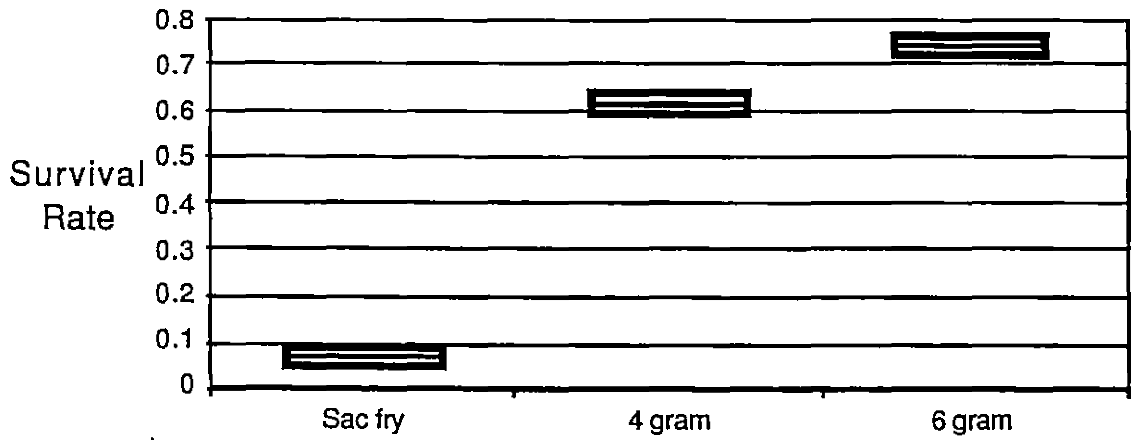


Figure 4. Estimates of mean rate of survival to age 1 of Arctic grayling that were stocked as sac fry, 4-g, and 6-g fingerlings in 1986. The top and bottom lines represent the upper and lower 95% confidence limits.

Table 4. Estimates of abundance, survival rate, and cost per survivor at age 1 for Arctic grayling stocked as sac fry, 4-g, and 6-g fingerlings in the same lakes in 1986.

Area and Lake	Stocking Size	Number Stocked	Stocking Cost	Abundance Estimate	Abundance SE	Survival Rate Estimate	Survival Rate SE	Cost per Survivor Estimate	Cost per Survivor SE
Fairbanks									
Steese 31.6	Sac fry	4,000	$80	133	3	0.033	0.0009	$0.60	0.011
Mile	4-g	200	$23	1	0.1	0.005	0.0005	$22.16	6.42
	6-g	200	$28	0		0			
Steese 34.6	Sac fry	8,000	$160	59	20	0.008	0.0026	$2.71	0.64
Mile	4-g	400	$46	359	13	0.90	0.033	$0.13	0.0008
	6-g	400	$55	386	14	0.97	0.036	$0.14	0.008
Luke Lake	Sac fry	10,000	$200	4,980	1,462	0.50	0.15	$0.40	0.002
	4-g	500	$58	110	49	0.22	0.098	$0.53	0.15
	6-g	500	$69	162	75	0.32	0.15	$0.43	0.095
Sheefish Lake	Sac fry	10,000	$200	239	29	0.024	0.0029	$0.84	0.14
	4-g	500	$58	486	59	0.97	0.12	$0.12	0.015
	6-g	500	$69	383	46	0.77	0.093	$0.18	0.026
Glennallen									
Junction Lake	Sac fry	36,000	$720	658	13	0.02	0.0004	$1.09	0.050
	4-g	1,800	$208	647	13	0.36	0.0071	$0.32	0.015
	6-g	1,800	$249	772	15	0.43	0.0085	$0.32	0.012
Buffalo Lake	Sac fry	10,000	$200	74	5	0.007	0.0005	$2.70	0.37
	6-g	500	$69	350	25	0.70	0.051	$0.20	0.014
Kettle Lake	Sac fry	12,000	$240	0					
	4-g	600	$70	0					
	6-g	600	$83	0					
Palmer									
Farmer Lake	Sac fry	42,000	$840	0		0			
	4-g	1,610	$187	819	11	0.51	0.0070	$0.23	0.007
	6-g	2,080	$288	1,363	19	0.66	0.0090	$0.21	0.004
Sliver Lake	Sac fry	14,400	$288	0		0			
	4-g	720	$84	243	7	0.34	0.0098	$0.32	0.021
	6-g	720	$100	533	16	0.74	0.022	$0.19	0.007
Meirs Lake	Sac fry	33,600	$672	600	24	0.018	0.0007	$1.12	0.074
	4-g	1,695	$197	1,496	59	0.88	0.035	$0.13	0.005
	6-g	1,680	$233	1,916	75	1.14	0.045	$0.12	0.005
Canoe Lake	Sac fry	42,400	$848	238	25	0.0056	0.0006	$3.57	0.89
	4-g	1,207	$140	1,140	123	0.94	0.10	$0.12	0.022
	6-g	2,120	$293	2,128	230	1.00	0.11	$0.14	0.022

survival for each size group were 0.08 (SE = 0.018), 0.63 (SE = 0.021), and 0.75 (SE = 0.022), respectively. Analysis of variance indicated that at least one of the estimates of the mean rate of survival was statistically different ($F = 2{,}488$, $P < 0.0005$). To create the ANOVA table, I used a procedure described by Zar (1984, p. 168) when the observations are actually linear combinations of independent variants. The results of Tukey's test for multiple comparisons (Zar 1984, p. 189) showed that the estimates of the mean rate of survival were significantly different between the three size groups ($P < 0.001$ for each comparison).

Cost per Survivor

The mean cost per survivor at age 1 decreased when larger Arctic grayling were stocked (Figure 5). The costs per survivor at age 1 for Arctic grayling stocked as sac fry, 4-g, and 6-g fingerlings ranged from $0.04 to $3.57 (Table 4). The mean costs per survivor at age 1 for the three size groups were $1.58 (SE = 0.18), $0.24 (SE = 0.02), and $0.21 (SE = 0.01), respectively. Analysis of variance indicate that at least one of the estimates of mean cost was statistically different ($F = 520$, $P < 0.0005$). The results of Tukey's test for multiple comparisons showed that the mean costs per survivor were significantly different between Arctic grayling that were stocked as sac fry and 6-g fingerlings ($q = 51$, $P < 0.001$) and between Arctic grayling that were stocked as sac fry and 4-g fingerlings ($q = 49$, $P < 0.001$). However, there was no significant difference between the mean costs for Arctic grayling that were stocked as 4-g and 6-g fingerlings ($q = 1$, $P > 0.5$). Although the mean

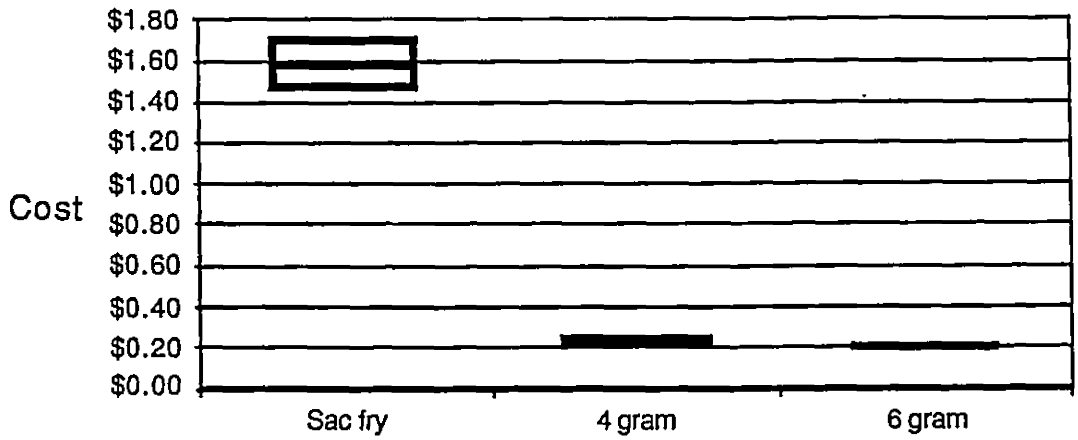


Figure 5. Estimates of mean cost per survivor to age 1 of Arctic grayling that were stocked as sac fry, 4-g, and 6-g fingerlings in 1986. The top and bottom lines represent the upper and lower 95% confidence limits.

cost per survivor at age 1 was lower for Arctic grayling stocked as fingerlings, the single lowest cost per survivor at age 1 was for Arctic grayling that were stocked as sac fry in barren Luke Lake in 1986 ($0.04, SE = $0.002).

Length

At age 1, Arctic grayling stocked as sac fry were larger (138 mm, SE = 50 mm) than Arctic grayling stocked as 4-g fingerlings (112 mm, SE = 10 mm) and 6-g fingerlings (112 mm, SE = 9 mm) (Figure 6 and Table 5). Analysis of variance showed that the estimates of mean length were not significantly different between the three groups ($F = 3.1$, $0.10 > P > 0.05$).

In Farmer and Sliver lakes, the Arctic grayling at age 1 that were stocked as 6-g fingerlings were larger than those stocked as 4-g fingerlings (Table 5). Also, growth was poor compared to most of the other lakes. No sac fry were captured in either lake.

Single Size Group Experiment

Arctic grayling were captured in only 5 of the 10 lakes that had been stocked with sac fry in 1986 (Table 6). However, the estimate of abundance of age-1 Arctic grayling was less than 50 at Chena Hot Springs Road (CHSR) 42.9 Mile. No Arctic grayling were captured that had been stocked as 4-g fingerlings in 1986 in Walden Pond and Unnamed Lake (Table 6). In 1988, Arctic grayling

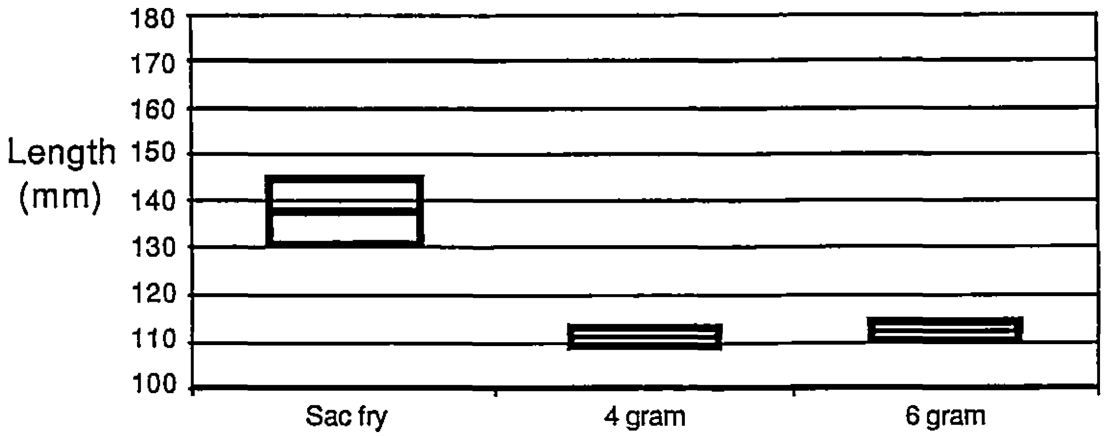


Figure 6. Estimates of mean length of Arctic grayling at age 1 that were stocked as sac fry, 4-g, and 6-g fingerlings in 1986. The top and bottom lines represent the upper and lower 95% confidence limits.

Table 5. Mean lengths of age-1 Arctic grayling captured in 1987 that were stocked as sac fry, 4-g, and 6-g fingerlings in 1986.

