Fishery Data Series No. 11-41

Comparison and Assessment of Relative Survival Rates to Age 1 between Triploid All-Female Rainbow Trout Stocked as Fingerlings and Subcatchables in Birch Lake, 2007–2008

by

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and

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September 2011

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)	
centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm
Weights and measures (English)	
cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd
Time and temperature	
day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s
Physics and chemistry	
all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General	
Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics	
all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

FISHERY DATA SERIES NO. 11-41

COMPARISON AND ASSESSMENT OF RELATIVE SURVIVAL RATES TO AGE 1 BETWEEN TRIPLOID ALL-FEMALE RAINBOW TROUT STOCKED AS FINGERLINGS AND SUBCATCHABLES IN BIRCH LAKE, 2007–2008

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September 2011

This investigation was partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-23, Job E-3-1.

ADF&G Fishery Data Series was established in 1987 for the publication of Division of Sport Fish technically oriented results for a single project or group of closely related projects, and in 2004 became a joint divisional series with the Division of Commercial Fisheries. Fishery Data Series reports are intended for fishery and other technical professionals and are available through the Alaska State Library and on the Internet: http://www.adfg.alaska.gov/sf/publications/. This publication has undergone editorial and peer review.

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This document should be cited as:
Behr, A. and C. Skaugstad. 2011. Comparison and assessment of relative survival rates to age 1 between triploid all-female rainbow trout stocked as fingerlings and subcatchables in Birch Lake, 2007-2008. Alaska Department of Fish and Game, Fishery Data Series No. 11-41, Anchorage.

TABLE OF CONTENTS

Page

LIST OF FIGURES ii
LIST OF APPENDICES ii
ABSTRACT 1
INTRODUCTION 1
- Background 2
- Objectives 3

METHODS 3
RESULTS 7
DISCUSSION 9
- Stocked Fisheries Program Model 10
- Results from the Model 10
- Management Implications 11

ACKNOWLEDGEMENTS 12
REFERENCES CITED 13
APPENDIX A STOCKING HISTORY FOR BIRCH LAKE (1999–2007) 15
APPENDIX B STOCKED FISHERY ANALYSIS MODEL 17

LIST OF FIGURES

Figure **Page**

1. Location of Birch Lake 89 km south of Fairbanks, Alaska. 2
2. Length frequency distribution of rainbow trout captured in Birch Lake, June 2008. 7
3. Length frequency distribution of unmarked rainbow trout captured in Birch Lake, June 2008. 8
4. Length frequency distribution of Arctic grayling captured in Birch Lake, June 2008. 8
5. Length frequency distribution of Arctic char captured in Birch Lake, June 2008. 9

LIST OF APPENDICES

Appendix **Page**

A. Stocking History for Birch Lake (1999–2007) 15
B. Stocked Fishery Analysis Model 17

ABSTRACT

We estimated the relative survival rates to age 1 for triploid all-female rainbow trout *Oncorhynchus mykiss* that were stocked in Birch Lake as fingerlings and subcatchables. The fingerling group was reared at the Fort Richardson Hatchery and about 106,228 were stocked August 2007 with no mark (mean length when stocked was 45 mm fork length (FL)). The subcatchable group was reared at the Fairbanks Experimental Hatchery and 22,933 were counted, marked, and stocked March 2008 (mean length when stocked was 120 mm FL). In June 2008, 1,903 age-1 rainbow trout ranging in size from 57 to 197 mm FL were captured (1,685 marked, 218 unmarked). The relative survival rate for the subcatchable group was approximately 36 times that for the fingerling group. Assuming that survival rates for both groups will be similar in future years, this difference was sufficient to conclude that subcatchable-size rainbow trout is the preferred stocking product for Birch Lake.

We used these results to further explore how the production of different size fish for stocking would impact fish hatchery operations and the cost of maintaining a stocked fishery. A model based on hatchery bio-programming and cumulative biomass showed the hatchery resources needed by the subcatchable group was slightly more than that needed by the fingerling group for one scenario and less than that needed by the fingerling group for a second scenario. At the time of stocking the biomass for the subcatchable group for both scenarios was much smaller compared to that for the fingerling group. The number of female broodstock needed to produce subcatchable rainbow trout was much less compared to that needed to produce fingerlings. Other comparisons also favored the production and stocking of subcatchables over fingerlings to maintain a stocked fishery.

Key words: Birch Lake, rainbow trout, *Oncorhynchus mykiss*, relative survival, stocking, age-1, fingerling, subcatchable.

INTRODUCTION

The stocked fisheries program in Interior Alaska is exploring ways to reduce the overall cost of maintaining stocked fisheries by simultaneously considering and adjusting fish stocking methods and fish hatchery operations. The focus of this study was to estimate the relative survival rate for triploid all-female rainbow trout (*Oncorhynchus mykiss*) that were stocked as fingerlings (45 mm FL or 1 g) and subcatchables (120 mm FL or 21 g) into Birch Lake. This information was used to estimate the number of fingerling or subcatchable rainbow trout needed to sustain the current fishery and to evaluate how fish hatchery operations would be impacted.

The impetus for this study was Alaska Department of Fish and Game (ADF&G) stopping the stocking of catchable rainbow trout into Birch Lake as a precaution after QPCR (quantitative polymerase chain reaction) detection of DNA from *Myxobolus cerebralis* (Mc) from a single brood year of rainbow trout rearing at the ADF&G fish hatchery at Elmendorf Air Force Base (AFB) (Arsan 2006)[1]. The Birch Lake fishery had relied on stocking catchable size fish that were reared at Elmendorf AFB hatchery. Parasite spores or clinical disease were never observed and there was no further detection of genetic material by QPCR[2]. However, it was prudent to not stock catchable rainbow trout from Elmendorf AFB hatchery because a small stream flows from Birch Lake to the Tanana River which could have potentially provided a path for spreading Mc to Interior streams should Mc have been present. The fish used in this study didn't come from Elmendorf AFB hatchery.

Presently, fishery managers are not able to stock catchable rainbow trout into Birch Lake which, from the perspective of a fishery manager, leaves the undesirable and possibly more expensive

[1] Report of Laboratory Examination 2005-0089, Division of Commercial Fisheries–Fish Pathology. Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, Alaska 99518-1565.

[2] Report of Laboratory Examination 2010-0066, Division of Commercial Fisheries–Fish Pathology. Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, Alaska 99518-1565.

option of stocking fingerling rainbow trout. This situation will continue until the new sport fish hatchery in Fairbanks begins producing catchable rainbow trout in 2012. Until then ADF&G needs a stocking scheme that minimizes the cost of maintaining the popular rainbow trout fishery at Birch Lake.

BACKGROUND

Birch Lake is one of the largest stocked fisheries in Interior Alaska, receiving an annual average of 6,593 angler days of fishing effort from 2003 through 2007 (Jennings et al. 2006, 2007, 2009a-b, 2010). Birch Lake surface area is 327 hectares (808 acres) and the lake is about 89 km (55 miles) south of Fairbanks on the Richardson Highway (Figure 1). A rotating–drum weir in the outlet stream blocks fish passage between Birch Lake and the Tanana River. The lake is currently stocked with rainbow trout, coho salmon (*O. kisutch*), Arctic char (*Salvelinus alpines*), and Arctic grayling (*Thymallus arcticus*). From 1998 through 2006 the rainbow trout fishery was maintained by stocking catchable-size fish (Appendix A).

