Fishery Data Series No. 16-22

A Population Model for Evaluating Stocked Fisheries in Interior Alaska

by

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June 2016

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. 16-22

A POPULATION MODEL FOR EVALUATING STOCKED FISHERIES IN INTERIOR ALASKA

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ABSTRACT

We established quantitative and visual standards that were used along with other information to determine whether stocked fisheries in Interior Alaska were meeting performance criteria established by the Alaska Board of Fisheries for each of three management approaches (regional, conservative, and special). Length standards were generated for each management approach using a general model for stocked rainbow trout *Oncorhynchus mykiss* populations that describes the minimum population length-frequency distribution that we determined was needed to provide the type of fishery intended by the Alaska Board of Fisheries. A fish population with statistics similar to length standards generated by our model will provide a fishery that most anglers will consider an acceptable minimum for fish size.

We used both statistical and visual comparisons between observed and model length-frequency distributions to evaluate our model against six stocked rainbow trout populations and found the model agreed with what we had subjectively determined in the field were underperforming, acceptable, or exceptional fisheries. Comparing stocked rainbow trout populations to model standards provided insight into probable causes for a population's failure to meet or exceed standards for a management approach. We can use this information to modify stocking strategies with the goal of achieving management objectives.

Key words: Population model, rainbow trout, *Oncorhynchus mykiss*, length-frequency distribution, survival at age, length at age, age cohort, management approach, Gompertz growth model, nonlinear least squares

INTRODUCTION

The Stocked Fisheries Program in the Tanana River Area and the Upper Copper River and Upper Susitna River Area creates and sustains popular sport fisheries using hatchery-reared fish. The goal of this project was to develop quantitative (i.e., statistics) and visual (i.e., graphs) standards that can be used to determine whether stocked fisheries in Interior Alaska[1] are meeting management objectives established by the Alaska Board of Fisheries (BOF).

In 2009, Alaska Department of Fish and Game (ADF&G) Division of Sport Fish Region III[2] developed a management plan for stocked waters fisheries (Swanton and Taube 2009) and the plan was adopted by the BOF for each of the six management areas within Region III (Figure 1). The six management plans are similar and all use three approaches (regional, conservative, and special) to meet public demand for diverse fishing opportunities (e.g., *Tanana River Area Stocked Waters Management Plan*, Appendix A). Although management plans describe general intent for fishery management and provide specific regulations, they do not have quantifiable objectives or standards that we can use as targets to determine whether stocked fisheries are meeting the general intent of the BOF. In the management plans the terms "reasonable expectation", "reasonable chance", and "high probability" are used to qualify catch rates, chance of harvesting a daily bag limit, and fish size. These terms are subjective, making them poor metrics for evaluation of stocked fisheries and subsequent determination of success.

Consequently, for Interior Alaska, we developed a general model (Appendix B) that describes the minimum population length-frequency distribution (*m*LFD)[3] that we determined was needed to provide the type of fishery intended by the BOF. We used this model to develop regionwide

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1 For this report, Interior Alaska includes the Tanana River Area and the Upper Copper River and Upper Susitna River Area. These are two of six management areas within Region III, Division of Sport Fish, Alaska Department of Fish and Game (ADF&G).

2 5 ACC 52.065. *Upper Copper River and Upper Susitna River Area Stocked Waters Management Plan.*
5 ACC 69.165. *North Slope Area Stocked Waters Management Plan*.
5 ACC 70.065. *Northwestern Area Stocked Waters Management Plan*.
5 ACC 71.065. *Kuskokwim Goodnews Area Stocked Waters Management Plan*.
5 ACC 73.065. *Yukon River Area Stocked Waters Management Plan*.
5 ACC 74.065. *Tanana River Area Stocked Waters Management Plan*.

3 Lower case *m* identifies a minimum population metric (i.e., length-frequency distribution *m*LFD or length standard *m*LS) derived from our model.

minimum length standards (*m*LS) that stocked fish populations should meet or exceed. By comparing stocked fish populations to *m*LFD and *m*LS for the appropriate management approach, we can quantitatively and visually (graphically) assess each fishery to determine if BOF objectives were achieved. A fish population with statistics similar to the appropriate *m*LFD and *m*LS will provide a fishery that most anglers will consider an acceptable minimum for fish size. We don't directly address standards for catch rate or number harvested because these factors are outside the scope of our model and they may be evaluated with other methods, such as the annual mail survey conducted by ADF&G to estimate participation, effort, catch, and harvest of sport-caught fish[4].

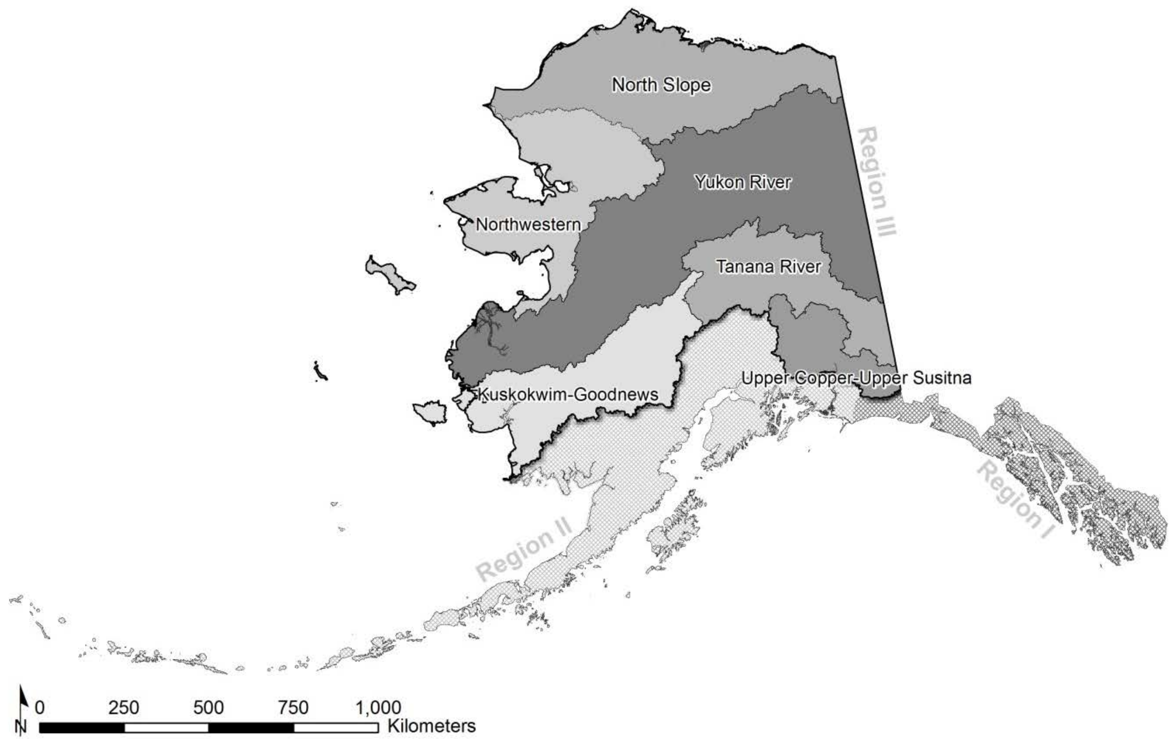

Figure 1.–Region III Sport Fish Management Areas.

In the following sections we describe the approach we used to create our model and how we used it to develop *m*LFD and *m*LS for each of the three management approaches.

