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Sockeye Salmon Mark-Recapture and Radio Telemetry Studies at McDonald Lake, 2005–2006

by

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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)

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

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by

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ABSTRACT

Since 1985, a standardized series of foot surveys has been used to estimate the escapement of sockeye salmon at McDonald Lake. Through run reconstruction, these escapement estimates formed the basis for the commercial catch estimates as well, and formed the basis for the current escapement goal for this system. To validate this historical time series, we conducted mark-recapture studies in 2005 and 2006 to estimate the escapement into McDonald Lake independently of the foot-survey escapement estimates. Additionally, in 2006, we radio tagged 70 adult sockeye salmon to look for lake spawning in the system, as lake spawners would be unobserved by the foot-survey crew. We found no evidence of lake spawning, although a surprisingly large number of the radio tagged fish (29%) were unaccounted for at the end of the study. The preliminary mark-recapture estimates of escapement in 2005 and 2006 were 61,000 (SE 6,300) and 31,000 (SE 3,000) respectively—much larger than the foot-survey estimates of 46,000 and 17,000 sockeye salmon. We concluded that the historical escapement time series is useful for tracking trends in escapement level, but that this time series may not be adjusted to the current escapement magnitude. We recommend that a minimum of three more years of mark-recapture estimates be undertaken to support the two preliminary estimates from this study, before using mark-recapture estimates to recalibrate the escapement series. That recommendation is based on the fact that the current calibration factor seems to have been based on too few years of observation.

Key words: area-under-the-curve methods, escapement, mark-recapture, McDonald Lake, *Oncorhynchus nerka*, radio tracking, scaled foot counts, sockeye salmon, Southeast Alaska.

INTRODUCTION

McDonald Lake, located on the Southeast Alaska mainland, approximately 70 km north of Ketchikan (Figure 1), is the largest sockeye salmon (*Oncorhynchus nerka*) producing system in southern Southeast Alaska. The McDonald Lake sockeye salmon run is the only southern Southeast Alaskan sockeye salmon stock that the Northern Boundary Technical Committee of the Pacific Salmon Commission specifically accounts for under the harvest allocation agreement outlined in the U.S.-Canada Pacific Salmon Treaty (English et al. 2004). This stock has contributed substantially to the mixed-stock commercial seine and drift gillnet fisheries of southern Southeast Alaska, and from 1993 to 2003 it was the target of a near-terminal purse seine fishery in upper west Behm Canal (Johnson et al. 2005). The system has also supported an important personal use fishery in Yes Bay, and a small sport fishery in Wolverine (outlet stream) and Hatchery (inlet stream) creeks (Figure 1).

The first attempts to systematically enumerate the escapement of sockeye salmon into McDonald Lake occurred in the early 1980s. From 1981 to 1984, 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, Hoffman et al. 1984). The weir was a tri-pod, channel, and picket design, with an upstream trap for enumerating and sampling salmon. The weir was placed on soft, sandy substrate on Wolverine Creek, in an area that was approximately 100m wide (Olson 1989). ADF&G field personnel recorded escapements of 130 thousand (1981), 16 thousand (1982; undercount due to fish passing through the weir during high water), 56 thousand (1983), and 121 thousand (1984; Bergander 1989; Johnson et al. 2005). The large size of the first escapement count surprised biologists at the time, because they believed the run was severely depressed and were preparing to “restore” the run through lake fertilization. The weir was difficult to maintain; the area was prone to flooding, and high water flowed over the top of the weir in several years. Increased flow during high water also caused the sandy substrate to shift, resulting in questionable weir integrity. In 1982, these problems resulted in sockeye salmon circumventing the weir, and biologists considered the weir count a gross underestimate of the total escapement (Johnson et al. 2005). In 1984, small holes were found in the weir on 14 August

(ADF&G unpublished weir data). Although the weir crew felt that not many fish had escaped uncounted, nearly 35 thousand fish had been enumerated through the weir between 8 August, the last time the weir was inspected by a diver, and 14 August, when the holes were discovered. Although ADF&G biologists and weir personnel knew that fish passed through the weir uncounted, no attempt was made to validate weir counts through a mark-recapture or secondary estimate. We must conclude, therefore, that weir counts from the 1980s represent minimum escapement estimates.

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, then scaled, or calibrated, the surveys to the final weir counts in those years (Johnson et al. 2005). The foot surveys were used to develop a long-term, logistically and economically feasible escapement series for this system (Johnson et al. 2005).

Since 1985, the scaled foot surveys have been the sole means of estimating the sockeye salmon escapement to McDonald Lake. This scaled, foot-survey method is closely related to the area-under-the-curve approach (e.g., 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 several key parameters that vary annually (e.g., stream life or observer bias) are not observed and are assumed to be constant in the scaled foot-survey approach. The area-under-the-curve method has been much better studied and may be expected to have better statistical properties (Bue et al. 1998) than “peak-count” methods, which have been used to set other escapement goals in Southeast Alaska. Foot surveys have provided ADF&G with long-term escapement measurements and have been a reliable tool for tracking the trends in the escapement. Yet, with only two years of comparisons to unvalidated weir counts, we cannot be sure that the McDonald Lake series is scaled to a value that approximates the true escapement magnitude in any particular year (Johnson et al. 2005).

In implementing the foot surveys, biologist made the assumption that all spawning occured in the main inlet stream. However, we know that some sockeye salmon systems in Southeast Alaska support populations that spawn in the lake (Cartwright et al. 2005). It has been assumed that there is no lake spawning by sockeye salmon in McDonald Lake (Olson 1989), or that lake spawners composed only a very small portion of the run (T. Zadina, ADF&G, pers. comm.). In other systems, the use of radio telemetry has been used to determine lake spawning, mortality, residence time, and fish movement in the lake and on the spawning grounds (Viavant 1997, Wuttig and Evenson 2002). Radio telemetry has also been used to estimate handling mortality and to adjust mark-recapture estimates (Jones et al. 2001).

Improving our estimates of the sockeye salmon escapement at McDonald Lake has taken on increasing importance in recent years due to a decreasing trend in the escapement. From 1981 to 2000, the average estimated escapement, based on the calibrated foot surveys, was approximately 90 thousand sockeye salmon. From 2001 to 2006, these escapement estimates decreased to an average of 31 thousand sockeye salmon, and the lowest escapement ever observed, 17 thousand, occurred in 2006. The current sustainable escapement goal of 70 thousand to 100 thousand adult spawners (Johnson et al. 2005) has not been reached in five of the past six years, raising the possibility that the stock could merit status as a “management stock of 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).

