Fishery Data Series No. 13-32

Coastal Cutthroat Trout Maturity Studies in Southeast Alaska, 1997–1998

by

Roger D. Harding

July 2013

Alaska Department of Fish and Game **Division 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. 13-32

COASTAL CUTTHROAT TROUT MATURITY STUDIES IN SOUTHEAST ALASKA, 1997–1998

by
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ABSTRACT

Proportions of female coastal cutthroat trout *Oncorhynchus clarkii clarkii* that were sexually mature were estimated for 21 lakes in Southeast Alaska that spanned a range of lake sizes, lake types (resident or anadromous), and fish sizes present in the region. Sampling occurred between late September and the middle of November in 1997 and 1998. Each captured fish was measured, and each sacrificed fish was weighed to the nearest gram, classified by sex, sampled for scales and otoliths, and later evaluated for sexual maturity. Overall, 60% (SE = 1.1%) of the females sampled were sexually mature in the 11-inch total length category, and 62% (SE = 1.1%) of the females were sexually mature in the 12-inch length category. At lengths below 11 inches, anadromous cutthroat trout maturity rates quickly dropped. At 10 inches, only 28% (SE = 2.2%) of the anadromous females were mature. Fecundity-at-length, ovary weight, and egg size in relation to maturity were also evaluated. Current trout (cutthroat and rainbow trout) regulations are evaluated and various management options are discussed, including implications from this study.

Keywords: length at maturity, fecundity, egg size, egg diameter, cutthroat trout, rainbow trout, ovary weight, age at maturity, trout regulations, steelhead, management

INTRODUCTION

In 1994, new trout regulations were adopted in Southeast Alaska (SEAK) that combined creel limits, size limits, and bait restrictions. A 12-inch minimum size limit for trout, was implemented throughout the region to: 1) protect coastal cutthroat trout *Oncorhynchus clarkii clarkii* (henceforth called cutthroat trout) and resident/nonanadromous rainbow trout *O. mykiss* until the majority could spawn at least once; and 2) provide protection for juvenile steelhead *O. mykiss* and cutthroat trout before they emigrate to the ocean. Although both cutthroat and rainbow trout in SEAK can exhibit resident and anadromous life histories, the regulations do not differentiate between them. A larger size limit (14-inch minimum size) was adopted for areas with developed access and/or intensive sport fisheries. A maximum size limit of 22 inches was also implemented to protect returning adult steelhead trout, even though it could unnecessarily restrict the harvest of larger cutthroat and rainbow trout. In addition, a 10-month (November 16 through September 14) ban on fishing with bait was implemented in freshwater systems to reduce hooking mortality on trout and steelhead. The regulations were germane to cutthroat and rainbow trout because of difficulties anglers had in distinguishing between the two species (Harding and Jones 2005). Alaska Department of Fish and Game, Division of Sport Fish (ADF&G-SF) staff based the initial 12- and 14-inch size limits on available length-at-maturity data collected from anadromous fish in Petersburg Creek (ADF&G files) in SEAK, landlocked populations in Mosquito Lake in the Queen Charlotte Islands, British Columbia (de Leeuw 1987), and literature on trout populations in Washington and Oregon (Wright 1992).

The need for more extensive length-at-maturity data from a variety of trout populations and lake types in SEAK was apparent. For example, advisory committee reports and public testimony given at the 1997 Board of Fisheries (BOF) meeting indicated the 1994 regulations were too restrictive in lakes that contain few trout of legal harvestable size (i.e., >12 inches). In general, ADF&G-SF staff recognized that length- and/or age-at-maturity in fish populations was an expression of the growth of individual populations (Trippel and Harvey 1990; Clark 1992), and the type, size, and location of the lake (Schmidt 1994; Harding 1995). However, very little data were available for trout populations in lakes in SEAK. In 1997, the BOF requested ADF&G to evaluate cutthroat trout length-at-maturity in more lakes and report the results during the next meeting in 2000; this report summarizes the results of that project.

Length- and age-at-maturity, fecundity, and egg diameter of cutthroat trout were investigated in a range of locations and lake types throughout SEAK. The focus was on cutthroat trout because this species is more vulnerable to fishing pressure and habitat degradation than rainbow trout

(Behnke 1992), so the biological principles used to protect cutthroat trout would also serve to adequately protect rainbow trout populations (Harding and Jones 2005). The data collected were used to help reevaluate the minimum size limits for trout in a range of lakes in SEAK. The products of the analysis were used to further develop the scientific basis for regional trout fishing regulations that should ensure ample fishing opportunities and sustainable fisheries.

Much of the information reported here may be relevant to other cutthroat trout subspecies and it is noted when comparisons are made between other coastal cutthroat trout populations as well as to other subspecies (e.g., westslope cutthroat trout *O. clarkii lewisi).*

OBJECTIVES

The objective of this project was to:

1) Estimate the proportion of sexually mature female cutthroat trout in 1-inch length increments in a range of lake types throughout SEAK.

In addition to the objective outlined above, the project was responsible for the following tasks:

2) Evaluate fecundity-at-length of female cutthroat trout in a range of lake types throughout SEAK.

3) Collect scales and otoliths to allow estimation of the proportion of sexually mature cutthroat trout by age, and fecundity-at-age.

METHODS

Area management biologists selected 21 lakes that spanned a range of lake sizes, lake types (resident or anadromous), and fish sizes present in the region (Table 1; Figures 1 and 2). It was believed that these lakes were not, in general, heavily exploited so that a range of fish sizes were present, and that destructive sampling (e.g., subsample of fish killed to visually examine gonads) would not jeopardize the health of the populations. It was also believed that these lakes were representative of most lakes in SEAK and would not lead to any bias either geographically (northern versus southern) or by life history type (resident versus anadromous).

Sampling occurred between late September and the middle of November during 1997 and 1998. Although cutthroat trout in SEAK typically spawn in early spring, gonads must be in an advanced stage of development by fall if the fish are going to spawn the next spring (Behnke 1992). Test sampling at Florence Lake during July, August, and September 1997, and at Little Lake on Prince of Wales Island during September 1997, indicated that sexual maturity could be determined with confidence by the middle of October. Samples were thus collected late enough in each year so that the maturity stage could be easily determined and before inclement weather, freezing conditions, and spring spawning occurred.

Cutthroat trout in each lake were captured using 3 gear types: floating and sinking variable mesh gillnets, hoop traps, and hook-and-line gear. Gillnets were set parallel to the bottom of the lake at depth intervals <30 m using random or systematic placements across the lake. Hoop traps baited with Betadine,®[1] treated salmon roe were similarly set. Hook-and-line sampling was conducted in varied habitats by casting towards shore from a boat traveling along the perimeter of the lake.

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[1] This and subsequent product names are included for a complete description of the process and do not constitute product endorsement.

Table 1.–Estimated surface area (ha), maximum depth, abundance of cutthroat trout, species present, relative average size of cutthroat trout, and lake type germane to Southeast Alaska lakes selected for cutthroat trout length-at-maturity studies, 1997–1998. Estimated abundance of cutthroat trout for each lake was obtained from abundance studies when available (e.g., Harding et al. 1999b); if no abundance estimates were available then abundance was "guesstimated" by multiplying the respective surface area (ha) by the density from studied lakes with similar size and characteristics (e.g., depth, bathymetry, anadromous access, species in lake, and geographic location).

Area Lake name	Surface area (ha)	Maximum depth (m)	Estimated cutthroat trout abundance[a]	Species present[b]	Relative average size of cutthroat trout[c]	Lake type
Ketchikan						
North Saddle	25.3	20	550[d]	CT, DV	Medium	Resident
Upper Wolf	41.6	10	1,233[e]	CT,DV	Medium	Resident
Mirror	487	200	5,633[f]	CT,DV	Medium	Resident
Winstanley	177	60	NA[g]	CT,KO	Medium	Resident
POW Island						
Little	25	30	550[d]	CT	Small	Resident
Neck	373	58	6,714[h]	CT,DV,KO	Medium	Resident
St. Nicholas	96	>30	NA[g]	CT,DV	Medium	Resident
Klawock	1207	>30	NA[g]	CT,RB,DV	Medium	Anadromous
Wrangell/Petersburg						
Long	23.1	27	507[i]	CT,DV	Small	Resident
Colp	20.2	18	443[i]	CT	Very small	Resident
Thoms	135	30	NA[g]	CT	Medium	Anadromous
Slippery	51	15	407[j]	CT	Medium	Anadromous
Sitka						
Buck	20.3	19	441[e]	CT	Small	Resident
Goulding	390.6	94	4,300[k]	CT,DV	Medium	Resident
Eva	98	22	2,150[l]	CT	Medium	Anadromous
Sitkoh	200	42	2,000[m]	CT	Medium	Anadromous
Juneau						
Shelter	24	7	528[i]	CT,DV	Small	Resident
Thayer	1133.2	58	12,500[k]	CT,DV,KO	Medium	Resident
Florence	364.2	27.4	8,000[n, e]	CT,DV,KO	Medium	Resident
McKinney	120	35	2,400[o]	CT,DV,KO	Medium	Resident
Kook	240	41	NA[g]	CT,RB,DV	Medium	Anadromous

[a] Resident fish >180 mm FL, unless otherwise noted.
[b] CT = cutthroat trout; DV = Dolly Varden; KO = kokanee; RB = rainbow/steelhead trout
[c] <170 mm FL = very small, 171–189 mm FL = small, 190–209 mm FL = medium.
[d] Based on density of Buck Lake (Schmidt 1994); small landlocked lake without kokanee).
[e] Density estimate based on data from mark-recapture estimate (Schmidt 1994).
[f] Jones, D.E. *Unpublished report*. ADF&G, Douglas Office Trout Bibliography Reports Record #32: Darwin E Jones. Recreational surveys of selected lakes in southern Southeast Alaska- Mirror Lake. 1985. Accessed 1/11/2013
[g] NA = not enough information or data available to estimate fish density prior to maturity sampling.
[h] Average density of 18 fish/ha (calculated from high density (Florence Lake; 21 fish/ha; Rosenkranz et al. 1999) and low density (Alexander Lake; 14 fish/ha; R. Harding, 1996, unpublished memo).
[i] High density calculated using highest trap catch in shallower areas of Florence Lake; 22 fish/ha (Rosenkranz et al. 1999).
[j] Density estimated using unpublished data from several lakes for trout>120 mm FL (Hubartt and Bingham 1989).
[k] Density estimate based on data from Hasselborg Lake (Laker 1994).
[l] Density estimate based on data from mark-recapture estimate (Yanusz and Schmidt 1996).
[m] Density estimate based on data from mark-recapture estimate (Brookover et al. 1999).
[n] Density estimate based on data from mark-recapture estimate (Rosenkranz et al. 1999)
[o] Density estimate based on data from mark-recapture estimate (Harding et al. 1999a).