Area and Lake	Stocking Size	Sample Size	Mean Length(mm)	Standard Error	Range Low	Range High
Fairbanks						
CHSR 47.9 Mile	Sac fry	38	103	1.39	85	118
	4-g	21	93	0.98	84	102
	6-g	19	97	1.92	83	114
Steese 31.6 Mile	Sac fry	99	114	0.61	94	128
	4-g	1	109			
	6-g	0				
Steese 34.6 Mile	Sac fry	35	100	1.20	82	112
	4-g	258	92	0.32	76	109
	6-g	277	94	0.40	78	110
Luke Lake	Sac fry	447	171	0.38	114	196
	4-g	24	124	1.14	113	138
	6-g	38	121	1.44	104	141
Sheefish Lake	Sac fry	60	120	2.47	77	158
	4-g	121	120	0.85	96	142
	6-g	97	119	1.04	90	148
Glennallen						
Junction Lake	Sac fry	499	118	0.57	59	148
	4-g	491	106	0.41	77	172
	6-g	584	104	0.40	73	128
Buffalo Lake	Sac fry	47	141	2.34	98	162
	4-g					
	6-g	221	119	0.54	102	150
Squirrel Ck Pit	Sac fry	8	138	6.30	118	165
	4-g	15	130	2.00	115	145
	6-g	80	130	1.37	101	159
Palmer						
Farmer Lake	Sac fry	0				
	4-g	151	85	0.54	72	102
	6-g	296	90	0.33	69	111
Sliver Lake	Sac fry	0				
	4-g	110	86	0.86	65	112
	6-g	332	98	0.55	74	128
Meirs Lake	Sac fry	148	176	1.09	151	219
	4-g	270	134	0.59	96	156
	6-g	356	129	0.54	98	169
Canoe Lake	Sac fry	32	194	1.85	167	212
	4-g	127	141	0.94	116	171
	6-g	188	137	0.82	99	169

Table 6. Number of age-1 Arctic grayling captured, marked, and released during the first sampling event and the number captured and recaptured during the second sampling event, 1987.[1]

Area and Lake	Event 1		Event 2		
	Date	Captured and Marked	Date	Total Captured	Recaptured
Fairbanks					
Steese 29.5 Mile	8 Jun	967	6 Aug	50	36
Steese 30.6 Mile	5 Jun	7	7 Jun	7	5
Steese 35.8 Mile	8 Jun	0			
Steese 36.6 Mile	10 Jun	314	5 Oct	16	7
Walden Pond	29 May	0			
CHSR 42.8 Mile	12 Jun	0			
CHSR 45.5 Mile	12 Jun	1,017	7 Aug	93	60
Bathing Beauty	15 Jun	71	14 Oct	54	50
Hidden Lake	15 Jun	0			
Grayling Lake	16 Jun	0			
Johnson Rd Pit #2	16 Jun	0			
Unnamed Lake	6 Jun	0			

[1] The Arctic grayling were stocked as sac fry or 4-g fingerlings in 1986.

were captured in 4 of the 7 lakes that had been stocked with sac fry in 1987 (Table 7). One of these lakes was not used in the analysis because fewer than 7 fish were recaptured. Arctic grayling were captured in 16 of the 17 lakes that had been stocked with 4-g fingerlings in 1987, however, fewer than 7 Arctic grayling were recaptured in 6 of these lakes. Also, I could not estimate the abundance of age-1 Arctic grayling in Bruce Lake because I could not distinguish age-1 fish from age-2 fish based on the distribution of lengths and analysis of scale patterns.

Survival Rate

The mean rate of survival to age 1 increased when larger Arctic grayling were stocked (Figure 7). The rates of survival for Arctic grayling stocked as sac fry and fingerlings ranged from 0.008 to 0.76 (Tables 8 and 9). The mean rates of survival at age 1 for Arctic grayling stocked in 1986 and 1987 as sac fry and 4-g fingerlings were 0.11 ($SE = 0.033$) and 0.34 ($SE = 0.12$), respectively. Results of an F-test (Zar 1984) indicated that the variances were significantly different ($F = 13$, $df = 6$ and 8, $0.002 > P > 0.001$). Results of a Student t-test, adjusted for unequal variances (Snedecor and Cochran 1980, p. 96-98), indicate that the mean rates of survival were statistically different ($t' = 5.6$, $df = 9$, $P < 0.001$).

Table 7. Number of age-1 Arctic grayling captured, marked, and released during the first sampling event and the number captured and recaptured during the second sampling event, 1988.[1]

Area and Lake	Event 1 Date	Event 1 Captured and Marked	Event 2 Date	Event 2 Total Captured	Event 2 Recaptured
Fairbanks					
Steese 29.5 Mile	14 Jun	84	16 Aug	12	7
Steese 30.6 Mile	14 Jun	358	16 Aug	247	178
Steese 31.6 Mile	6 Jun	56	18 Aug	10	7
Steese 33.0 Mile	13 Jun	990	15 Aug	683	255
Steese 33.5 Mile	13 Jun	438	15 Aug	68	59
Steese 34.6 Mile	6 Jun	314	18 Aug	137	86
Steese 35.8 Mile	6 Jun	129	19 Aug	94	24
Steese 36.6 Mile	4 Jun	194	19 Aug	12	8
Walden Pond	14 Jun	8			
CHSR 32.9 Mile	26 May	414	12 Aug	44	29
CHSR 42.8 Mile	28 May	11	12 Aug	0	
CHSR 45.5 Mile	27 May	59	11 Aug	16	5
CHSR 47.9 Mile	27 May	186	11 Aug	1	1
Bathing Beauty	17 Jun	34	23 Aug	38	11
Grayling Lake	17 Jun	0			
Johnson Rd Pit #1	17 Jun	0	23 Aug	0	
Johnson Rd Pit #2	17 Jun	3			
Sheefish Lake	23 Jun	0	25 Aug	0	
Luke Lake	23 Jun	99	25 Aug	22	5
Palmer					
Canoe Lake	5 May	586	6 Oct	83	34
Bruce Lake	24 May	457	7 Oct	42	33
Farmer Lake	19 May	458	28 Sep	29	8
Willow Lake	12 May	278	11 Oct	17	6
Sliver Lake		1			

[1] The Arctic grayling were stocked in 1987.

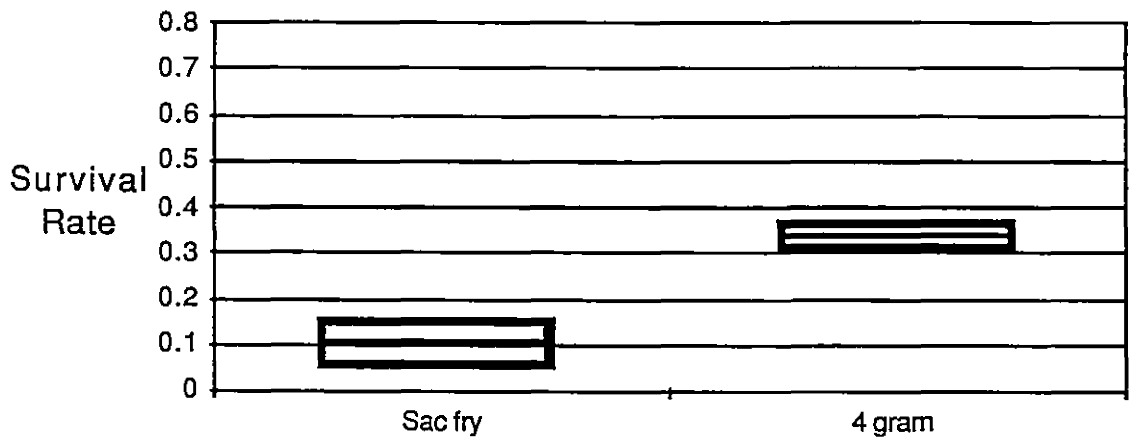


Figure 7. Estimates of mean rate of survival to age 1 of Arctic grayling that were stocked as sac fry and 4-g fingerlings in 1986 and 1987. The top and bottom lines represent the upper and lower 95% confidence limits.

Table 8. Estimates of abundance, survival rate, and cost per survivor for Arctic grayling stocked as sac fry and 4-g fingerlings in separate lakes in 1986.

Area and Lake	Stocking Size	Number Stocked	Stocking Cost	Abundance Estimate	Abundance SE	Survival Rate Estimate	Survival Rate SE	Cost per Survivor Estimate	Cost per Survivor SE
Fairbanks									
Steese 29.5 Mile	Sac fry	10,000	$200	1,333	111	0.13	0.011	$0.15	0.012
Steese 30.6 Mile	Sac fry	10,000	$200	10					
Steese 35.8 Mile	Sac fry	10,000	$200	0					
Steese 36.6 Mile	Sac fry	10,000	$200	668	106	0.084	0.016	$0.30	0.060
Walden Pond	4-g	1,500	$174	0					
CHSR 42.8 Mile	Sac fry	10,000	$200	0					
CHSR 45.5 Mile	Sac fry	10,000	$200	1,568	112	0.16	0.011	$0.13	0.009
Bathing Beauty	Sac fry	10,000	$200	77	2	0.008	0.0002	$2.60	0.031
Hidden Lake	Sac fry	10,000	$200	0					
Grayling Lake	Sac fry	10,000	$200	0					
Johnson Rd. Pit #1	Sac fry	10,000	$200	0					
Unnamed Lake	4-g	500	$58	0					

Table 9. Estimates of abundance, survival rate, and cost per survivor for Arctic grayling stocked as sac fry and 4-g fingerlings in separate lakes in 1987.

Area and Lake	Stocking Size	Number Stocked	Stocking Cost	Abundance Estimate	Abundance SE	Survival Rate Estimate	Survival Rate SE	Cost per Survivor Estimate	Cost per Survivor SE
Fairbanks									
Steese 29.5 Mile	4-g	1,000	$176	134	21	0.13	0.026	$1.32	$0.27
Steese 30.6 Mile	4-g	1,000	$176	496	14	0.50	0.013	$0.36	$0.0073
Steese 31.6 Mile	4-g	400	$70	77	13	0.19	0.001	$0.90	$0.15
Steese 33.0 Mile	Sac fry	10,000	$660	2,647	113	0.26	0.00013	$0.25	$0.0097
Steese 33.5 Mile	Sac fry	10,000	$660	504	22	0.05	0.0022	$1.31	$0.055
Steese 34.6 Mile	Sac fry	8,000	$528	499	24	0.062	0.0034	$1.06	$0.050
Steese 35.8 Mile	4-g	1,000	$176	493	75	0.49	0.075	$0.36	$0.049
Steese 36.6 Mile	4-g	1,000	$176	281	48	0.28	0.048	$0.63	$0.12
Walden Pond	Sac fry	15,000	$990						
CHSR 32.9 Mile	4-g	1,000	$176	622	62	0.62	0.062	$0.28	$0.029
CHSR 42.8 Mile	4-g	1,000	$176						
CHSR 45.5 Mile[1]	Sac fry	10,000	$660	169	49	0.017	0.0049	$3.93	$1.09
CHSR 47.9 Mile	4-g	1,000	$176						
Bathing Beauty	4-g	1,000	$176	113	21	0.11	0.021	$1.54	$0.28
Grayling Lake	4-g	1,000	$176						
Johnson Rd. Pit #1	Sac fry	10,000	$660						
Johnson Rd. Pit #2	4-g	1,000	$176						
Sheefish Lake	Sac fry	10,000	$660						
Luke Lake[1]	4-g	500	$88	382	121	0.76	0.24	$0.23	$0.068
Palmer									
Canoe Lake	4-g	4,240	$746	1,408	174	0.33	0.041	$0.53	$0.063
Bruce Lake	4-g	5,270	$928						
Farmer Lake	4-g	4,200	$739	1,529	401	0.36	0.095	$0.48	$0.13
Willow Lake	4-g	22,880	$4,027	716	716	0.026	0.0074	$6.59	$1.82
Sliver Luke	4-g	1,440	$253						

[1] These lakes were not included when estimating the mean survival rates and costs per survivor because fewer than 7 fish were recaptured.

Cost per Survivor

The cost per survivor at age 1 decreased when larger Arctic grayling were stocked (Figure 8). The costs per survivor at age 1 for Arctic grayling that were stocked in 1986 and 1987 as sac fry and 4-g fingerlings ranged from $0.13 to $2.60 (Tables 8 and 9). The mean costs per survivor at age 1 for both size groups were $0.82 (SE = $0.34) and $0.71 (SE = $0.25), respectively. Results of an F-test indicated that the variances were not significantly different ($F = 1.8$, df = 6 and 8, $0.50 > P > 0.20$). Results of a Student t-test showed that the estimates of the cost per survivor were not statistically different ($t = 0.75$, df = 14, $0.50 > P > 0.20$). Although the mean cost per survivor was lower for Arctic grayling stocked as fingerlings, the single lowest cost per survivor was for sac fry stocked in barren Steese 33.0 Mile ($0.25, SE = $0.0097). However, the cost per survivor for sac fry that were stocked into another barren lake (Steese 33.5 Mile) was $1.31 (SE = $0.055), which is greater than the mean.