METHODS

We decided to focus first on stocked rainbow trout *Oncorhynchus mykiss* populations[6] because this species supports the most popular and numerous stocked fisheries in Interior Alaska. Prior to the start of this project we had conducted an informal survey of anglers and biologists to determine what size rainbow trout would reasonably meet angler expectations for "satisfactory" or average size fish and "quality" or large size fish. General agreement was that most anglers would be satisfied catching a rainbow trout that was at least 250 mm and the minimum length for

4 Summaries of sport fishing participation, catch, and harvest for 1996–2014 are displayed at http://www.adfg.alaska.gov/sf/sportfishingsurvey/

6 A fish population in this report is defined as a species confined to a specific lake.

a "quality" rainbow trout was 460 mm. Fish lengths presented in this report are fork length (FL)[7].

Using these sizes for guidance, we decided that emphasizing average size fish from 200 mm to 350 mm was reasonable for the regional management approach, which focused on a high catch rate and a liberal bag limit. For conservative and special management approaches we proposed emphasizing fish larger than 350 mm. The goal for the last two approaches was to provide a greater proportion of large or "quality" fish in these populations.

Population Length-Frequency Distribution

In our model, age cohort *m*LFDs were the basic components that we used to build population *m*LFDs. To generate cohort *m*LFDs we used age-specific lengths and survival rates that were distinct to each management approach. To help determine initial values for lengths and survival rates, we used results from recent studies (Skaugstad 2001; Skaugstad and Clark 1991; Skaugstad and Fish 2000, 2002; Fish and Skaugstad 2004; Behr and Skaugstad 2006a, 2006b, 2007, 2011; Skaugstad and Behr 2010; Skaugstad et. al 2010; Skaugstad and Doxey 1996–1999; Skaugstad et al. 1994, 1995; Skaugstad and Clark 1991; Bentz et al. 1991; Havens et al. 1995) and reviewed rainbow trout population length-frequency distributions (LFDs) and other statistics from studies of stocked fisheries in Interior Alaska going back to 1986. Most of the information that we reviewed came from populations that were sampled in September and October. We mainly relied on populations that were maintained with alternate-year stockings of fingerlings (<80 mm) because age cohort LFDs for these populations have pronounced separations, allowing us to more accurately assign ages. Fingerling rainbow trout were typically stocked from mid-August to mid-October.

We found historical data (e.g., mean lengths, SDs, and survival rates at age) often varied greatly between populations as well as within populations through time. Variability was probably due to obtaining samples on different days of the year, using different fish stocks, stocking different size fish and inconsistent numbers of fish, different productivity between lakes, and natural variability between populations and within populations through time. Although these data were diverse, they displayed gross patterns that were useful for understanding the range of LFDs for rainbow trout populations in Interior Alaska.

For the regional management approach, data were sufficient for us to select stocked fish populations that we thought showed reasonable minimum LFDs and had well-defined separations between age cohorts. We applied a Gompertz growth model (Equation 1; described by Quinn and Deriso 1999) to paired age and length data and obtained Y_∞, κ, and t_0 estimates (Table 1) from nonlinear least squares using Excel Solver to minimize the sum of the squares of the errors (Harris 1998):

$$Y_{\mathrm{t}} = Y_\infty e^{\left[-\frac{1}{k}e^{-k(t-t_0)}\right]} \tag{1}$$

where Y_{t} is the estimated least squares mean length (*ls*-mean)[8] for age cohort t, Y_∞ is an asymptotic length parameter (maximum size), κ is a growth parameter (growth constant), and t_0 is a parameter that determines length at age 0. Y_∞, κ, and t_0 were used to estimate *ls*-mean lengths for age cohorts 0 through 5 (Table 2 and Figure 1). Data were from 6 different rainbow trout

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7 Fork length is measured from tip of snout to fork of tail.

8 *ls*-mean identifies a mean length obtained from fitting the Gompretz growth model to length-at-age data to minimize sum of squares of differences between observed data and estimated means. This is different from an arithmetic mean ($\hat{\bar{L}}$), which is a simple average of data.

populations collected from 2000 through 2007. Fish were stocked in alternate years. One population was sampled twice in different years. Sample sizes by age cohort were as follows: age-1 (n = 218), age-2 (n = 428), age-3 (n = 72), age-4 (n = 100), and age-5 (n = 100). Fitted curves were obtained using Equation 1.

Table 1.–Estimates of Y_∞, κ, and t_0 for regional, conservative, and special management approaches.

Management Approach	Y_∞ (mm)	κ	t_0
Regional	430	0.751	0.470
Conservative	480	0.751	0.470
Special	530	0.751	0.470

Table 2.–*ls*-Mean lengths, calculated weight, and survival rates by age cohort for regional, conservative, and special management approaches using values for Y∞, κ, and t0 from Table 1. Length SDs vary by age cohort within a management approach but not between management approaches.

Approach	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5
Regional						
ls-Mean Length (mm)	65	176	282	352	391	411
Weight (g)	1.8	46	212	438	617	725
Survival[9]	1	0.05	0.40	0.40	0.20	0.10
Conservative						
ls-Mean Length (mm)	72	196	315	393	437	459
Weight (g)	2.5	65	303	626	823	1,038
Survival[8]	1	0.05	0.50	0.50	0.40	0.40
Special						
ls-Mean Length (mm)	80	216	347	434	482	507
Weight (g)	3.5	90	418	865	1,219	1,433
Survival[8]	1	0.05	0.80	0.80	0.60	0.40
All						
Length SD (mm)	15	17	25	30	35	40

[9] Survival rates for regional, conservative, and special management approaches are for the period 16 October through 15 October the following year.