Accurate McDonald Lake escapement estimates are very important because past harvest estimates 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). Most of the harvest contribution and distribution information for McDonald Lake sockeye salmon comes from coded wire tagging studies conducted by ADF&G. McDonald Lake sockeye salmon smolt were coded-wire tagged in 1982 and 1986–1988, and tagged adults were recovered from the commercial fisheries and spawning grounds in 1983–1985 and 1988–1991. The harvest rate was calculated by expanding sampled commercial fishery tag recoveries for the fraction of the return not tagged, based on the observed tag ratio in the escapement (Johnson et al. 2005).

We conducted a two-event mark-recapture study to estimate the escapement of sockeye salmon into McDonald Lake in 2005 and 2006. We also estimated the sockeye salmon escapement at McDonald Lake using the standardized foot-survey method that has been employed since 1985. This allowed us to make comparisons between the scaled foot-survey estimates and the mark-recapture estimates, with the intention of modifying our foot-survey calibration if necessary. 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 were examined for marks on the spawning grounds in Event 2. We regularly surveyed the lakeshore in 2005 in an attempt to determine if any significant lake spawning was occurring in the system. In 2006, we used a radio-telemetry study to determine the lake residence time, spawning stream life, and the mortality rate of tagged fish, and to document the occurrence of lake spawning. Here we report on the first results from those studies, and make recommendations for further studies to be carried out at the lake.

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^{o} 58' N, 131^{o} 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, Hatchery Creek (ADF&G stream number 101-80-10680-2030; also know as Walker Creek, Orth 1967), flows southwest 9.6 km to the head of the lake. Movement of salmon 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.

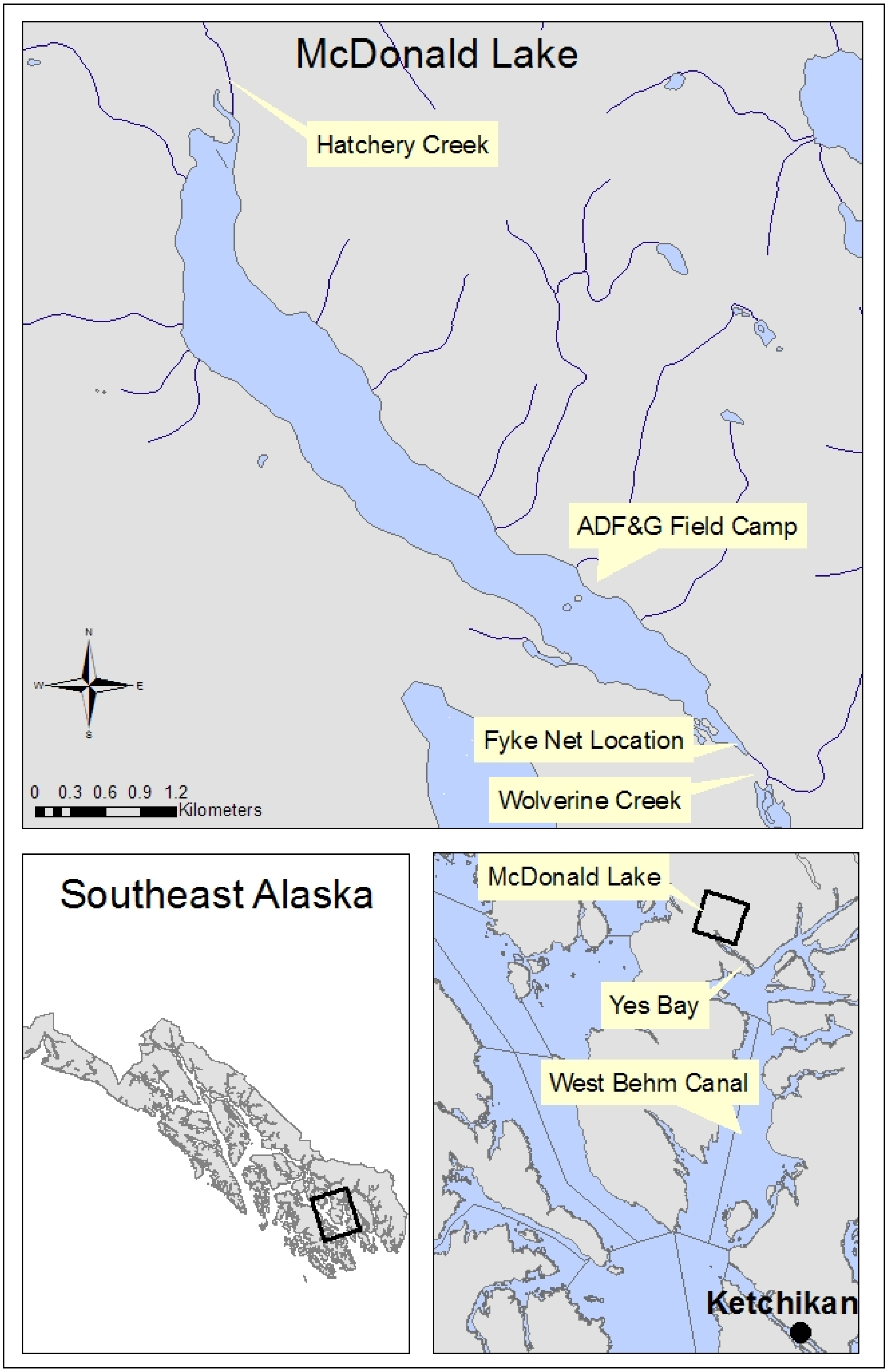

Figure 1.–The location of McDonald Lake, the fyke net, ADF&G field camp, and primary sockeye salmon spawning tributary (Hatchery Creek).

METHODS

MARK-RECAPTURE POPULATION ESTIMATE

Event 1: Marking at the Outlet of the Lake

Adult sockeye salmon were captured for sampling with a modified fyke net at the outlet of McDonald Lake from 8 July to 23 September in 2005 and 2006. The entire net was constructed of 3/8-inch nylon netting, and comprised three parts: an entrance, body, and wings (Figure 2). 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 wings were 8 feet high and 50 feet long, and attached to the vertical sides of the entrance of the fyke net. 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 in the morning, at noon, and in the evening before dark.