Length

At age 1, Arctic grayling stocked as sac fry were larger (140 mm, SE = 10 mm) than Arctic grayling stocked as 4-g fingerlings (112 mm, SE 11 mm) (Figure 9 and Tables 10 and 11). Arctic grayling stocked as sac fry in a barren lake (Steese 33.5 Mile) were the largest and Arctic grayling stocked as 4-g fingerlings in Farmers Lake were the smallest. Results of an F-test indicated that the variances were not significantly different ($F = 1.1$,

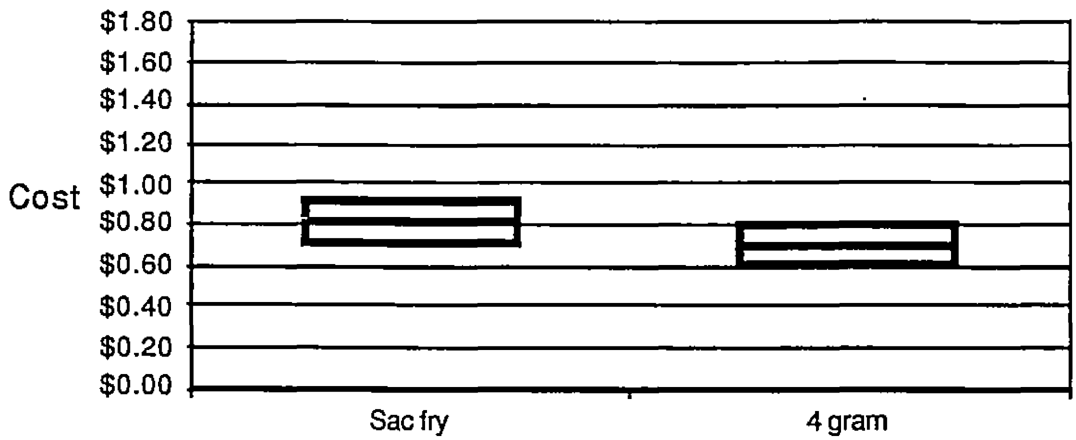


Figure 8. Estimates of mean cost per survivor to age 1 of Arctic grayling that were stocked as sac fry and 4-g fingerlings in 1986 and 1987. The top and bottom lines represent the upper and lower 95% confidence limits.

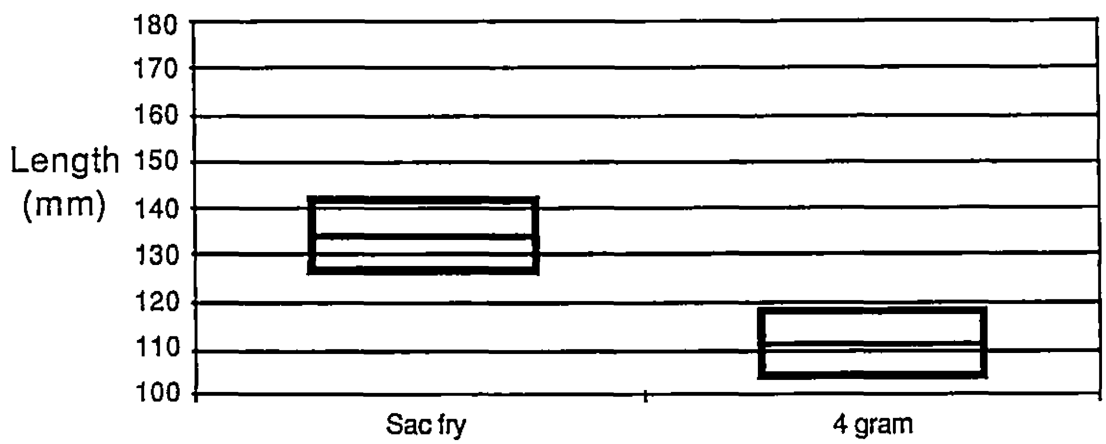


Figure 9. Estimates of mean length of Arctic grayling at age 1 that were stocked as sac fry and 4-g fingerlings in 1986 and 1987. The top and bottom lines represent the upper and lower 95% confidence limits.

Table 10. Mean lengths of age-1 Arctic grayling captured in 1987 that were stocked as sac fry in 1986.

Area and Lake	Stocking Size	Sample Size	Mean Length(mm)	Standard Error	Range Low	Range High
Fairbanks						
Steese 29.5 Mile	Sac fry	50	123	0.92	107	137
Steese 36.6 Mile	Sac fry	317	132	0.39	115	155
CHSR 45.5	Sac fry	131	148	0.80	107	168
Bathing Beauty	Sac fry	54	187	1.82	156	228

Table 11. Mean lengths of age-1 Arctic grayling captured in 1988 that were stocked as sac fry or 4-g fingerlings in 1987.

Area and Lake	Stocking Size	Sample Size	Mean Length(mm)	Standard Error	Range Low	Range High
Fairbanks						
Steese 29.5 Mile	4-g	84	108	0.77	88	126
Steese 30.6 Mile	4-g	360	125	0.48	87	146
Steese 31.6 Mile	4-g	56	104	1.02	77	122
Steese 33.0 Mile	Sac fry	991	121	0.18	95	145
Steese 33.5 Mile	Sac fry	438	158	0.31	140	275
Steese 34.6 Mile	Sac fry	314	112	0.22	98	119
Steese 35.8 Mile	4-g	129	105	0.68	84	130
Steese 36.6 Mile	4-g	194	103	0.84	95	127
Walden Pond	Sac fry	8	198	1.53	190	203
CHSR 32.9 Mile	4-g	414	110	0.40	77	132
CHSR 42.8 Mile	4-g	14	92	1.39	84	100
CHSR 45.5 Mile	Sac fry	59	108	1.35	85	130
CHSR 47.9 Mile	4-g	186	98	0.58	73	118
Bathing Beauty	4-g	35	127	1.56	110	144
Grayling Lake	4-g	0				
Johnson Rd. Pit #1	Sac fry	0				
Johnson Rd. Pit #2	4-g	3	160	3.51	157	164
Sheefish Lake	Sac fry	0				
Luke Lake	4-g	99	129	7.25	103	142
Palmer						
Canoe Lake	4-g	584	134	0.45	100	171
Bruce Lake[1]	4-g					
Farmer Lake	4-g	459	89	0.37	65	110
Willow Lake	4-g	268	89	0.49	64	110
Sliver Lake	4-g	0				

[1] Arctic grayling were captured in Bruce Lake; but I could not distinguish age-1 from age-2 fish.

df = 8 and 6, $P > 0.50$). Results of a Student t-test showed that the estimates of the mean lengths were statistically different ($t = 5.5$, df = 14, $P < 0.001$).

The results from equations 22 and 25 are biased. However, examination of the bias of the average weight for 10 of the populations shows that the bias is small (less than 3%) and the biased estimate is always less than the unbiased estimate (Table 12).

Breakeven Analysis

The average of the rates of survival to age 1 for Arctic grayling stocked as sac fry and 4-g fingerlings were 0.09 and 0.48. The breakeven ratio of the costs per Arctic grayling when stocked was 1:5.3. This means that fingerlings can cost up to 5.3 times more than sac fry to stock. The cost per survivor is less for fingerlings because their survival rate is higher.

Survival Rate and Growth in the Presence of Sticklebacks

In the Palmer area, Farmer, Sliver, Bruce, and Willow lakes contain populations of threespine stickleback. Meirs and Canoe lakes have no sticklebacks, however, they do have Arctic grayling from past stockings. The survival rate of Arctic grayling to age 1 for all size groups was lowest in the lakes with threespine sticklebacks (Tables 4 and 8). No Arctic grayling stocked as sac fry were captured in Farmer and Sliver lakes. In 1987, the rate of survival to age 1

Table 12. Average weight calculated using the average length[1] and the length of individuals[2] that were captured in 1988.

Lake	Size when Stocked	Average Weight (g)		
		Biased	Unbiased	%difference
Steese 29.5 Mile	4-g	14.42	14.59	1.2
Steese 30.6 Mile	4-g	22.03	22.34	1.4
Steese 31.6 Mile	4-g	12.83	13.02	1.5
Steese 33.0 Mile	sac fry	19.99	20.11	0.60
Steese 33.5 Mile	sac fry	43.57	43.77	0.46
CHSR 32.9 Mile	4-g	15.09	15.32	1.3
CHSR 47.9 Mile	4-g	10.95	11.14	1.7
Bathing Beauty	4-g	21.80	22.09	1.3
Canoe Lake	4-g	27.24	27.73	1.8
Farmer Lake	4-g	8.25	8.43	2.1

[1] Average weight (biased) $\bar{\omega}_{jk} = a\bar{l}_{jk}^{b}$

[2] Average weight (unbiased) $\bar{\omega}_{jk} = \frac{\sum_{i=1}^{n_{jk}} a l_{ijk}^{b}}{n_{jk}}$

for Arctic grayling stocked as 4-g fingerlings was about 0.51 and 0.34 in Farmer and Sliver lakes, respectively, but about 0.88 and 0.94 in Canoe and Meirs lakes, respectively. The survival rates to age 1 for Arctic grayling stocked as 6-g fingerlings was about 0.66 and 0.74 in Farmer and Sliver lakes, respectively, while about 1.0 in both Canoe and Meirs lakes. In 1988, survival rate to age 1 for Arctic grayling stocked as 4-g fingerlings was about 0.03 and 0.36 in Farmer and Willow lakes, respectively, and about 0.33 in Canoe Lake.

The mean lengths at age 1 for Arctic grayling stocked as 4-g and 6-g fingerlings were smallest in lakes that have threespine sticklebacks (Tables 5 and 11). In 1987 and 1988, the mean length at age 1 was less than 100 mm in Farmer, Sliver, and Willow lakes, while in Canoe and Meirs lakes the mean length was over 129 mm.

Length-Weight Relationship

The estimates of the parameters from the regression of the length and weight of age-0 and age-1 Arctic grayling were: a (y-intercept) = 1.98×10^{-6}, SE = 2.82×10^{-7}; b (slope) = 2.88, SE = 2.58×10^{-2}; and correlation (a,b) = 0.93.

Morphoedaphic Index and Production

The morphoedaphic indices (MEI) ranged from 6 to 116 (Table 13). Meirs Lake had the lowest MEI. The mean depth was about 11 m and the total alkalinity

Table 13. Physical and chemical measurements and morphoedaphic index of lakes near Fairbanks and Palmer.

Area and Lake	Alkalinity (mg/L as $CaCO_3$)	Surface Area (ha)	Volume (m^3)	Mean Depth (m)	Morphoedaphic Index
Fairbanks					
Steese 29.5 Mile	35	3.7	31,800	0.9	41
Steese 30.6 Mile	34	1.0	12,500	1.2	29
Steese 31.6 Mile	20	1.5	15,700	1.1	19
Steese 33.0 Mile	29	2.9	42,500	1.5	20
Steese 33.5 Mile	21	1.3	23,400	1.8	12
Steese 34.6 Mile	58	2.5	23,700	0.9	61
Steese 35.8 Mile	21	1.0	16,800	1.6	13
Steese 36.6 Mile	62	3.8	41,000	1.1	58
Walden Pond	40	1.9	52,800	2.9	14
CHSR 32.9 Mile	183	2.5	39,400	1.6	116
CHSR 42.8 Mile	80	3.2	48,600	1.5	53
CHSR 45.5 Mile	42	3.2	43,900	1.4	31
CHSR 47.9 Mile	43	2.3	71,100	3.1	14
Bathing Beauty	109	5.7	179,100	3.1	35
Grayling Lake	117	8.7	116,200	1.3	88
Johnson Rd Pit #1	105	5.7	54,300	1.0	110
Johnson Rd Pit #2	131	3.9	53,500	1.4	97
Palmer					
Farmer Lake	34	8.5	106,100	1.2	27
Canoe Lake	103	8.6	397,200	4.6	22
Bruce Lake	34	12.1	318,200	2.6	13
Meirs Lake	68	6.8	747,500	11.0	6
Willow Lake	51	58.0	603,200	1.0	49
Sliver Lake	103	2.8	85,100	3.0	34

about 68 mg/L. The highest MEI was for the lake at CHSR 32.9 Mile. The mean depth was about 2 m and the total alkalinity was about 183 mg/L. There were no clear trends in the morphological and edaphic characteristics of the lakes (Table 13).

