Fishery Data Series No. 14-12

Stock Assessment of Humpback Whitefish in the Chatanika River, 2012

by

Andrew D. Gryska

March 2014

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. 14-12

STOCK ASSESSMENT OF HUMPBACK WHITEFISH IN THE CHATANIKA RIVER, 2012

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ABSTRACT

Abundance of mature-sized humpback whitefish *Coregonus pidschian* within the Chatanika River during 2012 was estimated using a two-sample mark-recapture experiment. Electrofishing boats were used to capture humpback whitefish within a 50 km index area that comprised the majority of the spawning area. The Elliott Highway Bridge served as the upstream boundary of the index area, and the reach extended 50 km downstream. Sampling occurred September 11–13 and September 25–27. A total of 2,064 humpback whitefish were captured; they ranged from 315 to 549 mm fork length (FL). Estimated abundance of humpback whitefish ≥360 mm FL was 12,755 (SE = 1,405). The abundance of humpback whitefish in 2012 was within the range of most previous estimates, although it was significantly less than the 2008 estimate of 22,490 fish ≥360 mm FL (SE = 2,777). The proportion of the population composed of large fish (≥440 mm FL) increased from 60% in 2008 to 72% in 2012. Correspondingly, few smaller-sized fish (i.e., 360-439 mm FL) were present in the sample, indicating that short-term recruitment may be relatively small in subsequent years. Due to the likelihood of low recruitment and uncertainty about its impact on future abundance, harvest should remain closely monitored, and the stock should be reevaluated in 4–5 years.

Key words: humpback whitefish, *Coregonus pidschian,* Chatanika River, abundance, length composition, mark-recapture.

INTRODUCTION

Humpback whitefish *Coregonus pidschian* move from the Minto Flats wetlands complex into the Chatanika River beginning in early June (Dupuis 2010). During early August, they begin to migrate up the Chatanika River to spawning areas located within a 50-river kilometer section between the Elliott Highway Bridge and Murphy Creek (Dupuis 2010; Figures 1 and 2). Interestingly, both Dupuis (2010) and Wuttig (2009) found no evidence of humpback whitefish utilizing 12 km of the river upstream of the Elliott Highway Bridge, where they had previously been quite abundant during the spawning period (Fleming 1994). Spawning usually occurs between mid-September and early October, and downriver migrations are executed immediately afterward (Alt 1979).

During the 1980s, a significant fall spear fishery developed on spawning aggregations of humpback whitefish and least cisco *Coregonus sardinella*, primarily between the Elliott Highway Bridge and Olnes Pond Campground (Brase and Baker 2012; Figure 2). Reported harvests peaked in 1987 (25,074 fish), which were composed of both species because fishers could not discriminate between the two when spearing (Brase and Baker 2012). Monitoring programs were initiated on this fishery in 1986 (Hallberg and Holmes 1987). Later in 1987, the fishery went from having no bag limits to a 15-fish (humpback whitefish and least cisco combined) bag limit due to concerns of overexploitation. Complete closures of the fishery occurred in 1991 and during 1994–2006 (Brase and Baker 2012).

In 2007, a personal use spear fishery in the Chatanika River was established that provided for 100 permits (10-fish household limit) issued annually and had a total allowable harvest of 1,000 fish (Brase and Baker 2012). Because the participation rate was only 52% during 2007, the number of permits was increased to 200 thereafter (Brase and Baker 2012). Over the course of 4 years (2008–2011), participation ranged between 46% and 71% of permit holders, and annual harvests have not exceeded 1,000 fish (Table 1). Although harvest has not exceeded management objectives, a stock assessment of humpback whitefish was needed because the fishery has operated for 5 years, the last assessment occurred during 2008 after only one harvest event, and the management objectives for the fishery needed reevaluation.

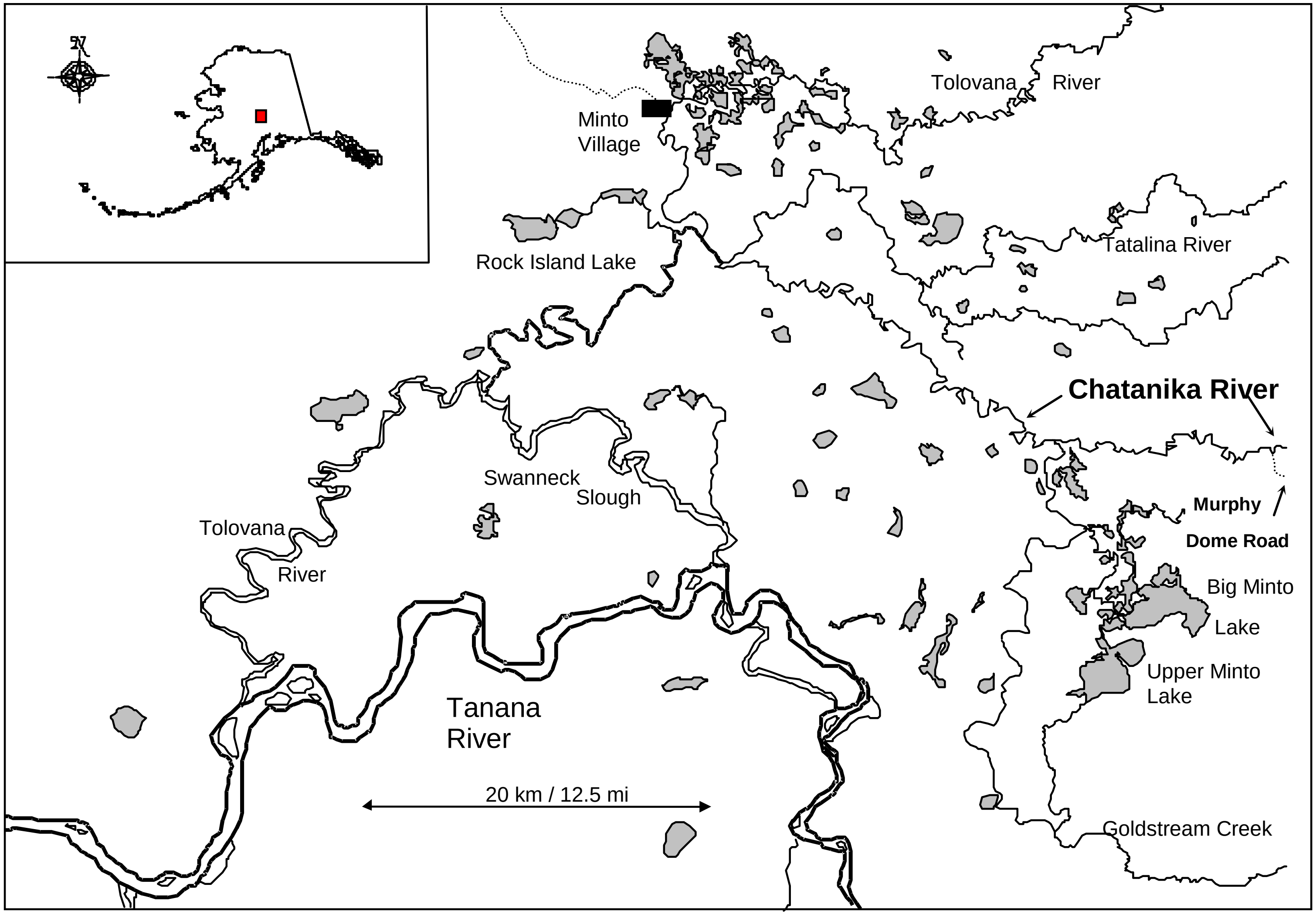

Figure 1.–Map of the Lower Chatanika River and the Minto Flats wetland complex.