Skaugstad et al (1995) reported that stocking diploid subcatchable rainbow trout into Birch Lake was more cost effective compared to stocking diploid fingerling rainbow trout. But, from a fish hatchery manager's perspective, subcatchable rainbow trout were not considered a desirable product because the fish were kept in the hatchery longer, possibly interfering with other fish production needs. In contrast, fingerling rainbow trout were kept in the hatchery for less time but from the perspective of a fishery manager fingerlings were not desirable due to poor survival rates after stocking and higher cost·survivor^{-1} to catchable size. ADF&G stopped producing subcatchable rainbow trout when the hatcheries were able to produce sufficient numbers of catchable rainbow trout to stock Birch Lake.

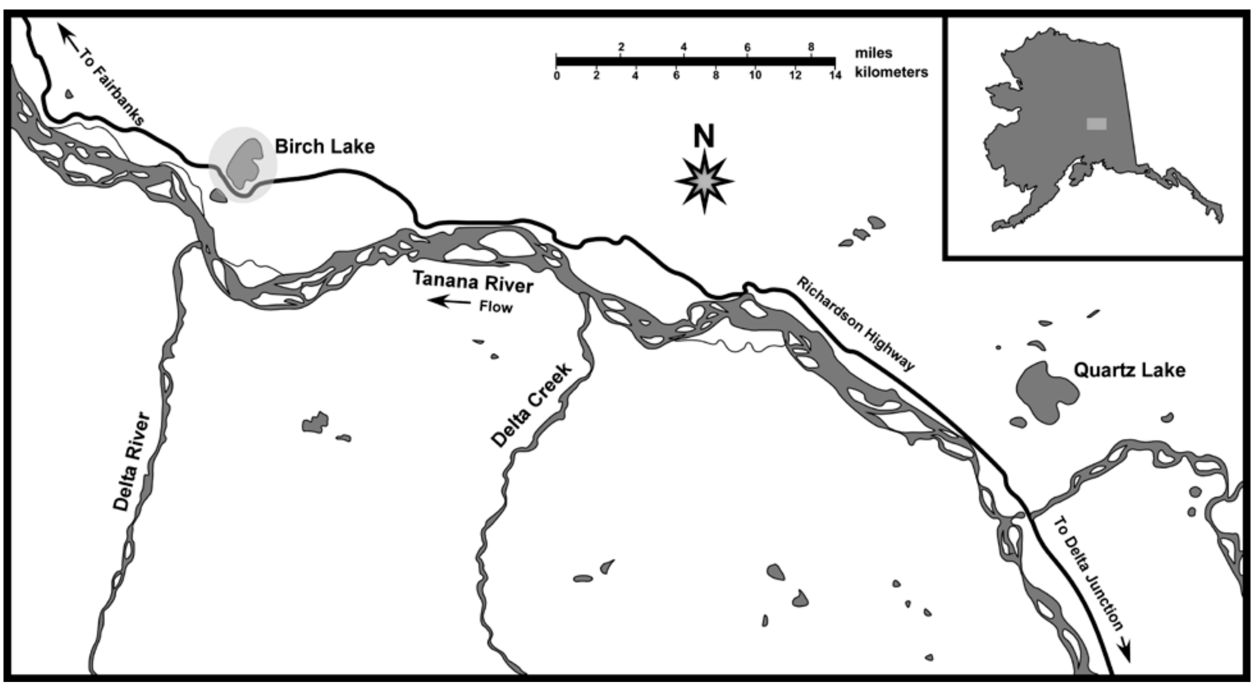

Figure 1.–Location of Birch Lake 89 km south of Fairbanks, Alaska.

Since the original study by Skaugstad et al. (1995), ADF&G has decided to produce only triploid all-female rainbow trout at the ADF&G fish hatcheries. Triploid all-female rainbow trout are reproductively sterile which will prevent interbreeding with wild rainbow trout populations if stocked fish somehow entered a system where wild rainbow trout are present.

A study by Havens and Sonnichsen (1993) found the average survival rate of triploid all-female rainbow trout stocked as fingerlings was less than half the average survival rate for diploid rainbow trout stocked as fingerlings. No studies have directly compared survival rates for triploid all-female rainbow trout that were stocked as fingerlings and subcatchables. Previous studies of diploid fingerling and subcatchable rainbow trout may not be relevant for triploid all-female rainbow trout.

OBJECTIVES

The objective of this study was to test the null hypothesis that subcatchable rainbow trout from Fairbanks Experimental Hatchery stocked into Birch Lake in March 2008 were ten times (or less) as likely to be present in Birch Lake the following spring compared to fingerling rainbow trout from Fort Richardson Hatchery stocked in August 2007. The alternative hypothesis was that the subcatchable group was more than ten times as likely to be present in Birch Lake the following spring compared to the fingerling group. The probability of a Type I error was 0.20, and the probability of a Type II error was 0.20 if the chance of subcatchables stocked in March being present was at least 13 times greater than fingerlings stocked in August.

METHODS

In August 2007, an estimated 106,228 (SE=1,619) unmarked rainbow trout fingerlings (45 mm FL or 1 g) from Fort Richardson Hatchery were stocked into Birch Lake. In March 2008, 22,933 marked subcatchable rainbow trout (120 mm FL or 21 g) from Fairbanks Experimental Hatchery were also stocked into Birch Lake. Fish from Fort Richardson were weighed prior to stocking and the number of fish stocked was estimated using the average weight following procedures in the Alaska Department of Fish and Game *Fish Culture Manual* (1983; p.44). The mean weight was calculated from three samples of 100 fish. Length was calculated from mean weight using a hatchery condition factor (Appendix B). All subcatchable rainbow trout from Fairbanks Experimental Hatchery were counted and marked with an adipose (AD) fin clip.

Current fish hatchery procedure is to stock fingerling rainbow trout sometime during August through September after shallow nearshore water temperature has cooled to < 18°C. When Birch Lake was stocked with fingerling rainbow trout in August, additional fingerlings from the Ft. Richardson Hatchery were transferred to the Fairbanks Experimental Hatchery for rearing to subcatchable size. These fish attained their target stocking size 7 months later. Fish size and stocking dates represent the production capability for current operating conditions at each facility (i.e. water temperature and hatchery production priorities).

In early June 2008, before Birch Lake water temperature exceeded 18°C, a single weeklong sampling event was conducted to estimate the proportion of rainbow trout captured from each stocking group. Fish were captured using 12 fyke nets (4 with center leads and 8 without) located near shore around the lake perimeter. Although each stocking group was a different size when stocked, the two groups were similar size in June and equally vulnerable to the sampling gear. A previous mark-recapture experiment at Quartz Lake using the same sampling gear detected no differential vulnerability for age-1 rainbow trout ranging in size from 55 to 170 mm (Fish and Skaugstad 2004).

Fyke nets were set near shore on the lake bottom in 1 to 2 m of water. Fyke nets had openings that were either 0.9 or 1.2 m^2, the body length from opening to cod end was about 5 m, hoop size was 0.9 m diameter, and mesh size was 9 mm^2. Wings measuring 7.5 m long by 1.2 m deep were attached to each side of the open end. The net body was positioned parallel to shore and the wings were set to form a "V". Each fyke net was pulled taut from the cod end and held in position with a weight.