In 1987 and 1988 the estimates of production (kg/ha) of age 1 Arctic grayling ranged from about 0.17 to almost 27 kg (Tables 14, 15, and 16). The highest estimates of production to age 1 were for Arctic grayling stocked as sac fry in Steese 33.0 Mile, Steese 33.5 Mile, and CHSR 45.5 Mile. The lowest estimates of production, less than 1 kg/ha, were for Arctic grayling stocked as sac fry in lakes with existing populations of rainbow trout, stickleback, and Arctic grayling. In these lakes, estimates of production to age-1 for Arctic grayling stocked as fingerlings were also less than 1 kg/ha.

Plots of production versus MEI show no clear relationships (Figures 10 and 11). The correlations between production and MEI for each size group and stocking method ranged from 0 to -0.9. The correlations were not significantly different from 0 at $\alpha = 0.05$. However, production was usually low at high values of MEI, and more variable at lower values of MEI.

Table 14. Production to age 1 of Arctic grayling stocked as sac fry, 4-g, and 6-g fingerlings in 1986.

Lake	Initial Biomass (kg)	Average Biomass (kg)	Production (kg)	Production/ha (kg/ha)
Sac fry				
Steese 31.6	0.07	0.62	4.31	2.87
Steese 34.6	0.12	0.34	2.22	0.80
Luke Lake	0.17	36.80	297.13	
Sheefish Lake	0.17	1.36	9.62	
Junction Lake	0.61	3.90	27.31	
Buffalo	0.17	0.82	6.17	
Farmer	0.71			
Sliver	0.25			
Meirs	0.57	8.47	69.09	10.16
Canoe	0.72	5.52	46.56	5.41
4-g fingerlings				
Steese 31.6	0.75	0.19	0.26	0.17
Steese 34.6	1.49	2.27	2.03	0.81
Luke Lake	1.86	2.11	3.70	
Sheefish Lake	1.86	4.71	7.82	
Junction Lake	6.71	7.75	10.1	
Farmer	6.01	5.98	34.00	0.47
Sliver	2.69	2.23	1.56	0.56
Meirs	6.32	18.37	36.37	5.35
Canoe	4.50	15.05	32.01	3.72

-Continued-

Table 14. Production to age 1 of Arctic grayling stocked as sac fry, 4-g, and 6-g fingerlings in 1986. (Continued).

Lake	Initial Biomass (kg)	Average Biomass (kg)	Production (kg)	Production/ha (kg/ha)
6-g fingerlings				
Steese 31.6	1.27			
Steese 34.6	2.53	3.10	1.33	0.53
Luke Lake	3.16	3.21	3.72	
Sheefish Lake	3.16	4.96	5.50	
Junction	1.39	10.70	7.70	
Buffalo	3.16	4.72	5.23	
Farmer	3.17	12.41	3.76	0.44
Sliver	4.56	5.17	2.82	1.01
Meirs	10.63	22.39	30.02	4.41
Canoe	13.42	31.43	47.61	5.52

Table 15. Production to age 1 of Arctic grayling stocked as sac fry and 4-g fingerlings in 1987.

Lake	Initial Biomass (kg)	Average Biomass (kg)	Production (kg)	Production/ha (kg/ha)
Sac fry				
Steese 33.0 Mile	0.17	9.24	65.37	22.54
Steese 33.5 Mile	0.17	4.47	35.07	26.98
Steese 34.6 Mile	0.12	1.94	13.27	5.31
Walden Pond	0.26			
CHSR 45.5 Mile	0.17	0.85	5.767	1.80
Johnson Road Pit #1	0.17			
4-g fingerlings				
Steese 29.5 Mile	3.73	2.74	3.72	1.00
Steese 30.6 Mile	3.73	6.71	11.93	11.93
Steese 31.6 Mile	1.49	1.23	1.54	1.02
Steese 35.8 Mile	3.73	5.02	6.41	6.41
Steese 36.6 Mile	3.73	3.64	4.45	1.17
CHSR 32.9 Mile	3,73	6.17	8.71	3.48
CHSR 42.8 Mile	3.73	1.00	0.90	0.28
CHSR 47.9 Mile	2.98	2.48	2.67	1.16
Bathing Beauty	3.73	3.14	5.73	1.00
Grayling Lake	3.73			
Johnson Road Pit #2	3.73			
Farmer	15.67	14.12	11.30	1.33
Canoe	15.81	25.32	50.12	5.83
Bruce	19.66	20.02	44.97	3.72
Willow	99.22	33.13	26.50	0.46

Table 16. Production (growth) to age 1 of Arctic grayling stocked as sac fry in 1986.

Lake	Initial Biomass (kg)	Average Biomass (kg)	Production (kg)	Production/ha (kg/ha)
Steese 29.5 Mile	0.17	5.47	38.98	10.53
Steese 36.6 Mile	0.17	3.70	27.12	7.14
CHSR 45.5 Mile	0.17	9.69	74.17	23.18
Bathing Beauty	0.17	1.52	12.66	2.22

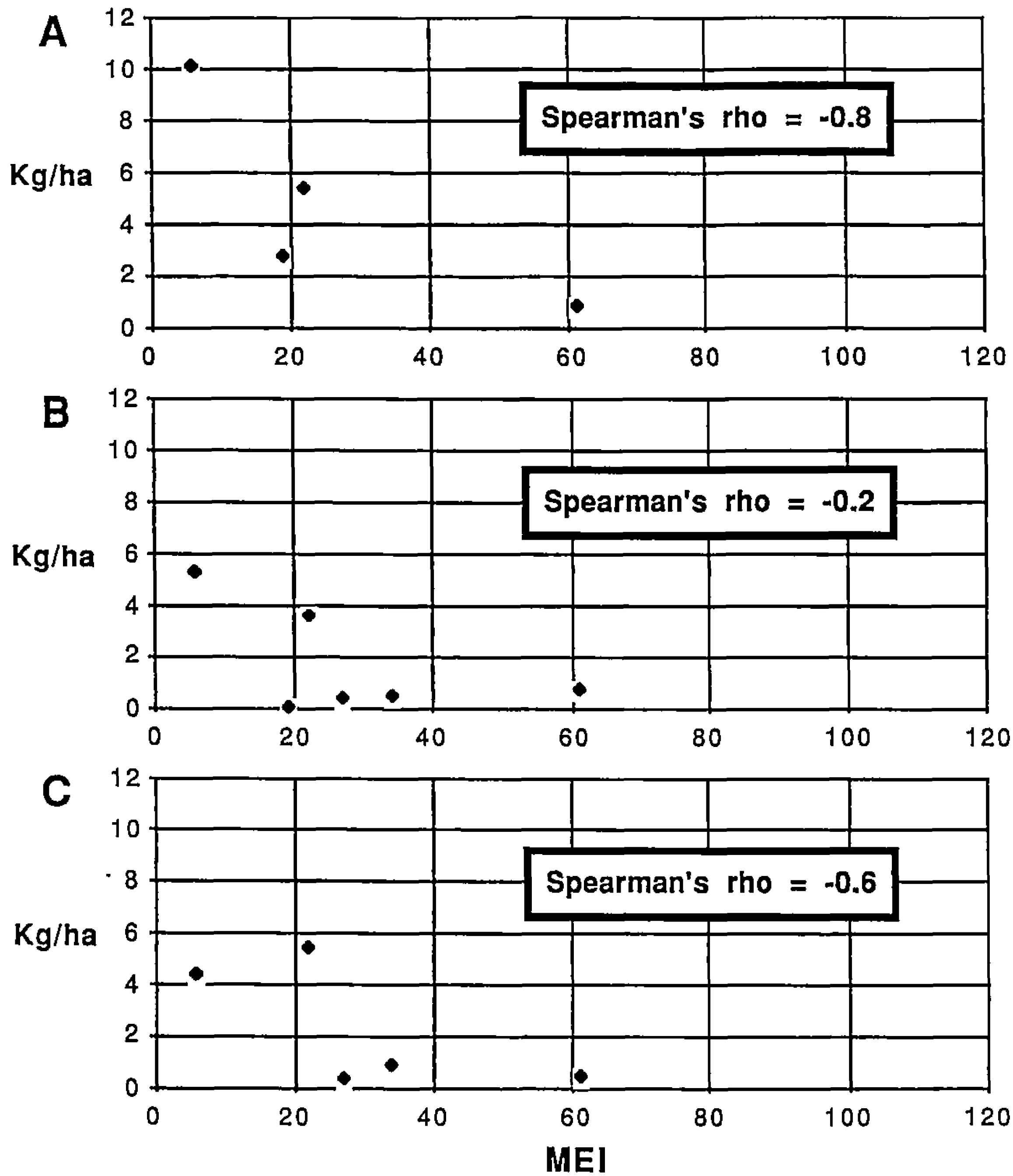


Figure 10. Production (kg/ha) to age 1 of Arctic grayling stocked as: (A) sac fry, (B) 4-g, and (C) 6-g fingerlings in 1986.

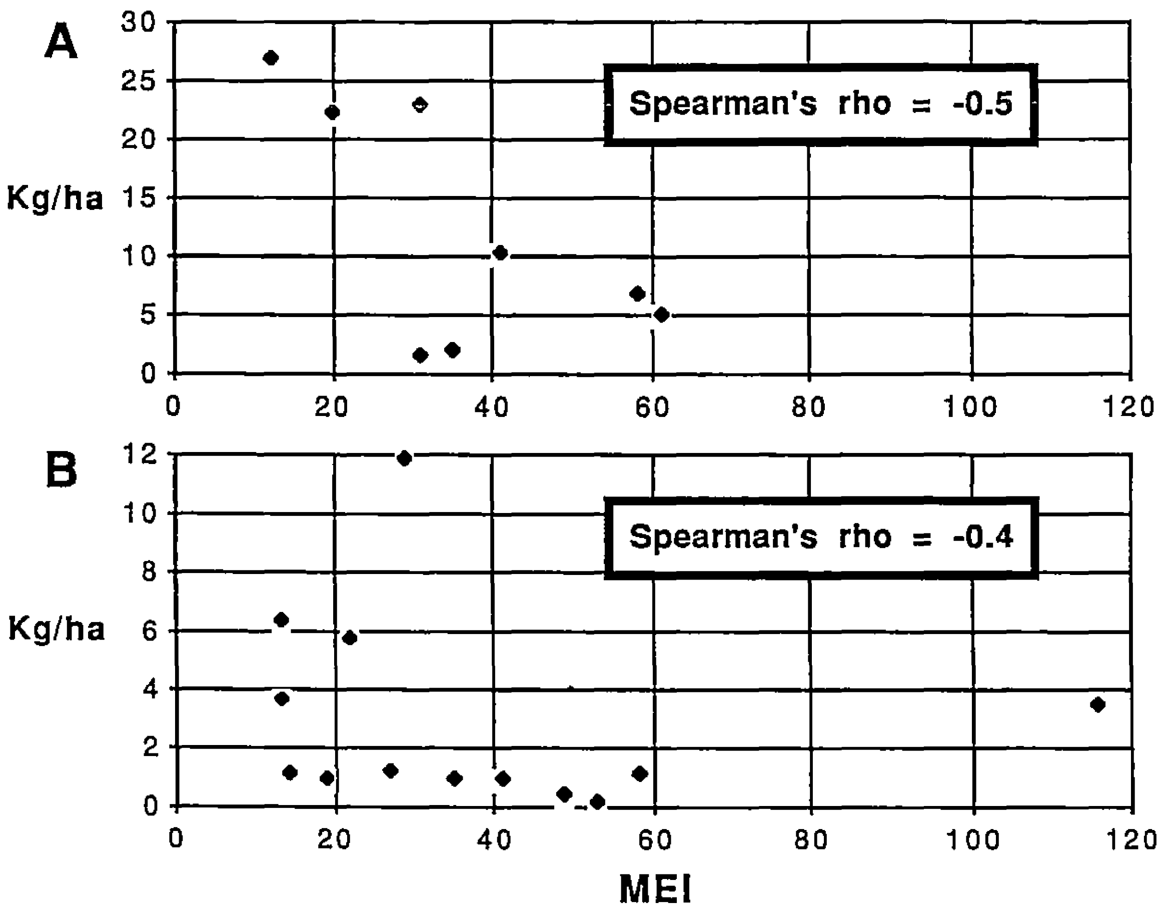


Figure 11. Production (kg/ha) to age 1 of Arctic grayling stocked as: (A) sac fry and (B) 4-g fingerlings in 1986 and 1987.