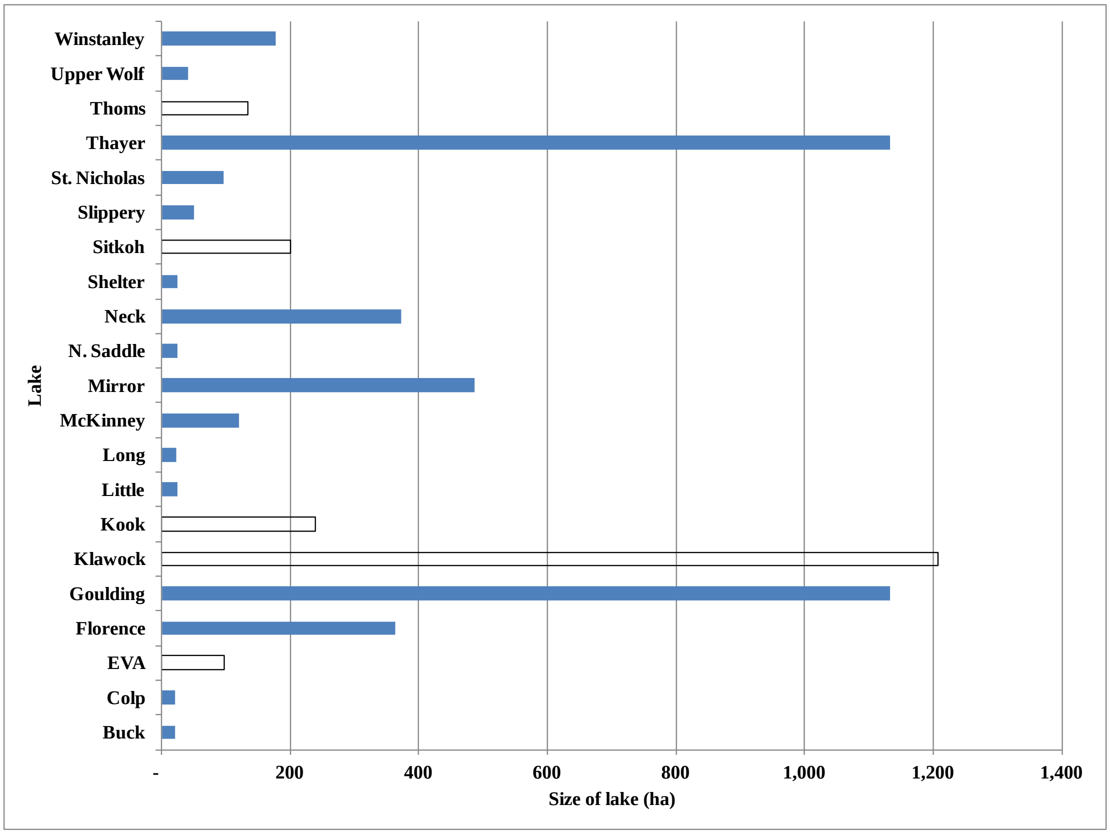

Figure 1.–Lakes sampled in Southeast Alaska during the cutthroat trout sexual maturity study by lake size in ha, 1997–1998. Anadromous lakes have clear bars and resident lakes have solid bars.

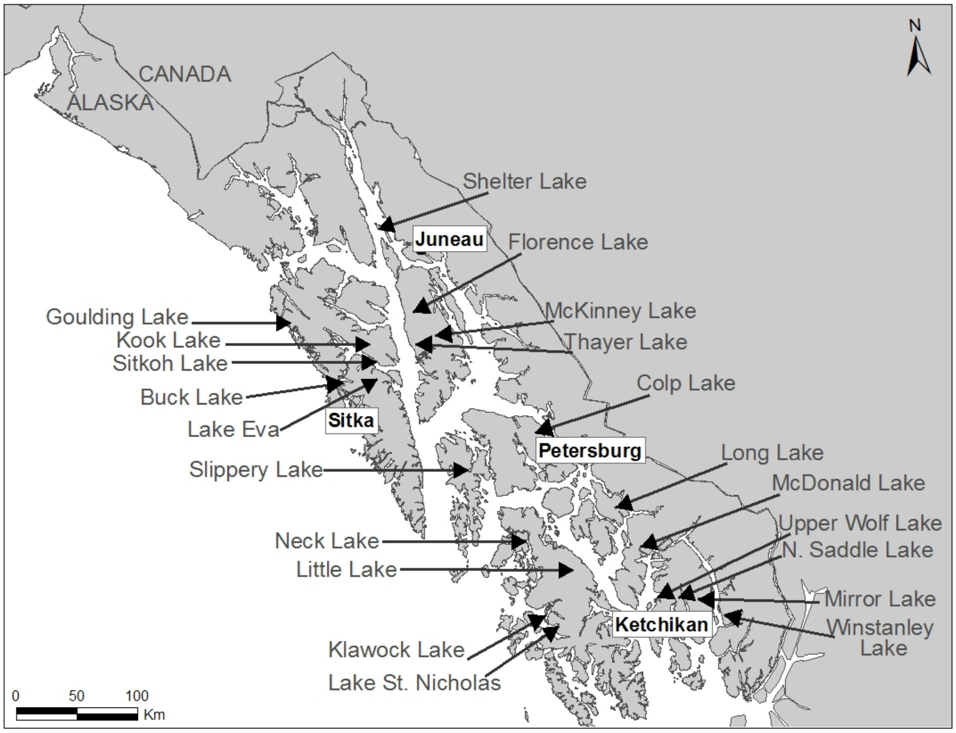

Figure 2.–Lakes sampled for cutthroat trout sexual maturity in Southeast Alaska, 1997–1998.

In an effort to minimize destructive sampling, an *a priori* model was used to predict the median or "most common size" of trout that might be expected to be found in each lake. A maturity-at-length relationship (a logistic curve) for brown trout (Avery 1985) was adopted that incorporated data from a preliminary maturity sample collected at Florence Lake (Foster 2003). The lakes that were selected for sampling were roughly categorized by size-at-maturity ("small" versus "large" fish) based on the brown trout-Florence Lake model. Sample sizes by length interval were subsequently selected so that most sampling would occur in the interval containing the middle of the logistic curve. This model guided sampling such that: 1) specific 20 mm FL size intervals were targeted (each 20 mm FL interval approximately equals a 1-inch TL increment); 2) sample sizes were minimized; and 3) estimates met statistical objectives (±20 percentage points for a 95% confidence interval).

Each fish captured was measured to the nearest mm (FL and TL), and the lengths were converted to inches (because the fishing regulations specify total length in inches). Each sacrificed fish was weighed to the nearest gram, classified by sex, sampled for scales and otoliths, and later evaluated for sexual maturity. Ovaries taken from sacrificed fish (including all residual eggs from prior spawning) were extracted and preserved on the day of capture. Before ovary extraction, the position of the most dorsally extended edge of the egg sack in relation to the front edge of the dorsal fin was recorded (i.e., anterior, posterior, or aligned with tip of dorsal fin). Ovaries were placed in a vial containing 10% buffered formalin. Upon collection, ovaries were classified as either mature or immature based on visual characteristics. Small ovaries that were granular in appearance and located dorsally were classified as immature, and ovaries that were much larger, "salmon egg" in color, and a more pronounced feature of the abdominal cavity were classified as mature (Downs 1995; Downs et al. 1997). Sacrificed males were also classified as mature, immature, or uncertain based on visual characteristics. Testes were classified as immature if they consisted of 2 clear or cloudy-white thread-like vessels that ran dorsally along the kidney. Testes were classified as mature if the testes were more pronounced (pencil-sized diameter), white and chalky in appearance, and an obvious feature of the abdominal cavity (Downs 1995; Downs et. al. 1997). Testes classified as mature or immature were discarded; testes classified as uncertain (not mature or immature) were preserved on the day of capture by placing them in vials containing 10% buffered formalin. All samples were clearly labeled and included: lake, date, length of fish, and sample number.

Scales and otoliths were taken to estimate the proportion of sexually mature fish at age, and fecundity-at-age. Scales were collected from the left side of the caudal peduncle immediately above the lateral line (Brown and Bailey 1949, 1952; Laakso and Cope 1956). Prior to taking a scale sample, the sample area was wiped with the blunt side of a knife to remove excess slime. A sample of 20–30 scales was removed from each fish and spread uniformly across a piece of transparent film. The film was stored inside a coin envelope labeled with the sample number. Both left and right otoliths were extracted, wiped to remove excess fluid, and stored dry in a small plastic vial.

The sexual maturity of females was further evaluated in the laboratory after assessing the size and weight of ovaries, egg diameter and color, and number of eggs. A random sample of eggs (30 eggs in 1997, and 10 eggs in 1998) was selected from each ovary sample categorized as mature, and egg diameter was measured using a small camera and the software computer program Image-Pro.© Fecundity of every mature fish was determined by counting the eggs. If needed, the number of eggs in each mature ovary was counted under a dissecting scope. Scales and otoliths were prepared and read according to the procedures and recommendations in Ericksen (1997). Ages were estimated from both scales and otoliths collected from sacrificed fish. Age reading was standardized by reading each otolith twice and if the readings agreed, then that age was assigned; a third reading was done if the readings did not agree. If after 4 readings there was still no agreement, the supervisor was consulted and an age was assigned once agreement was reached concurrently between the reader and supervisor.

The proportion $\hat{p}_a$ of mature fish in length (mm and inches TL and FL) or age group was calculated as:

$$\hat{p}_a = \frac{m_a}{n_a}, \tag{1}$$

where m_a is the number in length or age group a that are mature, and n_a is the number in length or age group a that were successfully classified with respect to maturity. The variance for $\hat{p}_a$ is:

$$v[\hat{p}_a] = \frac{\hat{p}_a(1-\hat{p}_a)}{n_a - 1}. \tag{2}$$

Nonlinear regression analysis was used to estimate the relationship between fecundity and fish length, based on a general 2-parameter allometric model:

$$F = aL^b. \tag{3}$$

The allometric model with an additive error structure is modeled as:

$$F_i = aL_i^b + \varepsilon_i, \tag{4}$$

where F_i = fecundity (eggs per female), L_i = length, and ε_i is a random error term with mean 0 and constant variance σ^2. The allometric model with a multiplicative error structure is modeled as:

$$\ln F_i = \ln a + b \ln L_i + \varepsilon_i. \tag{5}$$

Regression diagnostics (e.g., Draper and Smith 1981) were employed to determine appropriate transformations, error structures, etc., to ensure model adequacy.

Cutthroat trout length in SEAK has traditionally been measured and reported by ADF&G as fork length. Management regulations, however, are always specified in total length. Appendix A1 provides a regression formula for converting cutthroat trout fork length (mm) into total length (mm) using length measurements collected during this project (n = 3,533).

RESULTS

MATURITY

Cutthroat trout from 21 lakes were sampled in 1997 (n = 1,635) and 1998 (n = 1,550) for maturity and fecundity. Fork lengths averaged 220 mm (SE = 0.9 mm) and ranged from 92 to 425 mm FL. Total lengths averaged 230 mm (SE = 0.9 mm), or 9.1 inches (SE = 0.04 inches), and ranged from 96 to 433 mm TL. Weights averaged 122 g (SE = 1.6 g) and ranged from 6.4 to 901 g.

Sampling included 5 anadromous (mixed life history, overwintering stocks) lakes and 16 resident cutthroat trout lakes (i.e., lakes above migratory barriers). Overall, 60% (SE = 1.1%) of the 1,864 females sampled regionwide were mature in the 11-inch TL category, and 62% (SE = 1.1%) of the females were mature in the 12-inch TL category (Figure 3). At lengths below 11 inches, anadromous cutthroat trout maturity rates quickly decreased. At 10 inches, only 28% (SE = 2.2%) of the anadromous females were mature (Figure 4).

FECUNDITY

Fecundity was determined for 760 ovary samples collected from sexually mature female cutthroat trout. The number of eggs per mature female averaged 259 (SE = 4.7), and ranged from 54 eggs in a 249 mm FL fish to 802 eggs in a 357 mm FL fish. Eggs in immature females were not counted because they were too small to easily distinguish.

Fecundity-at-length was modeled by assuming either an additive or multiplicative error structure. The estimates of a were 0.0016 assuming additive error, and 0.0024 assuming multiplicative error; estimates of b were 2.16 assuming additive error, and 2.08 assuming multiplicative error. Residuals from both error structure models (allometric model) were plotted against length and predicted fecundity (Figure 5). The residual plots for each model were similar and indicated that each violated the assumption of homoscedasticity. The additive error model fit the data slightly better than the multiplicative model (r^2 = 0.77 versus 0.75; Figure 6).

