Fishery Data Series No. 09-42

Sockeye Salmon Mark-Recapture and Radio Telemetry Studies at McDonald Lake in 2007

by

Steven C. Heinl,

Douglas M. Eggers

and

Andrew W. Piston

August 2009

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

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

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)

Measures (fisheries)

fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL

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. 09-42

SOCKEYE SALMON MARK-RECAPTURE AND RADIO TELEMETRY STUDIES AT MCDONALD LAKE IN 2007

by
Steven C. Heinl and Andrew W. Piston
Alaska Department of Fish and Game, Division of Commercial Fisheries, Ketchikan

Douglas M. Eggers
Alaska Department of Fish and Game, Division of Commercial Fisheries, Douglas

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

August 2009

This manuscript was fully financed by a grant from the Pacific Salmon Commission Northern Fund, project NF-2007-I-21 McDonald Lake Sockeye Salmon Escapement Estimate.

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

Steven C. Heinl and Andrew W. Piston
Alaska Department of Fish and Game, Division of Commercial Fisheries,
2030 Sea Level Drive #205, Ketchikan, AK 99901, USA

Douglas M. Eggers
Alaska Department of Fish and Game, Division of Commercial Fisheries,
P.O. Box 240020, Douglas, AK 99811-0024, USA

This document should be cited as:
Heinl, S. C., D. M. Eggers, and A. W. Piston. 2009. Sockeye salmon mark-recapture and radio telemetry studies at McDonald Lake in 2007. Alaska Department of Fish and Game, Fishery Data Series No. 09-42, Anchorage.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF APPENDICES

ABSTRACT

Since 1985, a standardized series of foot surveys has been used to estimate the escapement of sockeye salmon *Oncorhynchus nerka* at McDonald Lake. Through run reconstruction, these escapement estimates formed the basis for commercial catch estimates and the current escapement goal for this system. The sum-of-surveys expansion factor used to estimate escapements was based on only two years of comparison to total weir counts in 1983 and 1984. To validate this historical time series, we conducted a third year of mark-recapture studies in 2007 and compared total escapement estimates from weir counts (1981, 1983, and 1984) and mark-recapture studies (2005–2007) to escapement estimates derived from linear regression models that we developed here. Our 2007 mark-recapture estimate (29,086; SE = 084) compared well to the historical sum-of-surveys estimate (29,160); however, the historical sum-of-survey method accounted for an average of only 82% of the total escapement for the six years of paired total-escapement and escapement-index data, and exhibited greater variability compared to estimates based on linear regression of escapement indices on total escapement. The best predictor of the escapement was the peak survey, multiple-regression model that incorporated an index of annual September precipitation. We recommend that this model be used to estimate the annual escapement of sockeye salmon to McDonald Lake, and to recast the historical escapement series. In 2007, we radio tagged 69 adult sockeye salmon to document lake spawning in the system, as lake spawners would be unobserved by the foot-survey crew. Lake spawning was documented at two locations near the mouths of very small, intermittent creeks. Ten percent of radio tagged fish that reached known spawning areas were ultimately found near lake spawning sites. Future escapement studies should be coupled with a more intensive radio-telemetry study to better document the extent of lake spawning.

Key words: sockeye salmon, *Oncorhynchus nerka*, escapement, expansion factor, lake spawning, McDonald Lake, mark–recapture, radio telemetry, Southeast Alaska.

INTRODUCTION

Historically, McDonald Lake has been the largest sockeye salmon *Oncorhynchus nerka* producing system in southern Southeast Alaska. Escapements averaged more than 90,000 fish a year in the 1980s and 1990s, and this stock contributed substantially to several mixed-stock, commercial fisheries (Johnson et al. 2005). An average of 5,800 McDonald Lake sockeye salmon were harvested annually in the personal use fishery at Yes Bay, including a harvest of more than 10,000 in 1994 (Johnson et al. 2005). Marine tagging studies in the early 1980s showed that a portion of this stock was also harvested in treaty-area fisheries (Hoffman et al. 1983 and 1984). Because of its importance, McDonald Lake is the only wild Alaska sockeye stock that is specifically identified in the sockeye salmon run-reconstruction model currently used by the Northern Boundary Technical Committee (NBTC) of the Pacific Salmon Commission to allocate harvests of sockeye salmon in the boundary area (Gazey and English 2000). Past harvest estimates of McDonald Lake sockeye salmon are based, to one extent or another, on the estimate of escapement magnitude, and these estimates are what drive the assessment and management of this stock (Johnson et al. 2005).

Systematic counts of the sockeye salmon escapement into McDonald Lake have been conducted since 1981. From 1981 to 1984, the Alaska Department of Fish and Game (ADF&G) operated an adult salmon weir at the outlet of the lake as part of joint U.S.-Canada studies (Hoffman et al. 1983 and 1984). The weir was expensive and difficult to operate and was only funded for four years. In an effort to maintain the escapement series, ADF&G biologists looked for an alternative method to quantify the escapement. In 1983 and 1984, ADF&G biologists conducted a series of systematic foot surveys of spawning sockeye salmon in Hatchery Creek, and scaled the sum of the surveys to the final weir counts in those years (Johnson et al. 2005). That sum-of-surveys expansion factor was used to estimate the escapements from foot surveys conducted annually from 1985 to the present.

Expansion factors have commonly been used to expand aerial survey counts to total estimates of escapements for Chinook salmon in Southeast Alaska (McPherson et al. 2003, Pahlke 2007); however, expansion factors have typically been multiplied by a peak survey count, rather than the sum of multiple surveys as was done at McDonald Lake. The scaled foot-survey method used at McDonald Lake is similar to the area-under-the-curve approach (English et al. 1992, Bue et al. 1998), which was developed to estimate total escapement from a series of foot or aerial survey observations. The principal difference between the scaled foot-survey approach and the area-under-the-curve approach is that two key parameters, which vary annually (stream life and observer bias), are not known and are assumed to be constant in the scaled foot-survey approach. The foot survey method has provided ADF&G with long-term escapement estimates that are useful to track escapement trends at McDonald Lake; however, the accuracy and precision of this method has not been measured.

The foot surveys at McDonald Lake were implemented as the primary method of estimating escapement with the assumption that all spawning occurred in the main inlet stream (Olson 1989); or that lake spawners composed only a very small portion of the run (T. Zadina, ADF&G, personal communication.). Lake spawning has not been formally documented at McDonald Lake, but has been observed at many other lakes in Southeast Alaska (e.g. Conitz and Cartwright 2005). In 2006, ADF&G conducted a radio-telemetry study at McDonald Lake but did not document lake spawning (Heinl et al. 2008).

Improving and validating the estimates of the sockeye salmon escapement at McDonald Lake has become increasingly important because of a recent decline in escapements. From 2001 to 2006, escapement estimates decreased to an average of 40,000 sockeye salmon—less than half of the average of the previous 20 years—including the smallest escapement yet recorded at the lake (17,000 in 2006). The current sustainable escapement goal of 70,000–100,000 sockeye salmon was not reached in five of the past six years, raising the possibility that the stock could merit status as a stock of “management concern” under the State of Alaska’s Policy for the Management of Sustainable Salmon Fisheries (Southeast Alaska and Yakutat Commercial Salmon Fishing Regulations 5 AAC 39.222).

In 2005, ADF&G began studies designed to improve annual estimates of the escapement of this important stock. We conducted a two-event mark-recapture study to estimate the total escapement of sockeye salmon into McDonald Lake in 2005 and 2006 (Heinl et al. 2008), and 2007 (reported here). During Event 1 of the mark-recapture study, sockeye salmon were captured at the outlet of the lake, marked, and sampled for age, sex, and length information. Sockeye salmon carcasses were examined for marks on the spawning grounds in Event 2. We conducted a second year of radio-telemetry studies at McDonald Lake in 2007 to estimate spawning stream life and to document the occurrence of lake spawning. The radio-telemetry study also provided an estimate of handling mortality, which we used to adjust the mark-recapture estimate as has been done in other studies (Jones et al. 2001, Weller et al. 2005). We estimated the sockeye salmon escapement at McDonald Lake using the standardized foot-survey method that has been employed since 1985, and used six years of paired foot-survey escapement indices and total-escapement estimates from weir counts (1981, 1983, and 1984) and mark-recapture studies (2005, 2006, and 2007) to investigate alternative foot-survey expansion models.

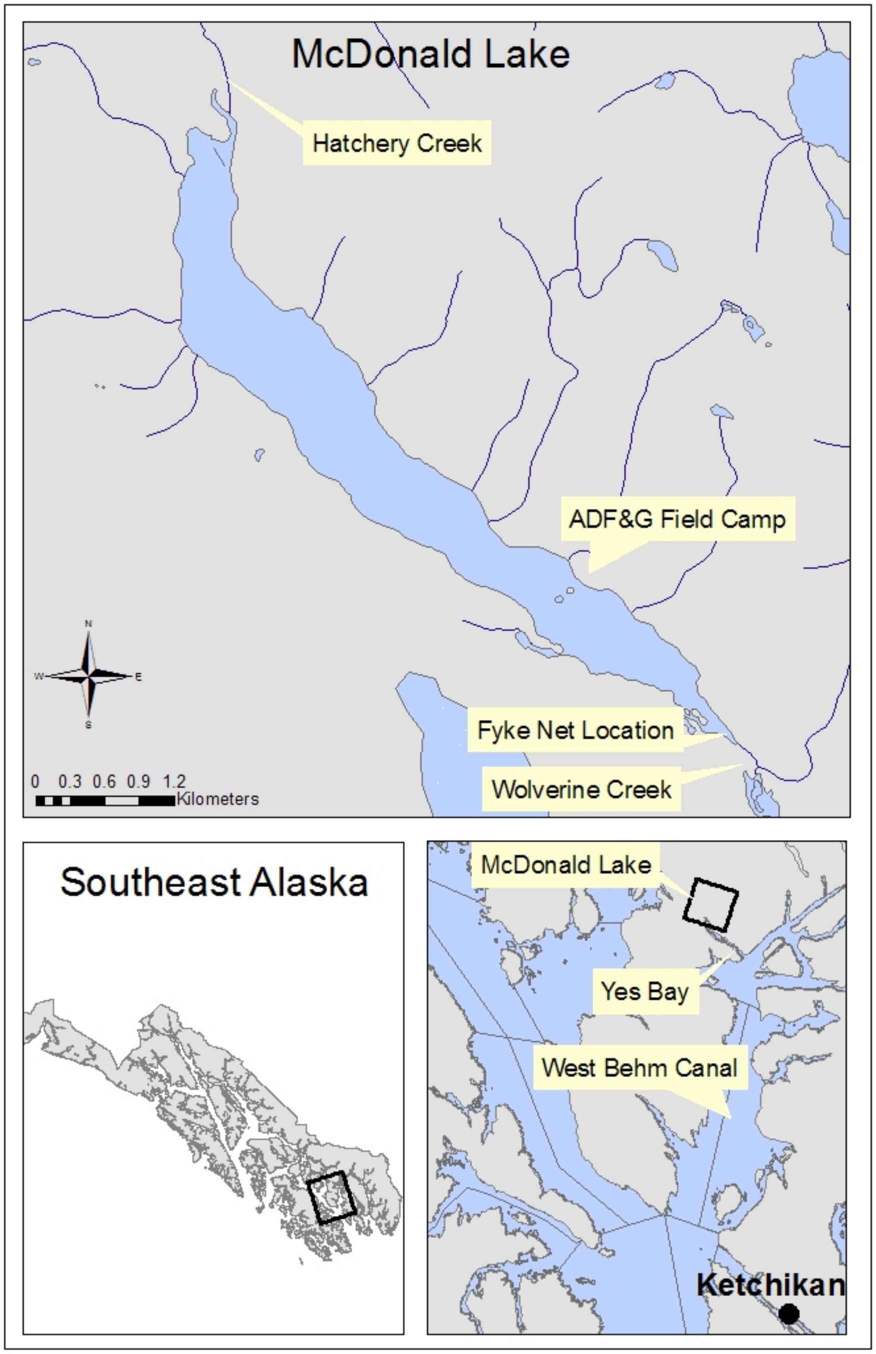


Figure 1.–Map of McDonald Lake and its location with respect to Ketchikan and Southeast Alaska.