DISCUSSION

For most evaluations of fish stocking programs, fishery biologists estimate the rate of survival or the weight of stocked fish returned to the angler's creel. Management decisions, such as the size and number of fish to stock or whether to continue or discontinue stocking, are made based on these estimates. Although useful, these estimates ignore the costs of producing, stocking, and maintaining a fishery.

Another useful concept to fishery managers is the cost per survivor or cost per kg (pound) of stocked fish returned to the angler's creel. These estimates are calculated by combining the estimates of the rates of survival or the weight of fish harvested with the costs of producing and stocking the fish. Rawstron (1977) compared the costs per pound returned to the angler's creel to determine the optimum stocking time and bag limit for stocked rainbow trout. In addition to other data, Cordone and Nicola (1970) and Rawstron (1972, 1973) compared the costs per pound returned to the angler's creel for different strains of rainbow trout to determine which strain to use for stocking. Wigglesworth and Rawstron (1974) recommended to continue stocking land-locked coho salmon because they grew faster than rainbow trout and the costs per pound returned to the creel were about the same. Flickinger and Clark (1978) used cost per survivor along with other information to determine the feasibility of stocking northern pike in small plains reservoirs in Colorado. In addition to the standard estimates of survival and weight returned to the creel, these studies also used costs to better evaluate and manage fisheries.

Stocking Costs

The cost per Arctic grayling when stocked is the result of the relation between two main factors: the costs accrued by the hatchery to produce Arctic grayling and the number of Arctic grayling produced. The cost per Arctic grayling when stocked was calculated as the total cost of producing sac fry and fingerlings at Clear Hatchery divided by the respective total number of sac fry and fingerlings that were stocked. Both of the components in this relationship varied annually which affected the cost per fish when stocked.

Any increase in hatchery operational costs will probably affect the costs of producing sac fry and fingerlings differently. Sac fry are in the hatchery for about three weeks and require very little of the hatchery's resources. Fingerlings are in the hatchery for up to four months and require more hatchery resources such as raceways, electricity, food, and personnel time. Because fingerlings require more of the hatchery resources, a rise in the costs of electricity, fish food, and/or personnel will increase the cost of producing fingerlings more than sac fry.

Also, the number of Arctic grayling produced affects the cost. The cost of producing Arctic grayling is usually inversely related to the number produced. When fewer Arctic grayling are required for stocking programs the cost per fish increases.

The costs for sac fry and fingerlings obtained from Clear Hatchery are different for both sac fry and 4-g fingerlings produced in 1986 and 1987. After discussing these cost differences with the hatchery manager, I determined that the differences were due to different methods used to calculate the cost of producing Arctic grayling and not to any changes in operational costs or numbers of Arctic grayling produced.

Different methods were used because there is no standard method of calculating the cost of producing fish. My results were not affected because the differences were not large. However, there is a potential problem of using misleading costs. Because the cost of producing fish must be considered when making management decisions for stocking programs, the method of calculating these costs should be standardized.

<u>Assumptions of the Petersen and Schnabel Mark-Recapture Estimators</u>

The assumptions for unbiased estimates of abundance from two-event (a Petersen estimator) and multiple-event (a Schnabel estimator) mark-recapture experiments on closed populations are:

1. Fish do not lose marks between sampling events;
2. Marking does not effect the catchability of a fish;
3. Every fish has an equal probability of being marked;
4. Every fish has an equal probability of being recaptured; and,
5. Marked fish mix completely with unmarked fish between sampling events.

Both assumptions 1 and 2 must be fulfilled for the mark-recapture experiment to succeed. Fish were unlikely to lose their marks because they were marked by removing pelvic and adipose fins which were unlikely to regenerate during the experiment.

However, marking may have affected the catchability of some fish in later capture events. Analysis of the data from the multiple-event mark-recapture experiments showed that the proportion of marked fish in the samples sometimes decreased. This may indicate that newly marked fish become "trap shy" and later avoid the fyke nets. If marked fish avoid the traps, the estimate of abundance would be inflated. Before the recapture event, I decided to wait about two months which would allow sufficient time for the marked fish to mix with the unmarked fish and to "forget" their experience with the fyke nets.

In addition to fulfilling the first two assumptions, any one of the three remaining assumptions need be fulfilled. These assumptions, however, cannot be tested directly with my sampling design. I have assumed that at least one was fulfilled based on conditions and observations during sampling.

The populations were closed to recruitment during the experiment because all fingerlings were marked with pelvic fin clips prior to stocking and there is no natural reproduction in most of the lakes. Sac fry, however, were not marked. Recruitment of unmarked fish would increase only the abundance estimate of the fish that were stocked as sac fry. However, the abundance estimates in the few lakes where natural reproduction may occur were less than the mean abundance which indicates that there was very little or no recruitment.

The two month wait between the marking and recapture samples and the small size of the lakes would promote mixing of marked and unmarked fish. Also, during the wait there was probably some mortality of marked and unmarked fish. The estimate of abundance, however, would not be affected because the estimate is germane to the size of the population when the fish were marked. Mortality does not affect the estimate as long as the rate of mortality is the same for both marked and unmarked fish. The process of capturing, handling, and marking did not appear to harm the fish. The few fish that were injured were not returned to the population.

Survival Rate and Cost per Survivor

The mean rate of survival to age 1 increased when larger Arctic grayling were stocked while the cost per survivor decreased. In other studies the survival also increased when larger fish were stocked. In seven lakes in the Matanuska-Susitna Valley, Alaska, Havens (1983, 1984) found that the mean survival rate of rainbow trout to age 1 increased when larger fish were stocked. In several small reservoirs in Colorado, Clark (1975) and Flickinger and Clark (1978) found that the mean survival rate of northern pike to age 1 also increased when larger fish were stocked. However, in the same study, when larger northern pike were stocked the cost per survivor at age 1 also increased.

The survival rate of Arctic grayling sac fry to age 1 was usually quite low (less than 10%) except in barren lakes. In several of these lakes, the number of survivors was less than 50 or the cost per survivor at age 1 was more than $5, or both. The survival rate of 4-g and 6-g fingerlings was usually higher (about 50%) in most of the lakes and the cost per survivor was usually less than $5. However, in a few of the lakes the survival rate of all size groups stocked in 1986 and 1987 was consistently quite low and the cost per survivor was more than $5. These few lakes probably are not suited to Arctic grayling because of the presence of predators, poor water quality, or some other factor.

Sac fry were stocked in June, 4-g fingerlings were stocked in August, and 6-g fingerlings were stocked in September; which may influence the rate of survival. The Arctic grayling were stocked when they reached the desired size using rearing procedures that are standard at Clear Hatchery (Parks et al. 1986, 1988). The consequence is that fingerlings are stocked later in the year because they require more rearing in the hatchery than sac fry.

The rate of survival to age 1 for Arctic grayling that had been stocked as 4-g fingerlings decreased by about 50% from 1987 to 1988. The change was probably not due to different climatic conditions because the rate of survival to age 1 for Arctic grayling stocked as sac fry increased by about 50% over the same period. Also, increased competition between the more abundant sac fry (due to increased survival rate) and 4-g fingerlings was unlikely because sac fry and 4-g fingerlings were not stocked in the same lakes in 1987. It's possible that 4-g fingerlings were unintentionally stocked in lakes that have environmental conditions less suitable to the survival of any size of stocked Arctic grayling. The reverse may also be true; sac fry were unintentionally stocked in lakes that have environmental conditions more suitable to the survival of any size of stocked Arctic grayling.

During the analysis of these data I treated the lakes (the primary unit or first stage in two-stage sampling) as a random sample from all lakes that are, or might be, stocked with Arctic grayling. In interior Alaska, the lakes in my sample actually include most of the lakes that are annually stocked with Arctic grayling. If no new lakes are stocked with Arctic grayling in the future then I may treat the stocked fish as a population instead of a sample.

When the lakes are treated as a population the variance of the cost per survivor between the lakes is zero and the variance of the overall cost per survivor is reduced. Only the comparison of the mean costs per survivor is changed for Arctic grayling stocked as sac fry and 4-g fingerlings in the single size group experiment. Assuming I sampled all populations, a Student t-test showed that the estimates of the cost per survivor were statistically different ($t = 7.4$, $df = 7$, $P < 0.001$).

Also, when I calculated the mean cost per survivor I did not include estimates made when fewer than seven fish were recaptured. In 1988, I did not use the costs per survivor of sac fry stocked in CHSR 45.5 Mile ($3.93) or of 4-g fingerlings stocked in Luke Lake ($0.23). Five fish were recaptured in each lake. If these costs had been included, the difference between the mean costs per survivor for fish stocked as sac fry and 4-g fingerlings would have been greater.

Breakeven Analysis

Because hatchery costs are likely to vary annually, fishery managers can use the breakeven analysis with estimates of survival rate and projected hatchery costs to determine if the cost per survivor at age 1 will be less for Arctic grayling that were stocked as sac fry or fingerlings. These costs, along with other information, can be used to determine the optimum size of fish to produce.

Length

The mean length of Arctic grayling at age 1 decreased when larger Arctic grayling were stocked. Sac fry were stocked in May and June and spent more time in the lakes than did the fingerlings that were stocked in August and September. Growth of Arctic grayling in the lakes evidently exceeded growth in the hatchery. In other studies, Arctic grayling that were reared in small 2 - 4 ha lakes near Fairbanks where generally larger than Arctic grayling produced at Clear Hatchery (Holmes 1985; Ridder 1985). Rainbow trout stocked in mid August at 0.9 g were larger at age 1 than rainbow trout that were stocked in late September at 2 g (Havens 1983). At Clear Hatchery, Arctic grayling grew faster at 16.4°C than 13.5°C (Parks et al. 1986). During the summer the water temperature near the surface in these lakes exceeds 17°C. Arctic grayling probably grow faster in the lakes because the water is warmer.

Survival Rate and Growth in the Presence of Sticklebacks

Poor growth of Arctic grayling fingerlings and little or no apparent survival of sac fry in Farmer Lake and Sliver Lake may be caused by trophic competition with threespine sticklebacks. Havens (1983) found that the length and weight of age-1 rainbow trout stocked as age-0 fingerlings in lakes that have threespine stickleback were usually less than the mean lengths and weights of rainbow trout stocked in lakes that did not have threespine stickleback. The Arctic grayling fingerlings in my study were also smaller when threespine stickleback were present. Havens (1982) and Wenderoff (1982) found that rainbow trout fed mainly on zooplankton in lakes that do not have threespine stickleback. When threespine stickleback were present, rainbow trout relied more on insects and benthic organisms in lakes. I did not analyze the stomach contents of the Arctic grayling in my study. However, Jennings (1983) found that chironomid pupae comprised 54 to 83% of the gut contents by volume of age-0 Arctic grayling in a shallow, 2 ha lake that did not have any other fish. Juvenile threespine stickleback and Arctic grayling sac fry may also compete for the same food items. Threespine stickleback spawn in the spring and the young hatch about two weeks later (Morrow 1980), just about the time that Arctic grayling sac fry are stocked in lakes.

In addition to trophic competition, adult threespine stickleback may be large enough to prey on Arctic grayling sac fry. I have observed small Arctic grayling and rainbow trout (about 150 mm) capture newly stocked Arctic grayling sac fry (about 15 mm). Cannibalism has also been observed between faster growing and slower growing age-0 Arctic grayling at Clear Hatchery (Parks et al. 1986). I suspect that adult threespine stickleback (about 100 mm) are also large enough to prey on Arctic grayling sac fry.

Jennings (1983) also noted that sac fry suffer high mortality about the time that the egg yolk is absorbed. At Clear Hatchery about 40% of sac fry mortality was attributed to starvation (Parks et al. 1986) during the first ten days of rearing. The mortality probably occurs after the yolk sac is absorbed and some sac fry are not able to adapt to an external food source.