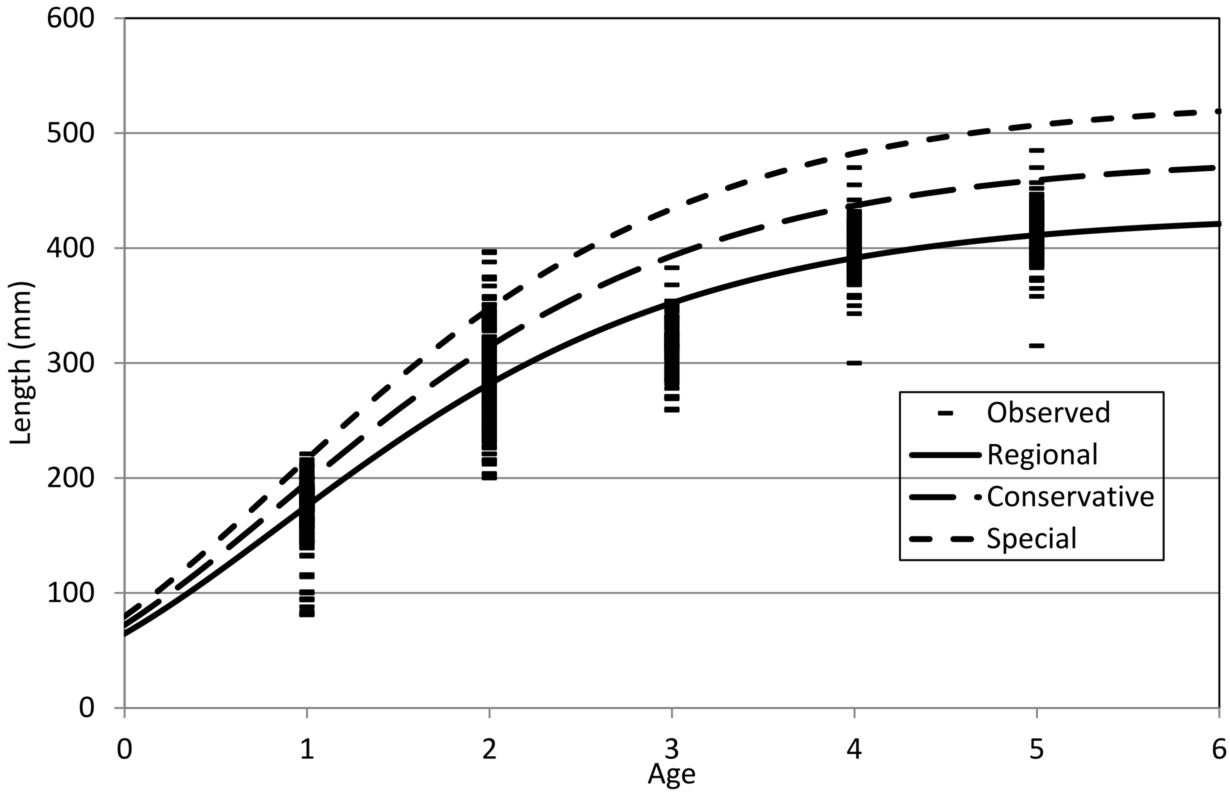

Figure 2.–Observed length data and fitted Gompertz curves for regional, conservative, and special management approaches. Smooth curves were drawn to identify age cohort ls-mean lengths for different management approaches and are not intended to represent interpolated values. Individual observed values are represented by a dash (–), appearing as a vertical bar when values bunch together.

Weight was calculated using the formula $W = aL^b$ where L = *ls*-mean length, a = 2.24E-06, and b = 3.256 (Table 2). This length-weight relation was based on 435 paired data samples collected from four stocked rainbow trout populations.

To generate age cohort *m*LFDs for the regional management approach we used appropriate *ls*-mean lengths and selected SDs (Table 2) for each age cohort to reasonably approximate length dispersions that we observed in selected stocked fish populations. We presumed fish lengths within an age cohort were normally distributed, which approximates what we observed for most stocked fish populations. We selected populations that were stocked every year, others that were stocked alternate years, and those that did not have defined stocking schedules. Our goal was to review a diverse range of stocked fish populations from large to small lakes and relatively fast growing to slow growing fish. There was sufficient overlap of age cohort LFDs in most of these populations to preclude directly estimating SDs.

We then selected annual survival rates for each age cohort in our model to approximate the relative abundance of age cohorts observed in LFDs. Annual survival rates are for the period 16 October through 15 October the following year. Fish transition from age t to age t+1 at the start of 16 October. We also compared these values to historical survival rates to determine if they were reasonable. Our annual survival rates account for both natural and fishing mortality because we lacked sufficient data to make separate estimates.

In contrast to the regional management approach, the idea behind the conservative and special management approaches is to increase growth rates by stocking fewer fish/hectare to reduce competition for limited lake resources and also to increase longevity by limiting harvest so a greater proportion of the population has additional time to grow. Although recent and historical data for survival rates and lengths were abundant for the regional management approach, data for conservative and special management approaches were sparse. Both approaches are new and there has not been sufficient time for populations to stabilize under these management approaches and for data to be gathered.

To help establish reasonable *ls*-mean lengths for age cohorts for conservative and special management approaches, we examined data from fish populations that exhibited exceptionally large lengths for age cohorts (Quartz Lake, Rainbow Lake, Dune Lake, and West Iksgiza Lake). Although some age cohorts were missing in some data sets, we found data were sufficient to aid our work. Relying on our experience with stocked fish populations, we increased Y_∞ for the regional management approach by 50 and 100 mm to obtain reasonable initial values of Y_∞ for conservative and special management approaches (Table 1). Estimates of κ and t_0 were unchanged. Age cohort *ls*-mean lengths were calculated for both management approaches using Equation 1 (Table 2 and Figure 2). These values should be verified as more data become available. We kept length SDs within an age cohort the same for all three management approaches (Table 2).

Survival rates for conservative and special management approaches were more difficult to approximate due to lack of data. To come up with provisional survival rates we again relied on our experience with various stocked fisheries and what we considered were reasonable expectations given the objectives for each management approach. We used the regional management approach for reference. For the conservative management approach we increased survival rates for ages 2-5 because we expect a lower harvest due to the 5 fish daily bag limit compared to 10 fish for the regional management approach. We also increased the survival rate for fish larger than 460 mm (predominately age-4 and -5) because we expect larger proportions of anglers fishing these populations will practice catch and release. We increased survival rates even more for all ages for the special management approach because the daily bag limit is 1 fish 460 mm or larger (Table 2). Both management approaches assume that more restrictive harvest regulations will result in smaller proportions of populations being harvested.

Model Structure and Population Standards

For each management approach we created mathematical models using Microsoft Excel to generate minimum acceptable age cohort *m*LFDs based on appropriate *ls*-mean lengths, SDs, survival rates (Table 2), and number of fish stocked. We then combined age cohort *m*LFDs to make a population *m*LFD for each management approach that describes a minimum acceptable population (Figure 3). We included annual number of fish stocked because for some populations this number varied by year, which in turn would affect the relative proportion that age cohorts contributed to the population. If annual number of fish stocked was consistent, then it was not necessary to use number of fish stocked.