STUDY AREA

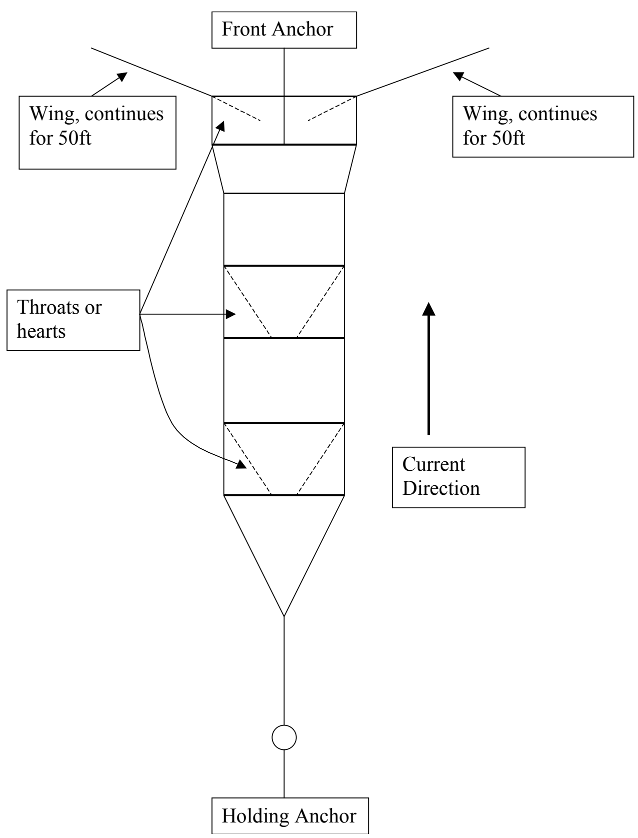
McDonald Lake is located in the Tongass National Forest, approximately 70 km north of Ketchikan, Southeast Alaska, on the Cleveland peninsula (Figure 1; 55° 58’ N, 131° 50’ W, Orth 1967). The lake is situated within a heavily forested watershed of 118 km^2 (Olson 1989), and has a surface area of 420 ha, a mean depth of 45.6 m, and a maximum depth of 110 m (Zadina and Heinl 1999). The lake is organically stained with a volume of 197 x 10^6 m^3 and a residence time of approximately 0.67 years (Zadina and Heinl 1999, Olson 1989). The primary inlet stream and spawning grounds is Hatchery Creek (ADF&G stream number 101-80-10680-2030; also know as Walker Creek, Orth 1967). Movement of salmon upstream into Hatchery Creek is blocked by a barrier falls approximately 1.5 km upstream of the lake. The outlet stream, Wolverine Creek (ADF&G stream number 101-80-10680), flows south 2.4 km to Yes Bay, in West Behm Canal.

METHODS

We conducted a two-event mark-recapture experiment for a closed population (Seber 1982), in conjunction with a radio-telemetry study, to estimate the abundance of sockeye salmon in McDonald Lake in 2007.

MARKING AND SAMPLING

In Event 1, adult sockeye salmon were captured for sampling with a modified fyke net at the outlet of McDonald Lake from 22 July to 15 September in 2007. The entire net was constructed of 3/8-inch nylon netting, and comprised three parts: an entrance, body, and wings (Figure 2).



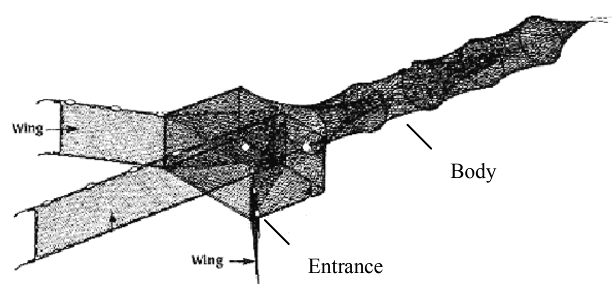


Figure 2.–Fyke net used to capture sockeye salmon at the outlet of McDonald Lake, 2007.

The entrance consisted of two rectangular frames (4 feet by 6 feet) separated by approximately two feet of netting. Within the entrance was a throat, a simple funnel-shaped part of the net that allowed fish to enter, but generally impeded escape. The body was attached to the entrance and had two throats, five 5-foot diameter hoops, and a draw-string cod end. The net was set along the stream bottom slightly to the west side of the channel. The mouth of the net was oriented downstream to sample fish moving upstream into the outlet of the lake. The wings were 8 feet high and 50 feet long and were tied off to a log in the mid-channel and onto a tree on the west stream bank. An additional 6-foot tall section of 3/8-inch netting was secured across the top of the fyke net and wings. This provided coverage to the water surface in normal water conditions (approximately 10 feet deep). The net was held in place by two anchors: one on the downstream side of the fyke net and one on the upstream side. The net was fished 24 hours a day, and was checked one to four times per day depending on the number of fish captured and water temperature.

Adult sockeye salmon captured in the net were anesthetized in a clove oil solution (Woolsey et al. 2004) and marked with a spaghetti tag and fin clip. The sex and mideye to fork length (MEF) of each sockeye salmon were recorded, and one scale sample was taken from the preferred area (INPFC 1963). Individually numbered, 30-cm spaghetti tags (Floy Tag and Manufacturing, Inc., Seattle, WA[1]) were inserted into the bony posterior of the base of the dorsal fin using a 15-cm needle, and tied with an overhand knot cinched to the back of the fish. The use of numbered tags allowed temporal stratification of our release and recovery data in the event that we would need to estimate the population using a stratified estimator, rather than a pooled estimator. Dark green or gray tags were used to reduce the possibility of selective predation on tagged fish. All fish marked with spaghetti tags were given an additional secondary mark (a partial dorsal fin clip) to ensure identification if tag loss occurred. Sampled fish were placed in 35-gallon recovery buckets suspended in fresh water, and released after they recovered from the anesthetic. Other species of fish and jack sockeye salmon (< 400 mm MEF) were enumerated and released. Sockeye salmon that appeared unhealthy were enumerated and released without marks.

In Event 2, sampling for marked fish was conducted daily on the spawning grounds from 1 September to 9 October. All available sockeye salmon carcasses were examined for marks and all carcasses that were examined were cut in half to eliminate double counting. In addition, a sub-sample of 20 carcasses were collected daily between 21 September and 4 October and measured (MEF length) to evaluate the possibility of size-selective sampling during our study.

RADIOTELEMETRY

In 2007, we conducted a radio-telemetry study to determine the stream life of tagged fish on the spawning grounds, and to document the occurrence of lake spawning. In addition, we assumed radio-tagged sockeye salmon that were not ultimately tracked to known spawning areas suffered handling-induced mortality or their behavior was affected by handling, and we used this information to make a conservative adjustment to our mark-recapture estimate as noted above (Jones et al. 2001, Weller et al. 2005).

We used an esophageal method (Eiler 1990, Ramstad 2003) to implant digitally encoded SR-M16-25 motion sensitivity tags (Lotek Incorporated, Ontario, Canada) into 69 healthy sockeye salmon over the course of the entire emigration period. The radio tags were programmed with varied burst rates (5.0 to 5.5 s) and transmitted over 12 channels to reduce interference between tags on schooling fish. The motion sensors would transmit a "mortality" signal (a different individual code) when a fish had not moved above a specific sensitivity threshold for a 24-hour

---

[1] Use of trade name is included for scientific completeness and does not imply endorsement of any product or service by the State of Alaska

period (indicating the fish was dead). Motion sensors were set at the highest level of sensitivity so that the sensor would not trigger a mortality signal if light movement was detected.

To test the transmission strength of radio tags in deep water, tags were lowered into the water column to depths ranging from 0 to 50 m and the signal strength was monitored with the receiver gain set to 85 and noise 20. Testing was conducted both with the antenna directly over the tag, and from a distance of about 200 m. The tag code could be read to a depth of 35 m when the boat was directly over the tag and the antenna was pointed directly at the tag. When the boat was at a distance of 200 m from the tag, the tag code could be read to a depth of 20 m. This information allowed for better understanding of the limits of detection of the transmitter signals.

The lake was divided into five zones for the purposes of tracking fish: zone 1) the outlet stream from the fyke net at the outlet of the lake, downstream to the mouth of the creek at salt water; zone 2) the lower third of the lake, zone 3) the middle third of the lake; zone 4) the upper third of the lake; and zone 5) the spawning stream from the mouth of the creek to the barrier falls 1.5 km upstream (Figure 3). Fish were tracked in each zone every two to four days, by boat or on foot, with a hand held antenna and an SRX-600 receiver. The receiver gain was set to 75–95 and noise 20.

Unfortunately, 15 radio tags transmitted false mortality signals for some period during the project, and we could not rely upon mortality sensors as true indicators of mortality. Fish that remained in any zone for more than two tracking sessions, and fish that transmitted a mortality signal, were individually located and evaluated for movement in order to determine if the fish was dead. For example, the field crew located the radio tag and monitored the signal strength as the boat was moved toward the fish: when the signal strength increased, the gain was reduced as movement was continued toward the fish; when the gain could not be further reduced or the signal strength increased, movement (or lack of movement) by the fish was determined by holding the position of the boat, checking for changes in the signal strength, or locating the fish or carcass by sight.

Potential lake-spawning locations were identified as areas in which groups of fish remained for two or more tracking periods. Shoreline surveys were conducted in those locations to look for fish and redds; particular attention was given to areas with suitable spawning habitat, such as medium-sized gravel substrate in shallow areas (determined by a stern-mounted portable depth sonar), and areas adjacent to small creeks and associated upwelling groundwater that might attract fish (Burgner 1991, Young 2005).

The stream life of radio-tagged sockeye salmon spawning in Hatchery Creek was estimated as the number of days between when the fish entered the creek and when the fish died or left the creek. A logging station consisting of two 12-volt batteries, a logging capable receiver (SRX-400), and an antenna, was erected at the mouth of the creek (55.992 °N, 131.844 °W). The reception range of the receiver was set to encompass an area of the spawning channel approximately 150 m long. Radio-tagged fish were logged by tag identification number, time, and date as they occupied the area within the reception range.

MARK-RECAPTURE ESCAPEMENT ESTIMATE

In 2007, we estimated the sockeye salmon escapement and associated variance using Chapman's Modified Petersen estimator (Seber 1982):

$$\hat{N} = \frac{(\hat{m}+1)(c+1)}{(r+1)} - 1 \text{, and} \tag{1}$$

$$Var(\hat{N}) = \frac{(\hat{m}+1)(c+1)(m-r)(c-r)}{(r+1)^2(r+2)}, \tag{2}$$

where $\hat{N}$ is the estimated population size, $\hat{m}$ is the estimated number of fish marked during Event 1, c is the number of fish captured and sampled for marks during Event 2, and r is the number of fish recaptured during Event 2 that were marked in Event 1. We adjusted for the proportion of fish tagged in Event 1 that died or left the system as a result of handling effects as determined from the radio-telemetry study (Jones et al. 2001, Weller et al. 2005). The number of fish marked, $\hat{m}$, during Event 1 was estimated as:

$$\hat{m} = m'(1-\hat{y}), \tag{3}$$

where m' is the number of salmon marked in Event 1, and $\hat{y}$ is the estimated proportion of tagged sockeye salmon that suffered handling effects.

The general assumptions that must hold for a two-sample mark-recapture estimate to be consistent were listed by Seber (1982) and Schwarz and Taylor (1998): "(1) either or both of the samples are a simple random sample, i.e., all fish in the population have the same probability of being tagged or all fish have the same probability of being captured in the second sample; or tagged fish mix uniformly with untagged fish, (2) the population is closed, (3) there is no tag loss, (4) the tagging status of each fish is determined without error, and (5) tagging has no effect on the subsequent behavior of the fish."

Assumption one could be violated if size- or gender-selective sampling occurred during the study. To test the hypothesis that fish of different sizes were captured with equal probability during Event 1 and Event 2, we compared the length distributions of fish for groups of marked (*m*), captured (*c*), and recaptured (*r*) sockeye salmon, by sex, using the Kolmogorov-Smirnov (K-S) two-sample test (Conover 1999). The test hypothesis for each comparison was that there were no differences in MEF lengths between the data sets being tested ($P < 0.05$). Similarly, we conducted two chi-square consistency tests to check for gender-selective sampling; the test hypothesis was there were no differences in the ratio of males to females between the data sets being tested ($P < 0.05$). Gear selectivity in Event 1 was examined by comparing the number of fish of each gender marked in Event 1, and the number of fish of each gender sampled for marks in Event 2. Sampling bias in Event 2 was examined by comparing the number of fish of each gender marked in Event 1 and recaptured during Event 2, to the number of each gender that were marked but not recaptured.

Additionally, we conducted two chi-square consistency tests for temporal violations of assumption one: a test for complete mixing, or the probability that the time of recovery of a marked fish in Event 2 was independent of when it was marked in Event 1; and a test of equal proportions of marked fish recovered in Event 2. We considered a test statistic with P-value < 0.05 as significant. Failure to reject one of these last two hypotheses was sufficient to conclude that at least one of the conditions in assumption one was satisfied, and that a Petersen-type model was appropriate to estimate abundance (Schwarz and Taylor 1998); if both tests were significant, a temporally-stratified estimate would be generated using SPAS software (Arnason et al. 1996). SPAS was designed for analysis of two-sample mark-recapture data and we used it to calculate maximum likelihood Darroch and pooled-Petersen (Chapman's modified) estimates, and their standard errors, and the two chi-square tests of complete mixing and equal proportions described above.