Effect of Fin Clips on Survival Rate

Fin clips do not seem to affect the rate of survival to age 1 of Arctic grayling stocked as 4-g fingerlings. In 1987, prior to stocking, 4-g fingerlings stocked near Fairbanks were given both left and right pelvic fin clips while 4-g fingerlings stocked near Palmer were not fin clipped. The survival rate to age 1 for the unclipped fingerlings was 0.33 (Canoe Lake) and 0.36 (Farmer Lake). Overall, the mean rate of survival for Arctic grayling, whether fin clipped or not, was about 0.34. In contrast, fin clips on rainbow trout may reduce survival by as much as 80% in a natural environment (Nicola and Cordone 1973). The survival rate of rainbow trout also varied with the fin that was clipped and the number of fins that were clipped.

Also, the number of fin clips does not seem to affect the rate of survival of Arctic grayling. Arctic grayling stocked in 1986 were given either a left or right pelvic fin clip while Arctic grayling stocked in 1987 were given both left and right pelvic fin clips or were not fin clipped. The rate of survival was highest for the Arctic grayling that were given a single fin clip in 1986. However, the rate of survival was about the same for clipped and unclipped Arctic grayling stocked in 1987. These results suggest that some other factor affected the rate of survival rather than the number of fins clipped.

Relationship between Production and Morphoedaphic Index

There is usually a positive relation between the morphoedaphic index and the production of fish in lakes and reservoirs (Ryder 1965; Ryder et al. 1974; Jenkins 1967; Oglesby and Jenkins 1982; Schlesinger and Regier 1982). In my study, the correlation between MEI and production, while negative, was not significantly different from 0. A negative correlation may indicate some form of biological stress in the system (Ryder et al. 1974; Viitanen 1971). However, I observed no obvious cause for biological stress in the lakes in my study.

To use the morphoedaphic index to predict the production of fish, Ryder et al. (1974) suggest that the lakes be "geographically associated with somewhat similar fish populations." The lakes used in my study do not have similar fish populations. Four lakes were barren prior to stocking while other lakes have a long history of previous Arctic grayling stockings. In three lakes, Arctic grayling were stocked together with rainbow trout. Several lakes near Fairbanks also have populations of predators such as land locked coho salmon, burbot, or northern pike. Lakes near Palmer have populations of threespine sticklebacks that may compete with Arctic grayling for food.

In nine small lakes in the Matanuska-Susitna Valley, Alaska, Woods (1985) found no significant correlation between total phosphorus concentration, chlorophyll a concentration, Secchi disc transparency, or the morphoedaphic index with the survival and growth rates of rainbow trout. Woods concluded that the survivability of rainbow trout stocked in these lakes was possibly a more important indicator of potential production than are indicators of lake fertility, especially when the possibility of winterkill is high.

In shallow lakes an abundance of aquatic plants may cause a winterkill as the plants die and consume oxygen during decomposition. The relative abundance of aquatic plants was not measured, but observations in the spring and fall during the mark-recapture experiments indicated that the percent of lake bottom covered by aquatic plants was variable among lakes. Also, during the winter, snow cover restricts the amount of light available for photosynthetically produced oxygen, and the amount of available light varies inversely with the thickness of the snow cover.

The use of the morphoedaphic index to predict production may not be applicable in my study because I limited the estimates of production to only age-1 Arctic grayling. I did not account for older Arctic grayling and other species that were present in some of the lakes. Additionally, in most of the lakes the mean depth is less than the potential euphotic zone (about 12 m).

Production may be limited by lake depth which may account for some of the variability of production at lower values of MEI.

MANAGEMENT IMPLICATIONS

Although hatchery reared Arctic grayling fingerlings cost more to produce, the cost per survivor at age 1 decreased when large Arctic grayling were stocked because the increased survival rate offset the higher cost. The rate of survival to age 1 was higher for Arctic grayling stocked as 6-g fingerlings but the difference between the costs per survivor for 4-g and 6-g fingerlings was small and not significant.

I recommend stocking 4-g Arctic grayling fingerlings in most lakes because at age 1 the overall cost per survivor is less than that for Arctic grayling stocked as sac fry. The 4-g fingerlings require less rearing than 6-g fingerlings and more quickly release hatchery resources for other projects. In barren lakes I recommend stocking Arctic grayling sac fry because the cost per survivor is about the same as the cost per survivor for 4-g fingerlings but the hatchery rearing time is much shorter and transportation of the sac fry is easier. I recommend against stocking Arctic grayling in the few lakes where the number of survivors at age 1 is consistently less than 50 or the cost per survivor is consistently more than $5.00.

The method of calculating the cost of producing fish should be standardized to avoid misleading costs and permit fishery managers to more accurately compare costs for different years. The costs associated with creating and maintaining fisheries should also be considered during evaluations of stocking programs.

LITERATURE CITED

Bickel P. J. and D. A. Freedman. 1981. Some asymptotic theory for the bootstrap. The Annals of Statistics, 9(6): 1196-1217.

Buckland, S. T. Quantifying precision of mark-recapture estimates using the bootstrap. International American Tropical Tuna Commission, 8604 La Jolla Shores Drive, La Jolla, California 92093.

Chapman, D. 1951. Some properties of the hypergeometric distribution with applications to zoological censuses. University of California Publications in Statistics, 1: 131-160.

______. 1952. Inverse multiple and sequential sample censuses. Biometrics, 8: 286-306.

Clark, J. H. 1975. Management evaluation of stocked northern pike in Colorado's small plains reservoirs. Thesis. Colorado State University, Fort Collins, Colorado. 66 p.

Cochran, W. G. 1977. Sampling techniques. Wiley. New York, New York. 428 p.

Cordone, A. J. and S. J. Nicola. 1970. Harvest of four strains of rainbow trout, *Salmo Gairdnerii*, from Beardsley Reservoir, California. California Fish and Game, 56(4): 271-287.

Davis, J. C. 1973. Statistics and data analysis in geology. John Wiley & Sons, New York. p. 298-411.

Efron, B. 1981. Nonparametric estimates of standard error: The jackknife, the bootstrap and other methods. Biometrika, 68(3): 589-599.

______. 1982. The jackknife, the bootstrap, and other resampling plans. CBMS Regional Conference Series in Applied Mathematics 38, Society for Industrial and Applied Mathematics, Philadelphia. 92 p.

Efron B. and G. Gong. 1983. A leisurely look at the bootstrap, the jackknife, and cross-validation. The American Statistician, 37(1): 36-48.

Flickinger, S. A. and J. H. Clark. 1978. Management evaluation of stocked northern pike in Colorado's small irrigation reservoirs. American Fisheries Society Special Publication, 11: 284-291.

Goodman, L. A. 1960. On the exact variance of products. Journal of American Statistical Association, 55: 708-713.

Hankin, D. G. 1984. Multistage sampling designs in fisheries research: applications in small streams. Canadian Journal of Fisheries and Aquatic Sciences, 41: 1575-1591.

Havens, A. 1982. Population studies of game fish and evaluation of managed lakes in the upper Cook Inlet drainage. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1981-1982, Project F-9-14, 23(G-III-D).

______. 1983. Population studies of Game fish and evaluation of managed lakes in the upper Cook Inlet drainage. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1982-1983, Project F-9-15, 24(G-III-D).

______. 1984. Population studies of Game fish and evaluation of managed lakes in the upper Cook Inlet drainage. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1983-1984, Project F-9-16, 25(G-III-D).

______. 1986. Population studies of Game fish and evaluation of managed lakes in the upper Cook Inlet drainage. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1985-1986, Project F-9-18, 27(G-III-D).

Holmes, R. 1985. Population structure and dynamics of the Arctic grayling with emphasis on heavily fished stocks. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1984-1985, Project F-9-17, 26(R-I): 59-102.

_______. 1986. Tanana Arctic grayling study. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1985-1986, 26(G-8-1).

Jenkins, R. M. 1967. The influence of some environmental factors on standing crop and harvest of fishes in U.S. reservoirs. *In* Proceedings of Reservoir Fisheries Symposium, Southern Division of the American Fisheries Society. p. 298-321.

Jennings, T. R. 1983. Survival, growth and food habits of young-of-the-year Arctic grayling stocked in small, sub-arctic lakes. Thesis. University of Alaska, Fairbanks. 73 p.

Marquardt, D. W. 1963. An algorithm for least-squares estimation of nonlinear parameters. Journal of the Society of Industrial and Applied Mathematics, 11: 431-441.

Morrow, J. 1980. The freshwater fishes of Alaska. Alaska Northwest Publishing Company, Anchorage, Alaska. 248 p.

Nicola, S. and A. Cordone. 1973. Effects of fin removal on survival and growth of rainbow trout in a natural environment. Transactions of the American Fisheries Society, 4: 753-758.

Oglesby, R. T., and R. M. Jenkins. 1982. The morphoedaphic index and reservoir fish production. Transactions of the American Fisheries Society, 111: 133-140.

Parks, D., T. Burke, and D. Bee. 1986. Arctic grayling culture. Federal Aid in Sport Fish Restoration, F-23-R, 3(5).

______. 1988. Arctic grayling culture. Federal Aid in Sport Fish Restoration, F-27-R, 3(1).

Peckham, R. 1975. Evaluation of interior Alaska waters and sport fish with emphasis on stocked lakes. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1974-1975, Project F-9-7, 16(G-III-E): 52-77.

Rawstron, R. R. 1972. Harvest, survival, and cost of two domestic strains of tagged rainbow trout stocked in Lake Berryessa, California. California Fish and Game, 58(1): 44-49.

______. 1973. Harvest, mortality, and cost of three domestic strains of tagged rainbow trout stocked in large California impoundments. California Fish and Game, 59(4): 245-265.

______. 1977. Effect of a reduced bag limit and later planting date on the mortality, survival, and cost and yield of three domestic strains of rainbow trout at Lake Berryessa and Merle Collins Reservoir 1971-1974. California Fish and Game, 63(4): 219-227.

Ricker, W. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of Fisheries Research Board of Canada. Bulletin 191. 382 p.

Ridder, W. P. 1981. A study of a typical spring-fed stream of interior Alaska. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1979-1980, Project F-9-12, 21(G-III-G).

______. 1985. The life history and population dynamics of exploited stocks of Arctic grayling associated with the Delta and Richardson Clearwater Rivers. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1984-1985, Project F-9-17, 26(G-III): 1-58.

Ryder, R. S. 1965. A method for estimating the potential fish production of north-temperate lakes. Transactions of the American Fisheries Society, 94: 214-214.

Ryder, R., S. Kerr, K. Loftus, and H. Regier. 1974. The morphoedaphic index, a fish yield estimator - review and evaluation. Journal of Fisheries Research Board of Canada, 31: 663-688.

Schlesinger, D. A. and H. A. Regier. 1982. Climatic and morphoedaphic indices of fish yields from natural lakes. Transactions of the American Fisheries Society, 111: 141-150.

Schnabel, Z. 1938. The estimation of the total fish population of a lake. American Mathematical Monthly, 45: 348-352.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. Charles Griffin and Company Ltd., London.

Selby, S. M., editor. 1971. CRC Standard mathematical tables. The Chemical Rubber Company, 18901 Cranwood Parkway, Cleveland, Ohio 44128. 710 p.

Snedecor, G. and W. Cochran. 1980. Statistical methods. The Iowa State University Press, Ames, Iowa.

Viitanen, R. 1971. Helsingin läntisen merialeeun pohjaja rantaeläimistöstä. Vesiensuogelulab. Tied, 8. 90 p.

Wenderoff, L. 1982. Trophic competition between threespine stickleback and rainbow trout in three lakes in the Matanuska Valley southcentral Alaska. Thesis. Idaho State University. 76 p.

Wigglesworth, K. A. and R. R. Rawstron. 1974. Exploitation, survival, growth, and cost of stocked silver salmon in Lake Berryessa, California. California Fish and Game, 60(1): 36-43.

Woods, P. F. 1985. Limnology of nine small lakes, Matanuska-Susitna Borough, Alaska, and the survival and growth rates of rainbow trout. United States Department of the Interior Geological Survey, Water-Resources Investigations Report 854292. 32 p.

Zar, J. 1984. Biostatistical analysis. Prentice-Hall, Incorporated, Englewood Cliffs, New Jersey. 718 p.

Appendix 1. Stocking history of the lakes that were used in this study and the species that were captured.