Four 1.2 m^2 fyke nets were equipped with center leads. A center lead was a net 1.75 m deep by 33 m long with 12 mm^2 mesh, floats and lead lines. One end of the center lead net was anchored to shore and the other end of was attached to the center post in the open end of a fyke net. The fyke net and center lead were stretched away from and perpendicular to shore. The fyke net wings were set to form a "V" with the open end pointing toward shore.

All captured fish were identified by species, measured to the nearest millimeter (FL), and examined for an AD clip. Every fish was marked by excising the last quarter portion of the lower lobe of the caudal fin and then released. When large numbers of fish were captured, carbon dioxide-saturated water was used to expedite processing and minimize injury to the fish during handling.

Relative survival rates were inferred from numbers of fish from each stocking group that were stocked and subsequently recovered in fyke nets. The stocking groups were labeled:

G1 – fingerlings from Fort Richardson Hatchery stocked in August 2007; and

G2 – subcatchables from Fairbanks Experimental Hatchery stocked in March 2008.

The null (H_o) and alternative (H_a) hypotheses were:

H_o: $P_{G2} \leq P_0$

H_a: $P_{G2} > P_0$

where P_{G2} was the proportion of age-1 rainbow trout in Birch Lake in spring 2008 that originated from G2 and P_0 was the expected proportion of fish from G2 if a fish from G2 was ten times as likely to be available during spring sampling as a fish from G1. The hypothesis was evaluated using a one tailed Student's *t*-test (Zar 1984). The test statistic was calculated:

$$t_o = \frac{\hat{p}_{G2} - \hat{p}_o}{\sqrt{\hat{\text{var}}(\hat{p}_{G2}) + \hat{\text{var}}(\hat{p}_o)}} \quad (1)$$

If t_o was significantly greater than zero (α=0.20) we rejected H_o in favor of H_a.

The degrees of freedom (df_t) for this test was calculated using the methods of Satterthwaite (1946):

$$df_t = \frac{\left[\hat{\text{var}}(\hat{p}_{G2}) + \hat{\text{var}}(\hat{p}_o)\right]^2}{\frac{\left[\hat{\text{var}}(\hat{p}_{G2})\right]^2}{df_{p(G2)}} + \frac{\left[\hat{\text{var}}(\hat{p}_o)\right]^2}{df_{p(o)}}} \quad (2)$$

where the component terms were calculated as described below. Based on simulated data and expected sample sizes, the degrees of freedom (df_t) was expected to be approximately 223.

The following equations are appropriate when the numbers of fish stocked in G1 and G2 are estimated:

$$\hat{p}_o = 10\hat{N}_{G2} / (\hat{N}_{G1} + 10\hat{N}_{G2}) \tag{3}$$

and (Mood et al. 1974):

$$\hat{var}(\hat{p}_o) = \frac{100\,\hat{N}_{G2}^2\,\hat{var}(\hat{N}_{G1}) + 100\,\hat{N}_{G1}^2\,\hat{var}(\hat{N}_{G2})}{(\hat{N}_{G1} + 10\,\hat{N}_{G2})^4} \tag{4}$$

where:

$\hat{N}_{G1}$ = the estimated total number of fish in G1 stocked into Birch Lake; and

$\hat{N}_{G2}$ = the estimated total number of fish in G2 stocked into Birch Lake.

The procedures and variances associated with estimating $\hat{N}_{G2}$ were dropped in Equations 3 and 4 and following equations because all fish in G2 were counted when they were stocked. We include the complete equations for situations when N_{G2} is not known and must be estimated.

Estimates of total numbers of fish stocked and the respective variances were calculated by multiplying the total weight (kg) of fish stocked by the estimated mean number of fish·kg^{-1}:

$$\hat{N}_{Gk} = W_{Gk}\hat{r}_{Gk} \tag{5}$$

and,

$$\hat{var}(\hat{N}_{Gk}) = W_{Gk}^2\ \hat{var}(\hat{r}_{Gk}) \tag{6}$$

where W_{Gk} was the total weight (kg) of the fish stocked in group G_k (k=1,2).

The estimated number of fish·kg^{-1} at the time of stocking ($\hat{r}_{Gk}$) was calculated using a ratio estimator (Cochran 1977):

$$\hat{r}_{Gk} = \sum_{i=1}^{m_{Gk}} c_{Gki} \Big/ \sum_{i=1}^{m_{Gk}} w_{Gki} \tag{7}$$

$$\hat{var}(\hat{r}_{Gk}) = m_{Gk} \frac{\sum_{i=1}^{m_{Gk}} c_{Gki}^2 - 2\hat{r}_{Gk}\sum_{i=1}^{m_{Gk}} c_{Gki}w_{Gki} + \hat{r}_{Gk}^2\sum_{i=1}^{m_{Gk}} w_{Gki}^2}{(m_{Gk}-1)\left(\sum_{i=1}^{m_{Gk}} w_{Gki}\right)^2} \tag{8}$$

where:

df_{Gk} = $m_{Gk} - 1$

m_{Gk} = the number of samples of approximately 100 fish weighed prior to stocking;

c_{Gki} = the number of fish in sample i, i= 1 to m_{Gk}; and

w_{Gki} = the total weight in kg of the fish in sample i.

Based on historical stocking data for 2 g rainbow trout, we expected a coefficient of variation (CV) of less than 0.02 if mean weight of stocked fish was estimated from a minimum of m_k=3 samples of approximately 100 fish each. If three samples were weighed and the CV was greater than 0.02, then three more samples were weighed and the CV was again evaluated.

We determined:

$$df_{p(o)} = \min(df_{num}, df_{den}) \tag{9}$$

where df_{num} was the number of degrees of freedom for the estimated value $10\,\hat{N}_{G2}$ (df_{num}=df_{G2}) and df_{den} was the number of degrees of freedom for the estimated value $\hat{N}_{G1}+10\,\hat{N}_{G2}$ which was calculated using the methods of Satterthwaite (1946):

$$df_{den} = \frac{\left[\hat{\text{var}}(\hat{N}_{G1}) + 100\,\hat{\text{var}}(\hat{N}_{G2})\right]^2}{\frac{\left[\hat{\text{var}}(\hat{N}_{G1})\right]^2}{df_{G1}} + \frac{\left[100\,\hat{\text{var}}(\hat{N}_{G2})\right]^2}{df_{G2}}}. \tag{10}$$

Based on the number of fish with (G1) or without (G2) an adipose fin in the sample we estimated:

$$\hat{p}_{G2} = \frac{n_{G2}}{n} \tag{11}$$

and

$$\hat{\text{var}}(\hat{p}_{G2}) = \frac{\hat{p}_{G2}(1-\hat{p}_{G2})}{n-1}, \tag{12}$$

where:

n_{G2} = the total number of G2 fish in the sample;

n = the total number of age-1 (G1 plus G2) fish in the sample; and,

$df_{p(G2)}$ = n - 1 .