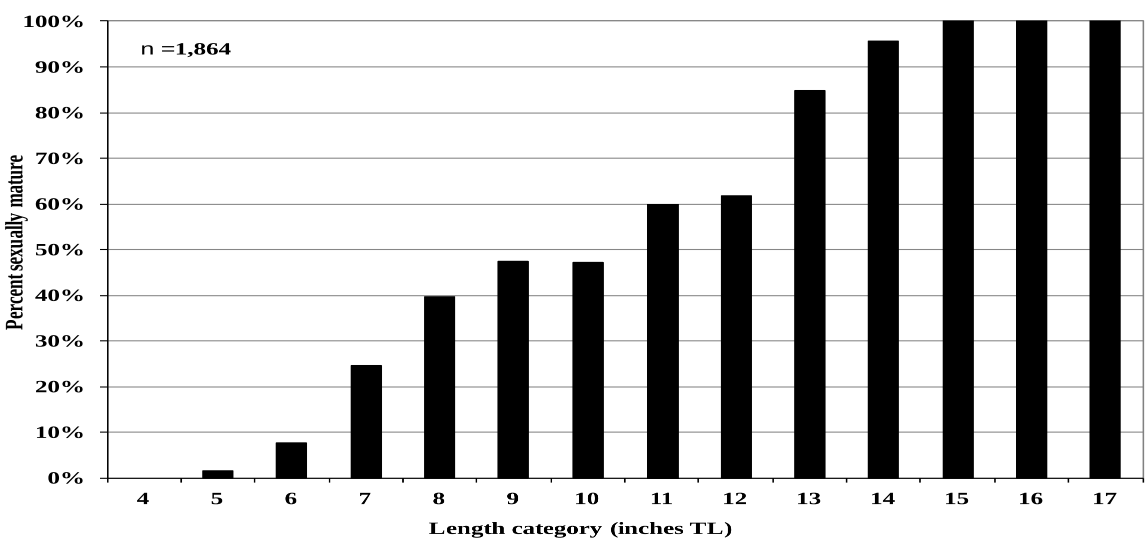

Figure 3.–Average percentage of sexually mature female cutthroat trout sampled in Southeast Alaska lakes, 1997–1998.

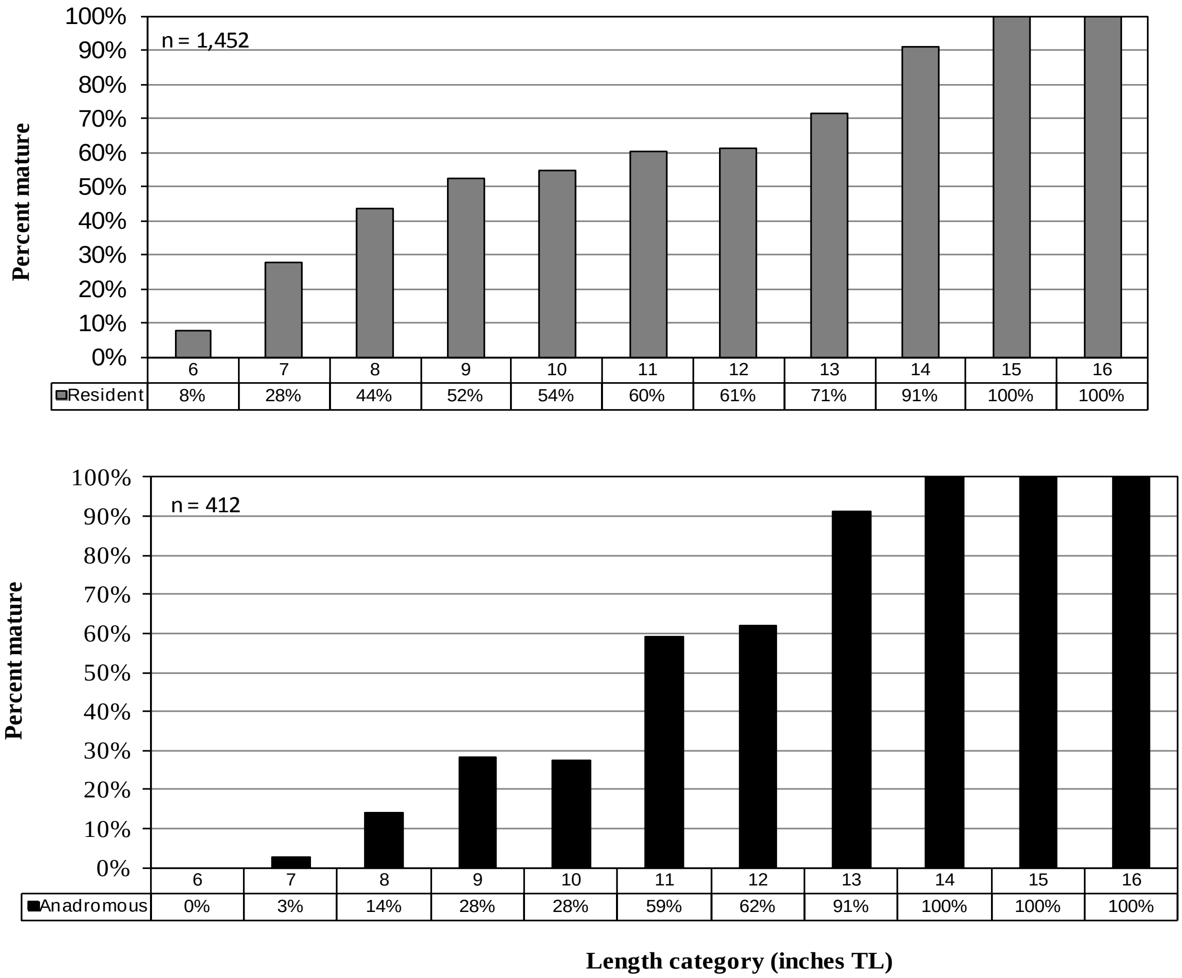

Figure 4.–Average percentage of sexually mature female cutthroat trout sampled by lake type (resident and anadromous) in Southeast Alaska lakes, 1997–1998.

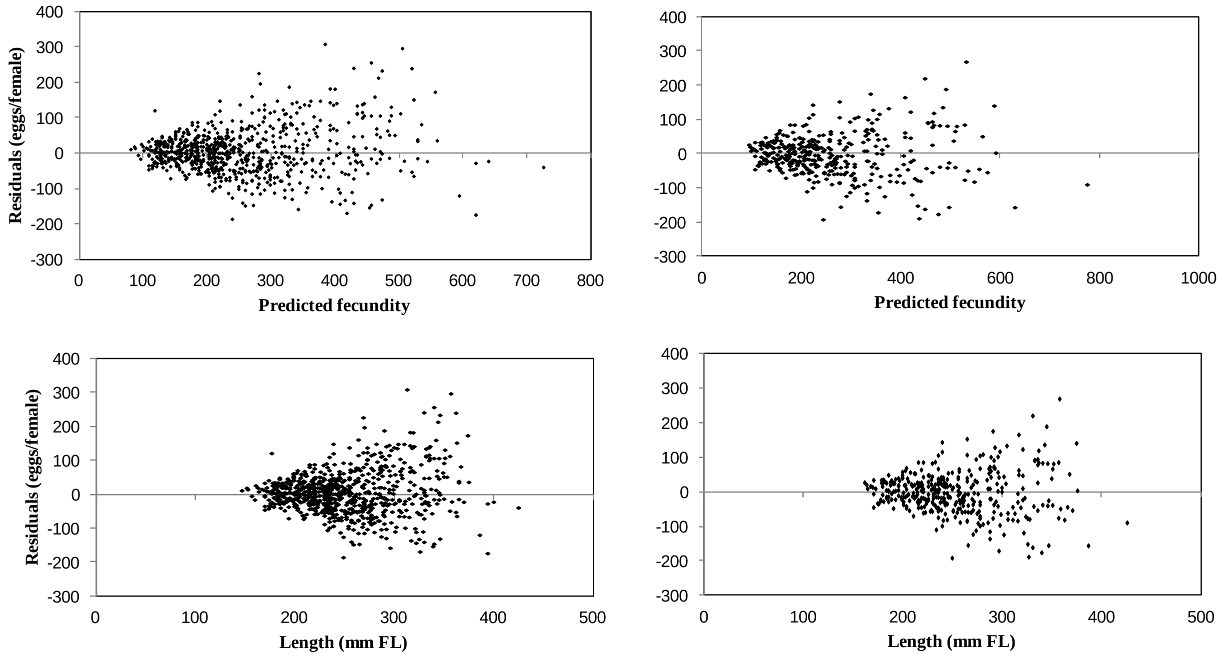

Figure 5.–Residuals from the allometric model versus length and predicted fecundity for cutthroat trout sampled in Southeast Alaska lakes, 1997–1998. Multiplicative error structure residuals are plotted in the left side panels, and additive error structure residuals are plotted in the right side panels.

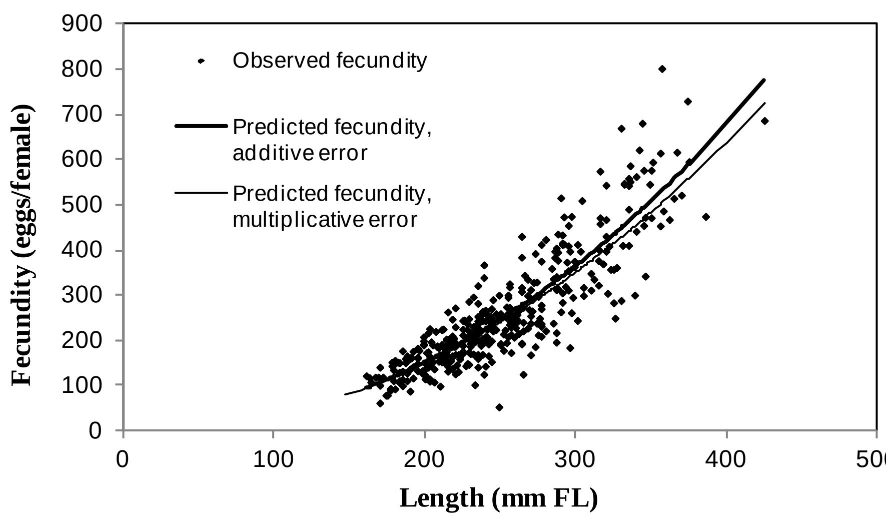

Figure 6.–Fecundity-at-length relationship with additive and multiplicative error structures for cutthroat trout sampled in Southeast Alaska lakes, 1997–1998.

OVARY WEIGHT

A total of 1,295 ovaries were weighed from all lakes except Florence Lake (see analysis in Foster 2003). Only complete ovary samples (i.e., 2 intact ovaries per female), were used in this analysis. The mean ovary weight from fish categorized as mature at the time of collection was 7.8 g (SE = 0.34 g), and ranged from 0.8 to 61.5 g. Ovary weight from fish identified as immature averaged 0.4 g (SE = 0.01 g), and ranged from 0.01 to 3.0 g. Ovary weight as a function of fork length for fish classified as immature or mature is presented in Figure 7. Approximately 2% of ovaries sampled had residual eggs in some state of reabsorption, and approximately 0.5% of the samples classified as immature also had residual eggs.

EGG SIZE

Egg diameter was measured for 30 randomly selected eggs per ovary collected during 1997. It was determined that a smaller sample (10 eggs) generated the same precision, so the number of eggs measured in 1998 was reduced to 10 eggs per ovary sample. The CV in egg size from a single fish was minimal (all CV ≤ 0.033%) in both years. For comparative purposes, the mean egg diameter from each fish will be used to singularly represent egg size for that fish.