The sampling process began by pulling the cod end of the fyke net into the front of the boat and securing the first hoop in a vertical position; this allowed easy access to the fish (Figure 3). Sockeye salmon were dip-netted from the cod end of the fyke net, anesthetized in a clove oil solution, marked, sampled for age, sex, and length (mid-eye-to-fork to the nearest 5 mm), and released upstream to recover. One scale was taken from the preferred area (INPFC 1963) of each sockeye salmon, mounted on a gum card and prepared for age analysis as described by Clutter and Whitesel (1956). Each sockeye salmon was marked with a readily identifiable fin clip and the adipose fin was removed. Fish that appeared unhealthy were not marked. Marking was broken into thirds of the run based on the 1981–1984 run timing through the weir, and fin clips were applied on the following schedule: right ventral fin clip, 5 July–5 August; left ventral fin clip, 6–27 August; and partial dorsal fin clip, 28 August–23 September. Other species of fish and sockeye salmon < 400 mm MEF (jacks) were enumerated and released. In 2006, each sockeye salmon was additionally marked with a uniquely numbered T-bar tag, and every tenth sockeye salmon was fixed with a radio tag. Applying two different marks in 2006, fin-clips and T-bar anchor tags, allowed us to estimate the spawning population with two separate mark-recapture estimates.

Event 2: Mark-recovery on the spawning grounds

In 2005, we used two methods (beach seine and carcass sampling) to examine sockeye salmon at the spawning grounds for marks applied in Event 1. We captured live adult sockeye salmon with a beach seine and examined them for fin clips. The captured sockeye salmon were enumerated and marked with a left operculum punch that indicated the fish had been sampled. In addition, we sampled carcasses on the spawning grounds for fin clips and Event-2 operculum punches. All sampled carcasses were cut in half with a sharp knife to prevent re-sampling. Only carcasses without operculum punches were enumerated. In 2006, we sampled only carcasses for marks and did not sample live sockeye salmon.

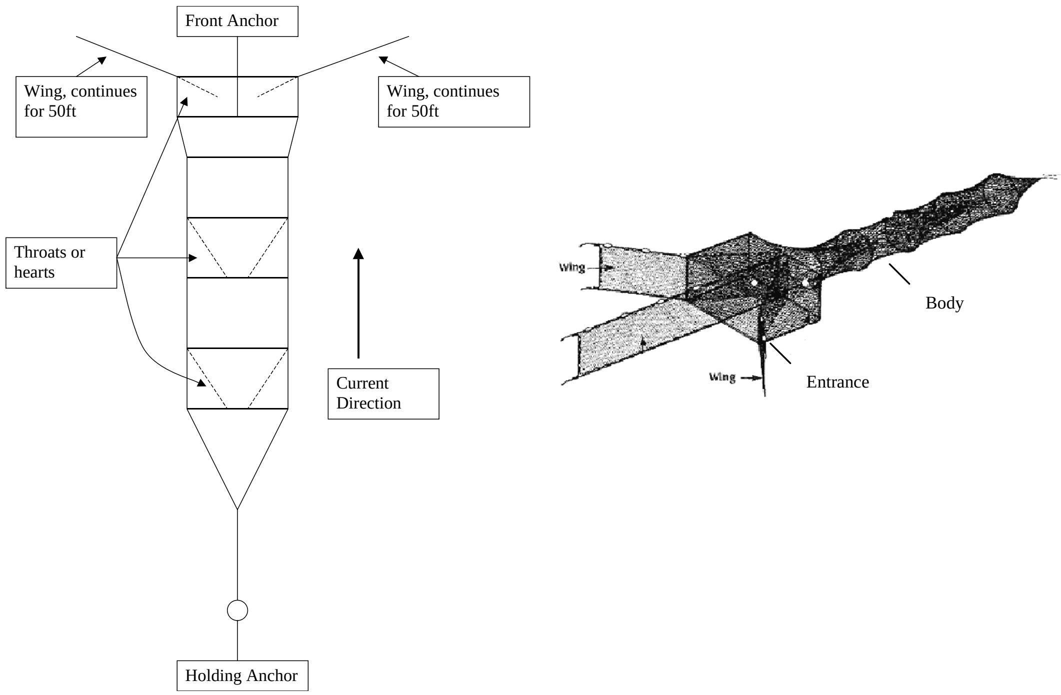

Figure 2.–Arrangement of the modified fyke net used to capture sockeye salmon at the outlet of McDonald Lake. (Note that this figure is not to scale.)

Figure 3.–This photograph illustrates how the cod-end of the fyke net was pulled onto the bow of a skiff for sampling under normal water conditions. The crew member in the bow of the boat is releasing trout that were dip netted from the cod end of the fyke net.

Carcasses were sampled daily starting in early September when sockeye salmon began spawning and dying in sufficient numbers. Samplers walked the entire creek and sampled every carcass available. When high water prevented access to the creek, carcasses that had been washed into deep water at the mouth of the creek were retrieved and sampled by snorkeling and by dip netting from a boat. We also sampled all dead sockeye salmon found floating in the lake for marks, though this represented a very small portion of the total recoveries.

In 2006, we examined fin-clipped carcasses for the uniquely numbered T-bar anchor tags that had been applied in Event 1. For each tag recovery, we recorded the tag number and fin clip.

Foot-survey Population Estimate

A complete description of the standardized method that we used to estimate the spawning escapement through stream surveys can be found in Zadina and Heinl (1999) and Johnson et al. (2005). Seven foot surveys of Hatchery Creek were conducted on, or near, the following dates: 23 August, 31 August, 10 September, 20 September, 28 September, 10 October, and 20 October. The survey area was divided into mouth counts (all fish off the mouth and the outer shelf of the creek) and stream counts. Stream counts began just upstream of the mouth (GPS coordinates: 55.992° N, 131.844° W), and ended approximately 1.5 km upstream, just downstream of a barrier falls (GPS coordinates: 56.002° N, 131.840° W). Stream counts included the old hatchery side channel on the lower section of the creek. 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. Counts of live and dead fish of all other species were also obtained during these foot surveys. 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). The sum of counts made during the foot surveys for 1983 to 1984 averaged 75% of the weir counts in those two years (an expansion factor of 1.33). From 1985 to 2006, the total escapement to McDonald Lake was estimated by dividing the sum of the foot surveys by 75% (Johnson et al. 2005).

RADIO TAGGING AND TRACKING 2006

We used an esophageal method (Eiler 1990, Burger et al. 1995, and Spencer et al. 2005) to implant Advance Telemetry Systems (ATS) pulse-coded radio transmitters (model 1840B) into 70 sockeye salmon over the course of the run. Each transmitter was identifiable by a unique combination of frequency and pulse-code, and was equipped with a mortality switch that activated when the transmitter remained motionless for approximately 12 hours. A 0.7 cm diameter PVC applicator was used to guide the transmitter down the fish’s esophagus until the transmitter rested against the pylorus or “stomach bend.” Only sockeye salmon visually determined to be in good health were fitted with a transmitter. An R4500C ATS receiver, in conjunction with a 3-element Yagi handheld antenna and a GPS receiver, was used to track radio tagged sockeye salmon and record the approximate location of targets.