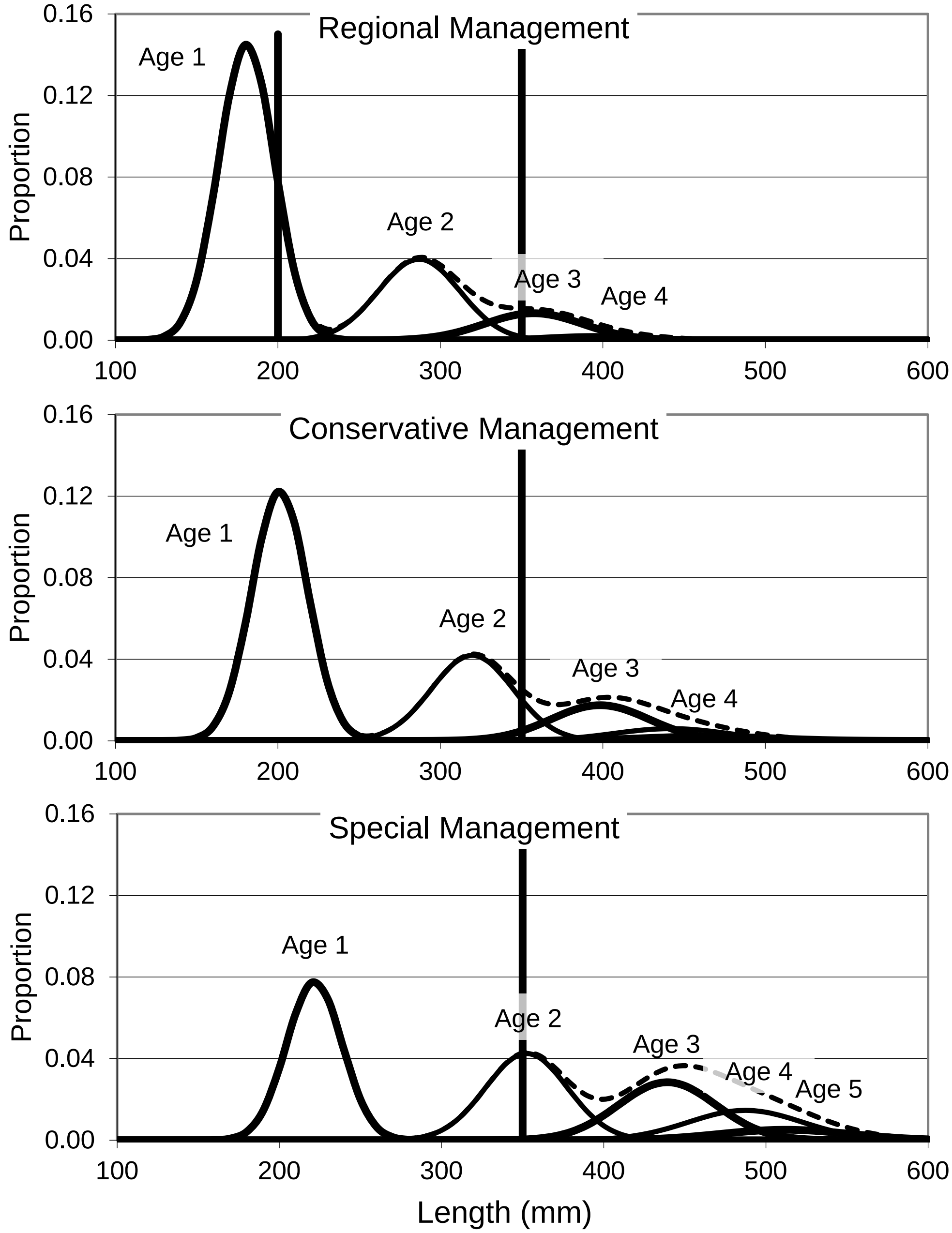

Figure 3.–Age cohort composition of population *m*LFDs that meet minimum length requirements for an acceptable fishery for each management approach. Solid lines represent individual age cohort *m*LFDs and dashed lines represent population *m*LFDs (sum of age cohort *m*LFDs). Area beneath each dashed line is 1. Portions of dashed lines are not apparent when they overlay solid lines. Vertical bars represent boundaries for specific size groups.

We determined *m*LS for each management approach by first calculating the expected length for the portion of each age cohort *m*LFD within an appropriate length interval (Equation 2, Olive 2008). We then calculated *m*LS of all fish in the length interval using a weighted average based on abundance of each age cohort within the length interval (Equations 3–5). The *m*LS for the regional management approach was 277 mm for the portion of the population > 200 mm and ≤ 350 mm. The *m*LS for conservative management and special management approaches were 405 mm and 432 mm for the portion of the population > 350 mm. These standards are for fish populations that are sustained with annual stockings. When stockings are every other year or are variable, standards must be calculated for each situation.

If $X\ is\ N(\mu, \sigma^2)$ then let L_j be a truncated normal $TN(\mu, \sigma^2, a, b)$ random variable. Then

$$E(L_j) = \mu + \left[\frac{\phi\left(\frac{a-\mu}{\sigma}\right) - \phi\left(\frac{b-\mu}{\sigma}\right)}{\Phi\left(\frac{b-\mu}{\sigma}\right) - \Phi\left(\frac{a-\mu}{\sigma}\right)}\right]\sigma, \tag{2}$$

$$n_j = n_{j0} \prod_{k=1}^{j} S_{k,}, \tag{3}$$

$$E(n_j) = n_j \left[\frac{1}{\sigma\sqrt{2\pi}} \int_a^b e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt\right], and \tag{4}$$

$$E(L) = \frac{\sum_{j=1}^{5} E(L_j)E(n_j)}{\sum_{j=1}^{5} E(n_j)} \tag{5}$$

where:

ϕ	=	standard normal pdf $\left[\phi(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}x^2}\right]$;
Φ	=	standard normal cdf $\left[\Phi(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{1}{2}t^2}\, dt\right]$;
μ and σ	=	predicted length and standard deviation for age cohort *j* taken from Table 2;
a and *b*	=	lower and upper bounds of truncated normal distribution *TN*;
$E(L_j)$	=	expected length of age cohort *j* in truncated interval *a* to *b*;
$E(L)$	=	expected length of all fish in truncated interval *a* to *b*. This is the minimum acceptable length standard, *m*LS;
n_j	=	number of fish in age cohort *j*;
$E(n_j)$	=	expected number of fish from age cohort *j* in truncated interval *a* to *b*;
S_k	=	annual survival rate for age cohort *k* (Table 2); and
n_{j0}	=	number of fish that were stocked for age cohort *j*.

These population *m*LFDs and *m*LSs are specific to 15 October, typically the latest date that population sampling occurs due to developing ice. Traditionally, most sampling of stocked game fish populations occurred in September and October when water temperature was <18°C and because biologists were working other projects during spring and summer. We now sample fish populations from 15 May when ice cover is generally gone through 15 October when ice cover generally develops. During this period, to prevent stress and mortality, we curtail sampling when water temperature 1 m beneath the surface exceeds 18°C.

To calculate *m*LS for any day from 15 May through 15 October, our model uses size of fish on 15 October (Table 2) as an end point to calculate *m*LFD for each age cohort and create population *m*LFDs. We presume that 70% of fish growth (weight gain) occurs during this period for all age cohorts due to warmer water and more abundant food resources compared to the rest of the year. Our presumption is based on our experience working with these populations. We are not aware of any study in Interior Alaska lakes that specifically examined rainbow trout growth rates throughout the year. To estimate $m\mathrm{LS}_d$ (where d = day) we calculated fish growth using weight (Equations 6 and 7) and then converted to length (Equation 8):

$$\mathrm{W}_n^s = \mathrm{W}_{n-1}^f + \left(\mathrm{W}_n^f - \mathrm{W}_{n-1}^f\right)(1-0.7), \tag{6}$$

$$\mathrm{W_d} = \mathrm{W}_n^s \left(\frac{\mathrm{W}_n^f}{\mathrm{W}_n^s}\right)^{\left(\frac{d}{153}\right)}, \text{ and} \tag{7}$$

$$m\mathrm{LS}_d = \left(\frac{W_d}{a}\right)^{\frac{1}{b}} \tag{8}$$

where:

W_n^s = weight (g) on 15 May *(spring)* in year *n*;

W_n^f = weight (g) on 15 October *(fall)* in year *n* (taken from Table 2);

W_{n-1}^f = weight (g) on 15 October the previous year *n-1* (taken from Table 2);

W_d = weight (g) on day *d* in year *n* from 15 May *(d* = 0*)* through 15 October *(d=153)*;

$m\mathrm{LS}_d$ = *m*LS (mm) on day *d* in year *n* from 15 May *(d* = 0*)* through 15 October *(d=153)*; and

a and *b* = from length-weight relation used in Table 2 where *a* = 2.24E-06 and *b* = 3.256.

During model testing we noticed that *m*LFDs for age-1 fish were consistently larger compared to LFDs we saw in population samples. The difference was greatest when populations were sampled near 15 May and decreased as sampling dates approached 15 October. Consequently, in our model we subjectively reduced winter growth for age-0 fish from 30% to 15% for the first winter after stocking (16 October to 15 May). Preliminary examination of data collected at the Ruth Burnett Sport Fish Hatchery in Fairbanks for rainbow trout (brood year 2013, tanks 103A and 302B) indicated growth rates were low for small fish (~0.1 g) and increased as fish grew (fish for this data set grew from a start mean weight 0.1 g [21 mm[10]] to an end mean weight 97 g [201 mm]). This is typical for fishes where growth approximates a sigmoid curve and growth is occurring before the inflection point.

[10] Lengths calculated at Ruth Burnett Sport Fish Hatchery use an isometric length-weight relation that is different from the allometric length-weight relation we use in our model. The allometric relation was derived from fish that were stocked and then subsequently measured months or years after stocking and is more appropriate when dealing with lake populations.

We compared observed means ($\hat{\bar{L}}$) to mLS using a bootstrap procedure that generated a p-value to evaluate H_0: $\hat{\bar{L}} \geq mLS$, α = 0.05 (Appendix C). A fishery did not meet or exceed its minimum standard when we rejected H_0.