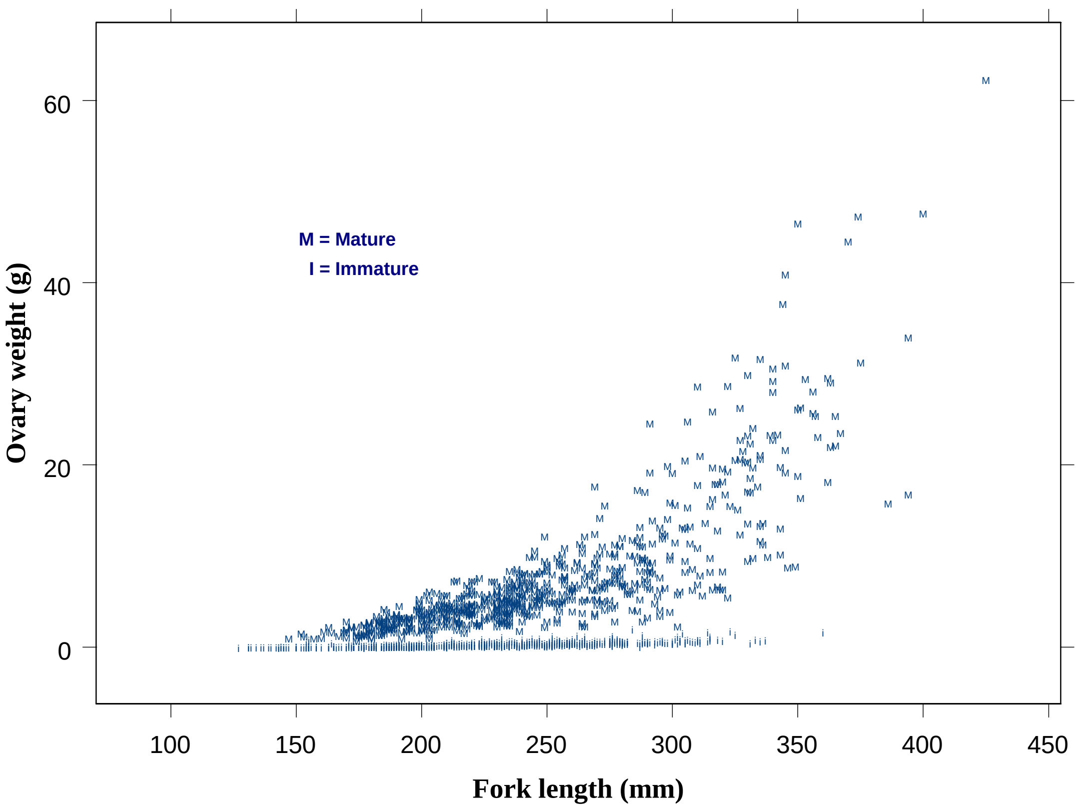

Figure 7.–Ovary weight and fork length of cutthroat trout classified during field collection as immature or mature at lakes sampled in Southeast Alaska, 1997–1998.

The average diameter of eggs collected from sexually mature female cutthroat trout in all lakes was 3.3 mm; (SE = 0.02 mm; n = 612), and ranged from 1.9 to 5.2 mm. Egg diameter varied considerably by fork length of fish (Figure 8) and lake (Figure 9). There was a significant difference (Kolmogorov-Smirnov: d = 0.44, P $\leq$ 0.001) in distribution of mean egg diameter from anadromous and resident cutthroat trout populations (Figure 10).

AGE

Female cutthroat trout as young as 1-year old were classified as mature and approximately 30% of the female cutthroat trout sampled were classified as mature at age 3 and 4 (Figure 11). Not until age 3 did the cumulative percent of mature females exceed 50% (Figures 12 and 13).

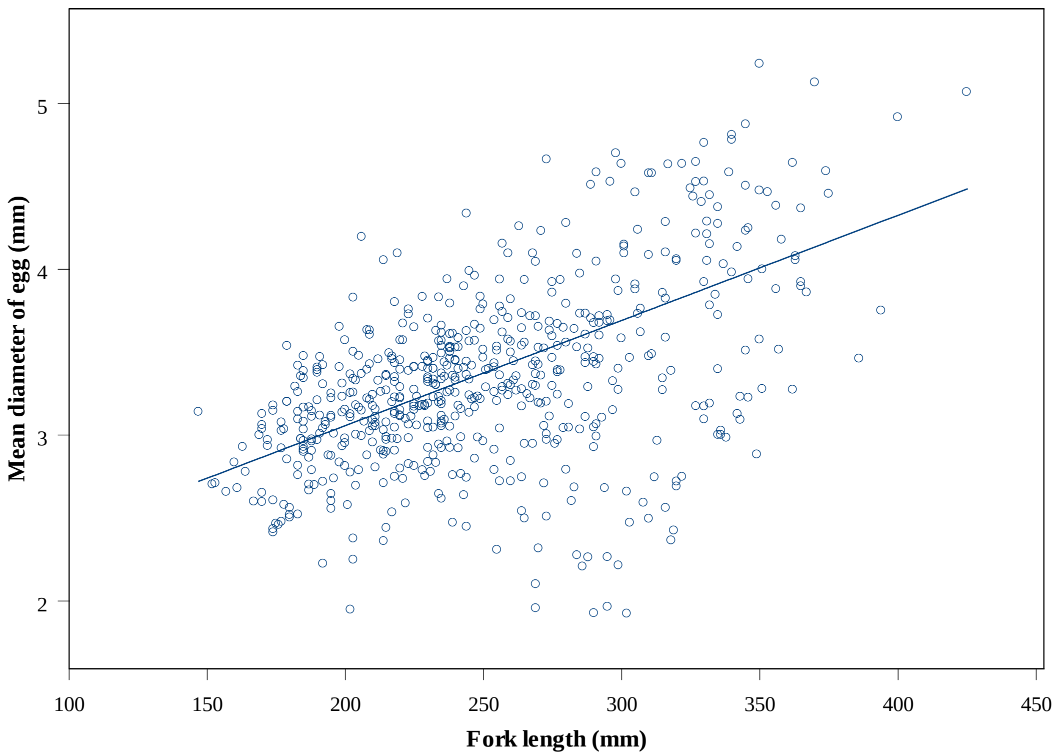

Figure 8.–Fork length and mean egg diameter for all eggs collected from 21 lakes that were sampled in Southeast Alaska, 1997–1998.

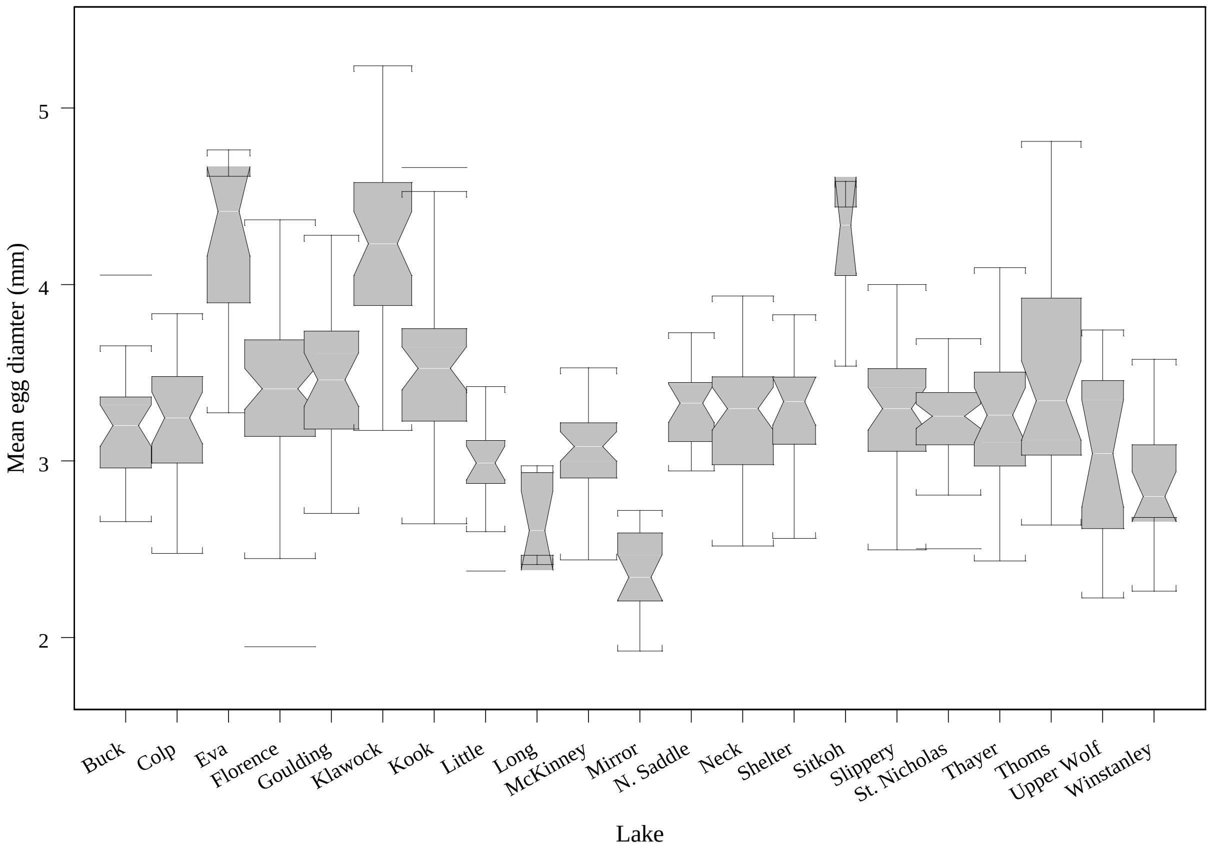

Figure 9.–The distribution of egg diameter by lake for cutthroat trout ovaries sampled in Southeast Alaska, 1997–1998. The notches in the box-plots provide an approximate 95% test of the null hypothesis that the median egg diameters are equal; width of the boxes represent sample size.

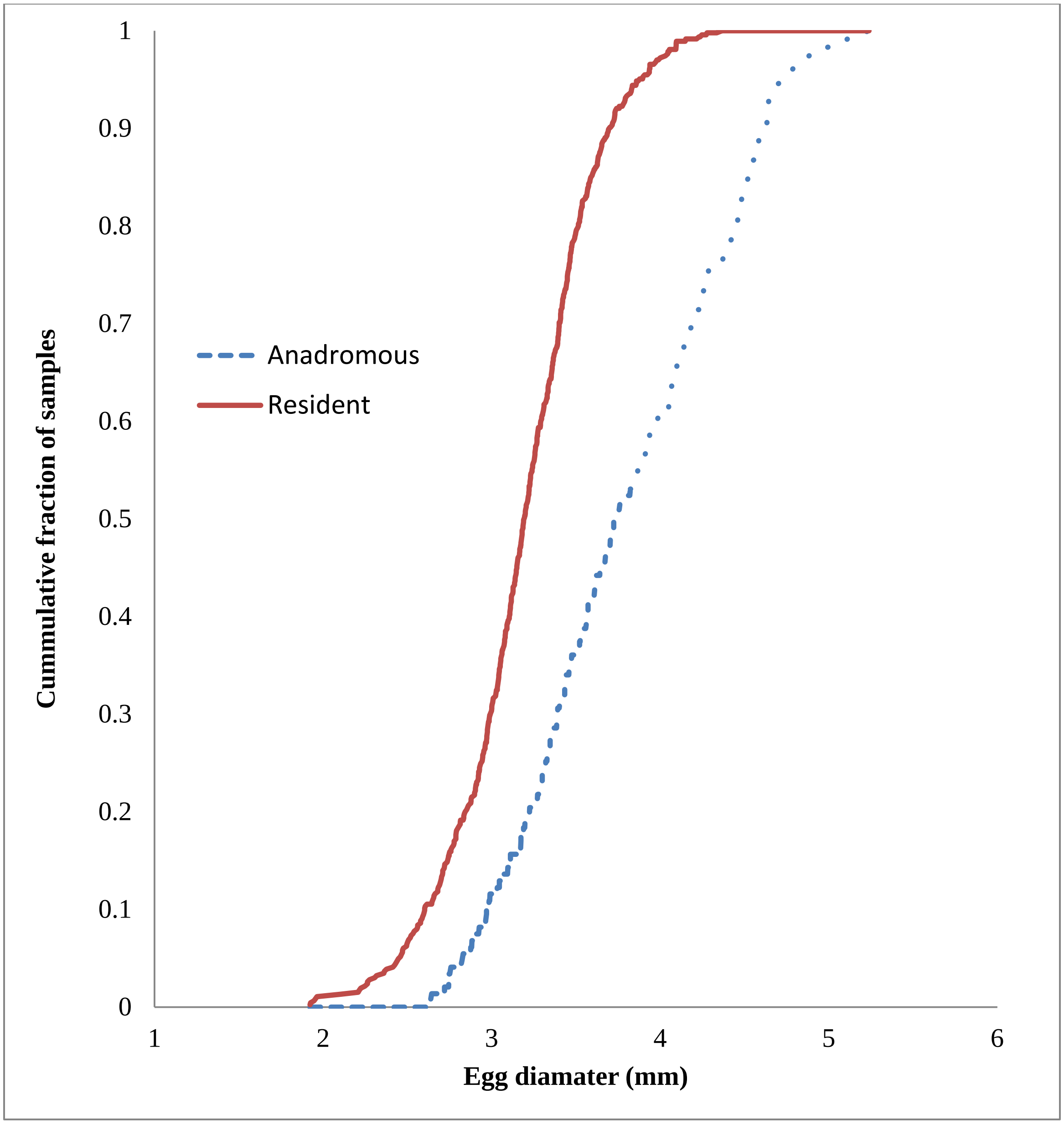

Figure 10.–The cumulative fraction of cutthroat trout egg diameter from anadromous and resident lakes sampled in Southeast Alaska, 1997–1998