The actual sample size required to evaluate the difference between the two parameter estimates was calculated prior to sampling by using the proper substitutions and solving for n in:

$$t_\alpha + t_\beta = CD / \sqrt{\hat{\text{var}}(\hat{p}_o) + \hat{\text{var}}(\hat{p}_{G2(@13:1)})} \tag{13}$$

which yields:

$$n = \frac{\hat{p}_{G2(@13:1)}(1-\hat{p}_{G2(@13:1)})(t_\alpha + t_\beta)^2}{CD^2 - (t_\alpha + t_\beta)^2\,\hat{\text{var}}(\hat{p}_o)} + 1 \tag{14}$$

where:

$$CD = \hat{p}_{G2(@13:1)} - \hat{p}_o \tag{15}$$

CD is the difference between 10:1 and 13:1 in probability of recovery of G2 fish over that of G1 fish and t_α and t_β were the appropriate critical values calculated from Student's *t*-distribution with df_t (eq. 2). The value of 13 was chosen to make sure that the probability of Type II error for this test does not exceed 0.20. If the true difference is less than 13 times greater, but larger than 10 times greater, the null hypothesis may still be rejected but the probability of Type II error will be greater than 0.20.

If we fail to accept H_o then stocking subcatchable rainbow trout in winter is preferred to stocking fingerlings in fall.

RESULTS

In June 2008, 1,903 age-1 rainbow trout ranging in size from 57 mm to 197 mm FL were captured and examined for the presence (G1) or absence (G2) of an adipose fin (Figure 2). The adipose fin was absent on 1,685 fish. Age-1 rainbow trout with adipose fins (G1) were distinguished from older fish by examining the length frequency distribution of unmarked rainbow trout captured during sampling (Figure 3). We also captured 81 age-2 and older rainbow trout (from 185 to 445 mm FL, Figure 3), 488 Arctic grayling (from 69 to 120 mm FL, Figure 4), and 28 Arctic char (from 295 to 415 mm FL, Figure 5).

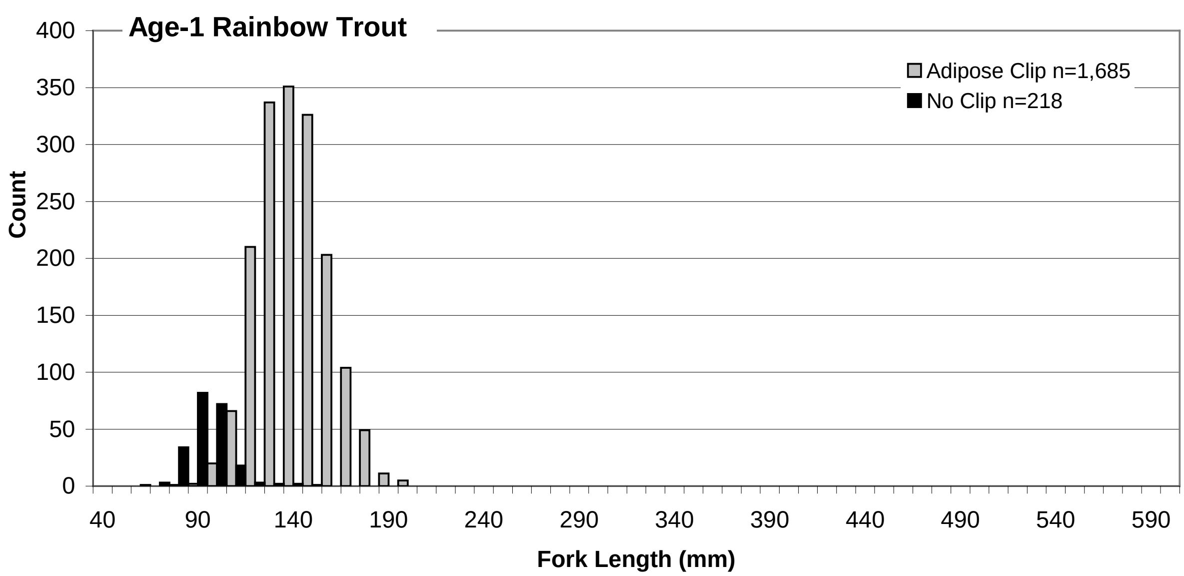

Figure 2.–Length frequency distribution of rainbow trout captured in Birch Lake, June 2008.

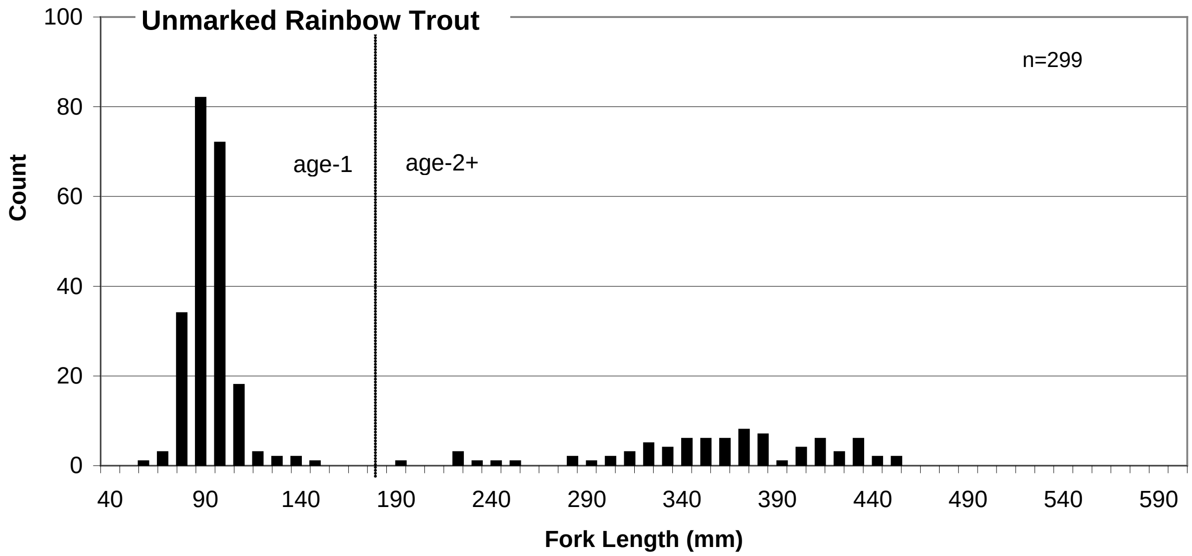

Figure 3.–Length frequency distribution of unmarked rainbow trout captured in Birch Lake, June 2008.

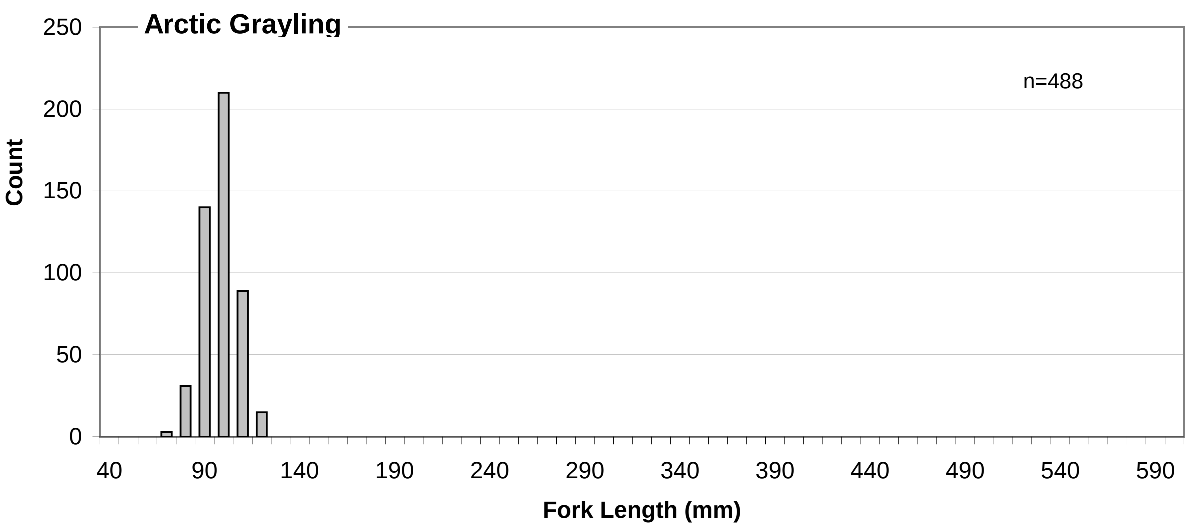

Figure 4.–Length frequency distribution of Arctic grayling captured in Birch Lake, June 2008.