The receiver was pre-programmed with eleven frequencies into a frequency scanning table. We tracked frequency signals using the aerial mode on the receiver with a scan rate of 4 seconds per programmed frequency. It took 44 seconds to completely cycle through all programmed frequencies on the receiver. The gain on the receiver was set at the highest setting available and was not changed during the course of the study. When a tag was detected with signal strength of

100 or greater, we recorded the frequency and code, signal strength, time, date, and GPS location of the receiver for all tags detected within that frequency. Tracking was conducted twice a week by boat along the entire lake shore to determine the movement of sockeye salmon throughout the lake and to detect activity along the shoreline that might indicate lake spawning. We conducted telemetry surveys of the entire spawning stream on foot every other day, or as often as water conditions allowed. Tracking data were downloaded to a field laptop after each tracking event. Data were sorted by frequency, pulse code and signal strength, and reduced to the strongest signal strength for each tag for each tracking event. Tags were tracked throughout the season or until a tag was recovered and turned off.

Radio-tagged sockeye salmon were tracked to four possible fates: Fate 1), probable spawning in Hatchery Creek—the fish was tracked into Hatchery Creek; Fate 2), probable spawning in the lake—the fish was repeatedly tracked at a lakeside location without broadcasting in mortality mode and never entered the Hatchery Creek spawning grounds; Fate 3), died in the lake—a fish that died in the lake and broadcast in mortality mode without exhibiting behavior that suggested lake spawning (though this could include a fish that regurgitated its transmitter); and Fate 4), unknown—a fish that was not successfully tracked because the tag was never detected after the fish was released, or only detected a few times before it disappeared.

DATA ANALYSIS

Escapement Estimates

We used SPAS software (Arnason et al. 1996) to generate mark-recapture estimates of the total spawning population of sockeye salmon. SPAS was designed for analysis of two-sample mark-recapture data and is based on work by Chapman and Junge (1956), Darroch (1961), Seber (1982), and Plante (1990). We used this software to calculate: 1) maximum likelihood (ML) Darroch estimates and pooled-Petersen (Chapman's modified) estimates, and their standard errors; 2) chi-square tests for goodness-of-fit based on the deviation of predicted values (fitted by the ML Darroch estimate) from the observed values; and 3) two chi-square tests of the validity of using fully pooled data—a test of complete mixing of marked sockeye salmon between release and recovery strata, and a test of equal proportions of marked sockeye salmon in the recovery strata. We considered passing either of those tests ($p>0.05$) as sufficient to validate full pooling of the data (i.e., the pooled-Petersen estimate). Schwarz and Taylor (1998) discussed the manipulation of release and recovery strata in calculating estimates (the method used in SPAS). We expected to generate a pooled-Petersen estimate with a coefficient of variation of 15% or less.

For 2006, we assumed that radio-tagged sockeye salmon identified with Fates 3 and 4 suffered handling-induced mortality; i.e., they died or disappeared from the system due to the effects of capture and handling, and we used this information to make a conservative adjustment to our mark-recapture estimate (Jones et al. 2001, Weller et al. 2005). We let n_1' denote the number of salmon marked in Event 1 and we let $\widehat{p}$ denote the estimated proportion of marked sockeye salmon that suffered "handling-induced mortality." The estimated number of marks released, $\hat{n}_1$, was calculated as:

$$\hat{n}_1 = n_1'(1-\widehat{p}). \tag{1}$$

We estimated the sockeye salmon escapement using Chapman's Modified Petersen estimator (Seber1982):

$$\hat{N}_e = \frac{(\hat{n}_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1, \quad (2)$$

letting $\hat{N}_e$ denote the number of adult sockeye salmon in McDonald Lake in 2006, $\hat{n}_1$ denote the estimated number of sockeye salmon marked during the Event 1, n_2 denote the number inspected for marks during Event 2, and m_2 denote the number of marks recovered during sampling Event 2. The SE of the Petersen estimate was calculated using SPAS.

Age Composition Sampling

Our goal was to collect 1,000 scale samples to estimate the age composition of the run. 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) and Cochran (1977).

RESULTS

POPULATION ESTIMATES

Mark-Recapture Estimates: Fin Clip Marking

2005

In 2005, we marked and released 880 of the 888 adult sockeye salmon captured at the outlet of the lake for marking (Table 1). One sockeye salmon was sacrificed for coded-wire tagging information because it was missing its adipose fin (no coded-wire tag was subsequently recovered). Seven captured fish were in poor health and were released unmarked. Of those seven, four had marks characteristic of escape from net fishing gear. High water conditions made it difficult to keep our fyke net fully operational and, as a result, the net was not fished during three short periods: 22–23 August, 9–10 September, and 20 September.

We examined 7,759 sockeye salmon on the spawning grounds, and recovered 79 marked sockeye salmon (Table 1). Although we marked sockeye salmon in three temporal strata (using right ventral, left ventral, and dorsal fin clips), it was apparent that our field crews did not correctly separate right and left ventral marks when sampling for marks on the spawning grounds. We marked a total of 26 sockeye salmon with right ventral fin clips and recovered 15 of those fish; a recovery rate of 58%. Recovery rates for the left ventral and dorsal clips were 8% and 7% respectively. It seems very unlikely that the recovery rate of the right ventral marks could be so much higher than the recovery rates of the other two marks, particularly when so few marks were released from that stratum. Therefore, we pooled the ventral marks together for mark-recapture analysis.

A chi-square test of the pooled data gave a non-significant result for complete mixing of marked sockeye salmon between release and recovery strata (p=0.15), though the test for equal proportions of marked sockeye salmon was significant (p<0.01). Since the data passed one of the chi-square tests, we pooled the data and calculated a Petersen population estimate of 85 thousand sockeye salmon (SE=9,000; CV=11%). In 2005, we did not have an estimate of marking mortality to apply to the mark-recapture estimate, so we chose to apply the 29% estimated marking mortality obtained in the 2006 radio-telemetry study. We reduced the number of marks released ($\hat{n}_1$) to 628, which produced a Petersen estimate of 61 thousand sockeye salmon (SE=6,300; CV=10%).

Table 1.–Initial mark-recapture data for sockeye salmon at McDonald Lake with marking stratum, number released, and number recovered in 2005.