We assumed that the population at McDonald Lake was closed to emigration and recruitment (assumption two), because sampling activities in Event 1 and Event 2 were conducted daily, spanned nearly the entire known emigration timing of sockeye salmon into the lake, and spanned the entire sockeye salmon spawning season. We addressed assumption three (tag loss) through the use of multiple marks (spaghetti tag combined with a fin clip), so fish that lost their spaghetti tag would still be identifiable from the fin clip. Careful inspection of all fish sampled on the spawning grounds helped to ensure that tag status was determined without error during Event 2 (assumption four).

Finally, substantial stress from capture and handling in Event 1 could lead to a reduction of tagged fish in the recovery sample (assumption five) and a positive bias in the mark-recapture estimate. As noted above, assumption five was primarily addressed through the radio-telemetry study. We also conducted daily observations and periodic snorkel surveys near the marking area (around the fyke net and downstream) to look for mortalities.

ESCAPEMENT ESTIMATES BASED ON FOOT SURVEY DATA

A standardized method of estimating the escapement through a series of foot surveys has been employed at McDonald Lake since the early 1980s (Johnson et al. 2005), and we continued that method (which we call the "historical" model) in 2007. We also used six years of paired foot-survey escapement indices and total-escapement estimates from weir counts (1981, 1983, and 1984) and mark-recapture studies (2005, 2006, and 2007) to investigate alternative foot survey expansion models that we developed here.

The historical model of estimating escapement was based on seven foot surveys of Hatchery Creek conducted on, or near, the following dates: 23 August, 31 August, 10 September, 20 September, 28 September, 10 October, and 20 October. Stream counts began just upstream of the mouth (GPS coordinates: 55.992° N, 131.844° W), included the old hatchery side channel on the lower section of the creek, and ended approximately 1.5 km upstream, just downstream of the barrier falls (GPS coordinates: 56.002° N, 131.840° W, Figure 3). Two experienced observers conducted a survey simultaneously, and counted the number of live sockeye salmon in the study area. The average of the two counts for each survey was used as the estimated number of live sockeye salmon. A survey was considered missed if it was not conducted within ± 3 days of the designated date. If a survey was missed, the value for that date was interpolated using an iterative EM algorithm (McLachlan and Krishnan 1997) as described by Johnson et al. (2005). Foot surveys were expanded to an estimate of the total escapement by multiplying the sum of the surveys by 1.33; the expansion factor that was developed in 1983 and 1984, when the sum of the seven foot surveys was compared to the final weir count in each of those years (Johnson et al. 2005).

In addition to the historical sum-of-surveys escapement estimate, we developed alternative models to estimate total escapement using the six years of paired total foot-survey and total-escapement data. We examined a hierarchy of linear regression models based on two foot-survey escapement indices: the sum-of-survey counts and the peak survey count. Because weather conditions during the spawning season can affect the ability of observers to see fish in the water, we also examined the affect of precipitation on the ability to predict total escapement from the escapement indices. Water levels during the spawning season can potentially affect the run-timing and stream life of spawning fish as well, and, therefore, the proportion of the total escapement present during the peak of the run. For this analysis, we used NOAA precipitation data from the Ketchikan airport, because we do not have annual precipitation data from McDonald Lake.

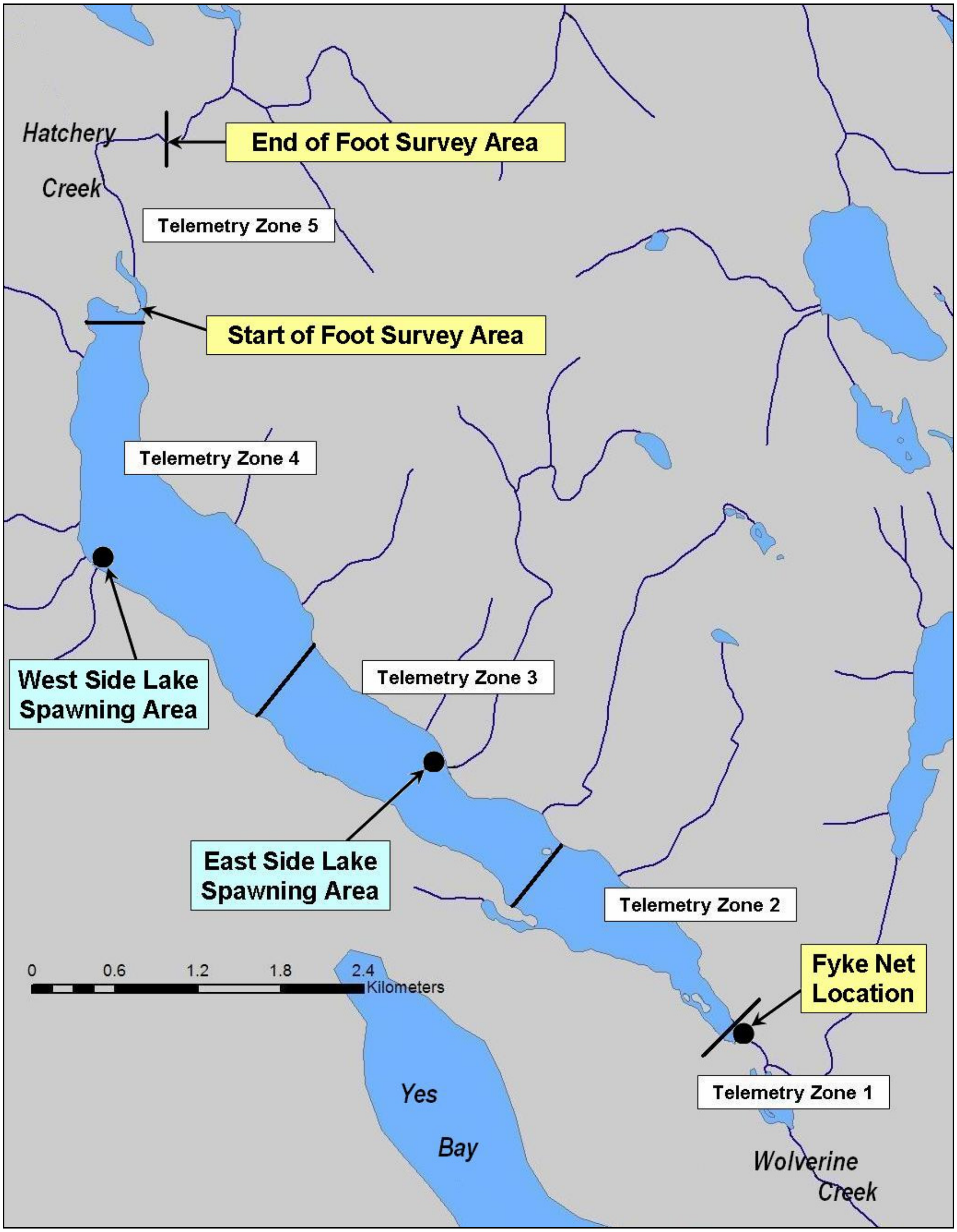


Figure 3.–Map of McDonald Lake showing the fyke net location, telemetry tracking zones, foot survey area on Hatchery Creek, and the locations of lake spawning areas, 2007.

For each data set we fit the linear regression model:

$$\hat{Y}_i = A + BE_i^I + CT_i + \sigma, \quad (4)$$

where $\hat{Y}_i$ is the estimated total escapement; E_i^I is the respective escapement index from the foot survey data; T_i is the index of precipitation during September; A, B, and C are model parameters; and σ is standard deviation. The hierarchy of linear regression models based on the sum-of-survey counts were:

1. Model S1: a simple regression of escapement on the sum-of-surveys escapement index with zero intercept (A and C = 0);
2. Model S2: a simple regression of escapement on the sum-of-surveys escapement index (C = 0); and
3. Model S3: a multiple regression of escapement on the sum-of-surveys escapement index and September precipitation.

Models P1, P2, and P3 were based on an identical treatment of the peak survey counts. The linear regression models were fit by method of maximum likelihood (note that this is equivalent to the least squares method which is the standard in linear regression). Our criteria for model selection was based on goodness of fit determined as minimum log likelihood, minimum root-mean-squared-error (RMSE), R^2, and minimum Akeike's information criterion (AIC) (Hilborn and Mangel 1997).

The linear regression models were used to produce hind-cast estimates (or predictions) of the escapements in 1981, 1983, 1984, 2005, 2006, and 2007. We estimated the sample standard deviation of these predictions from the sum of the squared errors of the log of the observed values, minus the log of the predicted values. The 80% confidence interval was calculated as the estimated escapement plus or minus the sample standard deviation times the appropriate *t*-value (1.476; 5 df). Predicted escapement estimates were also expressed as percentages of the corresponding weir count or mark-recapture estimate to evaluate the relative efficiency of each method (Bue et al. 1998).

AGE COMPOSITION

One scale was collected from the "preferred area" of every adult sockeye salmon captured during Event 1 (INPFC 1963) and mounted on a gum card. Scale samples were later prepared for age analysis as described by Clutter and Whitesel (1956), and aged at the ADF&G, Commercial Fisheries, Aging Lab in Douglas, Alaska. We used a standard treatment of the age and scale sampling data to estimate multiple age-class proportions and means. Estimates of the standard error for age-class proportions were calculated using methods described by Thompson (2002).

PHYSICAL DATA COLLECTION

Precipitation and stream flow data were collected to assist with development of temporal strata for the mark-recapture study, if needed. We measured 24-hour precipitation with a manual rain gauge located in an open area adjacent to the field camp, and water depth was measured daily at stream gauges (meter sticks) fixed into the stream channel at both the inlet and outlet streams. Stream discharge at both the inlet and the outlet streams was estimated on six occasions over the course of the season and at a variety of water depths, from the lowest water level recorded during the study, to the highest level in which it was still possible to wade the stream to collect measurements (Appendix A1). A Marsh McBirney™ hand-held flow meter and wading rod were used to measure water depth and velocity. Flow readings were recorded at 60% of water depth (from surface to bottom) at four-foot subsections across a total transect width of 160 feet at the outlet stream, and every six feet across a transect width of 240 feet at the inlet stream. Total stream discharge (*Q*) was calculated as,

$$Q = w_1 d_1 v_1 + w_2 d_2 v_2 + ... + w_n d_n v_n \, , \tag{5}$$

where *w* is width, *d* is depth, and *v* is mean velocity for each subsection (1, 2,…, *n*), and *Q* is cubic feet per second (Murphy and Willis 1996). We regressed the six stream-discharge estimates on the corresponding water level measured at the stream gauges, and we used these relationships to predict daily stream discharge for both the inlet (Appendix A2) and the outlet streams (Appendix A3).

RESULTS

MARK-RECAPTURE ESCAPEMENT ESTIMATE

A total of 1,090 sockeye salmon were captured and tagged between 21 July and 15 September 2007: 380 males and 710 females (Appendix B1). We stratified release data by time: approximately 33% of the tagged fish were grouped into each period, 21 July–11 August, 12–20 August, and 21 August–15 September (Table 1). Heavy precipitation during 29–31 August resulted in high water flows that collapsed the west wing of the trap and possibly reduced the fishing efficiency during that three-day period (Figure 4); the net was operated in a normal fashion during the rest of the season. Five sockeye salmon pre-handling mortalities were found inside of the trap and we released 36 sockeye salmon that were determined to be in too poor of condition to be tagged (Appendix B1). Evidence of post-handling mortality was not observed: no marked sockeye salmon carcasses were observed during the trap checks or during periodic stream snorkel surveys. High water temperatures during mid-August (e.g., maximum lake temperature 18.0 C at 0.5 m depth on 18 August) caused some fish to become stressed in the net. Consequently, the number of daily trap checks was increased to reduce holding stress, and stressed fish were released unmarked. Fish captured in mid-September, just prior to removal of the net, were generally near full spawning colors and also in poor condition.

A total of 12,074 carcasses were examined for marks on the spawning grounds from 1 September through 9 October 2007: 4,246 males and 7,828 females, of which 405 were marked (Appendix B2; Figure 5). Of the 405 marked fish recovered, 65 (16%) had shed their spaghetti tag. Tag loss was generally quite easy to determine from the presence of a dorsal fin clip and the residual tag hole (Figure 6). We stratified recovery data by time: approximately 25% of the sampled carcasses were grouped into each period, 1–17 September, 18–23 September, 24–29 September, and 30 September–9 October (Table 1).