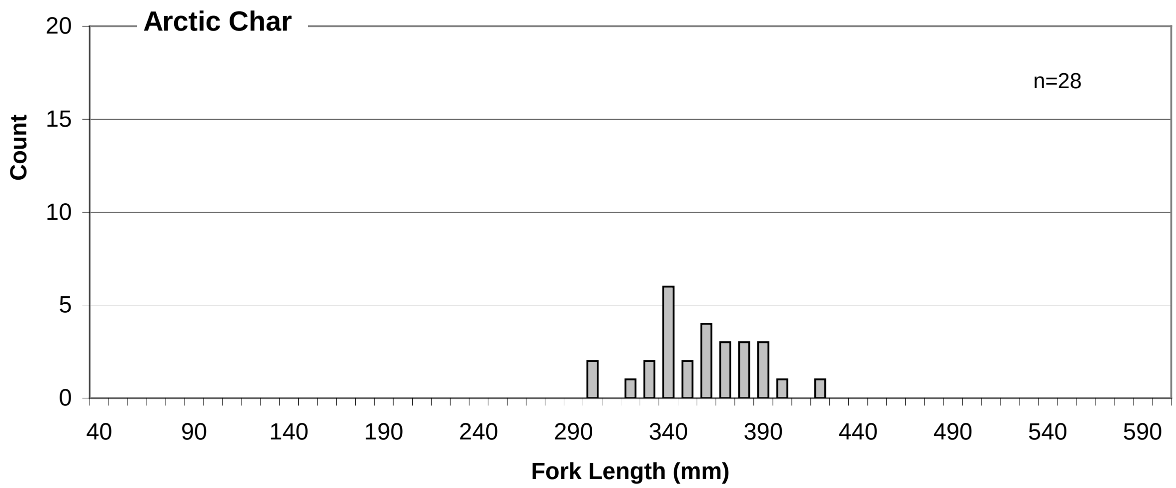

Figure 5.–Length frequency distribution of Arctic char captured in Birch Lake, June 2008.

The proportion of age-1 rainbow trout in Birch Lake in spring 2008 that originated from subcatchable stockings was 0.89 (SE=0.0073). The expected proportion was 0.74 (SE=0.0030). Student's *t*-test indicated that the difference between the two proportions was significant (t_o=25, df=68, p <0.0001). Consequently, H_o was rejected and the preferred method was to stock subcatchable rainbow trout in winter.

DISCUSSION

Further examination of the catch data showed the relative survival rate (RSR_{G2}) to age 1 for rainbow trout stocked as subcatchables (G2) was 36 times greater than that for stocked fingerlings (G1). We wanted to know what this difference meant for the stocked fisheries program in terms of hatchery resources needed by both groups to maintain the rainbow trout fishery at Birch Lake. We also wanted to compare the likely hatchery needs between rainbow trout stocked as fingerlings (57 mm or 2 g) and subcatchables (108 mm or 15 g) because these are the target sizes in the bio-programming standards for hatchery production. It should be noted that in comparing these two groups we are assuming that by age 1 both stocking groups will be approximately the same size and thus have similar survival rates in subsequent years. This assumption should be tested in future studies.

To maintain a stocked fishery such as Birch Lake, we wanted to know if it was better to stock a large number of small fish (fingerlings) or a small number of large fish (subcatchables). Generally, survival rates after stocking increase when larger fish are stocked but the $\text{cost}\cdot\text{fish}^{-1}$ to produce larger fish also increases because larger fish spend more time in the hatchery consuming resources. To justify producing larger fish, the benefit of an increase in survival rate must outweigh the resources needed to produce them. For one size group to be better there must be an overall advantage that benefits the entire stocked fisheries program from hatchery operation to performance in the fishery.

In the past we have used $\text{cost}\cdot\text{kg}^{-1}$ or $\text{cost}\cdot\text{survivor}^{-1}$ comparisons to determine which size group was better (Skaugstad 2001, Skaugstad et al 1995 and 1996). These methods, however, have not considered the total hatchery resources that are required to produce different size groups and other changes to hatchery operations that happen as a consequence of the size of fish that is produced. For example, the number of broodstock that must be kept at the hatchery was not included in these models but impacts overall hatchery operation costs, especially if production of one size group requires a significantly greater number of captive broodstock.

STOCKED FISHERIES PROGRAM MODEL

To evaluate the overall impact that hatchery resource needs and fishery performance of different size fish may have on the stocked fisheries program, we developed a model (Appendix B) that was based on the bio-programming standard for the new ADF&G sport fish hatcheries being constructed in Fairbanks and Anchorage and in-lake estimates of survival to age 1. The hatchery bio-programming standards allowed us to estimate the hatchery resources needed to produce each size group under existing and proposed operating conditions. But, instead of directly estimating the consumption of different hatchery resources such as water, electricity and feed, we used the cumulative biomass for each size group as a surrogate to represent resource consumption. The amount of resources used is mostly dependent on size and number of fish (biomass) and time spent in the hatchery. Biomass summed continuously over time is cumulative biomass. Our model also estimates the number of captive broodstock that are needed to support fish production for each size group. The estimates of in-lake survival rates came from studies conducted on stocked fish populations in Interior Alaska **(**Doxey 1985 and 1989; Skaugstad et al 1995; Fish and Skaugstad 2004**)**.

We estimated hatchery resource consumption for two size groups of rainbow trout under two different scenarios that were designed to sustain the Birch Lake fishery. Scenario 1 mimics the Birch Lake study comparing age-0 45 mm (1 g) fingerlings that were stocked in August (the current hatchery production schedule) and age-0 120 mm (21 g) subcatchables that were stocked the following March. Scenario 2 mimics two possible production schedules for the new fish hatcheries in Fairbanks and Anchorage. Age-0 57 mm (2 g) fingerlings stocked in June was compared to age-0 108 mm (15 g) subcatchables stocked in November. To demonstrate our model we arbitrarily determined that 10,000 age-1 rainbow trout were needed to sustain the Birch Lake fishery. The numbers of fish that were needed for stocking were then calculated using estimates of in-lake survival rates to age 1 for each size group (Appendix Tables B1 and B2).