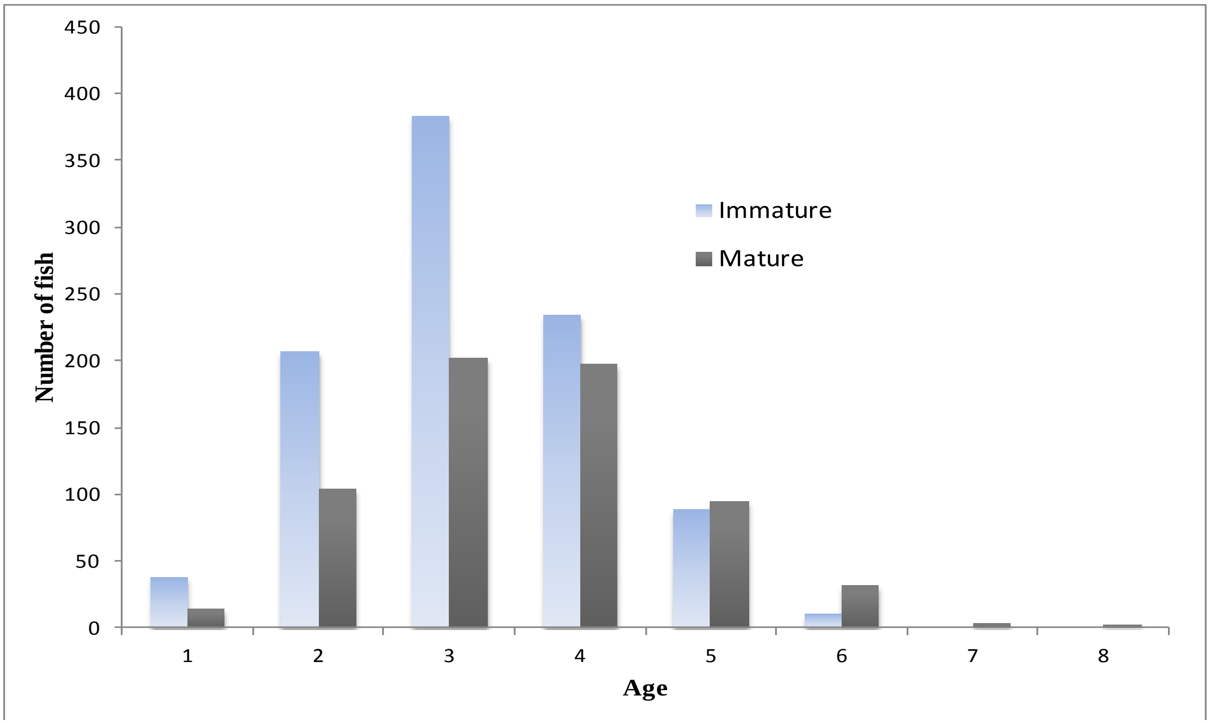

Figure 11.–The number and age of sexually mature and immature female cutthroat trout sampled in Southeast Alaska, 1997–1998.

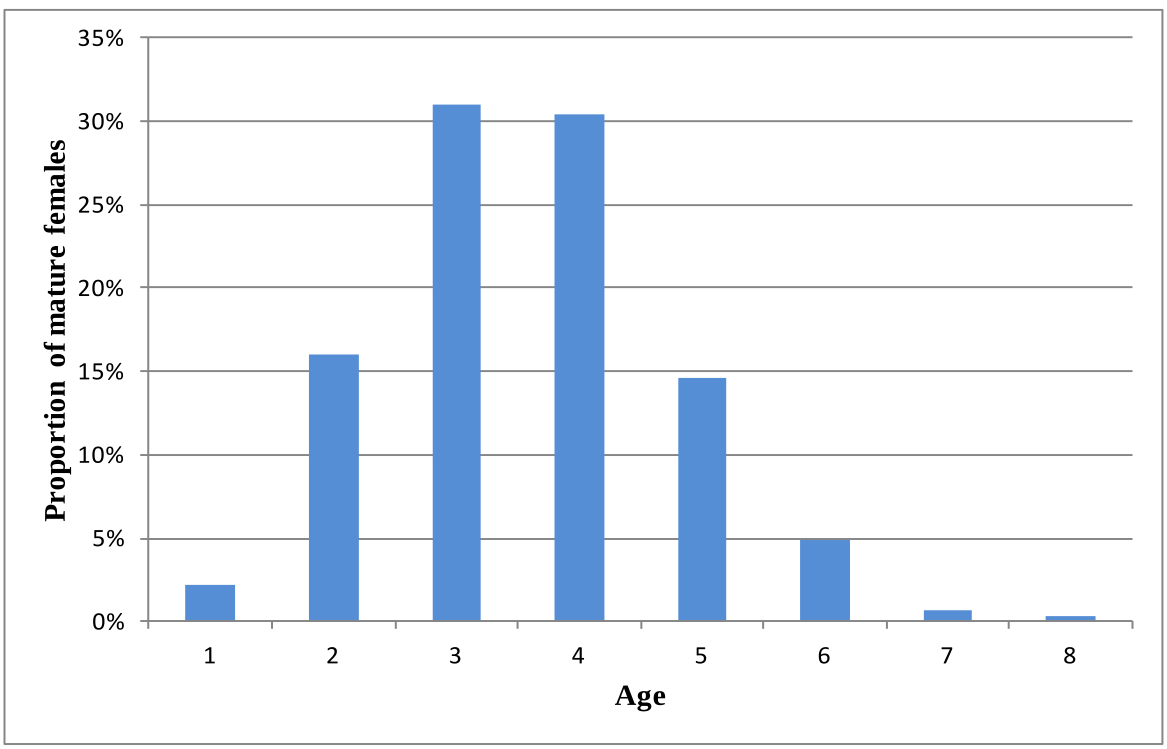

Figure 12.–The proportion of sexually mature female cutthroat trout by age class sampled in Southeast Alaska, 1997–1998.

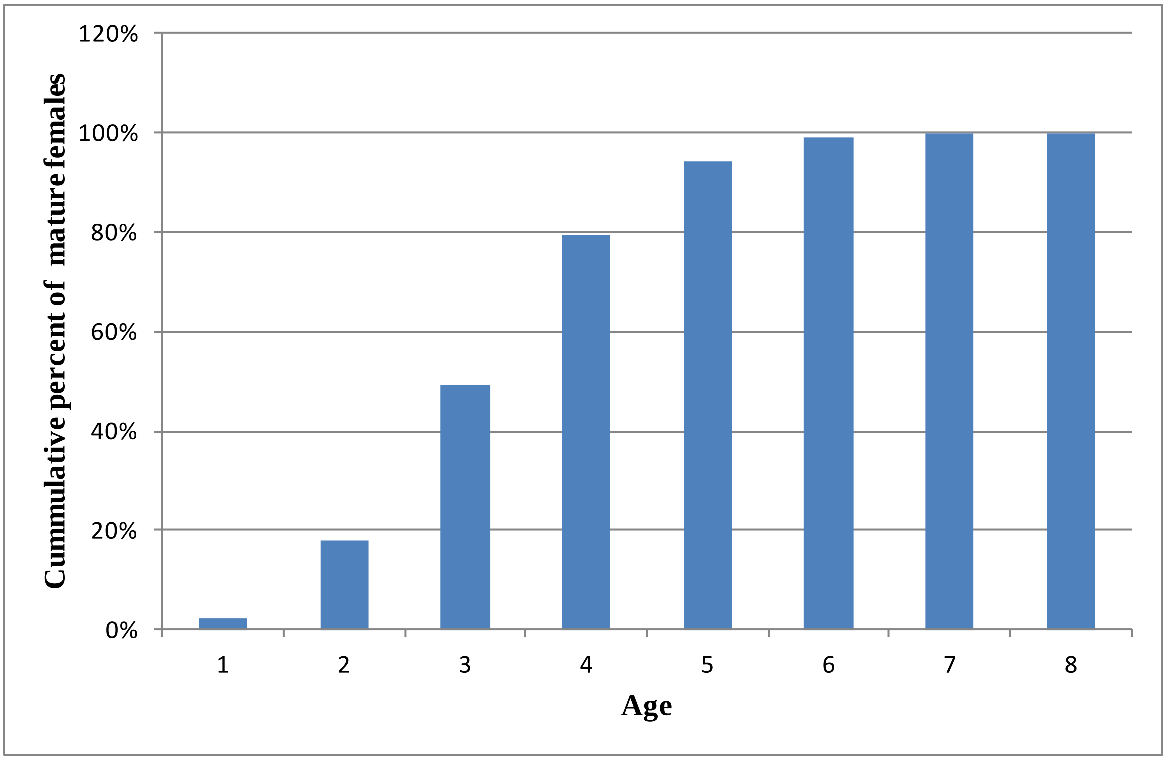

Figure 13.–The cumulative percentage of sexually mature female cutthroat trout by age class sampled in Southeast Alaska, 1997–1998.

DISCUSSION

MATURITY

The objective of this project was to estimate the proportion of sexually mature female cutthroat trout in 1-inch length increments (approximately 20 mm FL) in a range of lake types throughout SEAK. However, the primary goal of the sample design was to minimize, as much as possible, the number of fish that needed to be sacrificed. Thus, the sampling design was not completely random and fish were selected from a predetermined set of criteria to ensure an adequate number fish were selected for each 20 mm length category. Whenever possible, samplers strove to: 1) sample similar numbers of fish captured using each gear type; 2) sample the diverse range of lake habitats and depths (<30 m) present in the lake; and 3) meet overall sample size requirements for each 20 mm length category. Each of these goals had practical limitations (e.g., floatplane, vehicle, or foot access to lake, and availability of cabin or boat) that varied by the lake. The first objective assumed that CPUE for each gear type in a lake was such that sampling effort could be effectively regulated to achieve sampling goals (e.g., traps could be set multiple times per day).Yet regulating effort in some lakes would not yield the desired sample size if CPUE for a particular gear type in a lake was very low. However, the 2 year sampling design was fairly robust to this possibility because samples could be pooled across years in lakes that had similar characteristics. Depending on logistics (boats and weather), it also proved difficult to deploy sampling gear effectively across a diverse range of habitat types and depths in larger lakes. In these cases, gear was dispersed as widely as possible. Results from this project showed no meaningful difference for management purposes in the average percent of sexually mature fish between the 11 and 12 inch categories in the 21 lakes sampled throughout SEAK. Overall, 60% of the 1,864 females sampled were mature in the 11-inch length category, and 62% of the females were mature in the 12-inch length category. The department's management strategy to protect cutthroat and rainbow trout until the majority could spawn at least once could thus be met with an 11-inch minimum size limit while providing more harvest opportunities for sport anglers. Subsequently, the department recommended to the BOF that the regionwide minimum size limit be reduced from 12 inches to 11 inches, and the BOF adopted the lower minimum size limit in 2000. The BOF has made several regulation changes and exceptions to the regionwide minimum size limit since adopting the more conservative trout regulations in 1994, and details of these actions can be found in Harding and Jones (2005) and Harding and Coyle (2011).