RESULTS AND DISCUSSION

To evaluate our model we compared length data from six rainbow trout populations (Figures 4-6) to mLFDs and mLSs generated by our model. These populations were selected from a large pool of historical data because they represent a range of fisheries that we characterized as underperforming to exceptional. Peanut Lake, Four Mile Lake, and Dune Lake were stocked every other year with rainbow trout fingerling (<80 mm). West Iksgiza Lake was stocked two consecutive years with rainbow trout fingerling. Birch Lake and Quartz Lake were stocked every year with either catchable (>150 mm) rainbow trout or a combination of fingerling and catchable rainbow trout. Other stocked species were present in Four Mile Lake, Dune Lake, Birch Lake, and Quartz Lake. Records for fish stocking, population sampling, and wild species presence are maintained in ADF&G's Lake Database (ALDAT[11]) .

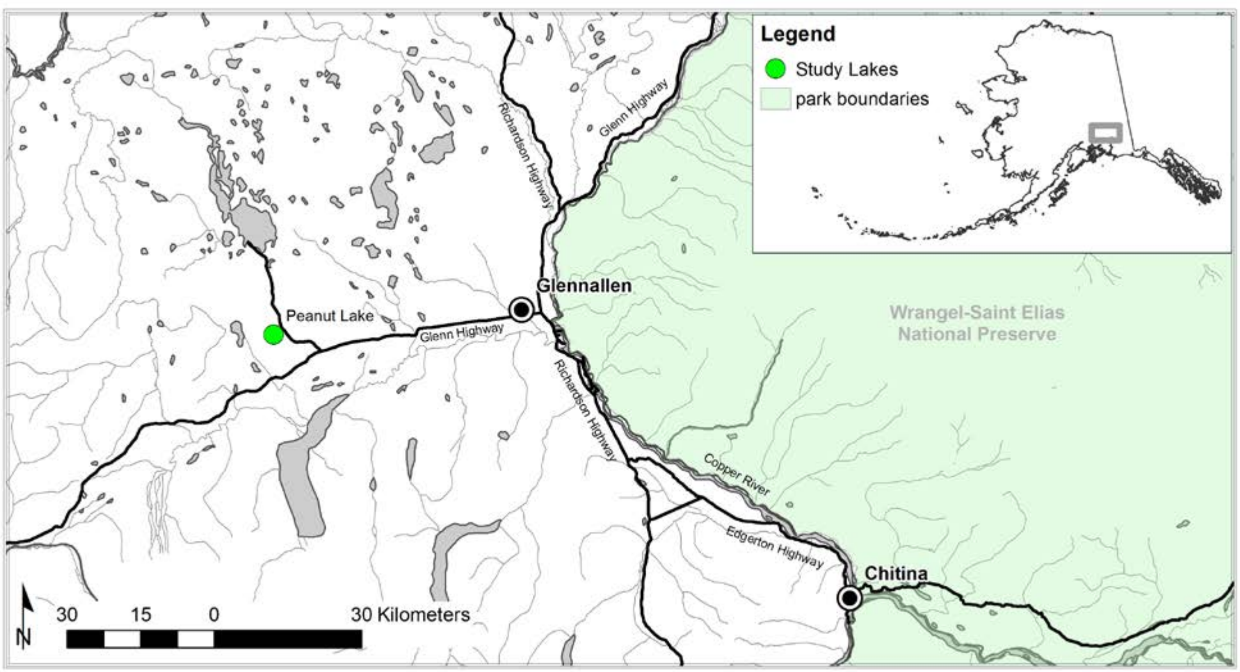

Figure 4.–Location of Peanut Lake.

[11] Alaska Lake Database: http://www.adfg.alaska.gov/index.cfm?adfg=fishingSportStockingHatcheries.lakesdatabase

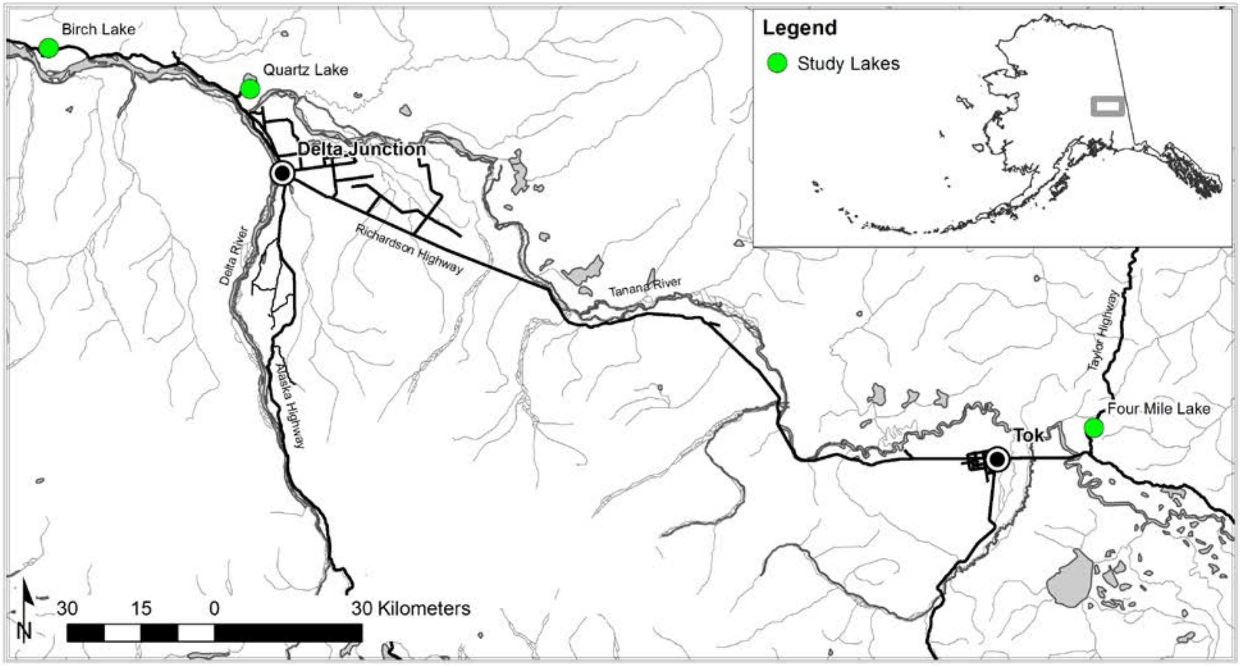

Figure 5.–Location of Four Mile Lake, Quartz Lake, and Birch Lake.