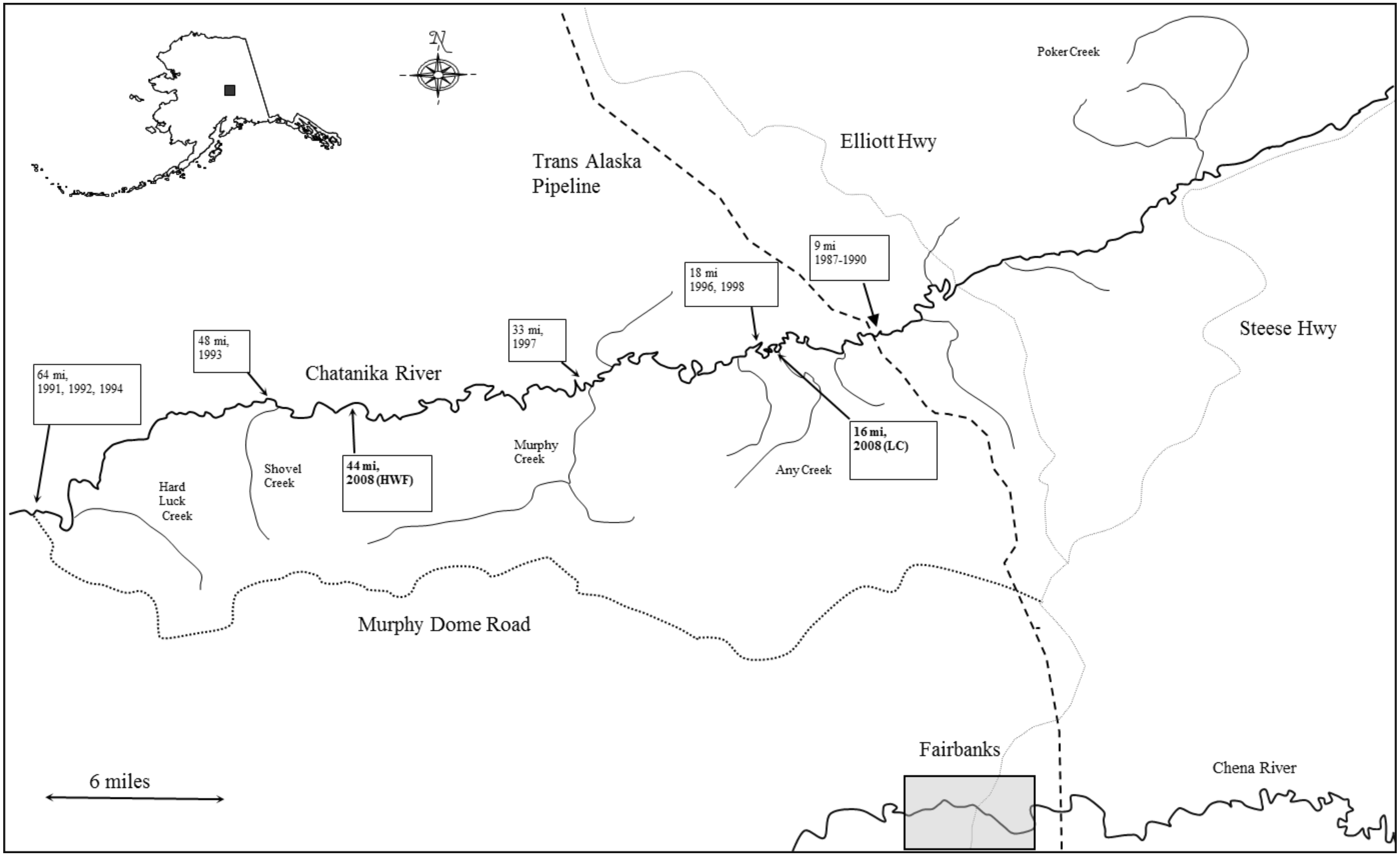

Figure 2.–Chatanika River study areas (1986–2008). Lower Chatanika River whitefish study areas, demarcated by area length and downriver boundary (1986–2008). This study focuses on the 50-mile section bounded by the Elliott Highway downstream to Murphy Creek.

Table 1.–Annual participation and harvest in the Chatanika River whitefish spear fishery.

Year	Permits Issued	Permits Returned	Number of Households that Fished	Whitefish Species: Least Cisco	Whitefish Species: Humpback	Whitefish Species: Round	Whitefish Species: Unknown	Total Whitefish Harvest	Average Harvest/ Permit
2007	100	97	52	47	158	9	53	267	5.13
2008	200	191	92	53	367	37	65	522	5.67
2009	200	194	124	104	501	77	68	750	6.05
2010	200	198	141	103	657	94	100	954	6.77
2011	200	194	129	172	284	66	22	583	4.52

OBJECTIVES

The research objectives for 2012 were as follows:

1. estimate the abundance of humpback whitefish ≥360 mm fork length (FL) in a 50 km section of the Chatanika River during mid-September, such that each estimate is within 25% of the true abundance 90% of the time; and,
2. estimate length compositions of humpback whitefish ≥360 mm FL in a 50 km section of the Chatanika River during mid-September, such that all proportion estimates are within 5 percentage points of the true proportion values 95% of the time.

The length criterion relative to Objectives 1 and 2 was selected because it relates to all previous mark-recapture experiments of similar design and generally corresponds to length at first maturity. The study was designed to attain an index of abundance for use in evaluating the ability of the population to sustain current levels of harvest, rather than estimating the abundance of the entire spawning population. It was recognized that some unknown amount of positive bias in the abundance estimates may occur because the populations being sampled were known to be migrating at the time. Therefore, the design of this study attempted to minimize the amount of bias to acceptable levels (i.e., ≤5%) rather than completely eliminate it.

METHODS

EXPERIMENTAL AND SAMPLING DESIGN

This study was designed to estimate abundance and length compositions of humpback whitefish within a 50 km index area of the Chatanika River using two-event Petersen mark-recapture techniques for a closed population (Seber 1982), intended to satisfy the following assumptions:

1. the population was closed (humpback whitefish did not enter the population, via growth or immigration, or leave the population, via death or emigration, during the experiment);
2. all humpback whitefish had a similar probability of capture in the first event or in the second event, or marked and unmarked fish mixed completely between events;
3. marking of fish did not affect the probability of capture in the second event;
4. marked fish were identifiable during the second event; and,
5. all marked fish were reported when recovered in the second event.