We determined that no gender-related gear selectivity occurred during Event 1: the test for equal proportions of males and females marked in Event 1 and sampled in Event 2 was not significant (χ^2 = 0.04, *P* = 0.84, df = 1). There also appeared to be no sampling bias related to gender during Event 2: the test of the frequency of marked males and females recovered compared to those not recovered in Event 2 was not significant (χ^2 = 0.66, *P* = 0.42, df = 1). A chi-square test of complete mixing of marked fish between release and recovery strata was significant (χ^2 =

7.07, P = 0.03, df = 2); however, the chi-square test of equal proportions of marked fish in the recovery strata yielded a non-significant result (χ^2 = 6.34, P = 0.10, df = 3). A non-significant result for one of these diagnostic tests indicated the pooled estimator (i.e., equation 1) was appropriate for estimating abundance in this study.

Table 1.–Number of tagged sockeye salmon released, by marking period, and number of fish sampled, tags recovered, and number of marked fish recovered without a tag, by recovery period, at McDonald Lake in 2007.

Release Strata	Number Tags Released	Recovery Strata 1 Sep–17 Sep	18 Sep–23 Sep	24 Sep–29 Sep	30 Sep–9 Oct	Total
21 Jul–11 Aug	360	51	25	24	18	118
12 Aug–20 Aug	367	38	28	25	35	126
21 Aug–15 Sep	363	17	19	26	33	95
Number recovered without a tag		10	12	20	24	66
Number unmarked		3,013	2,975	2,703	2,978	11,669
Total number sampled		3,129	3,059	2,798	3,088	12,074

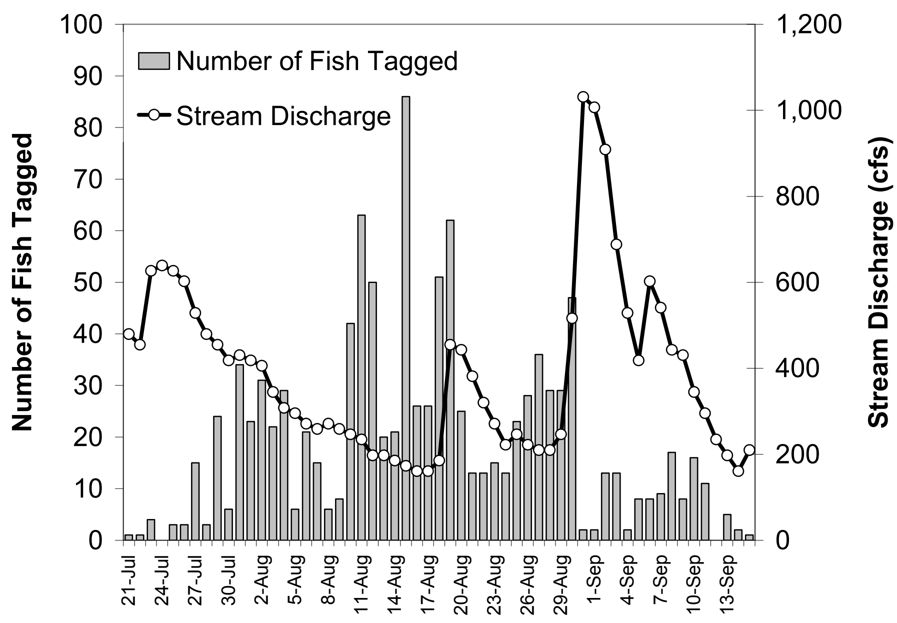


Figure 4.–Number of sockeye salmon tagged and released at outlet stream during Event 1, compared to the daily estimated stream flow, McDonald Lake, 2007.

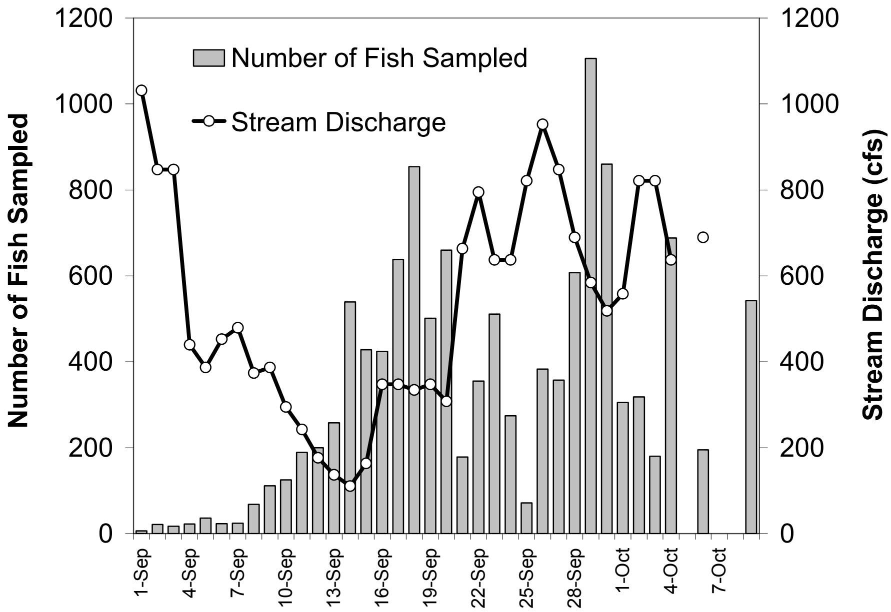


Figure 5.–Number of sockeye salmon carcasses inspected at the inlet stream during Event 2 compared to the daily mean stream flow, McDonald Lake, 2007.

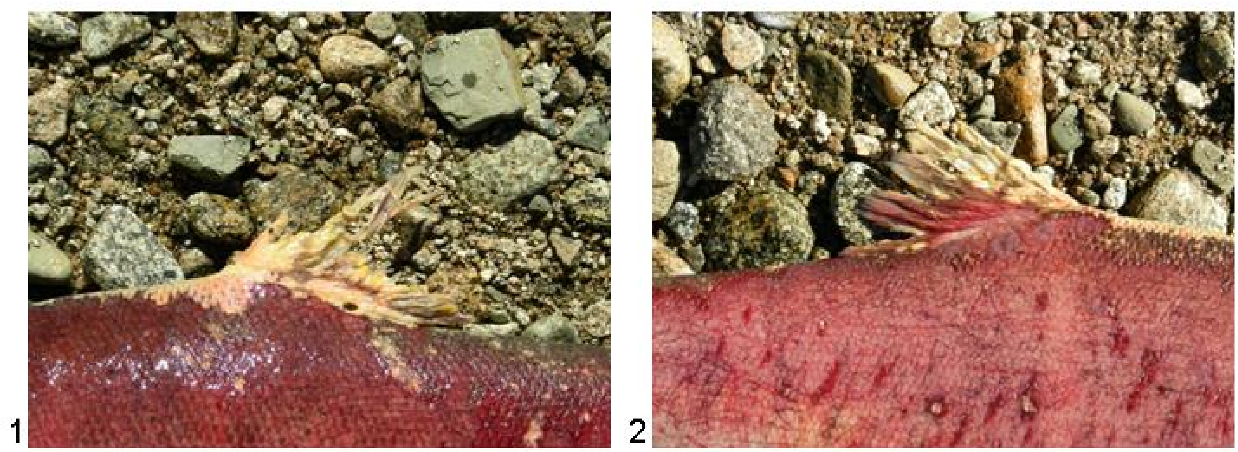


Figure 6.–Photographs of carcasses sampled for marks on the spawning grounds during sampling Event 2: photo 1 shows the dorsal fin clip and residual tag hole of a marked carcass, and photo 2 shows an unmarked carcass.

The average length of tagged fish that were recaptured as carcasses during Event 2, were shorter than when they were sampled in the fyke net during Event 1, particularly female fish (Table 2). The direct test for size bias indicated both a significant difference in the size of female fish marked (*m*) during Event 1 and the size of females captured and sampled for marks (*c*) during Event 2 (D = 0.29, *P* = 0.00); *and* in the size of female fish marked (*m*) during Event 1 and the size of marked females that were recaptured (*r*) during Event 2 (D = 0.40, *P* = 0.00; Appendix C1). Although these results suggest sampling bias, we do not believe size-selective sampling actually occurred. First, all carcasses were measured to the "fork-of-tail" (i.e., standard MEF measurement) regardless of their condition. Unfortunately, caudal fin erosion, which can be severe in spawned-out females, was not accounted for in the field. Second, no significant difference was detected in the size of female fish captured and sampled for marks (*c*) during Event 2 and the size of marked females recaptured (*r*) during Event 2 (D = 0.13, $P = 0.70$). Finally, no significant size difference was detected between males marked (*m*) during Event 1, or captured and sampled for marks (*c*) during Event 2, or marked males recaptured (*r*) during Event 2 ($P > 0.05$ for all cases; Appendix C1). We concluded, therefore, that our study was not biased by size-selective sampling.

Table 2.–Mean lengths of sockeye salmon marked at the fyke net (m), carcasses inspected for marks on the spawning grounds (c), and marked carcasses recovered on the spawning grounds (r), by sex, at McDonald Lake in 2007.

Sex	Group	Number Sampled	Average Length (mm)	SD
Female	Marked (*m*)	706	574	23.1
Female	Carcasses sampled (*c*)	153	558	24.7
Female	Marked carcasses recovered (*r*)	42	554	23.6
Male	Marked (*m*)	384	587	32.6
Male	Carcasses sampled (*c*)	140	587	29.0
Male	Marked carcasses recovered (*r*)	13	581	24.3

The radio-telemetry study provided information to address the loss of tagged fish in the population through handling mortality or handling effects. Sixty-nine sockeye salmon were fixed with radio tags from 25 July to 1 September, but two radio tags failed shortly after deployment. Of the remaining 67 transmitters, six were eventually tracked to the vicinity of lake-spawning areas, and 54 were tracked to the spawning grounds at Hatchery Creek. Of the remaining seven radio-tagged fish, one fish died at the outlet (most likely from handling stress), one moved downstream into Wolverine Creek where it remained through the end of the season, three died in the lake prior to reaching spawning areas, and two died as a result of predation prior to reaching spawning areas. (We assumed the latter fish were available to predators because they were not in good condition.) Thus, 60 of the 67 radio-tagged fish were tracked to a known spawning location. We estimated $\hat{y}$ = 7/67 (10.4%) to adjust for the loss of tagged fish in the population described in equation 2.

After addressing all of the assumptions of the pooled estimator, we used Chapman's modified Petersen estimator (equation 1) to generate the escapement estimate. The estimated sockeye salmon escapement was $\hat{N}$ = 29,086 (SE = 1,084; CV = 4%), based on $\hat{m}$ = 977, c = 12,074, and r = 405.

ESCAPEMENT ESTIMATES BASED ON FOOT SURVEY DATA

Most of the linear regression models were better predictors of total escapement than the historical sum-of-surveys model (Tables 3 and 4). Hind-cast estimates of the escapement produced from the historical sum-of-surveys model averaged 82% of the total escapements estimated from weir counts and mark-recapture studies (Table 4). Models using the peak survey count escapement index to predict total escapement exhibited a better fit than models using the sum-of-surveys escapement index, based on all fit criteria. It was also clear that the total September precipitation at the Ketchikan airport was related to model ability to predict escapement; e.g., the positive residuals (observed values minus predicted values) in the Model P2 fit were associated with years of higher total precipitation (1981, 2005, and 2006), whereas negative residuals were associated with years of lower total precipitation (1983, 1984, and 2007; Figure 7). The multiple regression models (Models S3 and P3) that incorporated the September precipitation and co-variate exhibited better fit (Table 3) and were more precise (Table 4) than other models (Table 4; Figure 8). Although Models S3 and P3 were very similar, we deemed Model P3 the best based on all fit criteria examined (Table 3), and hind-cast estimates based on that model were unbiased (averaged 100% of the total escapements) and the most precise (CV = 13%; Table 4; Figure 8).

Table 3.–Model parameter estimates and model fit criteria for the hierarchy of models examined to estimate total escapement from foot survey escapement indices.

		Model Parameter Estimates			Fit Criteria			
Foot Survey Data	Model[a]	A	B	C	- Log L	RMSE	AIC	R^2
Sum-of-surveys	Historical Model		1.33		27.39	19.37	29.39	
Sum-of-surveys	S1		1.56		26.29	18.25	28.29	
Sum-of-surveys	S2	12.52	1.35		25.94	18.25	29.94	0.79
Sum-of-surveys	S3	-48.75	1.48	3.87	19.21	5.95	25.21	0.98
Peak survey	P1		4.85		23.49	12.13	25.49	
Peak survey	P2	2.29	4.73		23.46	12.08	27.46	0.91
Peak survey	P3	-32.28	4.76	2.37	18.63	5.40	24.63	0.98

[a] Best fit model; i.e., minimum -Log L, root of mean squared error (RMSE), and Akeike's information criterion (AIC), and maximum R^2.