FECUNDITY

The fecundity of several subspecies of cutthroat trout, including westslope, Bonneville *O. clarki utah*, and Yellowstone *O. clarkii bouvieri* has proven to be an important parameter or variable when modeling trout populations. Estimates of fecundity have contributed to estimating female reproductive output (Peterson et al. 2010), for evaluating stock status (Pauley et al. 1989), and assessing environmental risk for potential Endangered Species Act listings. Fecundity varies greatly among western trout and is influenced by both environmental and hereditary factors, but fecundity typically ranges from 1,200 to 3,200 eggs/kg of body weight, or 1.2 to 3.2 eggs/g (Behnke 1992). The average number of eggs/g estimated by this study was 1.7 (SE = 0.02; n = 725), and ranged from 0.63 to 6.1 eggs/g.

Although the average fecundity (in eggs/g) estimated by this study falls within the wide range reported by Behnke (1992) for all western trout, it is considerably less than the most relevant analysis of fecundity, reported by hatcheries in Oregon and Washington for coastal cutthroat trout (Wydoski and Tipping 2001). Although their analysis primarily consisted of larger cutthroat trout, comparison between fish in the smallest common length range (326–350 mm FL) indicated that the fecundity estimated by this study was substantially less. Based on 2 fish sampled at Cowlitz Hatchery and 5 from Beaver Creek Hatchery, the average predicted fecundity was 871 (SE = 11.5) and 1,029 (SE = 3.0), respectively; for identically-sized fish sampled in the SEAK study, the mean fecundity was 479 (SE = 15; n = 53), and ranged from 250 to 713 eggs per female. Doing more meaningful fecundity and length comparisons is limited because other studies generally report the mean number of eggs per female from a range of lengths, e.g., in Washington no specific information about location or whether fish were anadromous or resident was provided when reporting that females ranging in total length from 200 to 430 mm produced between 226 to 4,420 eggs (Johnston and Mercer 1976).

The only fecundity information for SEAK comes from a few dozen fish captured at Petersburg Creek in the middle 1970s. Jones (1974) reports that fecundity from a small number of anadromous cutthroat trout sampled at Petersburg Creek ranged from 500 eggs for a 370 mm TL fish to 1,100 eggs for a 440 mm TL fish. In a subsequent report (Jones 1976), 12 fish from Petersburg Creek were sampled for fecundity, which ranged from 460 eggs for a 340 mm fish to 1,342 for a 422 mm fish, and averaged 862. The average estimated fecundity for fish sampled in this study is also less than Jones (1974, 1976) when similarly sized fish from anadromous systems are compared.

A thorough comparison of fecundity from this study with other coastal cutthroat trout is difficult due to the paucity of comparable studies, differences in length-at-maturity throughout their range, and adequate sample sizes. However, the comparisons that could be made suggest that fecundity of cutthroat trout in SEAK sampled in this study is substantially lower than in their southern range.

OVARY WEIGHT

A meaningful comparison between ovary weights collected during this study with similar data is also difficult to achieve due to the same reasons stated previously regarding fecundity. Many of the studies that provide ovary weights are generally related to artificial propagation programs with other subspecies and tend to be incomplete or inconsistent with the sampling protocol implemented in this study (e.g., weighing ovaries fresh versus preserved).

EGG SIZE

Eggs from anadromous coastal cutthroat trout in Washington reportedly ranged in diameter from 4.3 to 5.1 mm at the time of deposition (Johnston and Mercer 1976); no other details or specific location are provided. Egg diameter for anadromous cutthroat trout in the SEAK maturity study were slightly smaller (Figure 10) and ranged from 2.6 to 4.7 mm (n = 49). Although there is a scarcity of comparable data, it appears that egg diameters of cutthroat trout in SEAK are smaller than in the central and southern ranges of coastal cutthroat trout (Wydoski and Tipping 2001). Beacham and Murray (1993) also suggest that egg diameter may be smaller in northern populations of salmonids as a result of increased fecundity due to their older ages at maturity, and a limited amount of energy that can be expended on egg production.

There are several authors who provide insight as to the ecological and evolutionary adaptations of coastal cutthroat trout as it relates to egg size, length, fecundity, and size at maturity. Trotter (1997) states that larger cutthroat trout are more successful at spawning because they produce larger eggs and can effectively compete for the best spawning sites. Pearcy et al. (1990) theorizes that as coastal cutthroat trout co-evolved with coho salmon and steelhead trout, their small size at maturity may be an adaptation that allows cutthroat trout to spawn in the numerous small tributaries of coastal streams where no other salmonids (e.g., steelhead trout) are present or are less abundant.

Consistent with results presented by Wydoski and Tipping (2001), egg diameter of cutthroat trout in SEAK generally increased as female lengths increased (Figure 8). It is assumed, as with other species of fish, that a larger egg diameter results in higher fry survival, and thus, survival to other life stages. Larger alevins and fry are produced from larger eggs (Beacham and Murray 1990) and these larger alevins and fry may provide for a competitive advantage in survival of coastal cutthroat trout (Wydoski and Tipping 2001). This is fairly uniform across other trout species and most species of salmonids. However, in Atlantic salmon *Salmo salar* repeat spawners had significantly smaller eggs and significantly lower egg survival rates than first-time spawners (Reid and Chaput 2012). The reason given for this was the short time spent reconditioning, and consequently a shortage of available energy reserves. It should be pointed out that the SEAK maturity study focused primarily on estimating the length at which cutthroat trout first mature, and the relationship of fish length to egg size and fecundity might differ on larger trout not targeted for sampling in this study. Variations in egg diameter of cutthroat trout in SEAK may provide insight into the biology of individual populations and their reproductive potential, but does not appear to be a significant candidate variable in any maturity model.

AGE

The predominant age classes of cutthroat trout sampled during this study were age 3 and 4 (Figure 12). There were 13 fish classified as mature at age 1, but it is suspected improper ages were assigned to some of these fish. In reviewing the age-at-length data for the smaller and younger fish, several anomalies arose. There were 3 fish ≥250 mm FL that were estimated to be age 1, one of which was a recaptured (ventral fin clipped) fish from a multi-year mark-recapture experiment at Neck Lake (Harding et al. 1999a) that concluded only several months prior to maturity sampling; this fish could not have been only 1 year old. It is believed a smaller fish's otolith and scale sample was inadvertently placed in the wrong sampling envelope. There are reported difficulties in aging fish at 1 year of age (Ericksen 1997) and it is likely there was some type of age error associated with the 13 fish estimated to be mature at age 1. Three of the 13 mature fish estimated to be age 1 were <200 mm FL and were the only ones that could have realistically been that age.

The life history of coastal cutthroat trout may be the most diverse of any Pacific salmonid (Northcote 1997; Johnson et al. 1999) and their populations show a perplexing diversity in size and age-at-maturity, as well as timing of migrations and frequency of repeat spawning. The literature reports considerable variation in age- and size-at-maturity for coastal cutthroat trout. Trotter (1997) reports that resident or nonmigratory coastal cutthroat trout typically mature at 2 to 3 years of age, whereas anadromous cutthroat trout rarely spawn before age 4. Behnke's (1992) life history review reports that coastal cutthroat trout reach maturity and spawn for the first time as 3 or 4 year old fish. Coastal cutthroat trout scales are notoriously difficult to read and interpretations of scale patterns often vary greatly between readers (Ericksen 1997; Knudsen 1980); these difficulties may hinder meaningful comparisons among studies (Johnson et al. 1999).

There is nothing to suggest that cutthroat trout from SEAK mature much differently than those found elsewhere in their range. The natural variation in age-at-maturity found in SEAK encompasses the variations observed throughout their native range. Differences in growth rates, variations in life history strategies (anadromous versus resident), different environmental factors, including water temperature, contribute to the variation in age-at-maturity, fecundity, and egg size in SEAK.

MANAGEMENT IMPLICATIONS

The proportion of sexually mature female cutthroat trout from the SEAK maturity study was averaged by length increment across the 21 lakes sampled to help develop minimum size limit regulations (Hunt 1970). Managing several thousand trout populations using average length-at-maturity does provide a practical and cost-effective way to manage without the need for detailed biological data on each system. However, applying a management strategy developed from a small sample size (21 lakes) to several thousand populations could undoubtedly create situations where some populations are "overly-protected," while some populations may not be fully protected. In an effort to evaluate the effectiveness of the current trout regulations, length-at-maturity data from individual lakes were evaluated against the management strategy currently used at these lakes; the results for each management strategy are presented below.

High-Use Lakes

A larger size limit (14 inch minimum size) was adopted for areas with developed access and/or intensive fisheries with high angler use ("high-use"). This more restrictive limit was intended to protect all female cutthroat trout from harvest until they had the opportunity to spawn at least one time. The *a priori* goal of protecting "all" trout until they have had an opportunity to spawn at least once appears to be defined incorrectly or unobtainable. Length-at-maturity results suggested that no population sampled had length categories where 100% of the females were mature, either as a result of not spawning annually once reaching sexual maturity, or because larger fish avoided the sampling gear. A more realistic biological management goal may be to protect 90% of the population until they have had an opportunity to spawn at least once.

Five of the 21 lakes sampled for maturity are being managed as high-use lakes and the management goal of protecting all (>90%) of the spawners is being achieved (Figure 14). In Kook Lake the regional minimum size limit of 11 inches would also meet the high-use management objective, thus the regulations in Kook Lake may be overly protective. Sample sizes for the larger fish sampled for maturity were small and ranged from 5 at Sitkoh Lake to 54 at Kook Lake.

Regionwide Minimum Size Limit

Twelve of the lakes sampled are managed under the regionwide minimum size limit of 11 inches (Figure 15). The distribution of lengths for mature female trout sampled from these lakes fall below the 11-inch regionwide size limit, clearly meeting the strategy of protecting the majority (>50%) of female trout until they can spawn at least once. The length distribution of mature females from Mirror and Slippery lakes, however, fall above the 11-inch minimum size limit and few if any mature fish are being protected under this management strategy. Although not as clearly defined as the other lakes, 52% of the mature female trout are being protected in Winstanley Lake. A minimum size limit of 9 inches would protect nearly all of the mature female trout in 2 of the lakes (Colp and Little lakes, see next section).

Small Cutthroat Trout Lakes

Three of the lakes sampled were ultimately assigned to the management strategy category called "small cutthroat trout lakes" (Figure 16). The lakes managed under this strategy have a 9-inch minimum size limit and the length of female trout sampled in this lake show that few, if any, fish are >9 inches (Figure 16). There are a total 7 lakes in SEAK, including the three that were sampled (Figure 17), that are managed under the small cutthroat trout lakes regulations. Two additional lakes sampled during the maturity project (Colp and Little lakes) have length-at-maturity length distributions showing that >90% of the mature female population in these lakes would be protected under a 9-inch minimum size limit (Figure 15). Several other lakes (North Saddle, St. Nicholas, Thayer, McKinney, and Upper Wolf lakes) would have between 70% and 90% of their mature female trout protected under a 9 inch minimum size limit (Figure 15).

Trophy Lakes

No trophy lakes were sampled as part of this study primarily due to the destructive sampling required at the time of the study. Since the maturity study concluded there has been promising results of nondestructive sampling using ultrasound technology (Bangs and Nagler 2007) and techniques requiring only a blood sample (Bangs and Nagler *In press*).