Failure to satisfy these assumptions may result in biased estimates, so the experiment was designed to allow the validity of these assumptions to be ensured or tested. Sufficient data were collected to perform diagnostic tests to identify heterogeneous capture probabilities (violations of Assumption 2), and prescribed model-selection procedures were followed in the event of such violations. Diagnostic tests are not available to evaluate assumptions 1, 3, 4, and 5; instead, the experiment was designed to ensure that these assumptions were met, thereby avoiding or minimizing potential biases. The design ensured that sample sizes were adequate to meet objective precision criteria and to perform reliable diagnostic tests.

The general approach of this study was to sample humpback whitefish using an electrofishing boat after they had migrated to their spawning areas. Recent research has indicated that most humpback whitefish have completed their migrations to spawning areas located between Any

Creek and the Elliot Highway Bridge by the second week of September (Dupuis 2010; Wuttig 2009). Therefore, bias associated with closure violations would be kept negligible (i.e., <5%) by sampling between September 11 and 27 within the 50 km study area.

During each of the two sampling events, humpback whitefish were captured and sampled by researchers operating electrofishing boat(s) as described by Fleming (1994). However, the amount of effort was changed from using two boats operated side by side (i.e., each assigned to a bank) to a single boat assigned to its own section of river, as was done in 1997 and 2008 (Fleming 1999; Wuttig 2009). In general, the channel is too narrow to operate two boats at the same time, and one boat during 1997 and 2008 attained sample sizes that resulted in sufficient precision of the abundance estimates.

Effort was systematically and uniformly distributed over the study area by operating the electrofishing boats in 5- to 20-min intervals (runs). The duration of runs were adjusted based on catch rates (i.e., a run was complete once the sampling tub was full) but did not exceed 20 min. During both sampling events, the beginning and end points of all runs were recorded using a hand-held GPS so that movement could be evaluated at the scale of a run. At sectional boundaries, all runs ended regardless of run duration. The sectional boundaries were used to evaluate variability of capture probabilities by section (Figure 3).

Evaluation of Assumptions

Assumption 1: The hiatus between sampling events was of short duration (12–14 days for any particular run), and therefore, growth recruitment and mortality were considered insignificant. Emigration or immigration was not problematic in 2008, and it was assumed that it would not be in 2012. Moreover, the experiment started approximately 2 weeks later than in 2008, allowing even more time for the majority (i.e., >95%) of the spawning migration to be completed and compressed into a smaller reach downstream of the bridge. No spawning whitefish were observed upstream of the bridge in 2008, 2009, and 2011[1], and consequently no sampling was conducted there in 2012 (Dupuis 2010; Wuttig 2009).

Movements of recaptured humpback whitefish were evaluated at the scale of a run and are approximately accurate to ≤5.0 km. The scale and accuracy of fish movements were considered sufficient for examination of closure and movement patterns within the study area. The inaccuracy in measuring movement distances between events was due to varying run distances and fish being carried some distance by the boat if captured early at the beginning of the run. The endpoints of electrofishing runs varied in length between events because of varying catch rates (e.g., high catch rates required stopping after a short distance). Movement was only considered significant if a fish traveled more than 5 km.

Assumption 2: Complete mixing throughout the study area was not expected. Therefore, Assumption 2 was addressed by attempting to subject all fish to the same probability of capture during the first or second event and by relying on small scaled movement (localized mixing) to eliminate the potential of isolated pockets of fish avoiding capture during both events.

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[1] Author's unpublished field notes from investigations of sheefish in the Chatanika River during 2011. Located at Alaska Department of Fish and Game, Fairbanks.

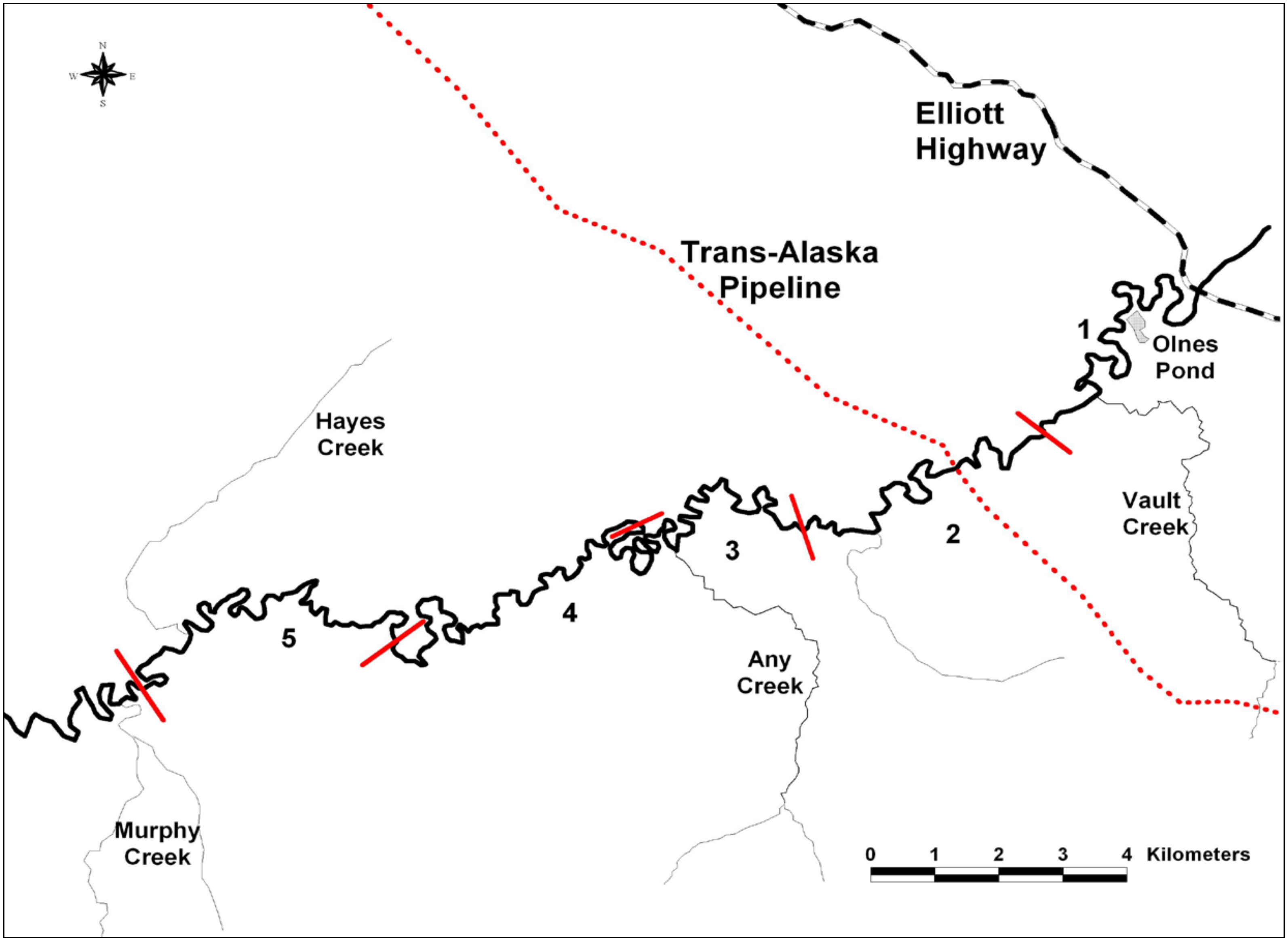

Figure 3.–Map of Chatanika River study area depicting five 10 km sample sections bounded by Elliott Highway Bridge and Murphy Creek.