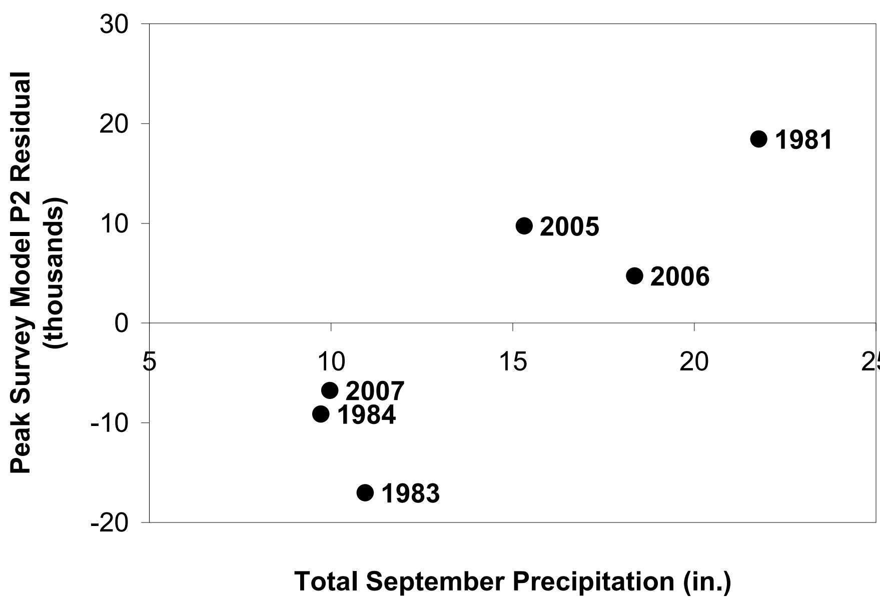


Figure 7.–Peak survey count Model P2 residuals (observed values minus predicted values), compared to the total September precipitation recorded at the Ketchikan airport.

Table 4.–Total escapement and foot survey escapement indices of sockeye salmon at McDonald Lake, compared to hind-cast estimates of escapement derived from the historical model and linear regression models.

	Weir Count			Mark-Recapture					
Year	1981	1983	1984	2005	2006	2007	Ave. %	CV	RMSE[a]
Total Escapement	129,653	56,142	121,224	61,043	31,357	29,086			
Sum-of-surveys[b]	59,016	41,231	92,800	34,464	12,570	21,870			
Peak live count	23,050	15,000	27,100	10,375	5,153	7,100			
Model									
Historical Sum-of-surveys Model[c]	78,688	54,975	123,733	45,952	16,760	29,160			
% of population estimate	61%	98%	102%	75%	53%	100%	82%	26%	22,531
80% CI - lower	44,885	31,358	70,579	26,212	9,560	16,633			
80% CI - upper	137,949	96,377	216,919	80,559	29,382	51,121			
Sum-of-surveys Model S1	92,007	64,280	144,677	53,730	19,597	34,096			
% of population estimate	71%	114%	119%	88%	62%	117%	95%	26%	19,366
80% CI - lower	59,689	41,701	93,858	34,857	12,713	22,119			
80% CI - upper	141,825	99,085	223,013	82,822	30,208	52,557			
Sum-of-surveys Model S2	92,135	68,143	137,710	59,014	29,479	42,024			
% of population estimate	71%	121%	114%	97%	94%	144%	107%	24%	18,250
80% CI - lower	63,766	47,161	95,309	40,843	20,402	29,085			
80% CI - upper	133,125	98,459	198,976	85,269	42,593	60,721			
Sum-of-surveys Model S3	122,886	54,646	126,333	61,557	40,874	22,210			
% of population estimate	95%	97%	104%	101%	130%	76%	101%	17%	5,948
80% CI - lower	95,296	42,377	97,969	47,736	31,697	17,223			
80% CI - upper	158,465	70,467	162,909	79,379	52,708	28,640			
Peak survey Model P1	111,682	72,678	131,305	50,269	24,967	34,401			
% of population estimate	86%	129%	108%	82%	80%	118%	101%	21%	12,133
80% CI - lower	82,347	53,588	96,816	37,065	18,409	25,365			
80% CI - upper	151,466	98,568	178,079	68,176	33,861	46,655			
Peak survey Model P2	111,206	73,168	130,344	51,313	26,637	35,837			
% of population estimate	86%	130%	108%	84%	85%	123%	103%	20%	12,082
80% CI - lower	82,823	54,493	97,076	38,216	19,838	26,690			
80% CI - upper	149,317	98,242	175,013	68,898	35,766	48,119			
Peak survey Model P3	129,129	65,089	119,783	53,477	35,842	25,185			
% of population estimate	100%	116%	99%	88%	114%	87%	100%	13%	5,400
80% CI - lower	107,371	54,122	99,600	44,467	29,802	20,941			
80% CI - upper	155,296	78,279	144,056	64,314	43,105	30,289			

[a] Root mean squared error.
[b] Sum-of-surveys is sum of seven foot survey estimates conducted on designated dates over the course of the spawning season.
[c] The historic sum-of-surveys model is based on the expansion factor of 1.33 that was used to estimate the escapement since 1985.

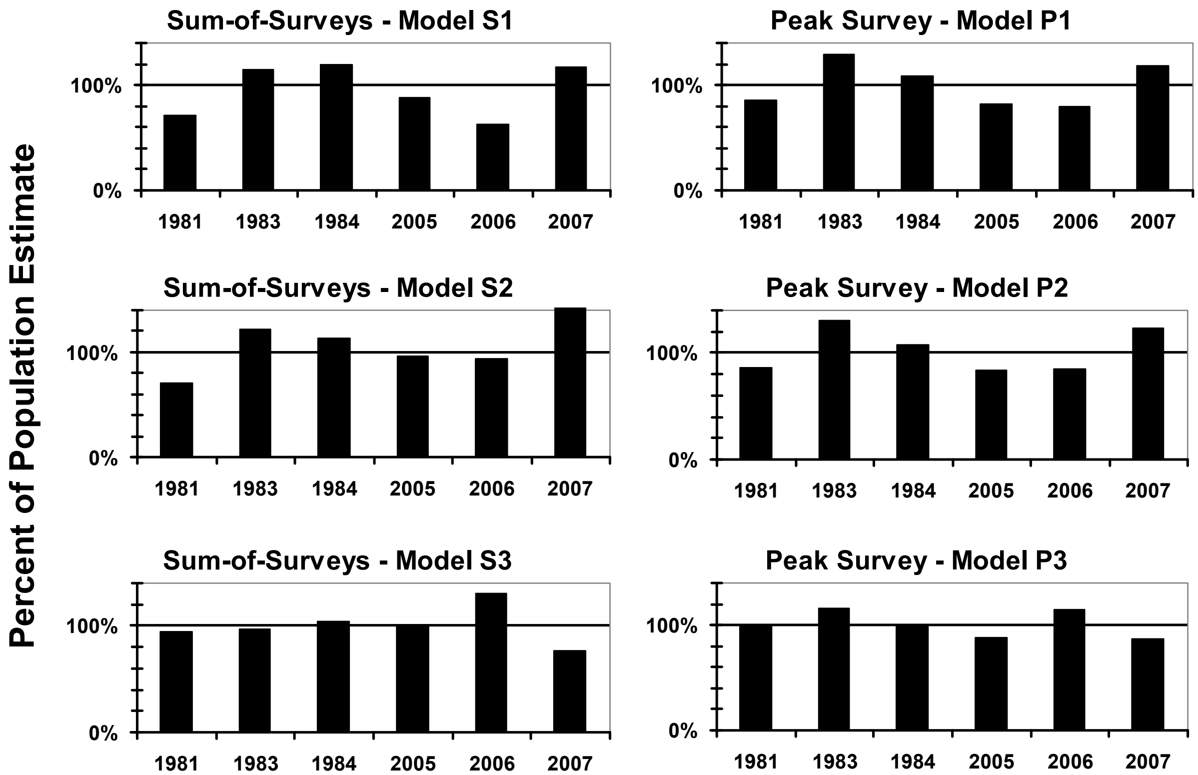


Figure 8.–Hind-cast estimates of the McDonald Lake sockeye salmon escapement based on linear regression models expressed as a percent of total escapement estimates from weir counts (1981, 1983, and 1984) and mark-recapture studies (2005, 2006, and 2007). The solid line at 100% indicates the total escapement estimate.

LAKE SPAWNING AND STREAM LIFE

Lake spawners were found on both the eastern and western shores of McDonald Lake, and six radio-tagged fish were tracked to within 150 m of lake-spawning areas on the eastern shore (Figure 3). Spawning areas were located in shallow water near the mouths of intermittent creeks where there was medium-sized, gravel substrate, and lower gradient benches 3–15 m in depth extending away from the shore. Active lake spawning was not observed until 26 September. During 26–30 September, seven adult fish (two females, four males, and one jack) were observed holding on redds in water less than 3 m deep at the mouth of a small creek on the western shore of the lake; the carcasses of five males and one female were found at that location on September 27. On 30 September, 20 adult fish were observed actively constructing and holding on redds in water less than 3 m deep near the mouths of two small creeks on the east side of the lake: 11 females, eight males, and one jack (carcasses were also observed but not counted). Two radio-tagged fish died within 30 m, and four others died within 150 m of those sites; all were in water too deep to recover the tags.

Of the 54 radio-tagged fish tracked to the spawning grounds at Hatchery Creek, only 49 were logged multiple times. Radio-tagged fish entered Hatchery Creek in three pulses associated with increased precipitation and stream discharge during 28–31 August, 4–7 September, and 14–21 September (Figure 9). Both male and female fish had an average stream life of 11.2 days (Table 5).

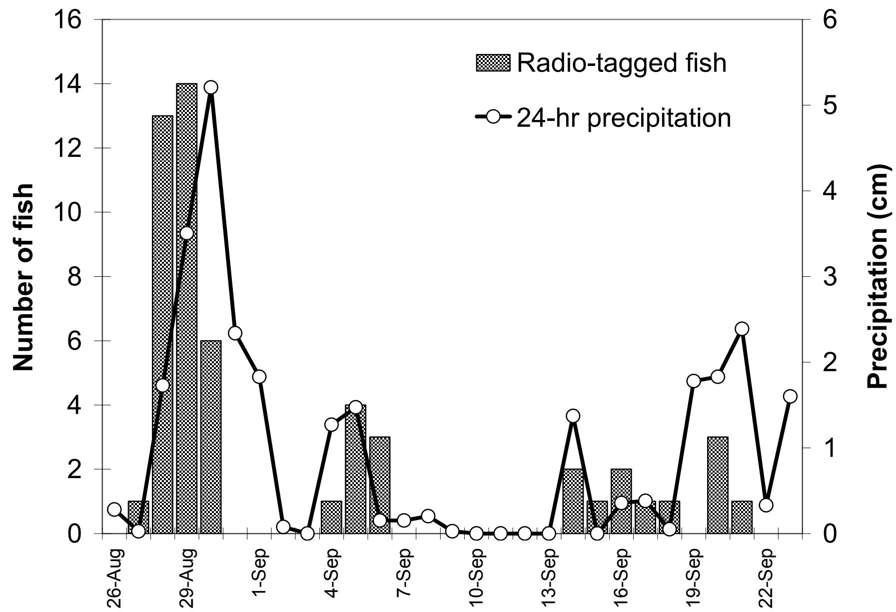


Figure 9.–Number of radio-tagged fish recorded on day of entry at the Hatchery Creek logging station compared to precipitation recorded during previous 24 hours at McDonald Lake, 2007.

Table 5.–Estimated stream life of radio-tagged sockeye salmon at McDonald Lake, 2007.

Sex	Number of Radio Tags	Average Stream Life (Days)	SD	Maximum	Minimum
Male	20	11.2	7.4	23	1
Female	29	11.2	7.8	29	1
Both sexes combined	49	11.2	7.6	29	1

AGE COMPOSITION

In 2007, over 56% of the sockeye salmon sampled were age-2.3 and 39 % were age-1.3 (Table 6). The proportions of age 1.2 and age 2.2 fish in the escapement were very low, less than 5% of the total. We did not sample jack sockeye salmon for age in 2007.

Table 6.–Estimated age-class proportions of adult sockeye salmon at McDonald Lake, 2007.