	Number of Fish Marked			Number	Total Number
Marking Date	**Right Ventral**	**Left Ventral**	**Dorsal**	**Unmarked**	**Sampled**
5-Jul to 5-Aug	26				
6-Aug to 27-Aug		616			
28-Aug to 23-Sep			238		
Recovery Date	Number of Marked Fish				
26-Aug	1			6	7
31-Aug	1			6	7
2-Sep		1		12	13
4-Sep	1			19	20
7-Sep				9	9
8-Sep				22	22
9-Sep			1	204	205
10-Sep		1		205	206
11-Sep		1		202	203
12-Sep		1	1	117	119
13-Sep		1		249	250
14-Sep				325	325
16-Sep	1	3	1	570	575
17-Sep	1	2	2	386	391
18-Sep		3		202	205
19-Sep		2	1	270	273
20-Sep	2	1	1	328	332
21-Sep		1		124	125
22-Sep		5	1	645	651
24-Sep	1	7	2	495	505
25-Sep	5	2	2	687	696
26-Sep		5		1,205	1,210
27-Sep	1	12	2	873	888
29-Sep				301	301
6-Oct	1	0	2	218	221
Total Recovered	15	48	16	7,680	7,759

2006

In 2006, we marked and released 1,123 of the 1,135 adult sockeye salmon captured at the outlet of the lake (Table 2). From 27 to 28 August, a large pulse of sockeye salmon entered the system and overwhelmed the net. We captured 492 sockeye salmon, and the net was so heavy with fish that the cod end could not be pulled from the water in a normal fashion—the first hoop of the fyke net was laid flat across the front of the boat, rather than secured in a vertical position, making it difficult to dip fish from the net (Figure 3 shows how the net was normally held in place.). We recovered 12 post-marking mortalities in the release area on 28 August. We assume those fish died from the stress of handling and marking, and we subtracted them from the total number of fish marked and released. Crew change and high water conditions caused the fyke net not to be fished during three short periods: 22–27 August (crew change), 29 August, and 1–3 September.

We examined 3,905 sockeye salmon on the spawning grounds, and recovered 99 marked sockeye salmon (Table 2). Recovery rates for right ventral, left ventral, and dorsal fin clips were 14%, 7%, and 9% respectively. A chi-square test of the pooled data gave a significant result for complete mixing of marked fish between release and recovery strata ($p<0.01$), and a non-significant result for the test for equal proportions of marked fish ($p=0.17$). Since the data passed one of the chi-square tests, we pooled the data and calculated a Petersen population estimate of 44 thousand sockeye salmon (SE=4,000; CV=9%). We adjusted this estimate by incorporating an estimate of handling-induced mortality as determined from the radio-telemetry study below. We assigned 29% ($\hat{p}$) of the radio-tagged fish to Fates 3 and 4 (i.e., fish that we categorized as having suffered handling-induced mortality). Accordingly, we reduced the number of marks released ($\hat{n}_1$) to 802, which produced a Petersen estimate of 31 thousand sockeye salmon (SE=3,000; CV=9%).

Table 2.–Initial mark-recapture data for sockeye salmon at McDonald Lake with marking stratum, number released and number recovered in 2006.

	Number of Fish Marked			Number	Total Number
Marking Date	**Right Ventral**	**Left Ventral**	**Dorsal**	**Unmarked**	**Sampled**
5-Jul to 5-Aug	221				
6-Aug to 27-Aug		453			
28-Aug to 23-Sep			449		
Recovery Date	Number of Marked Fish Recovered				
4-Sep	0	0	0	4	4
5-Sep	0	0	0	1	1
6-Sep	0	0	1	17	18
7-Sep	1	0	1	24	26
9-Sep	0	0	0	7	7
10-Sep	0	0	0	20	20
14-Sep	0	2	4	100	106
15-Sep	0	0	0	140	140
16-Sep	4	1	1	155	161
17-Sep	9	5	1	568	583
18-Sep	1	1	0	189	191
19-Sep	3	3	1	344	351
20-Sep	3	3		220	226
21-Sep	0	1	1	74	76
22-Sep	1	0	0	34	35
24-Sep	1	1	1	84	87
25-Sep	0	0	1	40	41
26-Sep	1	1	2	161	165
27-Sep	0	1	5	284	290
2-Oct	4	7	15	1,030	1,056
10-Oct	2	4	5	310	321
Total Recovered	30	30	39	3,806	3,905

Mark-Recapture Estimate: T-Bar Anchor Tags

In 2006, we tagged and released 819 (73%) of the 1,123 adult sockeye salmon captured at the outlet of the lake with a uniquely numbered T-bar anchor tag. Not all fish were tagged, because of equipment malfunctions and difficulties that we encountered with applying the tags. If a tag was not applied properly, we released the fish untagged to minimize handling effects as much as possible. We did not tag 216 sockeye salmon during a two-day period because our tagging equipment was inoperable.

Although we tagged and released 819 sockeye salmon with T-bar anchor tags, we experienced a 21% tag loss. We estimated the number of tags released to be 647 after adjusting for this tag loss. On the spawning ground we examined 3,905 sockeye salmon for marks and recovered 51 T-bar anchor tags. We calculated a Petersen estimate of 49 thousand sockeye salmon (SE=6,400; CV=13%). We adjusted this estimate by incorporating an estimate of handling-induced mortality as determined from the radio-telemetry study below. Here again, we assigned 29% ($\hat{p}$) of radio-tagged fish to Fates 3 and 4 (i.e., fish that we categorized as having suffered handling-induced mortality). Accordingly, we reduced the number of marks released ($\hat{n}_1$) to 465, which produced a Petersen estimate of 35 thousand sockeye salmon (SE=4,500; CV=13%).

Foot-survey Escapement Estimate

In 2005 and 2006, we conducted seven foot surveys of Hatchery Creek on, or near, the designated survey dates (Table 3). We were unable to conduct surveys on 28 September and 20 October 2005 because of high water and inclement weather, and we interpolated survey values for those dates. The sum of the seven foot surveys was 34,464 in 2005, which expanded to an estimated escapement of 46 thousand sockeye salmon. The sum of the seven foot surveys was 12,570 in 2006, which expanded to an estimated escapement of 17 thousand sockeye salmon.

Radio Tagging and Tracking

In 2006, we applied radio tags to 70 sockeye salmon captured at the outlet of the lake. We tracked 50 of these tagged fish into Hatchery Creek, where they were assumed to have spawned (probability Fate 1; Table 4). We found no evidence that radio-tagged fish were spawning in the lake (Fate 2). If radio-tagged fish were spawning in the lake, we would have expected to find them in the same location on multiple surveys; however, this was not the case. We also did not locate any congregations of fish along the lake shore during our visual surveys by boat. We determined that six tagged sockeye salmon died, likely from handling stress, shortly after release in the lake (Fate 3). The fate of 14 sockeye salmon was unknown (Fate 4); ten were tracked a few times in the lake, but were not subsequently relocated, and four were never relocated after they were released. We assume that sockeye salmon with Fates 3 and 4 suffered handling-induced mortality even though these fish may have simply left McDonald Lake.