RESULTS FROM THE MODEL

For Scenario 1 the cumulative biomass of 120 mm subcatchable rainbow trout was about 7% greater compared to 45 mm fingerling (Appendix Table B1). However, when we examined the ancillary information (broodstock) in Appendix Table B1 we decided that subcatchables probably provided a greater benefit to the stocked fisheries program. Almost 33 times more female broodstock was needed to provide the eggs necessary to produce the required number of fingerling. The fingerling group required more than 40 times the rearing volume compared to the subcatchable group when both groups were 45 mm. At stocking, fingerling biomass was 1.7 times the subcatchable biomass. To provide 10,000 age-1 fish, the stocking density (number of $fish \cdot ha^{-1}$) for fingerling was more than 4 times the stocking density typically used for fingerling by ADF&G in interior Alaska.

In contrast, Scenario 2 clearly showed 108 mm subcatchable rainbow trout provided a greater benefit compared to 57 mm fingerling (Appendix Table B2). The cumulative biomass for fingerling was almost 1.8 times greater compared to the subcatchable cumulative biomass.

Fingerling production needed almost 21 times more female broodstock to provide the necessary number of eggs. The fingerling group required more than 20 times the rearing volume compared to the subcatchable group when both groups were 57 mm. At stocking, fingerling biomass was slightly more than 3 times the subcatchable biomass and the stocking density for fingerling was about 2.8 times greater than the typical stocking density.

MANAGEMENT IMPLICATIONS

The results from our model support the production and stocking of 120 mm subcatchable over 45 mm fingerling and 108 mm subcatchable over 57 mm fingerling. The current practice of producing 45 mm and the proposed 57 mm fingerling rainbow trout makes poor use of hatchery resources for maintaining stocked fisheries similar to Birch Lake. Based on the results from this study, production objectives for other species at the new sport fish hatcheries should be evaluated to determine if a different size group will be better for the stocked fisheries program.

A problem that confounds hatchery and fishery managers is that fish size and stocking time are often constrained and influenced by other fish culture activities which require sharing limited resources. This makes hatchery and fishery managers' jobs more difficult because a change in one part of the hatchery to improve performance may require multiple changes in other parts that impact hatchery and fishery performance differently.

By design, the model is affected by in-lake survival rates and conclusions based on cumulative biomass comparisons can reverse when in-lake survival rates change. We expect survival rates to change when we stock the same size fish in June instead of August or when we intentionally keep fish longer in the hatchery so we can stock a larger fish in November or the following March. We need to evaluate these options to be sure that our actions really use hatchery resources efficiently to sustain recreational fisheries.

To improve the model we need to explore the relation between in-lake survival rate and stocking size to determine if a stocking size different from what was used in this study would provide a greater benefit to the stocked fisheries program. Also, we need to improve the model to estimate and compare water, electricity, feed, rearing space, and other resource consumption which will provide important information so we can evaluate alternative scenarios in greater detail.

Our model provides a simple but useful tool to explore and evaluate possible changes to hatchery operations and stocking methods. Managers can test different scenarios to see if reducing operating costs by producing smaller but more fish actually has a positive or negative impact on the stocked fisheries program. Managers can even test different rearing temperatures and compare different fish culture systems to see the affect on hatchery resource consumption and residence time for different groups. Selective breeding programs to improve fish performance in the hatchery and in the fishery can be compared, too. Budget changes can also be evaluated to determine what combination of hatchery operations and stocking methods provides the best fishery for a given budget. Our model can help managers use limited funds in the most efficient manner to maintain popular recreational sport fisheries.

ACKNOWLEDGEMENTS

Dan Reed and Anton Antonovich provided biometric review. Jim Fish, Travis Hyer, Seth Wietgrefe, Jessica Mitchell, Melissa McInelly, Kelly Mansfield, and Toby Viavant assisted with field work. Rachael Kvapil provided editorial and formatting assistance. The U.S. Fish and Wildlife Service provided partial funding for this study through the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-23, Job No. E-3-1.

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APPENDIX A
STOCKING HISTORY FOR BIRCH LAKE (1999–2007)

Appendix A.–Stocking history for Birch Lake, 1999–2007.

Species	Date	Number	Avg. Length (mm)
Rainbow trout	1-Jun-1999	16,849	156
Coho salmon	1-Jun-1999	24,666	136
Rainbow trout	30-Jun-1999	1,981	202
Rainbow trout	21-Jul-1999	2,360	117
Coho salmon	8-Sep-1999	11,712	118
Arctic char	29-Sep-1999	9,580	145
Arctic char	29-Sep-1999	24,306	136
Arctic grayling	18-May-2000	4,181	180
Rainbow trout	18-May-2000	13,322	208
Rainbow trout	6-Jul-2000	2,778	202
Coho salmon	20-Jul-2000	27,471	93
Coho salmon	3-Aug-2000	15,365	97
Rainbow trout	29-May-2001	16,468	214
Arctic grayling	19-Jun-2001	4,148	172
Arctic char	31-Aug-2001	7,034	108
Coho salmon	13-Jun-2002	40,000	72
Arctic grayling	13-Jun-2002	5,000	176
Rainbow trout	13-Jun-2002	8,278	217
Chinook salmon	17-Sep-2002	8,895	176
Chinook salmon	23-Oct-2002	3,020	203
Rainbow trout	22-May-2003	5,886	228
Arctic char	22-May-2003	6,261	222
Rainbow trout	30-May-2003	2,631	238
Rainbow trout	2-Jul-2003	2,027	235
Arctic grayling	20-Aug-2003	7,500	53
Chinook salmon	18-Sep-2003	9,926	186
Rainbow trout	10-Feb-2004	3,833	214
Rainbow trout	25-May-2004	4,788	226
Rainbow trout	26-May-2004	1,013	254
Rainbow trout	26-Aug-2004	10,550	193
Chinook salmon	20-Sep-2004	290	249
Arctic char	13-May-2005	5,982	222
Rainbow trout	13-May-2005	4,886	216
Rainbow trout	13-May-2005	3,497	211
Chinook salmon	22-Sep-2005	10,977	206
Rainbow trout	21-Apr-2006	25,313	93
Rainbow trout	25-May-2006	4,494	262
Rainbow trout	16-Aug-2007	93,981	46
Rainbow trout	21-Aug-2007	12,247	50
Arctic char	23-Aug-2007	7,390	95
Arctic grayling	13-Sep-2007	23,235	67

APPENDIX B
STOCKED FISHERY ANALYSIS MODEL

Our model is generic and is easily adjusted to simulate a stocked fishery and hatchery operation for different scenarios. To demonstrate the model we decided to mimic the stocked rainbow trout fishery in Birch Lake. To sustain the fishery we arbitrarily decided that 10,000 age-1 rainbow trout were needed annually in the population. The numbers of fingerlings and subcatchables that were then needed annually from the hatchery for stocking were calculated in the model.