Lake	Stocked	Date	Species	Life Stage	Number
Steese 29.5 Mile	Yes	20 Jun 1977	Arctic grayling	Sac fry	10,000
	Yes	12 Jun 1978	Arctic grayling	Sac fry	10,000
	Yes	3 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	7 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	21 Jun 1985	Arctic grayling	Sac fry	10,000
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	28 Aug 1987	Arctic grayling	4-g	1,000
	No		Chinook salmon *Oncorhynchus tshawytscha*		
	No		Round whitefish *Prosopium cylindraceum*		
	No		Least cisco *Coregonus sardinella*		
	No		Burbot		
Steese 30.6 Mile	Yes	27 Jun 1975	Arctic grayling	Sac fry	5,000
	Yes	12 Jun 1978	Arctic grayling	Sac fry	12,500
	Yes	3 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	7 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	21 Jun 1985	Arctic grayling	Sac fry	10,000
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	28 Aug 1987	Arctic grayling	4-g	1,000
Steese 31.6 Mile	Yes	20 Jun 1977	Arctic grayling	Sac fry	10,000
	Yes	3 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	7 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	25 Sep 1985	Arctic grayling	5.5-g	1,600
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	5 Sep 1986	Arctic grayling	4-g	200
	Yes	24 Sep 1986	Arctic grayling	6-g	200
	Yes	28 Aug 1987	Arctic grayling	4-g	400
	No		Burbot		
Steese 33.0 Mile	Yes	20 Jun 1977	Arctic grayling	Sac fry	10,000
	Yes	12 Jun 1978	Arctic grayling	Sac fry	10,000
	Yes	3 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	7 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	15 Jun 1987	Arctic grayling	Sac fry	10,000

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Appendix 1. Stocking history of the lakes that were used in this study and the species that were captured. (Continued).

Lake	Stocked	Date	Species	Life Stage	Number
Steese 33.5 Mile	Yes	20 Jun 1977	Arctic grayling	Sac fry	10,000
	Yes	12 Jun 1978	Arctic grayling	Sac fry	10,000
	Yes	3 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	7 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	1 Jun 1985	Arctic grayling	Sac fry	10,000
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	15 Jun 1987	Arctic grayling	Sac fry	10,000
Steese 34.6 Mile	Yes	27 Jun 1975	Arctic grayling	Sac fry	10,000
	Yes	12 Jun 1978	Arctic grayling	Sac fry	10,000
	Yes	12 Jun 1978	Arctic grayling	Sac fry	12,500
	Yes	3 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	7 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	25 Sep 1985	Arctic grayling	5.5-g	1,663
	Yes	11 Jun 1986	Arctic grayling	Sac fry	8,000
	Yes	5 Sep 1986	Arctic grayling	4-g	400
	Yes	24 Sep 1986	Arctic grayling	6-g	400
	Yes	15 Jun 1987	Arctic grayling	Sac fry	8,000
Steese 35.8 Mile	Yes	27 Jun 1975	Arctic grayling	Sac fry	10,000
	Yes	3 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	7 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	21 Jun 1985	Arctic grayling	Sac fry	10,000
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	28 Aug 1987	Arctic grayling	4-g	1,000
Steese 36.8 Mile	Yes	20 Jun 1977	Arctic grayling	Sac fry	10,000
	Yes	12 Jun 1978	Arctic grayling	Sac fry	10,000
	Yes	3 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	7 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	21 Sep 1985	Arctic grayling	Sac fry	10,000
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	28 Aug 1987	Arctic grayling	4-g	1,000
	No		Least cisco		
	No		Burbot		

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Appendix 1. Stocking history of the lakes that were used in this study and the species that were captured. (Continued).

Lake	Stocked	Date	Species	Life Stage	Number
CHSR 32.9 Mile	Yes	7 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	13 Jun 1985	Arctic grayling	Sac fry	40,000
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	5 Sep 1986	Arctic grayling	4-g	500
	Yes	24 Sep 1986	Arctic grayling	6-g	500
	Yes	28 Aug 1987	Arctic grayling	4-g	1,000
CHSR 42.8 Mile	Yes	3 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	7 Jun 1984	Arctic grayling	Sac fry	10,000
	Yes	1 Jun 1985	Arctic grayling	Sac fry	10,000
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	28 Aug 1987	Arctic grayling	4-g	1,000
	No		Lake chub *Couesius plumbeus*		
	No		Chinook salmon		
	No		Burbot		
	No		Longnose sucker *Catostomus catostomus*		
CHSR 45.5 Mile	Yes	3 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	7 Jun 1984	Arctic grayling	Sac fry	10,000
	Yes	21 Jun 1985	Arctic grayling	Sac fry	10,000
	Yes	5 Sep 1986	Rainbow trout	2.1-g	1,000
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	15 Jun 1987	Arctic grayling	Sac fry	10,000
	Yes	2 Sep 1987	Rainbow trout	2.2-g	1,000
CHSR 47.9 Mile	Yes	3 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	7 Jun 1984	Arctic grayling	Sac fry	10,000
	Yes	21 Jun 1985	Arctic grayling	Sac fry	10,000
	Yes	11 Jun 1986	Arctic grayling	Sac fry	8,000
	Yes	5 Sep 1986	Arctic grayling	4-g	400
	Yes	24 Sep 1986	Arctic grayling	6-g	400
	Yes	28 Aug 1987	Arctic grayling	4-g	800
	No		Burbot		

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Appendix 1. Stocking history of the lakes that were used in this study and the species that were captured. (Continued).

Lake	Stocked	Date	Species	Life Stage	Number
Walden Pond	Yes	7 Jun 1984	Arctic grayling	Sac fry	20,000
	Yes	21 Jun 1985	Arctic grayling	Sac fry	10,000
	Yes	5 Sep 1986	Arctic grayling	4-g	1,500
	Yes	15 Jun 1987	Arctic grayling	Sac fry	15,000
Bathing Beauty Lake	Yes	27 Jun 1975	Arctic grayling	Sac fry	25,000
	Yes	12 Jun 1978	Arctic grayling	Sac fry	12,500
	Yes	2 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	8 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	21 Jun 1985	Arctic grayling	Sac fry	10,000
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	Aug 1986	Rainbow trout	2-g	1,000
	Yes	28 Aug 1987	Arctic grayling	4-g	1,000
	Yes	29 Aug 1987	Rainbow trout	2-g	1,000
Grayling Lake	Yes	27 Jun 1975	Arctic grayling	Sac fry	25,000
	Yes	12 Jun 1978	Arctic grayling	Sac fry	12,500
	Yes	2 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	8 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	13 Aug 1984	Sheefish *Stenodus leucichthys*	9-g	500
	Yes	21 Jun 1985	Arctic grayling	Sac fry	10,000
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	Aug 1986	Rainbow trout	2.3-g	500
	Yes	28 Aug 1987	Arctic grayling	4-g	1,000
	Yes	29 Aug 1987	Rainbow trout	2.2-g	500
	No		Northern pike		
Hidden Lake	Yes	26 Jun 1975	Arctic grayling	Sac fry	10,000
	Yes	27 Jun 1975	Arctic grayling	Sac fry	25,000
	Yes	12 Jun 1978	Arctic grayling	Sac fry	12,500
	Yes	2 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	8 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	21 Jun 1985	Arctic grayling	Sac fry	10,000

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Appendix 1. Stocking history of the lakes that were used in this study and the species that were captured. (Continued).

Lake	Stocked	Date	Species	Life Stage	Number
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	20 Aug 1986	Rainbow trout	1.6-g	500
	No		Lake chub		
	No		Longnose sucker		
Johnson Road Pit #1	Yes	28 Jun 1976	Arctic grayling	Sac fry	12,500
	Yes	12 Jun 1978	Arctic grayling	Sac fry	12,500
	Yes	2 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	8 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	31 May 1985	Coho salmon	3.6-g	500
	Yes	6 Jun 1986	Coho salmon	4.0-g	500
	Yes	20 Aug 1986	Rainbow trout	1.8-g	500
	Yes	15 Jun 1987	Arctic grayling	Sac fry	10,000
	Yes	1 Jun 1987	Coho Salmon	5.2-g	500
	Yes	27 Aug 1987	Rainbow trout	2.2-g	500
Johnson Road Pit #2	Yes	27 Jun 1975	Arctic grayling	Sac fry	35,000
	Yes	28 Jun 1976	Arctic grayling	Sac fry	12,500
	Yes	12 Jun 1978	Arctic grayling	Sac fry	12,500
	Yes	2 Jun 1983	Arctic grayling	Sac fry	15,000
	Yes	8 Jun 1984	Arctic grayling	Sac fry	15,000
	Yes	21 Jun 1985	Arctic grayling	Sac fry	10,000
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	28 Aug 1987	Arctic grayling	4-g	10,000
Sheefish Lake	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	5 Sep 1986	Arctic grayling	4-g	500
	Yes	24 Sep 1986	Arctic grayling	6-g	500
	Yes	28 Aug 1987	Arctic grayling	Sac fry	10,000
	No		Slimy sculpin *Cottus cognatus*		
Luke Lake	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	9 Sep 1986	Arctic grayling	4-g	500
	Yes	24 Sep 1986	Arctic grayling	6-g	500
	Yes	28 Aug 1987	Arctic grayling	4-g	500

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Appendix 1. Stocking history of the lakes that were used in this study and the species that were captured. (Continued).

Lake	Stocked	Date	Species	Life Stage	Number
Unnamed Lake	Yes	5 Sep 1986	Arctic grayling	4-g	500
Junction Lake	Yes	14 Jun 1966	Arctic grayling	Sac fry	5,000
	Yes	13 Jun 1968	Arctic grayling	Sac fry	5,000
	Yes	10 Jun 1969	Arctic grayling	Sac fry	5,000
	Yes	4 Jun 1970	Arctic grayling	Sac fry	6,000
	Yes	3 Jul 1972	Arctic grayling	Sac fry	6,000
	Yes	12 Jun 1974	Arctic grayling	Sac fry	2,000
	Yes	26 Jun 1976	Arctic grayling	Sac fry	3,000
	Yes	19 Jun 1977	Arctic grayling	Sac fry	5,000
	Yes	11 Jun 1981	Arctic grayling	Sac fry	9,000
	Yes	4 Jun 1983	Arctic grayling	Sac fry	7,500
	Yes	11 Jun 1984	Arctic grayling	Sac fry	5,000
	Yes	28 Aug 1985	Arctic-grayling	1.5-g	1,750
	Yes	11 Jun 1986	Arctic grayling	Sac fry	36,000
	Yes	9 Sep 1986	Arctic grayling	4-g	1,800
	Yes	25 Sep 1986	Arctic grayling	6-g	1,800
Buffalo Lake	Yes	6 Sep 1983	Rainbow Trout	1.4-g	2,094
	Yes	4 Sep 1985	Rainbow trout	2.9-g	1,000
	Yes	11 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	4 Sep 1986	Rainbow trout	1.5-g	782
	Yes	25 Sep 1986	Arctic grayling	6-g	500
Squirrel Creek Pit	Yes	16 Jul 1984	Rainbow trout	fry	2,000
	Yes	13 Jun 1986	Arctic grayling	Sac fry	10,000
	Yes	4 Sep 1986	Rainbow trout	1.9-g	1,000
	Yes	9 Sep 1986	Arctic grayling	4-g	500
	Yes	25 Sep 1986	Arctic grayling	6-g	500
Kettle Lake	Yes	11 Jun 1986	Arctic grayling	Sac fry	12,000
	Yes	9 Sep 1986	Arctic grayling	4-g	600
	Yes	25 Sep 1986	Arctic grayling	6-g	600
	No		Burbot		
	No		Longnose sucker		
	No		Slimy sculpin		

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Appendix 1. Stocking history of the lakes that were used in this study and the species that were captured. (Continued).