Table 3.–Annual foot surveys and estimated escapement to McDonald Lake, 1979–2006.

Survey Date[a]	**23 Aug**	**31 Aug**	**10 Sep**	**20 Sep**	**28 Sep**	**10 Oct**	**20 Oct**	**Sum of**	**Escapement Estimate**	**Weir Count**
Survey No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Surveys**	**(x 1000)**	**(x 1000)**
1979	2	**1,191**	5,010	6,600	**6,732**	**2,395**	**286**	22,215	30	
1980	1,363	**4,714**	19,500	14,775	13,378	**2,119**	**185**	56,034	75	
1981[b]	1,370	2,825	**19,550**	23,050	11,000	1,025	**195**	59,016	130	130
1982	0	9,000	13,200	6,100	**7,444**	**1,410**	**123**	37,277	50	16[c]
1983[b]	500	3,200	11,500	15,000	8,000	2,500	**531**	41,231	55	56
1984[b]	0	12,000	21,600	27,100	24,800	7,100[d]	200	92,800	124	121
1985	35	1,425	15,600	27,300	23,890	6,250	**971**	75,471	101	
1986	1,500	9,000	9,200	24,900	25,400	600	**317**	70,917	95	
1987	2	5,000	16,100	**46,030**	**42,530**	27,880[e]	2,800	140,342	187	
1988	20	5,780	25,000	12,500	6,600	700	1	50,601	67	
1989	150	165	13,000	**18,617**	24,000	100	**730**	56,763	76	
1990	3	2,950	23,000	22,780	33,600	2,100	275	84,708	113	
1991	304	30,000	27,770	34,300	27,000	**4,714**	579	124,667	166	
1992	5	5,500	28,300	20,600	**14,948**	5,250	**248**	74,851	100	
1993	4	57	3,950	14,100	37,000	4,300	370	59,781	80	
1994	0	250	11,000	28,600	32,700	6,100	49	78,699	105	
1995	0	918	12,975	16,130	2,260	600	**147**	33,030	44	
1996	315	**2,489**	7,372	16,865	16,300	3,055	41	46,437	62	
1997	0	9,533	11,775	**14,144**	13,900	1,853	128	51,333	68	
1998	225	5,762	11,520	12,793	7,625	5,108	81	43,114	58	
1999	355	5,202	20,557	22,540	15,940	**2,540**	54	67,188	90	
2000	**109**	9,761	17,610	25,605	7,458	**7,325**	84	67,952	91	
2001	213	4,910	11,275	11,656	3,700	207	**106**	32,067	43	
2002	**40**	**1,253**	5,568	8,000	4,405	61	**0**	19,327	26	
2003	40	9,455	15,780	20,353	16,052	5,095	139	66,914	89	
2004	0	44	4,420	**5,434**	5,920	134	3	15,955	21	
2005	42	205	10,200	10,375	**9,839**	3,455	**348**	34,464	46	
2006	2	618	2,853	5,153	3,200	729	15	12,570	17	

Note: Bold entries indicate interpolated values for missed surveys.

[a] Survey dates are approximate

[b] Weir counts were used for the escapement estimates in 1981, 1983, and 1984.

[c] The weir was not fish tight in 1982, due to high water.

[d] The survey for 10 Oct. 1984 is the average of counts for 5 Oct. (14,000) and 16 Oct. (200).

[e] The survey for 10 Oct. 1987 is the average of counts for 7 Oct. (36,000) and 12 Oct. (19,760).

Table 4.–Fate of radio-tagged sockeye salmon at McDonald Lake with number and proportion of each group, 2006.

Fate	Group	Number of fish	Proportion
1	Probable spawning in Hatchery Creek	50	71%
2	Probable spawning in the lake	0	0%
3	Died in lake	6	9%
4	Unknown	14	20%
Total		70	

AGE COMPOSITION

In 2005, the escapement was dominated by age-1.3 sockeye salmon, which comprised 69.3% of the total escapement (Table 5). The proportion of age 1.1 jacks in the escapement was 4.1%, which is the highest proportion for that age-class we have ever recorded at McDonald Lake. This increase in jacks is likely a result of collecting scales from fish captured in the fyke net, rather than from carcasses on the spawning grounds, or at a weir, as we have done in the past.

In 2006, age-1.3 sockeye salmon were again the most numerous age-class, but the proportions of age-1.2 and age-2.2 fish in the escapement were only slightly lower (Table 5). Overall, 2-ocean fish outnumbered 3-ocean fish in the escapement. The proportion of jacks in the escapement was lower than in 2005, but was again higher than all of the previous years where samples were collected on the spawning grounds, or at a weir.

Table 5.–Proportion and number by age-class of the adult sockeye salmon escapement at McDonald Lake, 2005 and 2006.

	Sample		Age Class							Total
Year	Size		1.1	1.2	2.1	1.3	2.2	1.4	2.3	Escapement
2005	774	Proportion	4.1%	6.8%	5.0%	69.3%	2.2%	0.1%	12.4%	
		SE	0.7%	0.9%	0.8%	1.7%	0.5%	0.1%	1.2%	
		Number	1,900	3,147	2,316	31,830	1,010	59	5,701	45,964
2006	652	Proportion	1.2%	26.8%	0.9%	32.2%	24.8%	0.3%	13.7%	
		SE	0.4%	1.7%	0.4%	1.8%	1.7%	0.2%	1.3%	
		Number	206	4,500	154	5,399	4,165	51	2,288	16,764

TIMING OF FISH MOVEMENTS INTO MCDONALD LAKE

In 2005, the largest catch of sockeye salmon at the fyke net coincided with the start of the maximum precipitation event of the season. During this 3-day period we captured 36% of the total number of sockeye salmon that were marked and released (Figure 4). Twice a week, we conducted snorkel surveys of Wolverine Creek (the outlet stream) to estimate numbers of sockeye salmon holding in the creek below the lake. We started these surveys at the fyke net site at the outlet of the lake, and continued downstream to the start of a large unfloatable section of rapids that runs to saltwater. We observed only small numbers of sockeye salmon during these surveys. These results suggest that most sockeye salmon staged in saltwater, not in Wolverine Creek, and that they pulsed upstream into the lake in large groups that coincided with environmental cues.