Assumption 3: The 12- to 14-day hiatus between events for any given reach of river sampled allowed marked fish to recover from any behavioral effects induced by handling and marking during the first event; therefore, Assumption 3 was valid. In addition, marking-induced behavioral effects were further mitigated by using active gear to capture fish, as opposed to passive gear. Only those fish deemed healthy received a mark.

Assumptions 4 and 5: These assumptions were ensured by the selection of the sampling/tagging methods. During the first event of the experiment, all fish were double-marked using individually numbered Floy™ tags (primary mark) and a partial clip of the upper caudal fin (secondary mark). To prevent resampling during the second events, all sampled fish received a lower caudal finclip.

DATA COLLECTION

At the completion of a run, all captured fish were temporarily held in live wells, their length was measured (mm FL), and they were carefully examined for marks. In the first event, all fish were tagged with an individually numbered Floy FD-94[2] internal anchor tag and given an upper caudal finclip to identify tag loss. To eliminate duplicate sampling in the second event, all fish were given a lower caudal finclip. All fish in both events were carefully inspected for Floy tags and finclips, and GPS capture/release locations (decimal degree NAD27 Alaska datum) were recorded. Fish captured in the first event that exhibited signs of injury or excessive stress were not marked and were censored from the experiment.

DATA ANALYSIS

Abundance Estimate

When capturing fish in a downstream sequence with electrofishing boats, it is inherently difficult to approximate the taking of a simple random sample (i.e., a random sample without replacement). Therefore, samples from the Chatanika River were taken systematically in the sense of progressively moving downstream and sampling proportionally to the abundance of fish present. Under these circumstances, the Bailey-modified Petersen estimator (Appendix A1; Bailey 1951, 1952) was preferred over the Chapman-modified Petersen estimator (Chapman 1951) for estimating abundance.

Violations of Assumption 2 relative to size effects were tested using two Kolmogorov-Smirnov tests. There were 4 possible outcomes of these two tests relative to evaluating size-selective sampling (either one of the two samples, both, or neither of the samples were biased) and 2 possible actions for abundance estimation (length stratify or not). The tests and possible actions for data analysis are outlined in Appendix A2. If stratification by size was required, capture probabilities by location were examined for each length stratum.

The tests for consistency of the Petersen estimator (Seber 1982; Appendix A3) were used to determine if, for each identified length stratum, stratification by location was required due to spatiotemporal effects and to determine the appropriate abundance estimator: the pooled Bailey-modified Petersen estimator, the completely stratified Bailey-modified Petersen estimator, or a partially stratified estimator (Darroch 1961). Documentation of release location for each fish

[2] The use of product, software, and company names throughout this report is not an Alaska Department of Fish and Game recommendation or implied endorsement. The Alaska Department of Fish and Game, in accordance with State of Alaska ethics laws, does not favor one product over another through endorsement or recommendation.

permitted the examination of capture probabilities by section as well as at any other scale if needed.

Relative to Assumption 1, closure was not tested directly but inferred from examination of the movement of recaptured fish within the study area. The data were examined for evidence of movement away from, toward, or across the boundaries of the study area to provide evidence of immigration and emigration.

Length Composition

Kolmogorov-Smirnov tests for size-selective sampling and outcomes were used to determine if stratification was necessary and if data from the first or second event or both were to be used. Length composition of the population was estimated in 10 mm length categories using the procedures outlined in Appendix A4.

RESULTS

EVALUATION OF POPULATION CLOSURE ASSUMPTION

Of all the humpback whitefish recaptured, 65% moved less than 5 km from their original capture location; however, 35% of recaptured humpback whitefish moved greater than 5 km (31% upstream and 4% downstream). Most recaptured whitefish displayed an upstream movement between sampling events toward the upper boundary of the study area (Figure 4).