Cumulative biomass (expressed in kg-days and calculated using the integral in Equation B1) was how we estimated the total hatchery resources needed by each size group during the time each group was in the hatchery. Because the type and amount of most hatchery resources (e.g. water, electricity, feed, and rearing space) was determined by the number of fish, their size (weight), and the time spent in the hatchery, we reasoned that the cumulative biomass would account for the extent of time that a group of fish was in the hatchery and would be a reasonable surrogate for the resources needed to produce the fish. This allowed us to directly compare the hatchery resource needs for a large number of small fish that were in the hatchery for a short time with that for a small number of large fish that were in the hatchery for a longer time. It also allowed us to compare the impact that changing the water temperature (or some other factor that affects fish production) will have on hatchery resource needs for maintaining a stocked fishery. Cumulative biomass was calculated as:

$$\Sigma W_{kg\text{-}days} = \frac{N_o W_o}{1{,}000} \int_0^n [S(1+\%BW)]^n \qquad \text{(B1)}$$

where,

$\Sigma W_{kg\text{-}days}$ = cumulative biomass in kilograms

S = daily hatchery survival rate

N_o = initial number of fish

W_o = initial weight (g) of fish

$\%BW$ = daily percent body weight (g) increase

n = number of days fish were reared in the hatchery

Because the ADF&G plans to maintain a captive rainbow trout broodstock at one of its hatcheries, the model calculates the numbers of eggs and females required to provide the number of fish needed to sustain a stocked fishery. The number of broodstock that must be kept at the hatchery is important because these fish require hatchery resources. If the number of broodstock can be decreased by half then the potential savings can be significant.

Input values and other calculated output values for the model are described in Appendix Table B3.

Appendix Table B1.–Estimated hatchery resources required to produce fingerling and subcatchable rainbow trout for maintaining the Birch Lake rainbow trout fishery. Scenario 1 compares rainbow trout stocked as 45 mm fingerling and 120 mm subcatchable. Rearing temperatures were adjusted to mimic the actual hatchery conditions.

Line	Production Stage	Fingerling		Subcatchable	
	Number of Fish to Stock				
1	number of age-1 fish needed	10,000		10,000	
2	lake survival to age 1	0.014	[a]	0.5	[b]
3	number to stock	720,000	fish	20,000	fish
	Broodstock				
4	overall hatchery survival	0.49	[c]	0.45	[c]
5	number of eggs required	1,458,045	eggs	44,507	eggs
6	average fecundity	1,687	eggs/female [d]	1,687	eggs/female [d]
7	number of female broodstock	864	females	26	females
8	date of eggtake	15-Apr		15-Apr	
	Incubation				
9	green to eyed egg survival	0.87	[c]	0.87	[c]
10	number of eggs	1,268,499		38,721	
11	maximum egg density per tray	12,000	eggs/tray [c]	12,000	eggs/tray [c]
12	number of trays	105.7	trays	3.2	trays
13	eye to ponding survival	0.86	[c]	0.86	[c]
14	number of fry to pond	1,090,909	fish	33,300	fish
15	temperature	9	°C	9	°C
16	days in incubation	61	days [c]	61	days [c]
	8m^3 tanks				
17	maximum density	20	kg/m^3 [c]	20	kg/m^3 [c]
18	starting number of fish	1,090,909	fish	33,300	fish
19	starting weight	0.14	g	0.14	g
20	starting length (weight/K)$^{1/3}$	2.33	cm	2.33	cm
21	ending weight	1.00	g	2.00	g
22	ending length (weight/K)$^{1/3}$	4.50	cm	5.67	cm
23	growth	2.16	cm	3.33	cm
24	temperature unit growth rate (TUG)	0.0037	cm/°C day [c]	0.0037	cm/°C day [c]
25	temperature	8	°C	9	°C
26	condition factor (K)	0.011	g/cm^3 [c]	0.011	g/cm^3 [c]
27	maximum kg of fish in production	720	kg	44	kg
28	maximum kg per tank	160	kg/tank	160	kg/tank
29	number of tanks	4.50	tanks	0.28	tanks
30	fry to fingerling survival	0.66	[c]	0.66	[c]
31	resulting number of fingerling	720,000	fish	21,978	fish
32	days in 8m^3 tanks	73	days	100	days
33	cumulative biomass	26,717	kg-days	1,751	kg-days

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Appendix Table B1.–Page 2 of 2.

Line	Production Stage	Fingerling		Subcatchable	
	110m³ tanks				
34	maximum density	-		35	kg/m^3 [c]
35	starting number of fish	-		21,978	fish
36	starting weight	-		2.00	g
37	starting length $(weight/K)^{1/3}$	-		5.50	cm
38	ending weight	-		21.00	g
39	ending length $(weight/K)^{1/3}$	-		12.05	cm
40	growth	-		6.55	cm
41	temperature unit growth rate TUG	-		0.0045	cm/°C day [c]
42	temperature	-		9	°C
43	condition factor (K)	-		0.012	g/cm^3 [c]
44	maximum kg of fish in production	-		420	kg
45	maximum kg per tank	-		3,850	kg/tank
46	number of tanks	-		0.11	tanks
47	fingerling to subcatchable survival	-		0.91	[c]
48	resulting number of subcatchables	-		20,000	fish
49	days in $110m^3$ tanks	-		162	days
50	cumulative biomass	-		26,935	
	Summary				
51	days in $8m^3$ and $110m^3$ tanks	73	days	262	days
52	date of release	27-Aug		3-Mar	
53	size at stocking	1	g	21	g
54	total kg stocked	720	kg	420	kg
55	cumulative biomass (kg)	26,717	kg-days	28,686	kg-days
56	difference	1,969	kg-days		
57	percent difference	7.4%			
	Stocking density $(fish \cdot ha^{-1})$	2,200	Ha^{-1}	61	Ha^{-1}

[a] Fingerling survival rate calculated to be 36 times smaller than survival rate for subcatchables.

[b] Average in-lake survival rate for stocked subcatchable from Doxey (1989).

[c] ADF&G Sport Fish hatchery bio programming criteria.

[d] Average fecundity for Swanson River broodstock held at Fort Richardson Hatchery, Anchorage, Andrea Tesch, Fort Richardson Hatchery Manager, ADF&G, Anchorage; personal communication.

Appendix Table B2.–Estimated hatchery resources required to produce fingerling and subcatchable rainbow trout for maintaining the Birch Lake rainbow trout fishery. Scenario 2 compares rainbow trout stocked as 57 mm fingerling and 108 mm subcatchable using ADF&G hatchery bio-programming standards.

Line	Production Stage	Fingerling		Subcatchable	
	Number of Fish to Stock				
1	number of age-1 fish needed	10,000		10,000	
2	lake survival to age 1	0.0218	[a]	0.5	[b]
3	number to stock	458,716	fish	20,000	fish
	Broodstock				
4	overall hatchery survival	0.49	[c]	0.45	[c]
5	number of eggs required	928,928	eggs	44,507	eggs
6	average fecundity	1,687	eggs/female [d]	1,687	eggs/female [e]
7	number of female broodstock	551	females	26	females
8	date of eggtake	15-Apr		15-Apr	
	Incubation				
9	green to eyed egg survival	0.87	[c]	0.87	[c]
10	number of eggs	808,167		38,721	
11	maximum egg density per tray	12,000	eggs/tray [c]	12,000	eggs/tray [d]
12	number of trays	67.35	trays	3.23	trays
13	eye to ponding survival	0.86	[c]	0.86	[c]
14	number of fry to pond	695,024	fish	33,300	fish
15	temperature	10	°C	10	°C
16	days in incubation	55	days [c]	55	days [c]
	8m^3 tanks				
17	maximum density	20	kg/m^3 [c]	20	kg/m^3 [c]
18	starting number of fish	695,024	fish	33,300	fish
19	starting weight	0.14	g	0.14	g
20	starting length (weight/K)$^{1/3}$	2.33	cm	2.33	cm
21	ending weight	2.00	g	2.00	g
22	ending length (weight/K)$^{1/3}$	5.67	cm	5.67	cm
23	growth	3.33	cm	3.33	cm
24	temperature unit growth rate (TUG)	0.0037	cm/°C day [c]	0.0037	cm/°C day [d]
25	temperature	13.2	°C	13.2	°C
26	condition factor (K)	0.011	g/cm^3 [c]	0.011	g/cm^3 [c]
27	maximum kg of fish in production	917	kg	44	kg
28	maximum kg per tank	160	kg/tank	160	kg/tank
29	number of tanks	5.73	tanks	0.27	tanks
30	fry to fingerling survival	0.66	[c]	0.66	[c]
31	resulting number of fingerling	458,716	fish	21,978	fish
32	days in 8m^3 tanks	68	days	68	days
33	cumulative biomass	24,925	kg-days	1,194	kg-days

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Appendix Table B2.–Page 2 of 2.