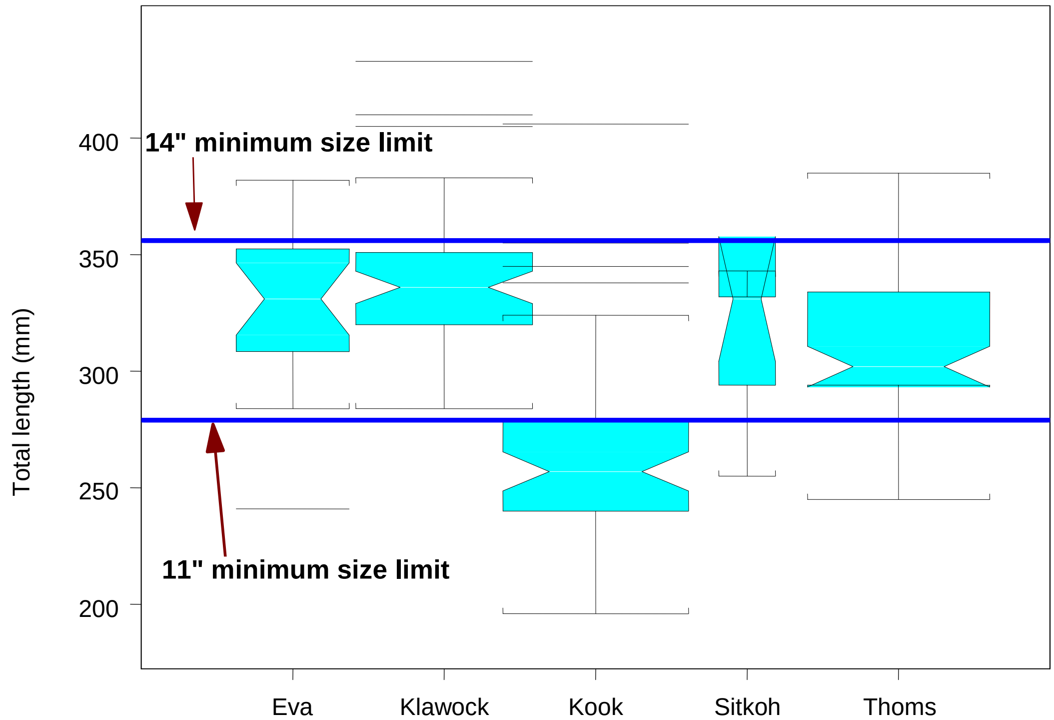

Figure 14.–Length distributions of mature female cutthroat trout in 5 lakes managed for high angler use in Southeast Alaska with lines showing regionwide minimum length restrictions (11 inches) and high angler use minimum length restrictions (14 inches).

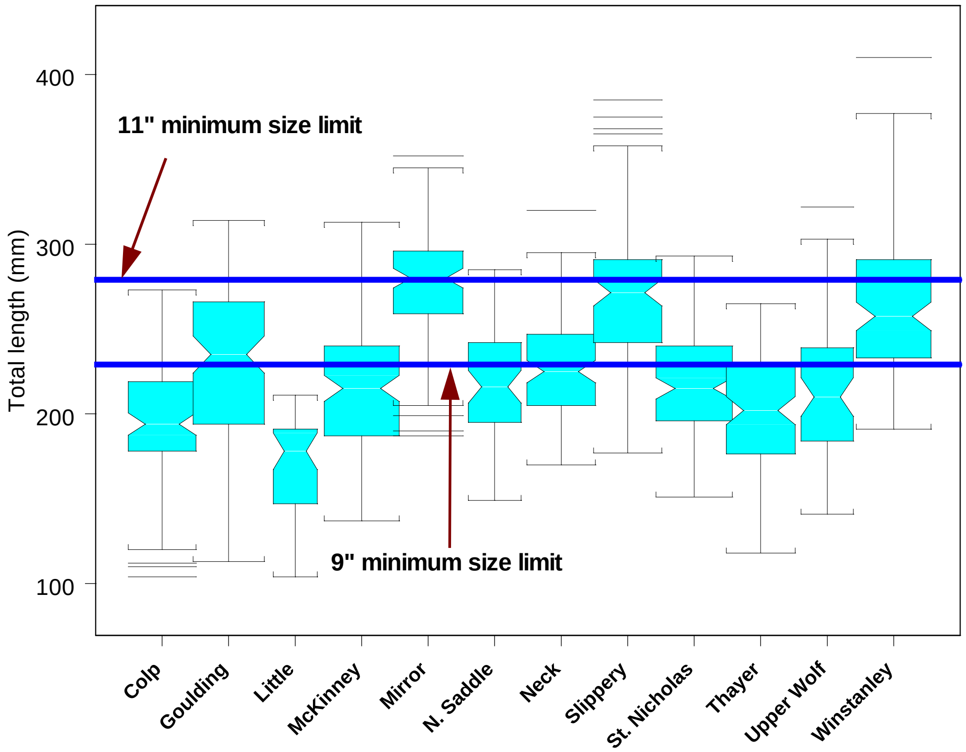

Figure 15.–Length distributions of mature female cutthroat trout in 12 lakes managed under the regionwide (11 inch) minimum size regulations as high angler use in Southeast Alaska with lines showing the 11-inch and 9-inch minimum size limits.

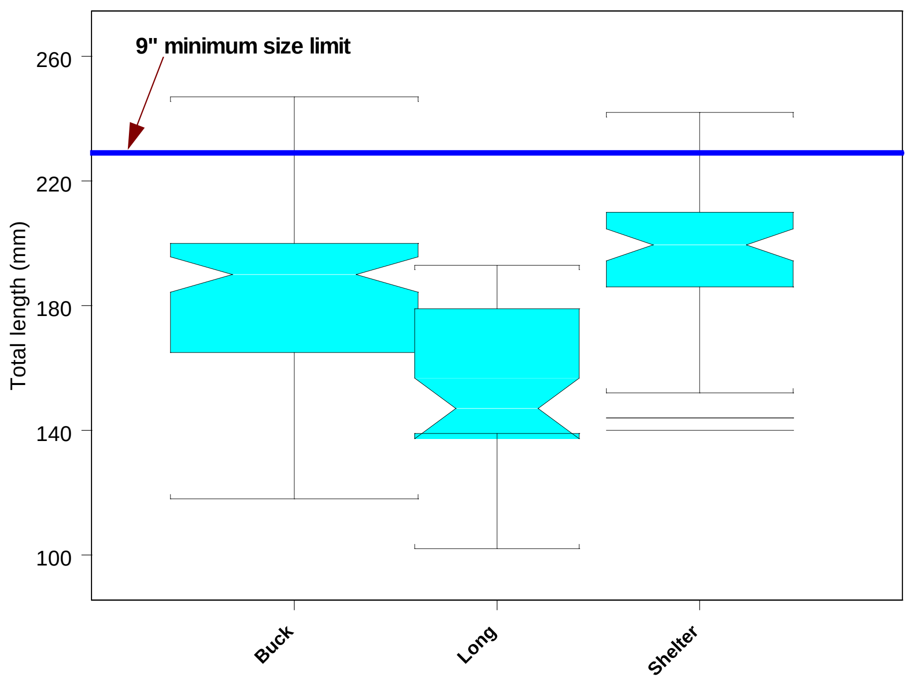

Figure 16.–Length distributions of mature female cutthroat trout in 3 lakes managed under the small cutthroat trout lake strategy with a 9 inch minimum size regulations with a line showing the 9-inch minimum size limit.

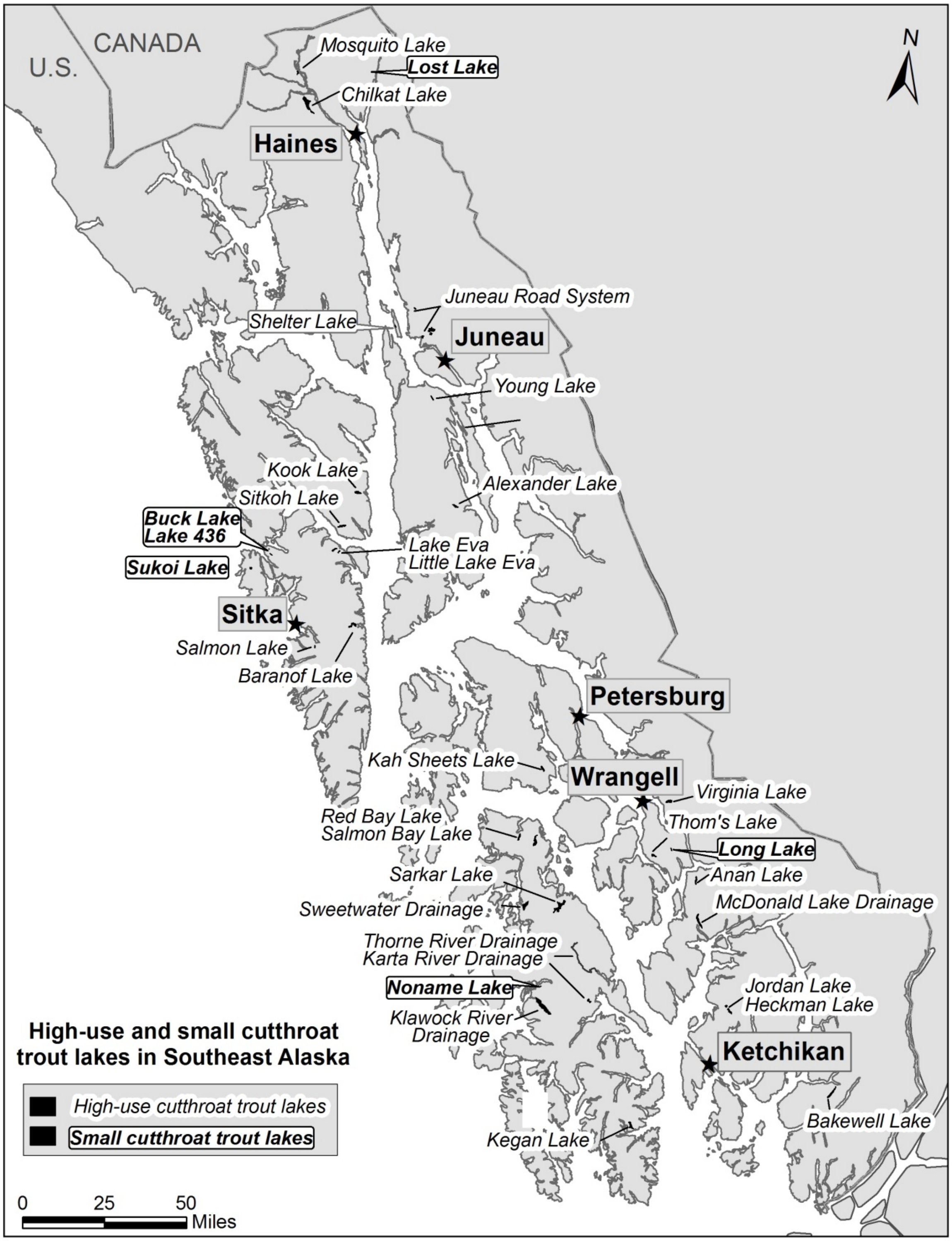

Figure 17.–Lakes in Southeast Alaska that are managed as either high angler use (14 inch minimum size limit) or small cutthroat trout lakes (9 inch minimum size limit).

Special Regulation Lakes

Florence Lake is managed under special regulations that have no minimum size limit and allow the use of bait while providing a more liberal bag limit of 5 fish/day and a possession limit of 10. These regulations were established because of extensive stock assessment studies that showed Florence Lake had some of the highest densities of cutthroat trout in the region. There was also a decline in angler effort following extensive clearcut logging around the lake. Additionally, the U.S. Forest Service closed one of its recreational cabins following the logging. If management strategies for Florence Lake changes, the regionwide minimum size limit of 11 inches would be effective in protecting >90% of the female trout until they had spawned at least once (Figure 18).

The data collected at Florence Lake served as the basis for a Master's thesis and is summarized in more detail by Foster (2003). Foster (2003) also includes estimated age- and length-based recruit analyses that were used to evaluate sustainable fishing mortality rates.