Lake	Stocked	Date	Species	Life Stage	Number
Canoe Lake	Yes	25 Jun 1976	Arctic grayling	Sac fry	12,600
	Yes	18 Jun 1977	Arctic grayling	Sac fry	12,600
	Yes	10 Jun 1978	Arctic grayling	Sac fry	12,500
	Yes	11 Jun 1981	Arctic grayling	Sac fry	13,200
	Yes	4 Jun 1983	Arctic grayling	Sac fry	26,000
	Yes	11 Jun 1984	Arctic grayling	Sac fry	13,000
	Yes	30 Aug 1984	Arctic grayling	2.7-g	4,200
	Yes	3 Sep 1985	Arctic grayling	1.2-g	4,240
	Yes	13 Jun 1986	Arctic grayling	Sac fry	42,400
	Yes	8 Sep 1986	Arctic grayling	4-g	1,215
	Yes	25 Sep 1986	Arctic grayling	6-g	2,120
	Yes	21 Aug 1987	Arctic grayling	4-g	4,240
Sliver Lake	Yes	10 Jun 1969	Arctic grayling	Sac fry	2,000
	Yes	3 Jun 1970	Arctic grayling	Sac fry	4,000
	Yes	13 Jun 1986	Arctic grayling	Sac fry	14,400
	Yes	8 Sep 1986	Arctic grayling	4-g	720
	Yes	25 Sep 1986	Arctic grayling	6-g	720
	Yes	28 Aug 1987	Arctic grayling	4-g	1,440
	No		Threespine stickleback		
Meirs Lake	Yes	3 Jun 1970	Arctic grayling	Sac fry	10,000
	Yes	5 July 1972	Arctic grayling	Sac fry	8,000
	Yes	15 Jun 1973	Arctic grayling	Sac fry	10,200
	Yes	12 Jun 1974	Arctic grayling	Sac fry	8,400
	Yes	25 Jun 1975	Arctic grayling	Sac fry	10,000
	Yes	25 Jun 1976	Arctic grayling	Sac fry	10,000
	Yes	18 Jun 1977	Arctic grayling	Sac fry	10,000
	Yes	10 Jun 1978	Arctic grayling	Sac fry	10,000
	Yes	11 Jun 1982	Arctic grayling	Sac fry	10,100
	Yes	4 Jun 1983	Arctic grayling	Sac fry	20,000
	Yes	11 Jun 1984	Arctic grayling	Sac fry	10,000
	Yes	30 Aug 1984	Arctic grayling	2.7-g	3,400
	Yes	12 Jun 1985	Arctic grayling	Sac fry	12,700
	Yes	16 Jun 1986	Arctic grayling	Sac fry	33,600
	Yes	8 Sep 1986	Arctic grayling	4-g	1,695

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Appendix 1. Stocking history of the lakes that were used in this study and the species that were captured. (Continued).

Lake	Stocked	Date	Species	Life Stage	Number
	Yes	25 Sep 1986	Arctic grayling	6-g	1,680
	Yes	16 Jun 1987	Arctic grayling	Sac fry	16,700
	Yes	21 Aug 1987	Arctic grayling	4-g	3,360
Farmer Lake	Yes	16 Jun 1986	Arctic grayling	Sac fry	42,000
	Yes	8 Sep 1986	Arctic grayling	4-g	1,610
	Yes	25 Sep 1986	Arctic grayling	6-g	2,080
	Yes	28 Aug 1987	Arctic grayling	4-g	4,200
	No		Threespine stickleback		
Bruce Lake	Yes	22 Sep 1986	Arctic grayling	6.4-g	2,910
	Yes	22 Sep 1986	Arctic grayling	6.4-g	3,090
	Yes	21 Aug 1987	Arctic grayling	4.0-g	5,270
	No		Threespine stickleback		
Willow Lake	Yes	27 Aug 1987	Arctic grayling	4.0-g	28,600
	No		Threespine stickleback		

Appendix 2. Program for generating the capture history of Arctic grayling and the variance of the estimate of cost per survivor based on data from two-sample mark-recapture experiments.

```
OPTION BASE 1
CLS

OPEN "FileOut.TXT" FOR OUTPUT AS #1

NumBoot = 500
NumSamp = 2
NumGroup = 1

InputArray:
  PRINT "Number of fish stocked":INPUT NumStocked
  PRINT "Cost per individual when stocked":INPUT StockCostIndv
    StockCostGroup=NumStocked*StockCostIndv

  PRINT "Number of Individuals in FIRST Sample":INPUT InputArray%(1,1)
  PRINT "Number of Individuals in SECOND Sample":INPUT InputArray%(2,1)
  PRINT "Number of Recaps in SECOND Sample":INPUT InputArray%(2,2)

CaptureArray:
NumRows = 0
FOR S=1 TO NumSamp
  LET Cap%(S) = InputArray%(S,1)
  LET Recap%(S) = InputArray%(S,2)
  LET NewFish%(S) = Cap%(S) - Recap%(S)
    NumRows = NumRows + NewFish%(S)
NEXT S
```

-Continued-

Appendix 2. Program for generating the capture history of Arctic grayling and the variance of the estimate of cost per survivor based on data from two-sample mark-recapture experiments. (Continued).

```
DIM CapHistArray%(NumRows,NumSamp)

RowStart = 0
RowEnd = Cap%(1)
FOR S=1 TO NumSamp
  FOR Row = RowStart + 1 TO RowEnd
    CapHistArray%(Row,S) = 1
  NEXT Row

  RowStart = RowStart + RowEnd - Recap%(S+1)
  RowEnd = RowStart + Cap%(S+1)
NEXT S

BootLoop:
  BootAbunEst=0       'Bootstrapped abundance point estimates.
  BootSumAbun=0       'Summation of bootstrapped abundance point estimates.
  BootSumAbun2=0      'Summation of bootstrapped abundance point
      estimates^2.

  BootCostEst=0          'Bootstrapped cost point estimates.
  BootSumCost=0          'Summation of bootstrapped cost point estimates.
  BootSumCost2=0         'Summation of bootstrapped cost point estimates
                          squared.

  SumBootSamp1=0         'Summation of Sample 1 during all bootstrapped
                          resamples.
```

-Continued-

Appendix 2. Program for generating the capture history of Arctic grayling and the variance of the estimate of cost per survivor based on data from two-sample mark-recapture experiments. (Continued).

```
  SumBootSamp2=0        'Summation of Sample 2 during all bootstrapped
                         resamples.
  SumBootRecaps=0       'Summation of Recaps during all bootstrapped
                         resamples.
FOR Sample = 1 TO NumBoot
  BootSamp1=0         'Number of individuals in first bootstrap event.
  BootSamp2=0         'Number of individuals in second bootstrap event.
  BootRecaps=0        'Number of recaps in second bootstrap event.
    FOR I = 1 TO NumRows
      Row%=INT(RND*NumRows)+1
        BootSamp1=BootSamp1+CapHistArray%(Row%,1)
        BootSamp2=BootSamp2+CapHistArray%(Row%,2)
        BootRecaps=BootRecaps+CapHistArray%(Row%,1)*
            CapHistArray%(Row%,2)
    NEXT I

Summations:
  BootAbunEst=((BootSamp1+1)*(BootSamp2+1))/(BootRecaps+1)-1
  BootSumAbun=BootSumAbun+BootAbunEst
  BootSumAbun2=BootSumAbun2+BootAbunEst^2

  BootCostEst=StockCostGroup/BootAbunEst
  BootSumCost=BootSumCost+BootCostEst
  BootSumCost2=BootSumCost2+BootCostEst^2

  SumBootSamp1=SumBootSamp1+BootSamp1
  SumBootSamp2=SumBootSamp2+BootSamp2
```

-Continued-

Appendix 2. Program for generating the capture history of Arctic grayling and the variance of the estimate of cost per survivor based on data from two-sample mark-recapture experiments. (Continued).

```
  SumBootRecaps=SumBootRecaps+BootRecaps

FileWrite:
  WRITE
#1,Sample,BootAbunEst,BootSumAbun,BootSumAbun2,BootCostEst,BootSumCost,
        BootSumCost2

ScreenDisplay:
  PRINT "Boot ";Sample ;"of ";NumBoot
  PRINT "BootAbunEst:",BootAbunEst
  PRINT "BootSumAbun:",BootSumAbun
  PRINT "BootSumAbun2:",BootSumAbun2
  PRINT "BootCostEst:",BootCostEst
  PRINT "BootSumCost:",BootSumCost
  PRINT "BootSumCost2:",BootSumCost2
  PRINT
  PRINT

NEXT Sample

Calculations:
 Abundance = BootSumAbun/NumBoot
 AbunVariance=(NumBoot*BootSumAbun2-BootSumAbun^2)/(NumBoot*(NumBoot-1))
 AbunSE=SQR(AbunVariance)
 AbunLowBound=Abundance-1.96*AbunSE
 AbunUpBound=Abundance+1.96*AbunSE
```

-Continued-

Appendix 2. Program for generating the capture history of Arctic grayling and the variance of the estimate of cost per survivor based on data from two-sample mark-recapture experiments. (Continued).

```
 Cost = BootSumCost/NumBoot
 CostVariance=(NumBoot*BootSumCost2-BootSumCost^2)/(NumBoot*(NumBoot-1))
 CostSE=SQR(CostVariance)
 CostLowBound=Cost-1.96*CostSE
 CostUpBound=Cost+1.96*CostSE

 MeanBootSamp1=SumBootSamp1/NumBoot
 MeanBootSamp2=SumBootSamp2/NumBoot
 MeanBootRecaps=SumBootRecaps/NumBoot

ScreenPrintOut:
  PRINT "Cost per individual:  ";StockCostIndv
  PRINT "Number stocked:       ";NumStocked
  PRINT "Stocking cost:        ";StockCostGroup
  PRINT
  PRINT "Number of individuals in Sample 1:";InputArray%(1,1)
  PRINT "Number of individuals in Sample 2:";InputArray%(2,1)
  PRINT "Number of recaps in Sample 2:     ";InputArray%(2,2)
  PRINT
  PRINT
"========================================================================"
  PRINT "                 ABUNDANCE" TAB (51) "COST"
  PRINT "                 --------------" TAB(51) "---------------"
  PRINT "PointEst:       ";Abundance TAB(51) Cost
  PRINT "Variance:       ";AbunVariance TAB(51) CostVariance
  PRINT "Standard Error: ";AbunSE TAB(51) CostSE
```

-Continued-

Appendix 2. Program for generating the capture history of Arctic grayling and the variance of the estimate of cost per survivor based on data from two-sample mark-recapture experiments. (Continued).

```
  PRINT "Lower 95% CI:     ";AbunLowBound TAB(51) CostLowBound
  PRINT "Upper 95% CI:     ";AbunUpBound TAB(51) CostUpBound
  PRINT
  PRINT
"=====================================================================
PRINT
PRINT"Number of Boots:";NumBoot
PRINT
PRINT"Mean number of individuals captured in Sample 1:  ";MeanBootSamp1
PRINT"Mean number of individuals captured in Sample 2:  ";MeanBootSamp2
PRINT"Mean number of individuals recaptured in Sample2: ";MeanBootRecaps

PaperPrintOut:
  LPRINT "Cost per individual:  ";StockCostIndv
  LPRINT "Number stocked:       ";NumStocked
  LPRINT "Stocking cost:        ";StockCostGroup
  LPRINT
  LPRINT "Number of individuals in Sample 1:";InputArray%(1,1)
  LPRINT "Number of individuals in Sample 2:";InputArray%(2,1)
  LPRINT "Number of recaps in Sample 2:     ";InputArray%(2,2)
  LPRINT
  LPRINT
"=====================================================================
  LPRINT "                 ABUNDANCE" TAB(51) "COST"
  LPRINT "                 --------------" TAB(51) "---------------"
  LPRINT "PointEst:        ";Abundance TAB(51) Cost
```

-Continued-

Appendix 2. Program for generating the capture history of Arctic grayling and the variance of the estimate of cost per survivor based on data from two-sample mark-recapture experiments. (Continued).

```
  LPRINT "Variance:       ";AbunVariance TAB(51) CostVariance
  LPRINT "Standard Error: ";AbunSE TAB(51) CostSE
  LPRINT "Lower 95% CI:   ";AbunLowBound TAB(51) CostLowBound
  LPRINT "Upper 95% CI:   ";AbunUpBound TAB(51) CostUpBound
  LPRINT
  LPRINT
  LPRINT
"=========================================================================="
  LPRINT
  LPRINT "Number of Boots:";NumBoot
  LPRINT
  LPRINT "Mean number of individuals captured in Sample 1:  ";
         MeanBootSamp1
  LPRINT "Mean number of individuals captured in Sample 2:  ";
         MeanBootSamp2
  LPRINT "Mean number of individuals recaptured in Sample2: ";
         MeanBootRecaps
  LPRINT CHR$(12)

CLOSE #1
END
```