Line	Production Stage	Fingerling		Subcatchable	
	110m³ tanks				
34	maximum density	-		35	kg/m^3 [c]
35	starting number of fish	-		21,978	fish
36	starting weight	-		2.00	g
37	starting length $(weight/K)^{1/3}$	-		5.50	cm
38	ending weight	-		15.00	g
39	ending length $(weight/K)^{1/3}$	-		10.77	cm
40	growth	-		5.27	cm
41	temperature unit growth rate TUG	-		0.0045	cm/°C day [c]
42	temperature	-		12.7	°C
43	condition factor (K)	-		0.012	g/cm^3 [c]
44	maximum kg of fish in production	-		300	kg
45	maximum kg per tank	-		3,850	kg/tank
46	number of tanks	-		0.08	tanks
47	fingerling to subcatchable survival	-		0.91	[c]
48	resulting number of subcatchables	-		20,000	fish
49	days in $110m^3$ tanks	-		92	days
50	cumulative biomass	-		12,291	
	Summary				
51	days in $8m^3$ and $110m^3$ tanks	68	days	160	days
52	date of release	16-Aug		16-Nov	
53	size at stocking	2	g	15	g
54	total kg stocked	917	kg	300	kg
55	cumulative biomass (kg)	24,925	kg-days	13,485	kg-days
56	difference			11,439	kg/m^3 [c]
57	percent difference			46%	
	Stocking density $(fish \cdot ha^{-1})$	1,402	Ha^{-1}	61	Ha^{-1}

[a] Average fingerling survival from Doxey (1985); and Fish and Skaugstad (2004).

[b] Average in-lake survival rate for stocked subcatchable from Doxey (1989).

[c] ADF&G Sport Fish hatchery bio programming criteria.

[d] Average fecundity for Swanson River broodstock held at Fort Richardson Hatchery, Anchorage, Andrea Tesch, Fort Richardson Hatchery Manager, ADF&G, Anchorage; personal communication.

Appendix Table B3.–Equations and data sources used in the stocked fishery program model.

Line	Production Stage	Data Source or Formula
	Number of Fish to Stock	
1	number of age-1 fish needed	Input value based on fishery management needs
2	lake survival to age 1	from in-lake survival rates after stocking[a,b]
3	number to stock	$= L1/L2$
	Broodstock	
4	overall hatchery survival	from ADF&G hatchery bio-programming
5	number of eggs required	$= L3/L4$
6	average fecundity	from Ft. Richardson hatchery records
7	number of female broodstock	$= L5/L6$
8	date of eggtake	from Ft. Richardson hatchery records
	Incubation	
9	green to eyed egg survival	from ADF&G hatchery bio-programming
10	number of eggs	$= L5 \times L9$
11	maximum egg density per tray	from ADF&G hatchery bio-programming
12	number of trays	$= L10/L11$
13	eye to ponding survival	from ADF&G hatchery bio-programming
14	number of fry to pond	$= L10 \times L13$
15	temperature	Input value or from ADF&G hatchery bio-programming
16	days in incubation	$= 550/L15$ (550 CTU required for incubation – from ADFG hatchery bio-programming)
	8m³ tanks	
17	maximum density	from ADF&G hatchery bio-programming
18	starting number of fish	$= L14$
19	starting weight	Input value or from ADF&G hatchery bio-programming
20	starting length $(\text{weight/K})^{1/3}$	$= \sqrt[3]{L19/L26}$
21	ending weight	Input value or from ADF&G hatchery bio-programming
22	ending length $(\text{weight/K})^{1/3}$	$= \sqrt[3]{L21/L26}$
23	growth	from ADF&G hatchery bio-programming
24	temperature unit growth rate (TUG)	from ADF&G hatchery bio-programming
25	temperature	from ADF&G hatchery bio-programming
26	condition factor (K)	from ADF&G hatchery bio-programming
27	maximum kg of fish in production	$= \frac{N_o W_o}{1{,}000}[S(1+\%BW)]^n$ (modified Equation B1)
28	maximum kg per tank	$= L17 \times 8m^3$
29	number of tanks	$= L27/L28$
30	fry to fingerling survival	from ADF&G hatchery bio-programming

-continued-

Appendix Table B3.–Page 2 of 2.

Line	Production Stage	Data Source or Formula
	8m³ tanks – continued -	
31	resulting number of fingerling	$= L18 \times S^{L32}$
32	days in $8m^3$ tanks	$= L23/(L24 \times L25)$
33	cumulative biomass	$= \frac{N_o W_o}{1{,}000} \int_0^n [S(1+\%BW)]^n$ (Equation B1)
	110m³ tanks	
34	maximum density	from ADF&G hatchery bio-programming
35	starting number of fish	$= L31$
36	starting weight	Input value or from ADF&G hatchery bio-programming
37	starting length $(\text{weight}/K)^{1/3}$	$= \sqrt[3]{L36/L43}$
38	ending weight	Input value or from ADF&G hatchery bio-programming
39	ending length $(\text{weight}/K)^{1/3}$	$= \sqrt[3]{L38/L43}$
40	growth	from ADF&G hatchery bio-programming
41	temperature unit growth rate TUG	from ADF&G hatchery bio-programming
42	temperature	from ADF&G hatchery bio-programming
43	condition factor (K)	from ADF&G hatchery bio-programming
44	maximum kg of fish in production	$= \frac{N_o W_o}{1{,}000} [S(1+\%BW)]^n$ (modified Equation B1)
45	maximum kg per tank	$= L34 \times 110m^3$
46	number of tanks	$= L44/L45$
47	fingerling to subcatchable survival	from ADF&G hatchery bio-programming
48	resulting number of subcatchables	$= L35 \times S^{L49}$
49	days in $110m^3$ tanks	$= L40/(L41 \times L42)$
50	cumulative biomass (kg)	$= \frac{N_o W_o}{1{,}000} \int_0^n [S(1+\%BW)]^n$ (Equation B1)
	Summary	
51	total days in hatchery	$= L16 + L32 + L49$
52	date of release	starting date + total days in hatchery
53	size at stocking	$= L38$
54	total kg stocked	$= L53 \times L48/1{,}000$
55	cumulative biomass (kg)	$= L33 + L50$

[a] Average fingerling survival from Doxey (1985).

[b] Average in-lake survival rate for stocked subcatchable from Doxey (1989).