Anadromous versus Resident Trout

Anadromous populations of cutthroat trout sampled during this study matured at a larger size than resident fish (Figure 19). Thus, regulations designed to protect resident female trout should also provide adequate protection for anadromous populations under any of the current management strategies.

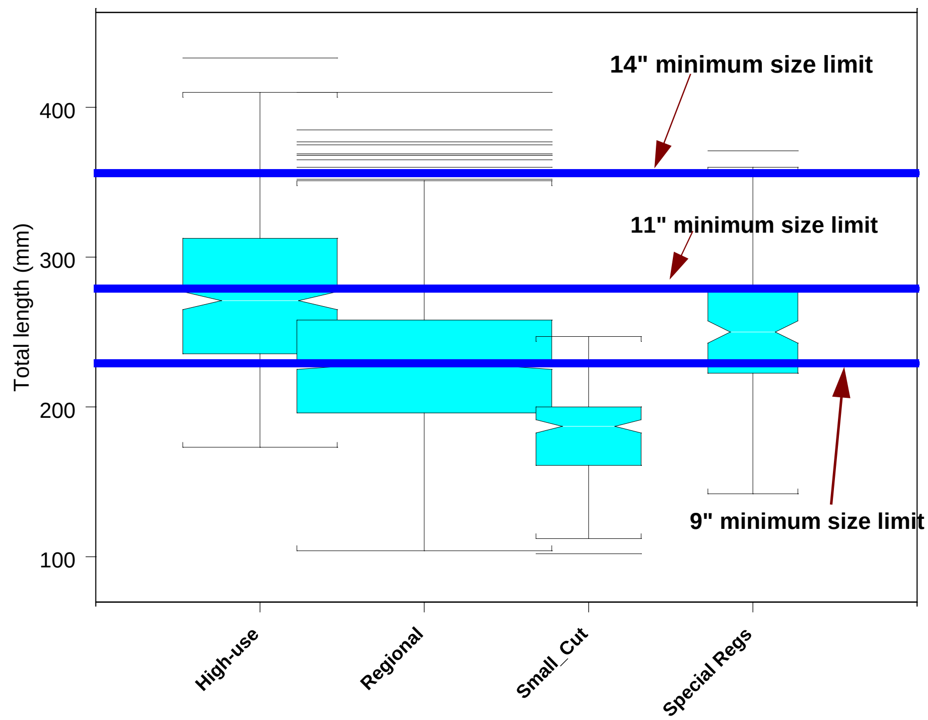

Figure 18.–Length distributions of sexually mature female cutthroat trout grouped by the management strategy used to manage lakes in Southeast Alaska (high angler use, 14 inch; regionwide, 11 inch; small cutthroat trout lakes, 9 inch; special regulations, Florence Lake).

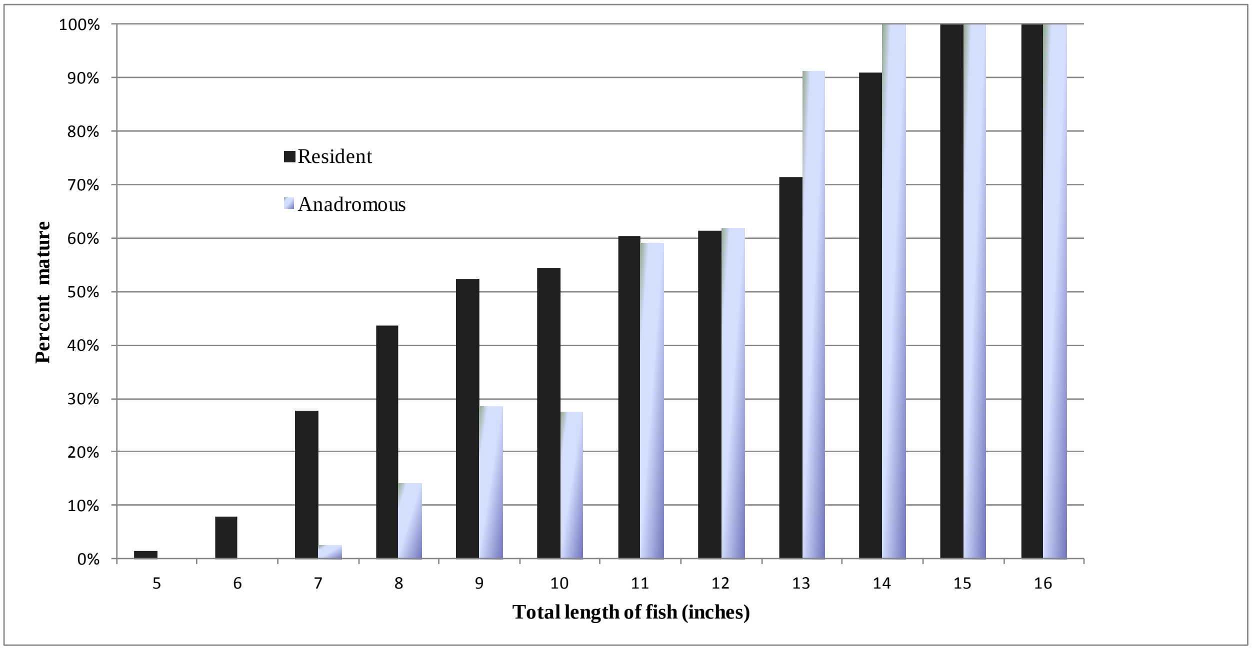

Figure 19.–The percent maturity by total length of cutthroat trout for anadromous and resident lake populations sampled in Southeast Alaska, 1997–1998.

Male versus Female Maturity

Males mature at a smaller size then females so a management strategy that is designed to protect female trout until they can spawn at least once will also protect a higher percentage of males. Thus, male cutthroat trout should be adequately protected under any of the current management strategies.

Summary of Management Implications

There have been several proposals submitted to BOF since the new trout regulations were adopted requesting additional opportunities to harvest trout and to use bait (Harding and Coyle 2011). At the 2012 BOF meeting, a proposal was submitted that would have allowed youth and disabled anglers to use bait in high-use cutthroat trout lakes. The BOF adopted an amendment to this proposal that allowed youth to use bait in a small lake near Wrangell (Pats Lake) for 2 weekends/year. Previous proposals to the BOF include a proposal requesting that the bag and possession limits in remote trophy lakes be increased to 2 fish with a 9-inch minimum size limit. Verbal comments from sport fishing anglers and written comments received on returned surveys from U.S. Forest Service recreational cabin users (Harding et al. 2009) indicate that some sport fish anglers would like more opportunities to use bait and harvest more trout. Results from the maturity study show that some smaller lakes do not produce trout ≥11 inches and a shorter minimum size limit may be able to protect the majority of female trout until they have had an opportunity to spawn at least once (Figure 16).

CONCLUSIONS AND RECOMMENDATIONS

Trout regulations currently being used to manage trout populations in SEAK are believed by management biologists to provide adequate protection and are effective in maintaining existing trout populations. The exceptions to this belief are the populations managed as trophy lakes because no maturity data have been collected from them. It is recommended that the length and maturity data be collected using nonlethal techniques on several populations of cutthroat trout that are managed under the trophy lakes category.

Results from this analysis suggest that there may be many lakes that have over-restrictive regulations where a shorter minimum size limit would still protect the majority of female cutthroat trout, yet provide increased harvest opportunity. However, to ensure trout populations remain sustainable, it is strongly recommended that sampling occur at these lakes prior to changing management strategies so that length-at-maturity can be evaluated for each lake.

The original regionwide minimum size limit adopted by the BOF in 1994 was based on length-at-maturity data available at the time. The data used primarily came from more southern trout populations (de Leeuw 1987; Wright 1992), but also incorporated the only available data from SEAK (Jones 1974, 1976). In a maturity study conducted in small lakes in British Columbia, Jonsson et al. (1984) reported that cutthroat trout females reach sexual maturity at age 4 (range 2–7 years of age) and a mean length of 202 mm FL (±15.9 mm; range 145–252 mm). Jonsson et al. (1984) concluded that cutthroat trout mature at an age that maximizes the overall reproductive potential, and that fish can adjust their age-at-maturity nongenetically to growth rate variations. Based on a comprehensive review of management strategies, Wright (1992) suggested that a 12-inch minimum size limit would allow approximately 85% of the cutthroat trout over 180 mm FL an opportunity to spawn at least once, and a 14-inch size minimum limit would allow nearly all fish an opportunity to spawn at least one time. The maturity study conducted during 1997 and 1998 provided sufficient data to reduce the 12-inch minimum size limit to 11 inches in SEAK, which provided more harvest opportunities for anglers. However, it is recommended that in the absence of length-at-maturity data, a more conservative management strategy (i.e., 12-inch minimum size limit) be employed.

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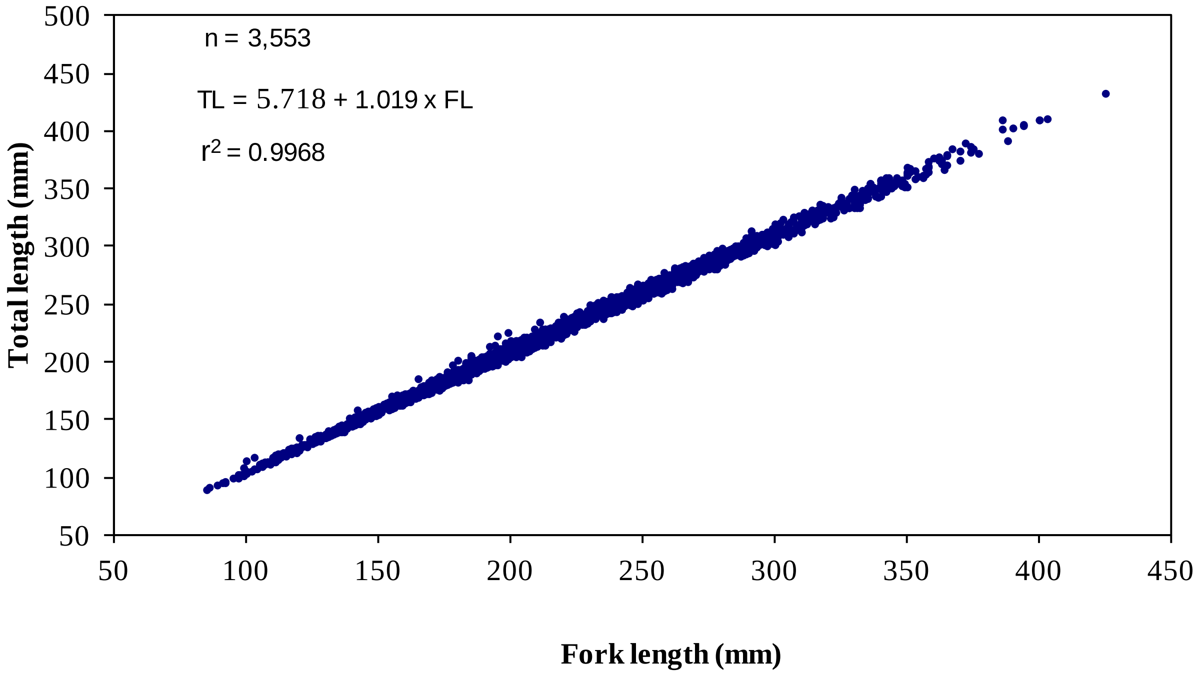
APPENDIX A

Appendix A1.–Regression formula for converting cutthroat trout fork length into total length.



APPENDIX B

Appendix B1.–Computer data files containing data for use in preparing this report. This table will be completed after the peer review.

File name	Description
ALL_MATURITY_DATA.XLS	Maturity data and analysis with graphs and tables.
Fecundity Regression.xls	Regression of maturity fecundity.
EGGDIA_97_Maturity	Diameter measurements of mature eggs, 1997.
EGGDIA_98_Maturity	Diameter measurements of mature eggs, 1998.