	Age Class						
	1.2	1.3	1.4	2.2	2.3	2.4	Total
Proportion	2.8%	39.5%	0.1%	1.3%	56.1%	0.1%	100%
SE (N = 703)	0.6%	1.8%	0.1%	0.4%	1.9%	0.1%	

DISCUSSION

Our studies of the sockeye salmon escapement at McDonald Lake over the past three years have clearly demonstrated that the historical escapement estimates for McDonald Lake, based on a sum-of-surveys expansion factor, have been biased low. Although the 2007 sum-of-surveys escapement estimate of 29,160 was essentially the same as the mark-recapture estimate of 29,086, the historical sum-of-surveys escapement estimates in the previous two years accounted for only 53% (2006) and 75% (2005) of the mark-recapture estimates, and, overall, the historical method of estimating the escapement accounted for an average of 82% of the total escapement (Table 4). The historical expansion factor was based on only two years of comparisons between foot surveys and weir counts (1983 and 1984); it is unlikely that two years of comparisons was enough to capture the variation that probably exists in observer estimates over varying run-sizes and environmental conditions at McDonald Lake.

Hind-cast escapement estimates based on linear regression models that incorporated all six years of available foot-survey-to-total-escapement comparisons were much improved over estimates based on the historical method (Tables 3 and 4). Models based on the peak survey count were generally more precise than models based on the sum-of-surveys method (Tables 3 and 4; Figure 8); however, the best predictor of the escapement was the peak survey, multiple-regression model (Model P3) that incorporated an index of annual September precipitation. Hind-cast escapement estimates based on that model accounted for an average of 100% of the total escapement, and were much less variable; e.g., estimates were within 20% of the observed escapement in all six years (CV = 13%; Table 4, Figure 8). We recommend that historical escapement estimates should be recast using this peak survey model (see Appendix D).

Expansion of peak survey counts has been used extensively to estimate Chinook salmon escapements in Southeast Alaska (McPherson et al. 2003, Pahlke 2007). At the Little Tahltan River (Bernard et al. 2000) and the Blossom River (Weller et al. 2007), multiple expansion factors were used to account for environmental conditions: a larger expansion factor was used when survey conditions (based on stream flow and water clarity) were "normal" or "poor," and a smaller expansion factor was used when conditions were "excellent." Environmental factors can affect the number of fish visible to surveyors (Cousens et al. 1982). Rainfall, and the accompanying rise in water levels and decreased water clarity, not only affects the ability of observers to accurately estimate the numbers of fish in a stream, the amount of rainfall over the spawning period can affect the run-timing of fish; greater water flow would cause the run to be less protracted with a more pronounced peak, and relatively more fish would be present in the stream exactly when survey conditions are less than optimal. This can be seen to some degree in our foot surveys at McDonald Lake; peak surveys account for a higher proportion of the run in years of higher precipitation, whereas the peak survey is less pronounced and the run appears more protracted in years of lower precipitation (Figure 10). Observers tend to estimate a smaller portion of the fish actually present as the number of fish increases (Jones et al. 1998). The same phenomenon likely occurs with visual estimates of sockeye salmon at McDonald Lake.

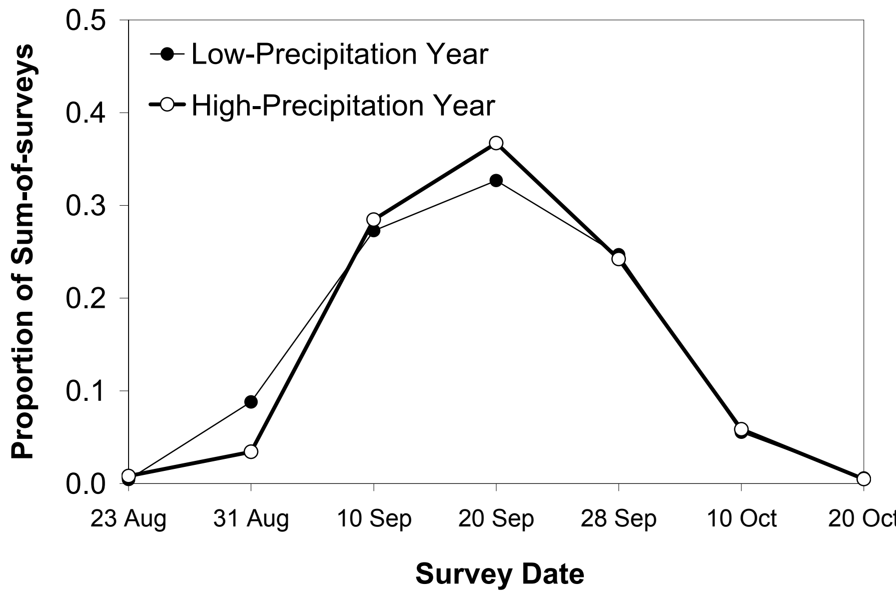


Figure 10.–Average run-timing of McDonald Lake sockeye salmon into the spawning stream based on foot surveys of Hatchery Creek, for years of lower precipitation (11 in. or less; 1983, 1984, 2007) compared to years of higher precipitation (15 in. or more; 1981, 2005, and 2006).

We had originally intended to use stream life data to develop an area-under-the-curve (AUC) escapement estimate in 2007. Our stream life estimates in 2007 were imprecise (Table 5) and based on a small sample size of radio-tagged fish that were not distributed evenly through the spawning period (Figure 9). AUC estimates are sensitive to variation in stream life, and stream life can vary annually within a single system (Dangel and Jones 1988, Perrin and Irvine 1990, Bue et al. 1998) in response to annual changes in water temperature and flow (Fukushima and Smoker 1997). Bue et al. (1998) and English et al. (1992) cautioned that stream life should be based on annual estimates and not treated as a constant. Annual estimates of observer efficiency and stream life would require considerable effort, and it does not seem likely that the AUC method would provide improved escapement estimates over those we obtained based on the peak survey models we developed here.

Lake-spawning has been observed at many other lakes in Southeast Alaska, including Kook, Kanalku, and Sitkoh (Conitz and Cartwright 2005), Chilkoot (Bachman and Sogge 2006), Chilkat (pers. obs.), Virginia (Cady 2004), Hetta (Cartwright et al. 2005), and Falls (Conitz and Cartwright 2007), so it should be no surprise to find lake spawners at McDonald Lake. Lake-spawning sockeye salmon typically spawn later than tributary spawners within a single water system and spawning areas are usually associated with upwelling ground water (see Burgner 1991). In 2007, active lake spawning was not observed at McDonald Lake until 26 September, approximately four weeks after spawning began in Hatchery Creek. Lake spawners were found in shallow water near the mouths of very small, intermittent creeks, where they were probably attracted to upwelling ground water. Genetic analysis of other sockeye salmon runs have shown that differences in spawning time and behavior reflect genetic differences (Wilmot and Burger 1985, Burger et al. 1997), and lake spawners and tributary spawners represent discrete populations within the same system (Varnavskaya et al. 1994, Burger et al. 2001).

Peak survey models provided reasonable estimates of the escapement at McDonald Lake for the six years that we have comparisons. We must assume that models developed to expand foot survey counts to total population estimates (i.e., the number of fish that entered McDonald Lake) account for low levels of lake spawning. If both marked and unmarked fish spawned in the lake in the same proportion as tributary spawners, our mark-recapture estimate would be an estimate of the total population size at the time of tagging (Schwarz and Taylor 1998), including lake spawners. In our study, 10% of the radio-tagged fish tracked to spawning areas were ultimately located near lake spawning areas on the eastern shore of the lake where they all died in deep water. Two of the radio-tagged fish were located within 30 m, and four within 150 m, of active spawning areas. We assumed they all spawned in the lake; however, this was not certain because schools of sockeye salmon also staged in the lake near the east shore spawning area until they eventually moved to Hatchery Creek to spawn. Lake spawning areas in the Bristol Bay region were primarily in water 3–4 m deep, but some fish spawned as deep as 30 m (Burgner 1991). McDonald Lake is heavily stained and it is not possible to detect lake spawners in depths greater than 3 m. There is no question that the McDonald Lake sockeye salmon run comprises lake-spawning and tributary-spawning populations; however, more intensive studies (e.g., Burger et al. 1995) would be needed to determine the annual magnitude of lake spawning in the system.

RECOMMENDATIONS

1. We recommend that the peak survey regression model that incorporates September precipitation be used to estimate the annual escapement of sockeye salmon to McDonald Lake, rather than the historical sum-of-surveys expansion factor. Historical escapement estimates should be recast using this peak survey model (Appendix D). We also recommend reducing the number of foot surveys conducted during the season to three surveys conducted on 10, 20, and 28 September to capture the peak of the run.
2. Mark-recapture studies, coupled with radiotelemetry, should be conducted periodically to estimate the sockeye salmon population over a series of run sizes and precipitation levels. We recommend that radio-telemetry studies be designed to provide adequate estimates of the magnitude and timing of lake spawning.

REFERENCES CITED

Arnason, A. N., C. W. Kirby, C. J. Schwarz, and J. R. Irvine. 1996. Computer analysis of data from stratified mark-recovery experiments for estimation of salmon escapements and other populations. Canadian Technical Report of Fisheries and Aquatic Sciences 2106.

Bachman, R. L., and M. M. Sogge. 2006. Chilkoot River weir results 1999–2003. Alaska Department of Fish and Game, Fishery Data Series No. 06-30, Anchorage.

Bernard, D. R., S. A. McPherson, K. A. Pahlke, and P. Etherton. 2000. Optimal production of chinook salmon from the Stikine River. Alaska Department of Fish and Game, Fishery Manuscript No. 00-01, Anchorage.

Bue, B. G., S. M. Fried, S. Sharr, D.G. Sharp, J.A. Wilcock, and H.J. Geiger. 1998. Estimating salmon escapement using area-under-the curve, aerial observer efficiency, and stream-life estimates: the Prince William Sound example. North Pacific Anadromous Fisheries Commission Bulletin Number 1.

Burger, C. V., J. E. Finn, and L. Holland-Bartels. 1995. Pattern of shoreline spawning by sockeye salmon in a glacially turbid lake: evidence for subpopulation differentiation. Transactions of the American Fisheries Society 124:1–15.

Burger, C. V., W. J. Spearman, and M. A. Cronin. 1997. Genetic differentiation of sockeye salmon subpopulations from a geologically young Alaskan lake system. Transactions of the American Fisheries Society 126:926–938.

Burger, C. V., K. T. Scribner, W. J. Spearman, C. O. Swanton, and D. E. Campton. 2001. Genetic contribution of three introduced life history forms of sockeye salmon to colonization of Frazer Lake Alaska. Canadian Journal of Fisheries and Aquatic Sciences 57:2096–2111.

Burgner, R. L. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). *In* C. Groot and L. Margolis [editors.] Pacific Salmon Life Histories. UBC Press, Vancouver, British Columbia.

Cady, T. 2004. Migration patterns and spawning site selection by Virginia Lake sockeye salmon and final conclusions for fishery management. USFWS Office of Subsistence Management, Fisheries Resource Monitoring Program, Annual Report No. FIS01-179-3, Anchorage.

Cartwright, M. A., J. M. Conitz, R. W. Bale, K. S. Reppert, and B. A. Lewis. 2005. Hetta Lake sockeye salmon (*Oncorhynchus nerka*) stock assessment project: 2003 annual report and 2001–2003 final report. Alaska Department of Fish and Game, Fishery Data Series No. 05-33, Anchorage.

Conitz, J. M., and M. A. Cartwright. 2005. Kanalku, Sitkoh, and Kook Lakes subsistence sockeye salmon project: 2003 annual report and 2001–2003 final report. Alaska Department of Fish and Game, Fishery Data Series No. 05-57, Anchorage.

Conitz, J. M., and M. A. Cartwright. 2007. Falls Lake subsistence sockeye salmon project 2004 annual report. Alaska Department of Fish and Game, Fishery Data Series No. 07-47, Anchorage.

Conover, W. J. 1999. Practical nonparametric statistics, 3rd edition. John Wiley and Sons, Inc., New York.

Cousens, N. B. F., G. A. Thomas, C. G. Swann, and M. C. Healey. 1982. A review of salmon escapement estimation techniques. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1108.

Clutter, R., and L. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. Bulletin of the International Pacific Salmon Fisheries Commission 9, New Westminster, British Columbia.

Dangel, J. R., and J. D. Jones. 1988. Southeast Alaska pink salmon total escapement and stream life studies, 1987. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 1J88-24., Juneau.

Eiler, J. H. 1990. Radio Transmitters used to study salmon in glacial rivers. American Fisheries Society Symposium 7:364–369.

English, K. K., R. C. Bocking, and J. R. Irvine. 1992. A robust procedure for estimating salmon escapement based on the area-under-the-curve method. Canadian Journal of Fisheries and Aquatic Sciences 49:1982–1989.

Fukushima, M., and W. W. Smoker. 1997. Determinants of stream life, spawning efficiency, and spawning habitat in pink salmon in the Auke Lake system, Alaska. Canadian Journal of Fisheries and Aquatic Sciences. 54:96–104.