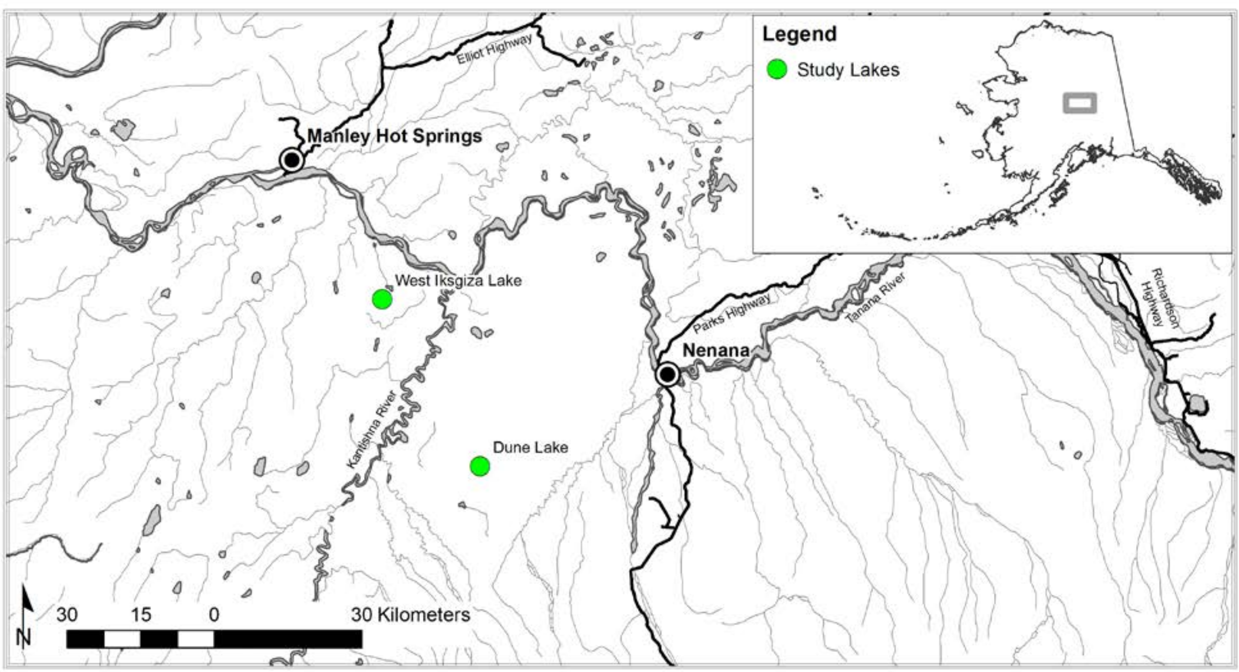

Figure 6.–Location of Dune Lake and West Iksgiza Lake.

While sampling the fish population in Peanut Lake, we noticed that lengths of captured rainbow trout were smaller overall compared to other rainbow trout populations that we sampled having similar age cohorts and stocking history. Our subjective assessment is backed up by data (Figure 7) showing the LFD of age-3 fish in the sample was located left of the *m*LFD generated by the model (i.e., age-3 fish were smaller than expected). In contrast, the LFD of age-1 fish in the sample was similar to the *m*LFD generated by our model. Our comparison procedure using bootstrap methods rejected H_0 ($p < 0.0001$), indicating mean length for the portion of the sample >200 mm and ≤350 mm was smaller compared to the *m*LS from our model (Table 3). We concluded the population did not meet the minimum acceptable length standard.

Fish captured in West Iksgiza Lake were noticeably larger than what we expected for a typical population having the same age cohorts. Visual inspection showed sample LFDs for both age-1 and age-2 cohorts exceeded corresponding *m*LFDs (Figure 7). However, our comparison rejected H_0 ($p < 0.0001$), indicating mean length for the portion of the sample >200 mm and ≤350 mm was smaller than the *m*LS (Table 3). This result is correct but misleading. For this situation, we need to also consider the growth characteristics (how quickly fish grow) of the sampled population. The sample interval >200 mm and ≤350 mm is composed of age-1 fish. Age-2 fish have grown out of the interval. The same interval in our model is composed mainly of age-2 fish that are larger than age-1 fish in the sample. Obviously, the fish population's exceptional growth resulted in us comparing age-1 fish in the sample against an *m*LS expected for larger age-2 fish. We decided the rainbow trout population in West Iksgiza Lake exceeded minimum acceptable standards.

The LFD for age-1 fish sampled from Four Mile Lake exceeded the age-1 *m*LFD, whereas the LFD for age-3 fish was similar to the age-3 *m*LFD (Figure 7). However, we rejected H_0 ($p = 0.0005$), indicating the sample mean for fish >200 mm and ≤350 mm was smaller compared to the *m*LS (Table 3). This is a consequence of fast-growing age-1 fish entering the length interval sooner than expected and lowering the sample mean length within the interval. Managers must be aware that fast-growing cohorts entering or leaving a length interval can result in sample mean lengths less than the minimum acceptable length standard. This situation is noticed more when stockings take place every other year. We have found that visual examination of LFDs is necessary to determine how the biological characteristics (e.g., age cohort growth and survival rates) affect test results. Visual examination of LFDs indicated fish were growing faster than model projections, and we concluded the *m*LS was achieved.

Dune Lake produces the fastest growing and largest rainbow trout in Interior Alaska, except for Quartz Lake. Fish in the older age cohort in Dune Lake were noticeably larger compared to the *m*LS (Figure 7). The fish population surpassed *m*LS for conservative management approach (H_0 not rejected, $p = 1$; Table 3) and even surpassed *m*LS for the special management approach (*m*LS = 427 mm).

From 2001 through 2005 Birch Lake was stocked annually with catchable rainbow trout that varied in size (211 to 254 mm mean length). Visual examination of Figure 8 suggests that most stocked fish were harvested within one year of stocking because a smaller than expected portion of fish survived to older age and larger size. This population structure is what we expect for a high-use fishery under regional management approach where the fishery is sustained by stocking catchable size fish and the management goal is a high catch rate and a liberal bag limit.