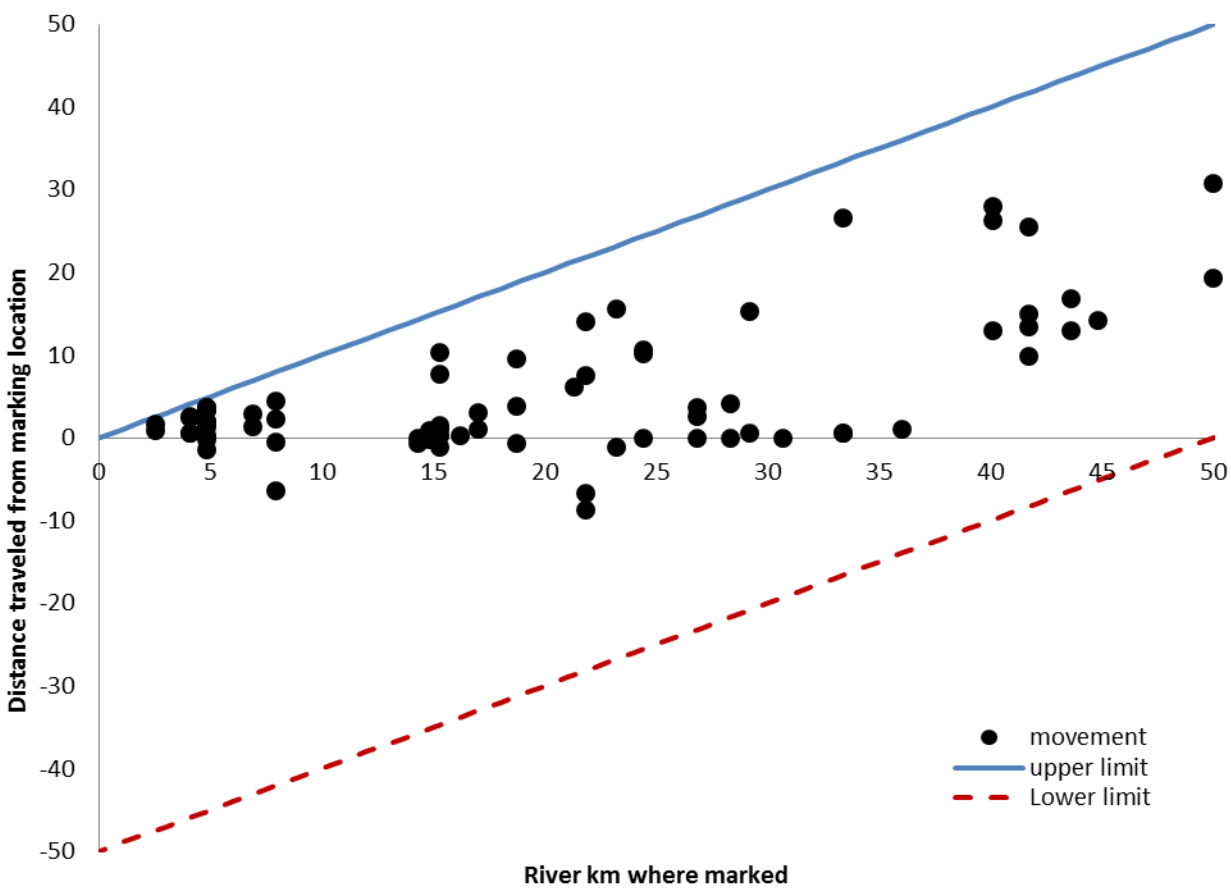

Figure 4.–Distance traveled by recaptured humpback whitefish between first and second events by river km, with limits of detection depicted.

ABUNDANCE AND LENGTH COMPOSITION

A total of 2,064 humpback whitefish were captured ranging from 315 to 549 mm FL. Of these, 1,993 were ≥360 mm FL and only one recaptured fish had a length <360 mm FL (356 mm FL). During the first event 840 humpback whitefish were captured, and 1,153 were captured in the second event, of which 75 were recaptured fish (Table 2). No recaptured fish were noted to have lost their primary mark (Floy tag), although two fish were accidentally released without determining their Floy tag numbers.

Kolmogorov-Smirnov tests resulted in Case I, which indicated that there was no size-selective sampling during both events, abundance was estimated for a single length stratum, and data from both events were pooled for composition estimates (Table 3). Consistency tests of capture probabilities during each event failed to be rejected, although the test of mixing did fail (Table 4). Therefore, there was no need to geographically stratify, and the Bailey-modified Petersen estimator was used to calculate an abundance estimate. Estimated abundance of humpback whitefish ≥360 mm FL within the 50 km study area was 12,755 (SE = 1,405). A substantial proportion (71%) of the estimated population of humpback whitefish was 430 to 499 mm FL (Figure 5; Appendix B1).

Table 2.–Number of humpback whitefish ≥360 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by section(s) in the Chatanika River study area, 2012.

Section where marked	Section where recaptured							
	1	2	3	4	5	m_2	n_1	(m_2/n_1)[b]
1	21	1	0	0	0	22	222	0.10
2	3	14	0	0	0	17	201	0.08
3	2	5	9	1	0	17	212	0.08
4	1	0	0	4	0	5	103	0.05
5	0	4	3	5	0	12	102	0.12
m_2	27	24	12	10	0			
n_2	584	252	171	132	14			
(m_2/n_2)[a]	0.05	0.10	0.07	0.08	0.00			

[a] Probability of capture during first event.

[b] Probability of capture during second event.

Table 3.–Results of diagnostics used to detect and correct for size-selective sampling for estimating abundance and length compositions of humpback whitefish in the Chatanika River, 2012.

Stratum	Comparison and Test Statistic			Result
	M vs. *R*	*C* vs. *R*	*M* vs. *C*	
≥360 mm FL	*D* = 0.066 *P*-value = 0.913 Fail to reject H_0	*D* = 0.075 *P*-value = 0.812 Fail to reject H_0	*D* = 0.051 *P*-value = 0.153 Fail to reject H_0	Case I, do not stratify, use lengths from both events for composition analysis

Table 4.–Results of consistency tests for the Petersen estimator for estimating abundance of humpback whitefish in the Chatanika River study area, 2012.

Length Stratum	Consistency Test		
	I	II	III
	Complete mixing	Equal probability of capture, 1st event	Equal Probability of capture, 2nd event
≥ 360 mm FL	χ^2 = 102.26 *P*-value < 0.001	χ^2 = 8.63 *P*-value = 0.071	χ^2 = 3.66 *P*-value = 0.452

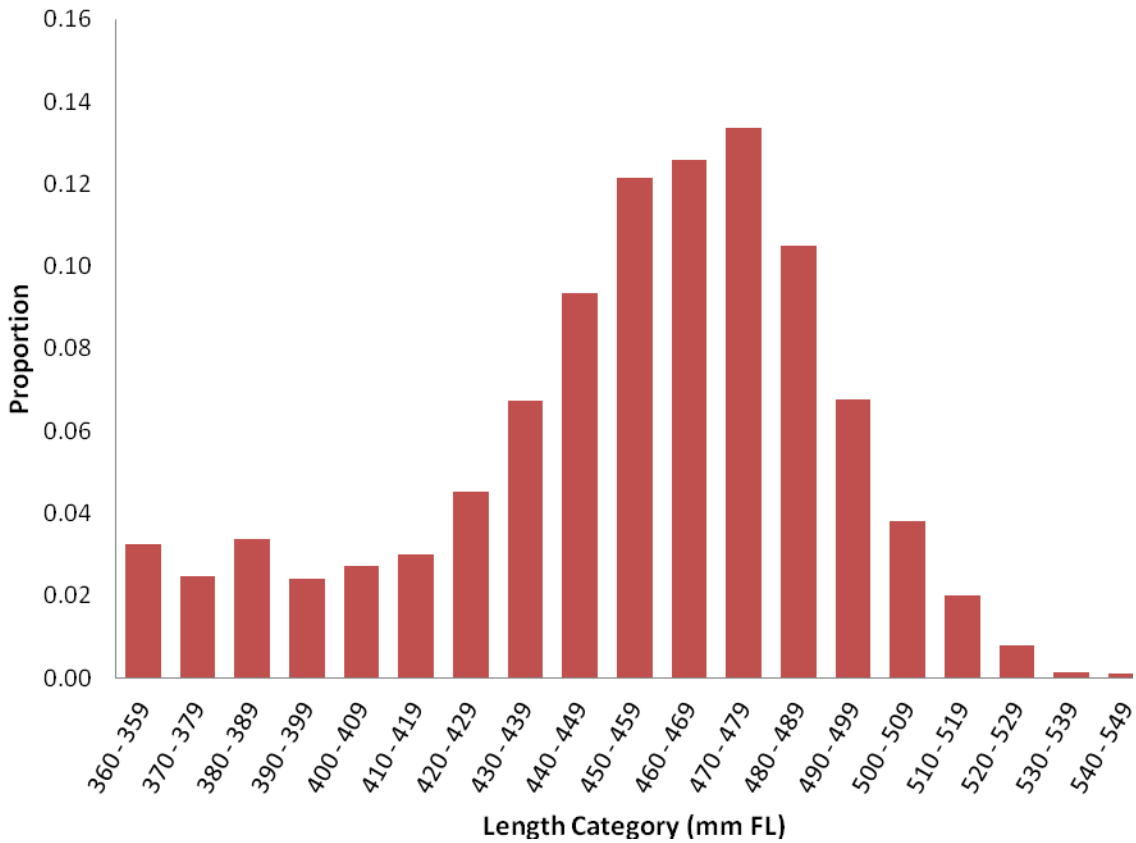

Figure 5.–Length-frequency distribution of humpback whitefish sampled in the Chatanika River study area, 2012.