Gazey, W. J., and K. K. English. 2000. Assessment of sockeye and pink salmon stocks in the northern boundary area using run reconstruction techniques, 1982–1995. Can. Tech. Rep. Fish. and Aquatic Sciences No. 2320, Vancouver.

Heinl, S. C., A. W. Piston, T. A. Johnson, and H. J. Geiger. 2008. Sockeye salmon mark-recapture and radio telemetry studies at McDonald Lake, 2005–2006. Alaska Department of Fish and Game, Fishery Data Series No. 08-42, Anchorage.

Hilborn, R., and M. Mangel. 1997. The Ecological Detective: Confronting Models with Data. Princeton University Press, Princeton.

Hoffman, S. H., L. Talley, and M. C. Seibel. 1983. 1982 U.S./Canada research pink and sockeye salmon tagging, interception rates, migration patterns, run timing, and stock intermingling in southern Southeast Alaska and Northern British Columbia. *In*: Final Report 1982 salmon research conducted in Southeast Alaska by the Alaska Department of Fish and Game in conjunction with joint U.S.-Canada Interception investigations. Contract No. NASO-82-00134.

Hoffman, S .H., L. Talley, and M. C. Seibel. 1984. 1983 sockeye and chum salmon tagging, notional contribution rates, migration patterns, run timing, and stock intermingling research in southern Southeast Alaska and northern British Columbia. *In* Final Report. 1983 salmon research conducted in Southeast Alaska by the Alaska Department of Fish and Game in conjunction with National Marine Fisheries Service Auke Bay Laboratory for joint U.S.-Canada Interception Studies. Contract No. WASC-83-ABC-00157.

International North Pacific Fisheries Commission (INPFC). 1963. Annual Report 1961. Vancouver, British Columbia.

Johnson, T., S. C. Heinl, and H. J. Geiger. 2005. McDonald Lake: stock status report and escapement goal recommendations. Alaska Department of Fish and Game, Fishery Manuscript No. 05-07, Anchorage.

Jones, E. L. III, J. A. Weller, and A. B. Holm. 2001. Production of coho salmon from the Unuk River, 1999–2000. Alaska Department of Fish and Game, Fishery Data Series No. 01-14, Anchorage.

Pahlke, K. A. 2007. Escapements of Chinook salmon in Southeast Alaska and Transboundary Rivers in 2005. Alaska Department of Fish and Game, Fishery Data Series No. 07-62, Anchorage.

Perrin, C. J., and J. R. Irvine. 1990. A review of survey life estimates as they apply to the area-under-the-curve method for estimating the spawning escapement of Pacific salmon. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1733.

McLachlan, G.J., and T. Krishnan. 1997. The EM Algorithm and Extensions. John Wiley and Sons, Inc., New York.

McPherson, S., D. R. Bernard, J. Clark, K. Pahlke, E. Jones, J. Der Hovanisian, J. Weller, and R. Ericksen. 2003. Stock status and escapement goals for Chinook salmon stocks in Southeast Alaska. Alaska Department of Fish and Game, Division of Sport Fish, Special Publication No. 03-01.

Murphy, B. R., and D. W. Willis, editors. 1996. Fisheries Techniques, 2nd ed. American Fisheries Society, Bethesda.

Olson, R. P. 1989. Effects of Lake Fertilization on Growth of Juvenile Sockeye Salmon (*Oncorhynchus nerka*) in Lake McDonald, Tongass National Forest, Alaska. Masters Thesis. Humboldt State University, Arcata.

Orth, D. J. 1967. Dictionary of Alaska place names. Geological Survey Professional Paper 567. United States Government Printing Office, Washington D. C.

Ramstad, K. M., and C. A. Woody. 2003. Radio tag retention and tag-related mortality among adult sockeye salmon. North American Journal Fisheries Management 23: 978–982.

Schwarz, C. J. and C. G. Taylor. 1998. Use of the stratified-Petersen estimator in fisheries management: estimating the number of pink salmon (*Oncorhynchus gorbuscha*) spawners in the Fraser River. Canadian Journal of Fisheries and Aquatic Sciences 55: 281–296.

Seber, G.A.F. 1982. On the estimation of animal abundance and related parameters, 2nd ed. Charles Griffin and Sons, Ltd., London.

Thompson, S.K. 2002. Sampling. John Wiley and Sons, Inc., New York.

Varnavskaya, N. V., C. C. Wood, R. J. Everett, R. L. Wilmot, V. S. Varnavsky, V. V. Midanaya, and T. P. Quinn. 1994. Genetic differentiation of subpopulations of sockeye salmon (*Oncorhynchus nerka*) within lakes of Alaska, British Columbia, and Kamchatka, Russia. Canadian Journal of Fisheries and Aquatic Sciences 51 (supplement 1):147–157.

Weller, J. L., E. L. Jones III and A. B. Holm. 2005 Production of coho salmon from the Unuk River, 2002–2003. Alaska Department of Fish and Game, Fishery Data Series No.05-21, Anchorage.

Weller, J. L., D. L. Magnus, D. J. Reed, and K. Pahlke. 2007. A mark-recapture experiment to estimate the escapement of Chinook salmon in the Blossom River, 2006. Alaska Department of Fish and Game, Fishery Data Series No. 07-66, Anchorage.

Wilmot, R. L., and C. V. Burger. 1985. Genetic differences among populations of Alaskan sockeye salmon. Transactions of the American Fisheries Society 114:236–243.

REFERENCES CITED (Continued)

Woolsey, J., M. Holcomb, and R. Ingermann. 2004. Effect of temperature on clove oil anesthesia in steelhead fry. North American Journal of Aquaculture 66: 35–41.

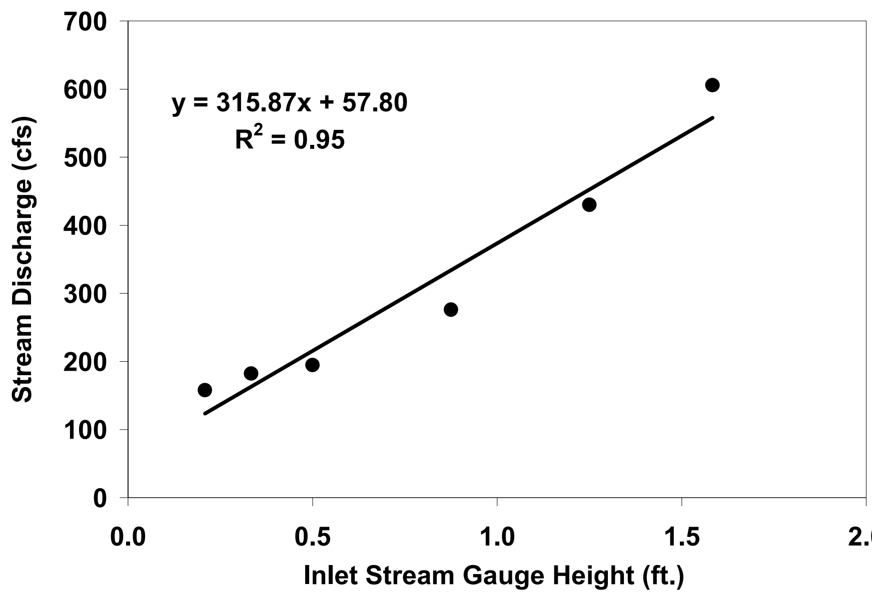
Young, D. 2005. Distribution and characteristics of sockeye salmon spawning habitats in Lake Clark watershed, AK. National Park Service. Technical report NPS/NRWRR/NRTR-2005/338.

Zadina, T. P., and S. C. Heinl. 1999. Limnological and fisheries investigations at McDonald Lake, Southeast Alaska, 1998. Alaska Department of Fish and Game, Division of Commercial Fisheries Regional Information Report 1J99-15, Juneau.

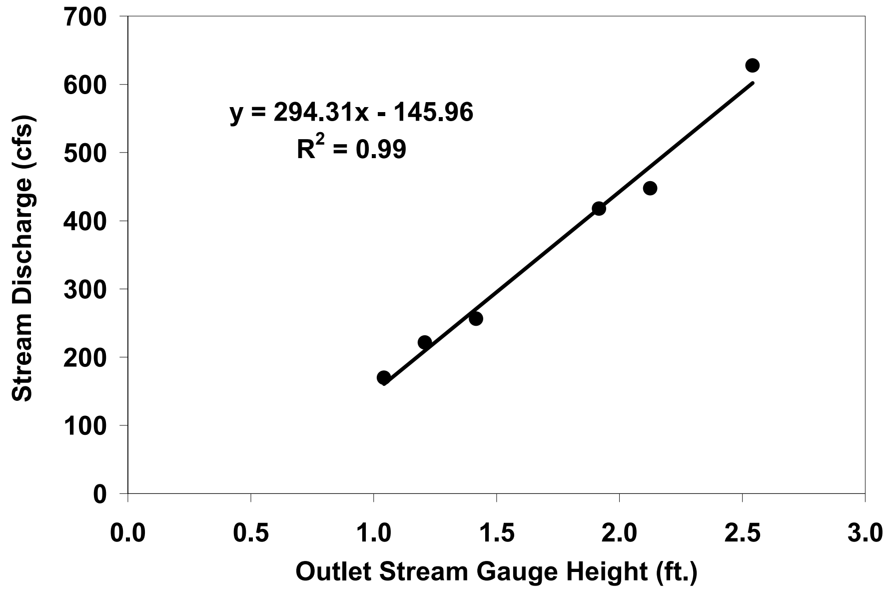
APPENDIX A. ESTIMATE OF DAILY STREAM DISCHARGE

Appendix A1.–Estimate of stream discharge (cubic feet per second) compared to stream gauge height at the inlet (Hatchery Creek) and outlet (Wolverine Creek) streams, McDonald Lake, 2007.

Stream	Date	Stream Gauge Height (feet)	Estimated Stream Discharge (cfs)
Hatchery Creek (Inlet)	23-Jul-07	1.6	606
	1-Aug-07	0.9	276
	8-Aug-07	0.5	195
	17-Aug-07	0.2	158
	27-Aug-07	0.3	182
	6-Sep-07	1.3	430
Wolverine Creek (Outlet)	21-Jul-07	2.1	448
	1-Aug-07	1.9	418
	8-Aug-07	1.4	256
	17-Aug-07	1.0	170
	27-Aug-07	1.2	222
	7-Sep-07	2.5	628



Appendix A2.–Regression of estimated stream discharge (cubic feet per second) on stream height (feet) at the inlet stream (Hatchery Creek), McDonald Lake, 2007.



Appendix A3.–Regression of estimated stream discharge (cubic feet per second) on stream height (feet) at the outlet stream (Wolverine Creek), McDonald Lake, 2007.

APPENDIX B. SOCKEYE SALMON DAILY MARK AND RECOVERY DATA

Appendix B1.–Daily number of sockeye salmon spaghetti-tagged and fin-clipped by sex, number fixed with radio tags, and number of fish released unmarked at the outlet of McDonald Lake, 2007.

Date	Number of Males Marked	Number of Females Marked	Number of Radio tags Released	Number of Fish Released Untagged
07/21/07	1	0	0	0
07/22/07	1	0	0	0
07/23/07	4	0	1	0
07/24/07	1	2	0	0
07/25/07	3	0	3	0
07/26/07	8	7	3	0
07/27/07	0	3	0	0
07/28/07	7	17	0	0
07/29/07	1	5	0	0
07/30/07	8	26	3	0
07/31/07	3	20	1	0
08/01/07	6	26	1	0
08/02/07	1	21	2	1
08/03/07	2	27	2	0
08/04/07	0	6	0	0
08/05/07	7	14	3	0
08/06/07	2	13	1	0
08/07/07	0	6	3	0
08/08/07	1	7	2	0
08/09/07	11	32	2	0
08/10/07	10	54	2	0
08/11/07	13	38	0	0
08/12/07	6	14	2	0
08/13/07	3	19	2	0
08/14/07	23	50	2	0
08/15/07	6	21	2	3
08/16/07	9	18	2	1
08/17/07	23	31	2	1
08/18/07	22	42	2	2
08/19/07	8	18	2	1
08/20/07	4	9	2	1
08/21/07	5	8	2	0
08/22/07	5	10	2	0
08/23/07	5	10	2	0
08/24/07	10	13	2	0
08/25/07	17	11	2	0
08/26/07	13	23	2	0
08/27/07	13	16	2	0
08/28/07	15	14	2	0
08/29/07	22	25	2	3

-continued-

Appendix B1.–Page 2 of 2.