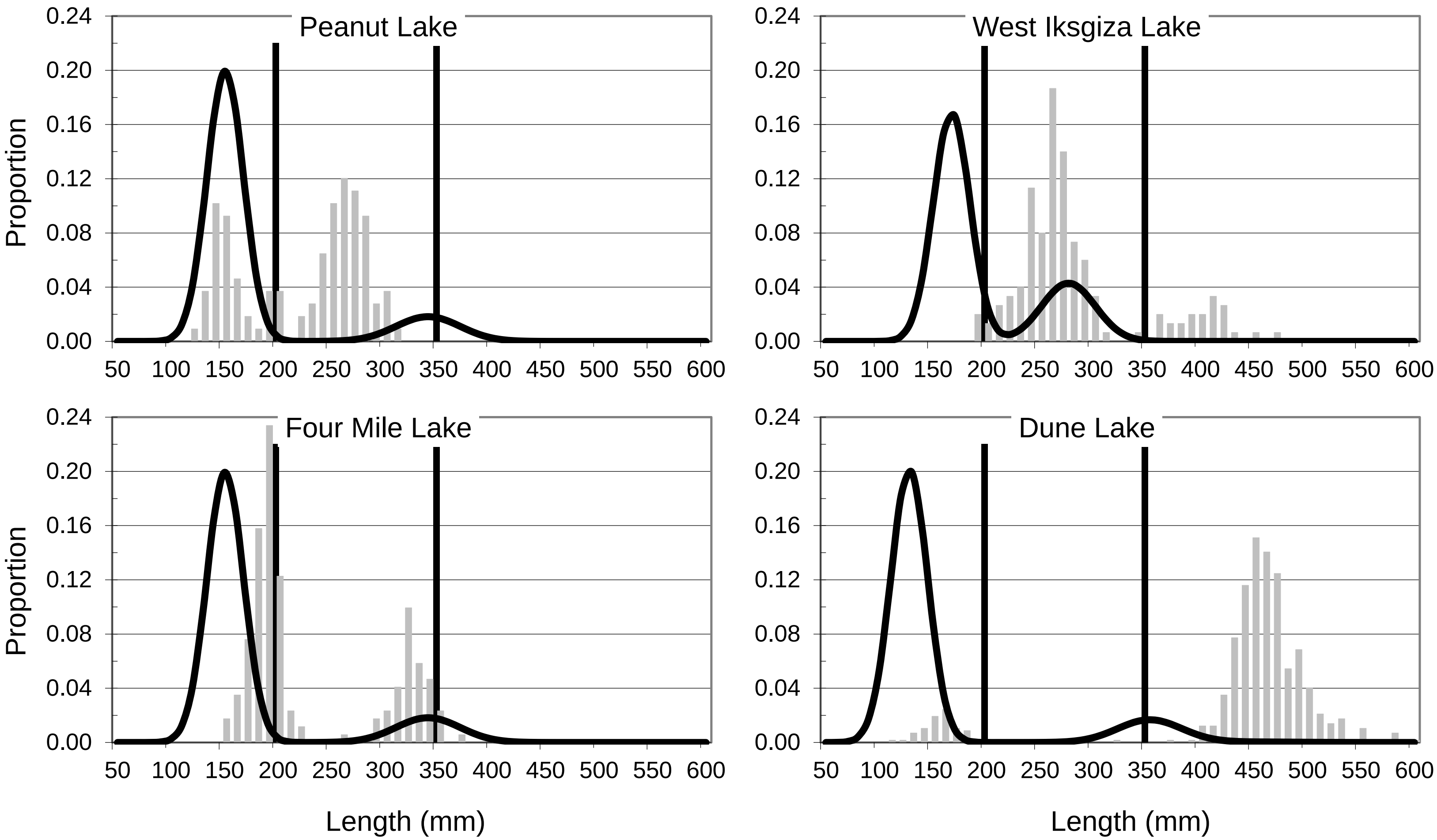

Figure 7.–LFDs from population sampling (grey columns) and minimum acceptable population LFDs (black curve) generated from our model. West Iksgiza Lake, Peanut Lake, and Four Mile Lake are managed using regional criteria, and Dune Lake is managed using conservative criteria. Black columns represent size-range boundaries along the horizontal axis.

Table 3.–Comparison of sampled fish populations to *m*LS for regional and conservative management approaches. Statistics computed using bootstrap methods are indicated with *.

Management approach	Population	Sample date	Length category (mm)	*m*LS (mm)	Sample mean length* (mm)	Percent difference	$SE_{\bar{L}}$ *	*P*-value*
Regional	Peanut	8/14/2007	>200 & ≤350	318	258	-18.9	2.48	<0.0001
	W Iksgiza	9/22/2006	>200 & ≤350	269	255	-5.2	2.07	<0.0001
	Four Mile	8/21/2007	>200 & ≤350	319	306	-4.1	4.81	0.0005
	Birch	6/7/2005	>200 & ≤350	261	243	-7.1	1.63	<0.0001
	Quartz	6/15/2001	>200 & ≤350	250	258	3.2	2.41	0.9998
Conservative	Dune	5/31/2006	>350	377	459	21.5	1.41	1

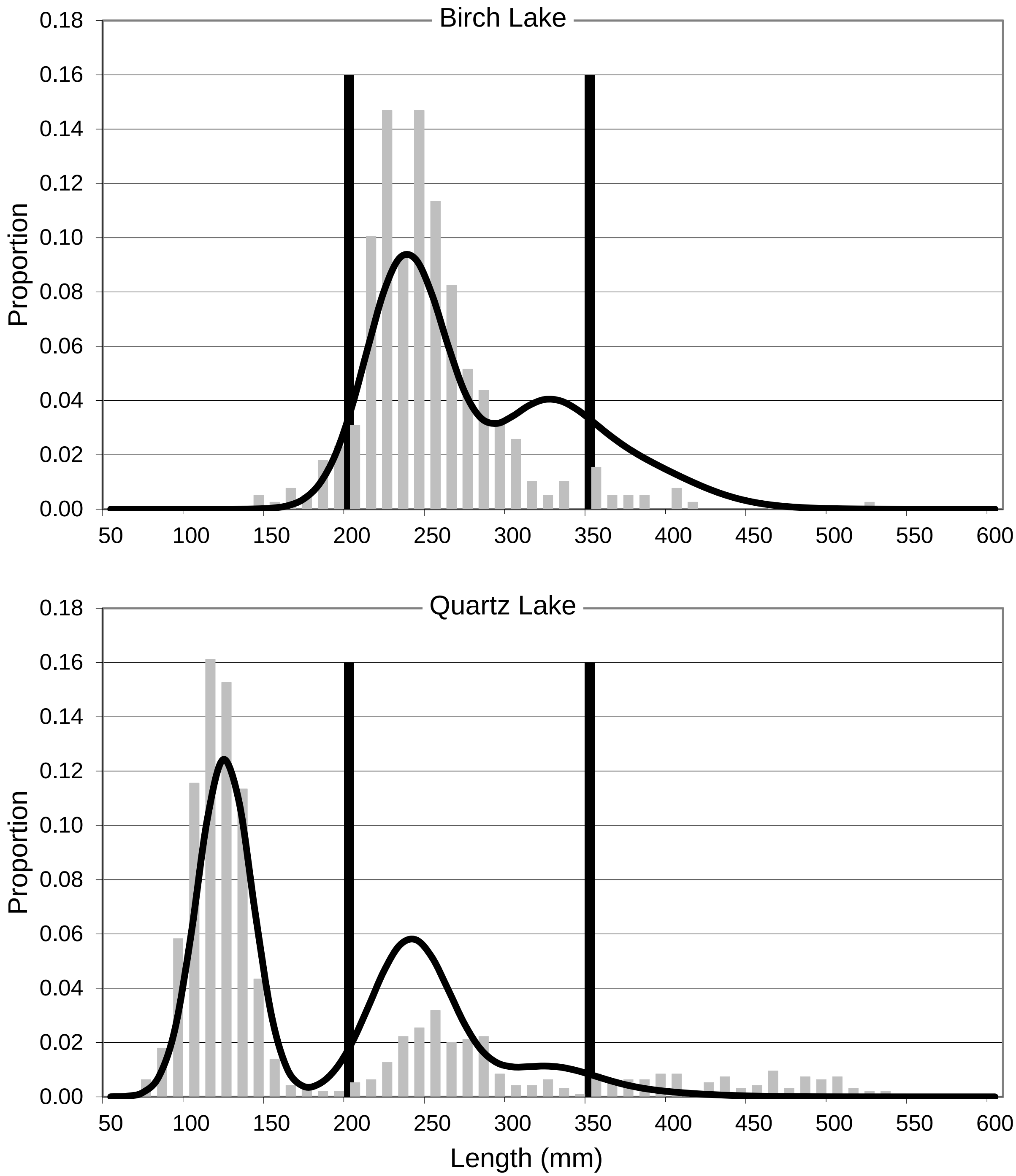

Figure 8.–LFDs from population sampling (grey columns) and minimum acceptable population LFDs (black curve) generated from our model for regional management approach. Black columns represent size-range boundaries along the horizontal axis.

The population structure did not meet *m*LS because the proportion of older, larger fish within length category >200 to ≤350 mm was less than expected (H_0 rejected, $p < 0.0001$; Table 3).

Quartz Lake usually produces sufficient numbers of catchable size rainbow trout from annual stockings of fingerlings to meet current harvest levels. Enough fish survive to older age and larger size to make the lake well-known for robust rainbow trout over 500 mm. Age-2 and older rainbow trout in Quartz Lake are larger and more robust compared to same age rainbow trout in most other stocked populations in Region III. In 1997 and 2001, a combination of fingerling and catchable size fish were stocked to make up for anticipated shortages of hatchery fish in following years. The population in 2001 exceeded *m*LS standard for regional management approach (H_0 not rejected, $p = 0.9998$; Table 3) and, overall, the population LFD clearly exceeded *m*LFD (Figure 8).