DISCUSSION

The general approach used in this study (a refinement of the 2008 study) to estimate abundance of humpback whitefish is recommended for future stock assessments. Delaying the projects from August to September resulted in a population concentrated into a smaller reach that simplified logistics, made the entire spawning stock available to sampling, and adequately addressed bias relative to closure violations. The use of a single electrofishing boat per stream reach resulted in good sample sizes, and focused effort on a single species eliminated overwhelming numbers of fish from being handled.

Immigration likely occurred across the downstream boundary, but its magnitude was likely insignificant based on the very low catch rates in the lowermost section. Catches within section 5 went from 103 humpback whitefish ≥ 360 mm FL during the first event to just 14 during the second (Table 2). Although immigration was minimal, estimates of abundance and size composition were considered germane to the second event.

The abundance of humpback whitefish in 2012 was judged to be within the range of most previous abundance estimates (Figure 6), although it was significantly less than the 2008 estimate of 22,490 (SE = 2,777) ≥360 mm FL. However, the examination of trends must consider changes over time in the study design and attendant uncertainty in abundance estimates. During 1986 to 1989, population assessments were conducted in a much smaller index area (15 km reach with its upstream boundary at the Elliott Highway Bridge), and these estimates are suspect because the sampling protocols were not yet fully refined and the studies did not adequately account for biases that were probably present (i.e., closure violations). Therefore, abrupt changes in the abundance estimates, such as in 1988, may not be accurate. During 1990 and 1991, sampling protocols were refined and much larger index areas (104 km) were developed, and all estimates thereafter are judged to more accurately reflect population abundances.

Since 2008, larger fish (≥440 mm FL) have become a more dominant component of the population (Figure 7), increasing from 60% to 72%. It is also apparent that a large cohort of young humpback whitefish has not been recruited during the intervening period. Recruitment of a large cohort is probably the result of conditions that are favorable for rearing but that may occur infrequently, such as once every 5–10 years. Because humpback whitefish of the Chatanika River are long-lived (e.g., up to 30 years; Brown et al. 2012), an adult has a reasonable chance of spawning at least once in its life when conditions conducive to producing a large cohort occur. It is not known whether recruitment of a strong cohort is essential to sustaining a spawning stock and its fishery, but it should be noted that a prolonged period of poor recruitment could result in decreasing abundance of the spawning stock over time. Therefore, it is important to assess the stock every 4–5 years to ensure abundance levels remain high enough to sustain current fishing levels and to identify recruitment of a large cohort. Despite the large decline in abundance between 2008 and 2012, current harvests are sustainable, and they should be closely monitored because the present fishery has the potential for greater harvests if participants' fishing behavior were to change (i.e., specifically targeting humpback whitefish and avoiding least cisco).

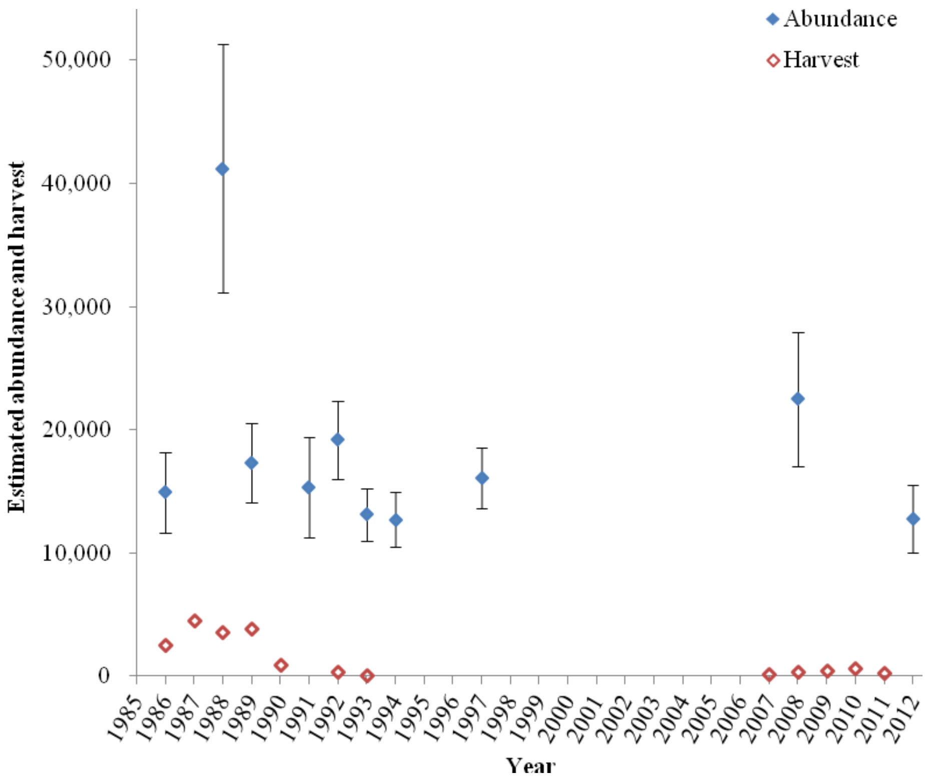

Figure 6.–Estimated abundance and harvest of humpback whitefish ≥360 mm FL in the Chatanika River from 1986 to 2012.