Date	Number of Males Marked	Number of Females Marked	Number of Radio tags Released	Number of Fish Released Untagged
08/30/07	2	0	1	0
08/31/07	2	0	2	0
09/01/07	1	2	1	0
09/02/07	9	4	0	2
09/03/07	2	0	0	0
09/04/07	8	1	0	0
09/05/07	7	1	0	0
09/06/07	7	2	0	2
09/07/07	11	6	0	0
09/08/07	6	2	0	4
09/09/07	9	7	0	3
09/10/07	7	4	0	4
09/11/07	5	0	0	2
09/12/07	2	0	0	1
09/13/07	1	4	0	0
09/14/07	2	0	0	4
09/15/07	0	1	0	1
Total	380	710	69	36

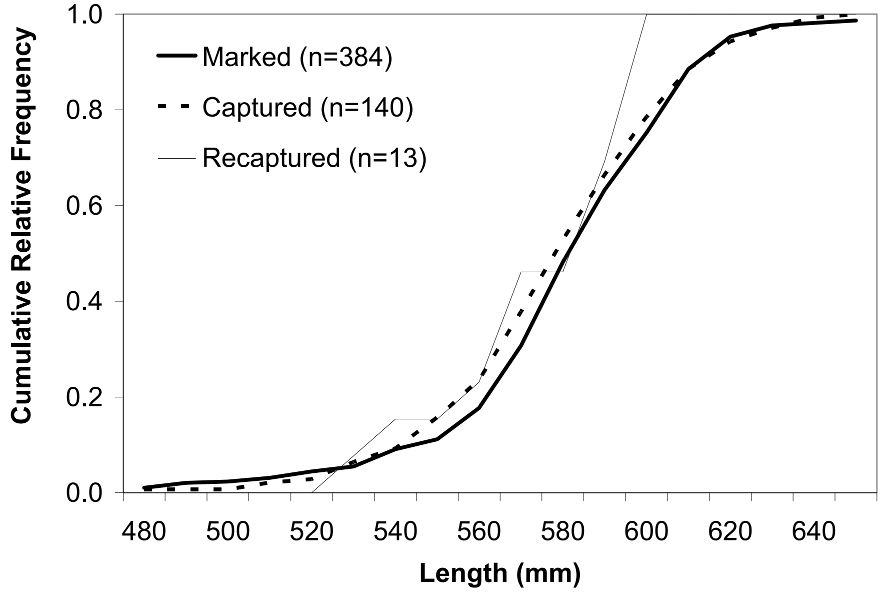
Appendix B2.–Daily number of tagged fish recovered by release strata, number of recovered fish that had lost their tag, and total number of carcasses sampled for tags at the spawning stream at McDonald Lake, 2007.

	Number of Tagged Fish Recovered							
Recovery Date	1 Jul–11 Aug	12 Aug–20 Aug	21 Aug–15 Sep	Number Lost Tag	Number Unmarked	Total Sampled	Total Males Sampled	Total Females Sampled
1-Sep-07					6	6	2	4
2-Sep-07	1		1		19	21	5	16
3-Sep-07					17	17	11	6
4-Sep-07					22	22	15	7
5-Sep-07		1			35	36	17	19
6-Sep-07	3				20	23	15	8
7-Sep-07			1		23	24	16	8
8-Sep-07	1	1	1		65	68	41	27
9-Sep-07	3	1	1		106	111	77	34
10-Sep-07		1	1		123	125	87	38
11-Sep-07	9	1	1		178	189	111	78
12-Sep-07	4	3			193	200	113	87
13-Sep-07	1	1	2	5	249	258	136	122
14-Sep-07	4	7	2	2	524	539	272	267
15-Sep-07	5	8	2		413	428	213	215
16-Sep-07	11	6	1	2	404	424	198	226
17-Sep-07	9	8	4	1	616	638	318	320
18-Sep-07	5	7	2	4	836	854	325	529
19-Sep-07	6	4	2	1	488	501	120	381
20-Sep-07	3	8	7	2	640	660	221	439
21-Sep-07	1	1	1		175	178	71	107
22-Sep-07	2	4	2	1	346	355	180	175
23-Sep-07	8	4	5	4	490	511	161	350
24-Sep-07	5	2	3	2	262	274	97	177
25-Sep-07	1	1		1	68	71	22	49
26-Sep-07	5	1	1	2	374	383	104	279
27-Sep-07	3	2	7	4	341	357	126	231
28-Sep-07	5	9	4	2	587	607	186	421
29-Sep-07	5	10	11	9	1,071	1,106	300	806
30-Sep-07	7	13	9	9	822	860	256	604
1-Oct-07	1	4	7	1	292	305	45	260
2-Oct-07	5	3	2	2	306	318	97	221
3-Oct-07	3	3	3	3	168	180	45	135
4-Oct-07		5	4	6	673	688	143	545
5-Oct-07						0		
6-Oct-07		3	4	3	185	195	31	164
7-Oct-07						0		
8-Oct-07						0		
9-Oct-07	2	4	4		532	542	69	473
Total	118	126	95	66	11,669	12,074	4,246	7,828

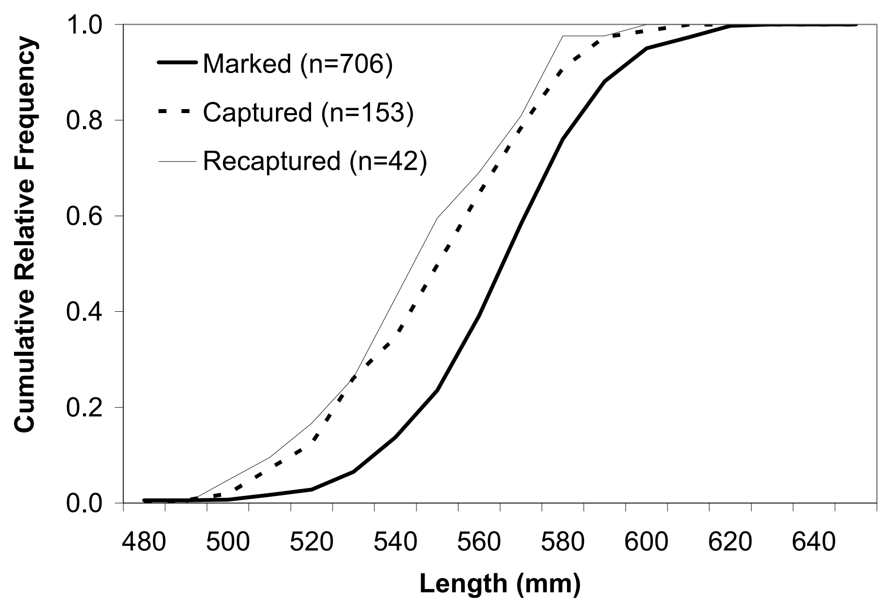
APPENDIX C. TESTS FOR SIZE-SELECTIVE SAMPLING BIAS

Appendix C1.–Kolmogorov-Smirnov test statistics for analysis of size-selective sampling of sockeye salmon at McDonald Lake, 2007. Size was mideye-to-fork length (mm).

Hypothesis Test	Sample Size (*n*)	*D* Statistic	*P* Value	Result
Female 1. There is no size difference between females marked (*m*) in Event 1, and females captured (*c*) and sampled for marks in Event 2.	*m*(706) *c* (153)	0.29	0.00	Reject
Female 2. There is no size difference between females marked (*m*) in Event 1, and marked females recaptured (*r*) in Event 2.	*m*(706) *r*(42)	0.40	0.00	Reject
Female 3. There is no size difference between females captured (*c*) and sampled for marks in Event 2, and marked females recaptured (*r*) in Event 2.	*c*(153) *r*(42)	0.13	0.70	Not sufficient evidence
Male 1. There is no size difference between males marked (*m*) in Event 1, and males captured (*c*) and sampled for marks in Event 2.	*m*(384) *c*(140)	0.08	0.56	Not sufficient evidence
Male 2. There is no size difference between males marked (*m*) in Event 1, and marked males recaptured (*r*) in Event 2.	*m*(384) *r*(13)	0.26	0.31	Not sufficient evidence
Male 3. There is no size difference between males captured (*c*) and sampled for marks in Event 2, and marked males recaptured (*r*) in Event 2.	*c*(140) *r*(13)	0.24	0.49	Not sufficient evidence



Appendix C2.–Cumulative relative frequencies of male sockeye salmon marked during Event 1 at McDonald Lake in 2007, compared to males captured and examined for marks on the spawning grounds in Event 2, and marked males recaptured in Event 2.



Appendix C3.–Cumulative relative frequencies of female sockeye salmon marked during Event 1 at McDonald Lake in 2007, compared to females captured and examined for marks on the spawning grounds in Event 2, and marked females recaptured in Event 2.

APPENDIX D. ESTIMATED SOCKEYE SALMON ESCAPEMENT TO MCDONALD LAKE, 1980–2007

Appendix D1.–Estimated sockeye salmon escapement to McDonald Lake, 1980–2007.

The best predictor of the McDonald Lake sockeye salmon escapement was the peak survey, multiple-regression Model P3 that incorporated an index of annual September precipitation (Table 3):

$$\hat{Y} = (-33283) + (4.8)(E) + (2375)(T) + \sigma , \tag{1}$$

where $\hat{Y}$ is the estimated total escapement, E is the annual peak foot-survey estimate, T is the index of precipitation during September, and σ is standard deviation. We recast the McDonald Lake sockeye salmon escapements from 1980 to 2007 using this model (Appendix Table D1). No peak survey was conducted in 1987, due to poor weather. In that case, we regressed the peak survey values on surveys conducted on 10 September (prior to the peak), and used that relationship to impute the missing peak value for 1987. Similarly, September precipitation was not available from the Ketchikan airport NOAA recording station for 1980, 1987, and 1988. We regressed precipitation at the Ketchikan airport on precipitation recorded at the nearby Beaver Falls NOAA recording station, and used that relationship to impute precipitation values for those years.

Appendix D2.–Annual peak live count of sockeye salmon at McDonald Lake, precipitation index, and estimated annual escapement of sockeye salmon compared to the historical escapement series (1980–2007), and to the observed escapement from weir counts (1981, 1983, and 1984) and mark-recapture studies (2005–2007).

Year	Peak Live Count	September Precipitation[a]	Estimated Escapement	80% Confidence Interval Lower Bound	80% Confidence Interval Upper Bound	Historical Escapement Estimate[b]	Observed Escapement
1980	19,500	**10.8**	86,285	71,746	103,770	74,732	
1981	23,050	21.8	129,129	107,371	155,296	78,709	129,653
1982	13,200	8.6	50,942	42,358	61,264	49,716	
1983	15,000	10.9	65,089	54,122	78,279	54,989	56,142
1984	27,100	9.7	119,783	99,600	144,056	123,766	121,224
1985	27,300	9.3	119,667	99,503	143,916	100,655	
1986	25,400	11.0	114,660	95,341	137,895	94,581	
1987[c]	**23,635**	22.3	133,116	110,687	160,091	187,173	
1988	25,000	12.3	115,891	96,364	139,375	67,486	
1989	24,000	6.5	97,358	80,954	117,087	75,704	
1990	33,600	6.5	143,050	118,947	172,038	112,974	
1991	34,300	6.0	145,147	120,691	174,560	166,267	
1992	28,300	23.3	157,624	131,065	189,565	99,828	
1993	37,000	2.8	150,542	125,176	181,048	79,729	
1994	32,700	18.2	166,527	138,468	200,272	104,960	
1995	16,130	4.5	55,103	45,819	66,270	44,052	
1996	16,865	13.7	80,449	66,893	96,751	61,932	
1997	13,900	**19.5**	80,160	66,653	96,403	68,462	
1998	12,793	**9.6**	51,447	42,778	61,872	57,501	
1999	22,540	20.1	122,729	102,049	147,598	89,609	
2000	25,605	17.3	130,763	108,730	157,260	90,627	
2001	11,656	21.8	74,938	62,312	90,124	42,768	
2002	8,000	15.3	42,102	35,008	50,633	25,776	
2003	20,353	19.4	110,633	91,992	133,052	89,243	
2004	5,920	13.8	28,759	23,913	34,586	21,279	
2005	10,375	15.3	53,477	44,467	64,314	45,964	61,043
2006	5,153	18.4	35,842	29,802	43,105	16,764	31,357
2007	7,100	10.0	25,185	20,941	30,289	29,168	29,086

[a] September precipitation recorded at the Ketchikan airport NOAA recording station. Precipitation records were not available for 1980, 1997, and 1998; missing values were imputed.
[b] The historical estimates are the sockeye salmon escapement estimates based on the sum-of-survey expansion used at McDonald Lake since 1985 (Johnson et al. 2005).
[c] The peak survey for 1987 was imputed, because no peak foot survey was conducted at McDonald Lake in 1987; the missing value was imputed based on other surveys conducted that year.