In 2006, the peak fyke net catches of sockeye salmon coincided with a large precipitation event (Figure 5). The second highest precipitation event of the season coincided with a 2-day period, 27–28 August, in which we captured 43% of the total number of fish that were marked and released. As in 2005, we did not see large numbers of sockeye salmon staging or holding in Wolverine Creek during our biweekly snorkel and foot surveys. For example, we did not find large numbers of fish during our check of Wolverine Creek during 27 August prior to the large pulse of fish that began that evening. This supported the idea that most McDonald Lake sockeye salmon staged at saltwater and then pulsed upstream into the lake in large groups.

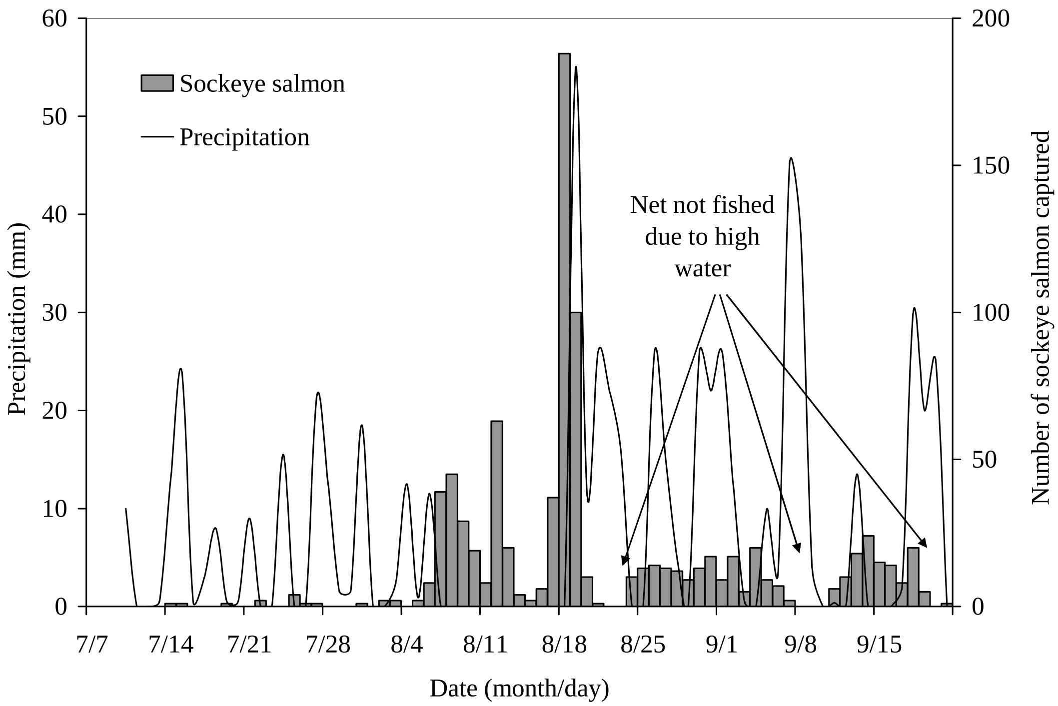

Figure 4.–Number of sockeye salmon captured daily in the fyke net at the outlet of McDonald Lake during sampling Event 1, compared to daily precipitation in 2005. Arrows point to three periods when fish were not captured due to high water.

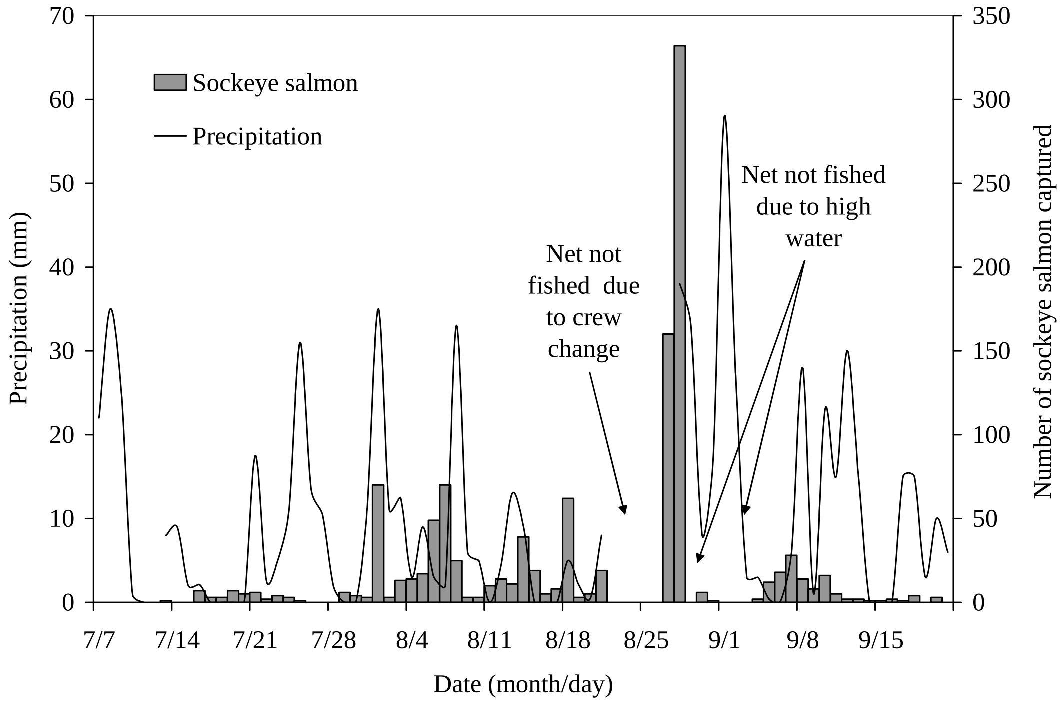

Figure 5.–Number of sockeye salmon captured daily in the fyke net at the outlet of McDonald Lake during sampling Event 1, compared to daily precipitation in 2006. Arrows point to two periods when fish were not captured due to high water, and one period when fish were not captured during an exchange of field personnel.

DISCUSSION

The results of our mark-recapture studies in 2005 and 2006 showed that our foot survey escapement estimates in those years were lower to varying degrees than the mark-recapture estimates. The 2005 foot survey estimate was approximately 75% of the mark-recapture estimate, while in 2006 the foot survey estimate was only 55% of the mark-recapture estimate for that year. There are several possible explanations for the discrepancies between the two escapement estimation methods: the weir estimates used to scale the foot survey counts may have been biased low, the mark-recapture estimates in 2005 and 2006 could have been biased high, the two years of foot survey estimates and weir counts that were used back in the 1980s for scaling the foot survey estimates to an estimate of total escapement may have been insufficient for capturing the relational variation between the two estimation methods, and the two years of comparisons we have between mark-recapture estimates and our foot survey escapement index are insufficient for capturing the true variation between the mark-recapture and foot survey estimates.