When comparing the six populations in this report and other rainbow trout populations to *m*LS, we found differences were significant even when small (<5%, Table 3). This is a result of the large numbers of fish we captured (large sample sizes). Because small differences between sample mean lengths and *m*LS are not meaningful to anglers, we decided that a population has met the standard when the difference between sample mean length $\left(\hat{\bar{L}}\right)$ and *m*LS was ≤5% $\left[i.e., \left(\hat{\bar{L}} - m\mathrm{LS}\right)/m\mathrm{LS} \times 100\right]$. The 5% test is necessary only when sample mean length is less than *m*LS. Any sample mean length greater than *m*LS is acceptable (Dune Lake, for example). When the 5% test is applied, all populations we have discussed, except Peanut Lake and Birch Lake, met or exceeded appropriate *m*LS (Table 3). The rainbow trout population in West Iksgiza Lake failed the 5% test but exceeded *m*LS as discussed previously.

To evaluate these six rainbow trout populations we relied on both quantitative assessment (testing a null hypothesis) and visual (graphic) comparison between observed LFDs and model *m*LFDs. Sometimes either method by itself was not sufficient to evaluate a fish population but both methods together were adequate to evaluate and verify what we had subjectively determined in the field were underperforming, acceptable, or exceptional fisheries. During our analysis we found percent difference (Table 3) was a reasonable indicator of quality of fishery performance. The fish population with the greatest negative percent difference (Peanut Lake) was also the one that we had subjectively determined in the field was underperforming. In contrast, the fish population with the greatest positive percent difference (Dune Lake) was the one that we had subjectively determined in the field was exceptional. The percent differences for the other four populations were much less extreme and generally clustered within ±5% difference. In the field we thought these populations were acceptable or close to acceptable. With further refinement it might be possible to develop a method using percent differences to rate quality of fishery performance.

Also, these methods combined with knowledge of a population's particular growth and fishery characteristics provided insight into probable causes for a population's failure to meet or exceed standards for a management approach. We can use this information to modify stocking strategies with the goal of achieving management objectives. As this model was being developed, Skaugstad et al. (2010), Skaugstad and Behr (2010), and Behr et al. (*In prep*) compared several rainbow trout population LFDs to *m*LFDs. When rainbow trout populations failed to meet *m*LS or visual standards, the investigators found numbers of fish stocked per hectare (all stocked species combined) often exceeded recommended stocking levels of 500 fingerlings/ha. As a result, numbers of fish stocked were reduced to recommended stocking levels.

Although our model adjusts for growth through time and uses different seasonal growth rates, it does not adjust for ongoing mortality. From past creel surveys and angler interviews we know that most fishing mortality occurs during summer and winter at larger, more popular lakes, but we don't know how natural mortality progresses through the year. We also have little information about timing and extent of fishing mortality for smaller lakes. For these reasons we decided not to use ongoing mortality in our model until we can obtain more information and develop a reasonable understanding. Failure to account for ongoing mortality will fail to adjust for changes in relative abundance between age cohorts during the year and subsequently have some effect on calculated *m*LFD and *m*LS.

To complete our model we had to rely on experience and observation to provide reasonable initial values for model components where data were deficient (e.g., estimates of survival at age for conservative and special management approaches, seasonal growth rates, and standard deviations for mean length at age). To strengthen our model's veracity we need to confirm our initial values through research and make corrections where necessary.

In its current state, our model has shown that *m*LFDs and mLSs are reasonable and provide useful standards for evaluating stocked rainbow trout populations. Our model also benefits other managers and researchers because it can be easily adapted by simply modifying model parameters to suit stocked rainbow trout fisheries (or fisheries for other species) in other locations. We plan to extend our model to use lake productivity and fish biomass carrying capacity to determine numbers of fish to stock to achieve desired population structures for different management objectives.

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APPENDIX A: EXAMPLE OF BOARD OF FISHERIES MANAGEMENT PLAN FOR STOCKED WATERS

Appendix A1.–Example of Board of Fisheries management plan for stocked waters.

5 AAC 74.065. Tanana River Area Stocked Waters Management Plan

(a) The department shall manage stocked waters in the Tanana River Area in order to meet public demand for diverse fishing opportunities. The department may manage fisheries to provide or maintain qualities that are desired by sport anglers. The department shall manage the stocked waters according to one of three management approaches. The management approaches are the

(1) regional management approach;

(2) conservative management approach; and,

(3) special management approach.

(b) The board's regulations that govern stocked waters in the Tanana River Area shall be consistent with the applicable management approach specified in (a) of this section.

(c) When a water body in the Tanana River Area is first stocked, it shall be placed under the regional management approach category. After receiving a proposal from the public, the department, or from the board to reclassify a water body, and when the proposal meets the criteria for a different classification, the board may reclassify the water body. The board will act on a proposal to reclassify a water body or to designate a water body for special management only if the proposal has been submitted according to the procedures set out in 5 AAC 96.610 and is consistent with the board's regular meeting cycle schedule.

(d) Regional management approach. Under the regional management approach, stocked waters will be managed so that there will be a reasonable expectation of high catch rates and harvesting a daily bag limit. The bag and possession limit is 10 fish in combination of all stocked species, and only one of those fish may be 18 inches or greater in length. The fishing season is open year round and bait may be used.

(e) Conservative management approach. Under the conservative management approach, stocked waters will be managed so that there will be a reasonable expectation to catch a daily bag limit with a reasonable chance of catching fish 18 inches or greater in length. The bag and possession limit is five fish in combination of all stocked species, and only one of those fish may be 18 inches or greater in length. The fishing season is open year round and bait may be used.

(f) Special management approach. Under the special management approach, stocked waters will be managed so that there will be a high probability of an angler catching more than one fish a day that is 18 inches or greater in length. When considering a proposal regarding this management approach, the board should consider taking the following actions:

(1) limit fishing to

(A) catch-and-release fishing;

(B) fly fishing;

(C) trophy fishing, which means that a fish retained must be 18 inches or greater in length;

(2) establish seasonal periods when fishing is closed or is restricted to catch-and-release fishing; or,

(3) establish a bag limit of one fish, 18 inches or greater in length, or another appropriate bag and size limit.

(g) Water bodies managed under the special management approach include Harding Lake.

-continued-

(h) Water bodies managed under the conservative management approach include

(1) Dune Lake;
(2) Koole Lake; and,
(3) Rainbow Lake.

(i) During times of low hatchery output, the commissioner may, by emergency order, modify methods and means, reduce bag limits, or institute a catch-and-release fishing only fishery.

APPENDIX B: ARCHIVED DATA FILES FOR STOCKED FISHERIES MODEL, 2015

Appendix B1.–Archived data files for Stocked Fisheries Model, 2015.

Data File	Description
Stocked Fisheries Model 2015[a]	Length data input, generation of age cohort length-frequency distributions and minimum acceptable standards.

[a] The spreadsheet file is archived at and is available from the Alaska Department of Fish and Game, Sport Fish Division, 1300 College Road, Fairbanks, Alaska 99701-1599.

APPENDIX C: *R* PROGRAM CODE FOR BOOTSTRAP MEAN AND *P*-VALUE CALCULATION

Appendix C1.–R program code (R Core Team 2014) for bootstrap mean and *p*-value calculation.

```
library (boot)                    #load bootstrap library (Canty and Ripley 2013; Davison
                                   and Hinkley 1997) at beginning of R session.

scan ()->data                     #copy observed fish lengths into data vector.

# change LLL to appropriate length standard.
LenStand=LLL          # minimum acceptable length standard from spreadsheet
n=10000                      # bootstrap sample size
bootpak<-boot(data, function(data,i) mean(data[i]), n)    # bootstrap call
p_value<-(sum(bootpak$t - LenStand >=0)+1)/(n+1)
bootpak                      # print bootstrap statistics
p_value                      # print p_value
hist(bootpak$t, breaks=50)            # create and print histogram
```