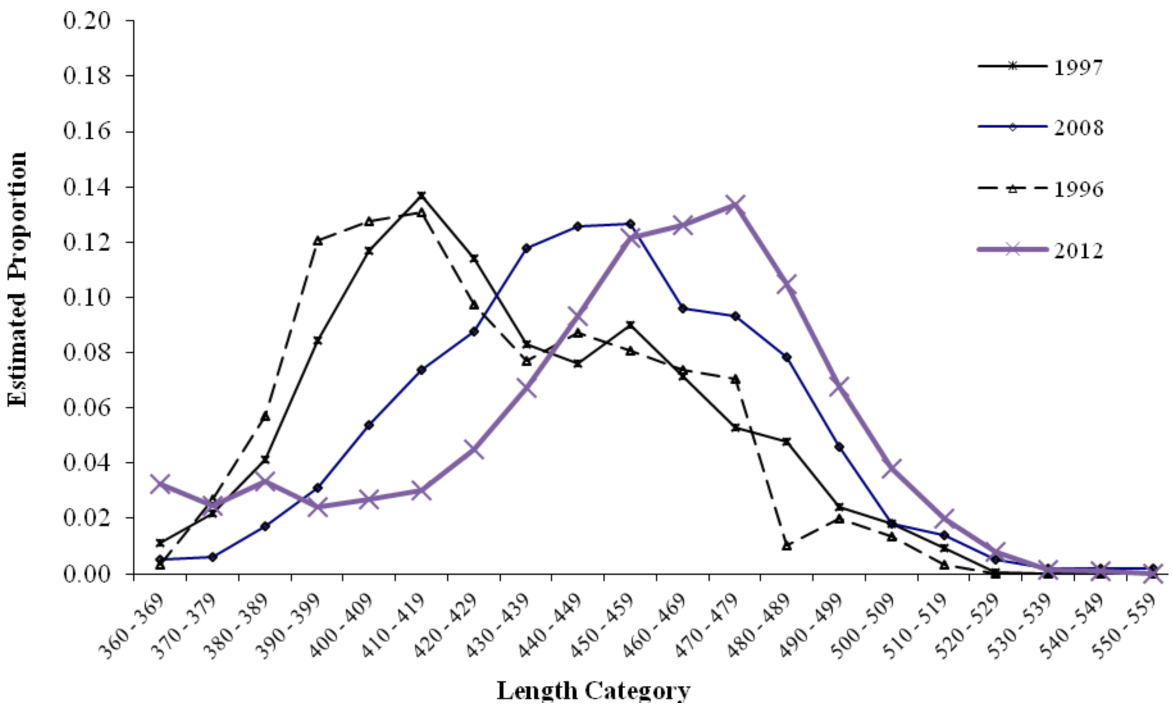

Figure 7.–Length composition of humpback whitefish sampled in the Chatanika River during 1996, 1997, 2008, and 2012. The years 1996 and 1997 were interpreted as probably having good recruitment, whereas 2008 and 2012 had poor recruitment.

ACKNOWLEDGMENTS

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APPENDIX A

Appendix A1.–Equations for calculating estimates of abundance and its variance using the Bailey-modified Petersen estimator.

The Bailey-modified Petersen estimator (Bailey 1951 and 1952) is used because the sampling design calls for a systematic downstream progression and its effect results in sampling without replacement.

The estimator and its variance are:

$$\hat{N} = \frac{n_1(n_2+1)}{(m_2+1)} \quad \text{and} \tag{A1-1}$$

$$V[\hat{N}] = \frac{n_1^{\,2}(n_2+1)(n_2-m_2)}{(m_2+1)^2(m_2+2)} \tag{A1-2}$$

where:

n_1 = the number marked during the first sampling event,

n_2 = the number examined during the second sampling event, and

m_2 = the number captured during the second sampling event with marks from the first sampling event.

The Bailey modification to the Petersen estimator may be used even when the assumption of a random sample for the second sample is false and a systematic sample is provided:

1) there is uniform mixing of marked and unmarked fish, and
2) all fish, whether marked or unmarked, have the same probability of capture (Seber 1982).

Appendix A2.–Procedures for detecting and adjusting for size or sex selective sampling during a 2-sample mark recapture experiment.

Overview

Size- and sex-selective sampling may result in the need to stratify by size and/or sex in order to obtain unbiased estimates of abundance and composition. In addition, the nature of the selectivity determines whether the first, second, or both event samples are used for estimating composition. The Kolmogorov-Smirnov two-sample (K-S) test (Conover 1980) is used to detect significant evidence that size-selective sampling occurred during the first or second sampling events, and contingency table analysis (Chi-square test) is generally used to detect significant evidence that sex-selective sampling occurred during the first or second sampling events.

K-S tests are used to evaluate the second sampling event by comparing the length frequency distribution of all fish marked during the first event (*M*) with that of marked fish recaptured during the second event (*R*), using the null test hypothesis (H_o) of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (*C*) with that of *R*. Chi-square tests are used to compare the counts of observed males to females between M&R and C&R according to the null hypothesis that the probability that a sampled fish is male or female is independent of the sample. When the proportions by gender are estimated for a subsample (usually from *C*) rather than observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are compared using a two-sample test (e.g., Student's *t*-test).

Mark-recapture experiments are designed to obtain sample sizes sufficient to 1) achieve precision objectives for abundance and composition estimates and 2) ensure that the diagnostic tests (i.e., tests for selectivity) have power adequate for identifying selectivity that could result in significantly biased estimates. Despite careful design, experiments may result in inadequate sample sizes, leading to unreliable diagnostic test results due to low power. As a result, detection and adjusting for size and sex selectivity involves evaluating the power of the diagnostic tests.

The protocols that follow are used to classify the experiment into 1 of 4 cases. For each case, the following are specified: 1) whether stratification is necessary, 2) which sample event's data should be used when estimating composition, and 3) the estimators to be used for composition estimates when stratifying. The first protocols assume adequate power. These are followed by supplemental protocols to be used when power is suspect and guidelines for evaluating power.

Protocols given adequate power

Case I:

M* vs. *R	***C* vs. *R***
Fail to reject H_o	Fail to reject H_o

There is no size or sex selectivity detected during either sampling event. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.

Case II:

M* vs. *R	***C* vs. *R***
Reject H_o	Fail to reject H_o

There is no size or sex selectivity detected during the first event, but there is during the second sampling event. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification. If composition is estimated from second-event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the *M* vs. *R* test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula.

-continued-

Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulas below.

Case III:

M* vs. *R		***C* vs. *R***

Fail to reject H_o		Reject H_o

There is no size or sex selectivity detected during the second event, but there is during the first sampling event. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification. If composition is estimated from first event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the *C* vs. *R* test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulas below.

Case IV:

M* vs. *R		***C* vs. *R***

Reject H_o		Reject H_o

There is size or sex selectivity detected during both the first and second sampling events. The *ratio* of the probability of captures for size of sex categories can either be the same or different between events. Data must be stratified to eliminate variability in capture probability within strata for one or both sampling events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

When stratification by sex or length is necessary prior to estimating composition parameters, an overall composition parameter (p_k) is estimated by combining within stratum composition estimates using:

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{ , and} \tag{A2-1}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \left(\sum_{i=1}^{j} \hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + (\hat{p}_{ik} - \hat{p}_k)^2 \hat{V}[\hat{N}_i] \right) \tag{A2-2}$$

where:
- j = the number of sex/size strata;
- $\hat{p}_{ik}$ = the estimated proportion of fish that were age or size *k* among fish in stratum *i*;
- $\hat{N}_i$ = the estimated abundance in stratum *i*;
- $\hat{N}_\Sigma$ = sum of the $\hat{N}_i$ across strata.

Protocols when power is suspect (re-classifying the experiment)

When sample sizes are small (guidelines provided in next section), power needs to be evaluated when diagnostic tests *fail to reject* the null hypothesis. If this failure to identify selectivity is due to low power (that is, if selectivity is actually present), data will be pooled when stratifying is necessary for unbiased estimates. For example, if both the *M* vs. *R* and *C* vs. *R* tests failed to identify selectivity due to low power, Case I may be selected when Case IV is true. In this scenario, the need to stratify could have been overlooked, leading to biased estimates. The following protocols should be followed when sample sizes are small.

Appendix A3.–Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during event 1; or
3. Every fish has an equal probability of being captured and examined during event 2.

To evaluate these 3 assumptions, the chi-square statistic will be used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests are rejected, a geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

I.–Test for complete mixing [a]

Section Where Marked	Section Where Recaptured				Not Recaptured
	A	**B**	**…**	**F**	$(n_1 - m_2)$
A					
B					
...					
F					

II.–Test For equal probability of capture during the first event [b]

	Section Where Examined			
	A	**B**	**…**	**F**
Marked (m_2)				
Unmarked $(n_2 - m_2)$				

III.–Test for equal probability of capture during the second event [c]

	Section Where Marked			
	A	**B**	**…**	**F**
Recaptured (m_2)				
Not recaptured $(n_1 - m_2)$				

[a] This tests the hypothesis that movement probabilities (θ) from section i (i = 1, 2, ...s) to section j (j = 1, 2, ...t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

[b] This tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among sections: H_0: $\Sigma_i a_i \theta_{ij} = kU_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum j at the time of sampling, and a_i = number of marked fish released in stratum i.

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapturing probabilities among sections: H_0: $\Sigma_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a fish in section j during the second event, and d is a constant.

Appendix A4.-Equations for estimating length composition and their variances for the population.

For Case I–III scenarios (Appendix A2), the proportions of humpback whitefish within each age or length class *k* were estimated:

$$\hat{p}_k = \frac{n_k}{n} \tag{A4-1}$$

where:

n_k = the number of humpback whitefish sampled within age or length class *k*, and

n = the total number of humpback whitefish sampled.

When calculating n and n_k the diagnostic test results were used to determine which fish were included (Appendix A2). For Case I, fish from both capture events are used.

The variance of each proportion was estimated as (from Cochran 1977):

$$\hat{V}[\hat{p}_k] = \frac{\hat{p}_k(1-\hat{p}_k)}{n-1}. \tag{A4-2}$$

The abundance of humpback whitefish in each length or age category, *k*, in the population was then estimated:

$$\hat{N}_k = \hat{p}_k \hat{N}, \tag{A4-3}$$

where:

$\hat{N}$ = the estimated overall abundance (Appendix A1).

The variance for $\hat{N}_k$ was then estimated using the formulation for the exact variance of the product of two independent random variables (Goodman 1960):

$$\hat{V}\left[\hat{N}_k\right] = \hat{V}[\hat{p}_k]\hat{N}^2 + \hat{V}\left[\hat{N}\right]\hat{p}_k^2 - \hat{V}[\hat{p}_k]\hat{V}\left[\hat{N}\right]. \tag{A4-4}$$

For the Case IV scenario (Appendix A2), which required stratification by size or sex, the proportions of humpback whitefish within each age or length class *k* were estimated by first calculating:

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \tag{A4-5}$$

where:

n_j = the number sampled from size stratum *j* in the mark-recapture experiment;

n_{jk} = the number sampled from size stratum *j* that are in length or age category *k*; and

$\hat{p}_{jk}$ = the estimated proportion of length or age category *k* fish in size stratum *j*.

When calculating n_j and n_{jk} the within-stratum diagnostic test results were used to determine which fish were included in the analysis following the rules for n and n_k provided above.

The variance calculation for $\hat{p}_{jk}$ is equation 2 substituting $\hat{p}_{jk}$ for $\hat{p}_k$ and n_j for n.

The estimated abundance of fish in length or age category *k* in the population is then:

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$$\hat{N}_k = \sum_{j=1}^{s} \hat{p}_{jk} \hat{N}_j \tag{A4-6}$$

where:

$\hat{N}_j$ = the estimated abundance in size stratum *j*; and

s = the number of size strata.

The variance for $\hat{N}_k$ will be estimated using the formulation for the exact variance of the product of two independent random variables (Goodman 1960):

$$\hat{V}\left[\hat{N}_k\right] = \sum_{j=1}^{s} \left(\hat{V}\left[\hat{p}_{jk}\right]\hat{N}_j^2 + \hat{V}\left[\hat{N}_j\right]\hat{p}_{jk}^2 - \hat{V}\left[\hat{p}_{jk}\right]\hat{V}\left[\hat{N}_j\right]\right). \tag{A4-7}$$

The estimated proportion of the population in length or age category *k* $\left(\hat{p}_k\right)$ is then:

$$\hat{p}_k = \hat{N}_k \big/ \hat{N} \tag{A4-8}$$

where: $\hat{N} = \sum_{j=1}^{s} \hat{N}_j$.

Variance of the estimated proportion can be approximated with the delta method (Seber 1982):

$$\hat{V}\left[\hat{p}_k\right] \approx \sum_{j=1}^{s} \left\{ \left(\frac{\hat{N}_j}{\hat{N}}\right)^2 \hat{V}\left[\hat{p}_{jk}\right] \right\} + \frac{\sum_{j=1}^{s} \left\{ \hat{V}\left[\hat{N}_j\right] \left(\hat{p}_{jk} - \hat{p}_k\right)^2 \right\}}{\hat{N}^2}. \tag{A4-9}$$

APPENDIX B

Appendix B1.–Estimated length composition of humpback whitefish ≥360 mm FL in the Chatanika River study area, 2012.

Length category (mm FL)	n	$\hat{p}$	SE ($\hat{p}$)	$\hat{N}$	SE ($\hat{N}$)
360–369	65	0.03	0.004	416	68
370–379	49	0.02	0.003	314	56
380–389	67	0.03	0.004	429	70
390–399	48	0.02	0.003	307	55
400–409	54	0.03	0.004	346	60
410–419	60	0.03	0.004	384	64
420–429	90	0.05	0.005	576	87
430–439	134	0.07	0.006	858	118
440–449	186	0.09	0.007	1,190	155
450–459	242	0.12	0.007	1,549	194
460–469	251	0.13	0.007	1,606	200
470–479	266	0.13	0.008	1,702	211
480–489	209	0.10	0.007	1,338	171
490–499	135	0.07	0.006	864	119
500–509	76	0.04	0.004	486	76
510–519	40	0.02	0.003	256	49
520–529	16	0.01	0.002	102	28
530–539	3	<0.01	0.001	19	11
540–549	2	<0.01	0.001	13	9

APPENDIX C

Appendix C1.–Data files for humpback whitefish sampled from the Chatanika River during 2012.

Data file [a]	Description
HWF data_2012.xls	File includes all humpback whitefish sampled and analysis for the mark-recapture experiment from the Chatanika River during fall 2012.

[a] Data files were archived at and are available from the Alaska Department of Fish and Game, Division of Sport Fish, 1300 College Road, Fairbanks, Alaska 99701.