There are good reasons to suspect that the weir estimates that were used to scale the foot survey estimates may have been biased low. From talking to personnel that were actually present in the 1980s when the conversion factor was established, we suspect that the McDonald Lake weir had problems with holes or fish passing undetected in the two years that were used to generate the conversion factor. The 1982 weir count, which was not used in the conversion factor, was considered at the time to have been a gross underestimate of the actual escapement (Johnson et al. 2005). In 1984, small holes were found in the weir on 14 August (ADF&G unpublished weir data). Although the weir crew felt that not many fish had escaped uncounted, nearly 35 thousand fish had been enumerated through the weir between 8 August, the last time the weir was inspected by a diver, and 14 August, when the holes were discovered. With large numbers of fish moving upstream any hole large enough for a sockeye salmon to pass through would allow for the passage of large numbers of fish; e.g., at the Hugh Smith Lake weir, the entire sockeye salmon run passes through a small hole created by lifting one picket (Piston et al. 2007).

Bue et al. (1998) cautioned that weirs will provide accurate counts of spawning salmon only if efforts are made to carefully maintain their integrity, which was apparently very difficult at McDonald Lake. At Chilkoot Lake, mark-recapture estimates tended to be higher than weir observations from 1997 through 2001 and 2003 (Bachman and Sogge 2006). Chilkat Lake mark-recapture studies have shown that historic weir counts were biased low, but not consistently biased (Geiger et al. 2005). At Klawock Lake, during a three year study from 2001–2003, mark-recapture estimates were two to four times higher than weir counts in 2001 and 2003, but weir counts were within the 95% confidence interval of the mark-recapture in 2002 (Cartwright and Conitz 2006). They recommended that a mark-recapture study be a necessary component of any weir project intended to estimate salmon abundance. At McDonald Lake, no secondary mark-recapture estimates were obtained to corroborate the weir counts; thus, the weir counts should be considered minimum estimates of escapement. If the weir counts were indeed low, the scaling factor that has been used to convert raw foot survey counts into estimates of total escapement would produce underestimates of escapement at McDonald Lake.

It is also possible that the mark-recapture estimates are biased high, and the scaled foot-survey estimates could be essentially unbiased. Balancing cost, feasibility, and risk of project failure, we chose to use mark-recapture estimates as the benchmarks with which to compare the scaled foot-survey estimates. Mark-recapture estimates of escapement at Hugh Smith Lake have a remarkable history of agreement with other escapement measures (Geiger et al. 2003, Piston et al. 2006 and 2007), seeming to demonstrate that mark-recapture studies of sockeye salmon can produce accurate estimates of escapement. Most sockeye salmon weir projects in Southeast Alaska include a weir validation component, which is typically a mark-recapture study (Geiger et al. 2005). However, when errors creep into mark-recapture studies, they almost always lead to an overestimation of the true escapement (Simpson 1984). The reasons for this overestimation are easy to understand. Because sockeye salmon can be fragile when they first enter freshwater, any additional stress associated with the marking process can result in the death or other kind of loss of some marked fish. For example, Yanusz (1998) experienced an inflated mark-recapture estimate of sockeye salmon at Windfall Lake, in part because some of the tagged fish never migrated to the recapture site. Because of the high catch rates and crowding during brief periods in the Event-1 samples in our study in both 2005 and 2006 (Figures 4 and 5), loss of marks from the statistical population because of handling mortality was a clear possibility. We feel that lowering the number of marked fish in our Petersen estimate calculations by the percentage of radio-tagged fish that did not reach the spawning grounds at Hatchery Creek in 2006, provides conservative estimates that are unlikely to be biased high.

If the regular marking process at McDonald Lake caused a loss of marks due to stress-induced mortality, then the radio tagging would be even more stressful and would cause an even greater loss of marks (radio tags) on the spawning grounds. However, after the radio tagged fish were released, both tagged and untagged fish continued to die at some rate. In other words, looking at the rate at which radio tagged fish were lost from the population before the Event-2 sample will overstate the relative loss of marks or tags, because some of the untagged fish would be lost from the population too. Therefore, the loss of radio tagged fish from the population should provide a good absolute upper bound by which to find the *maximum reasonable bias* in the mark-recapture population estimate, assuming that marks were not overlooked or otherwise missed by the samplers in the second sample.

If the missing marks were caused by mark-induced mortality, because approximately 29% of the radio tagged fish were lost, then the maximum statistical bias in the mark-recapture estimates is about 40% (i.e., 100%-1/(1-0.29)100%). Considering that the coefficient of variation was about 10% and the maximum bias was about 40%, both sources of error together cannot explain the discrepancy between the scaled foot-survey estimates and the mark-recapture estimates (45,000 scaled foot count vs. 85,000 unadjusted mark-recapture in 2005 and 17,000 scaled foot count vs. 44,000 unadjusted mark-recapture in 2006), and in spite of any problems with the mark-recapture estimates, we must therefore conclude that the two series are measuring escapements on entirely different scales and the historic estimates are too low. The most likely hypothesis for this discrepancy is that the scaling factor is too low.

It is unlikely that only two years of comparisons between weir estimates and foot survey estimates was enough to capture the variation that likely exists in observer estimates over varying run-sizes and environmental conditions at McDonald Lake. Likewise, the two years of comparisons we have between mark-recapture estimates and our foot survey escapement index may be insufficient for capturing all of the variation that could arise between the mark-recapture and foot survey estimates. The relationship between the two methods will vary depending on such things as run size, rainfall, and water clarity (Jones et al. 1998). Studies conducted at Traitors Creek in Southeast Alaska, from 1996 to 2005, showed that as pink salmon escapements increased, observers tended to count a smaller portion of the fish in the creek (ADF&G unpublished data). It is likely that the same phenomenon occurs with visual estimates of sockeye salmon at McDonald Lake, although this effect should have increased our foot survey estimates relative to other escapement estimation methods during the relatively weak sockeye salmon returns we have seen in recent years. Rainfall, and the accompanying rise in water levels and decreases in water clarity, also affects the ability of surveyors to accurately estimate the numbers of fish in a stream, and introduces increased variation in the way stream counts relate to what is actually present in the stream at the time of a survey. We plan on continuing this project for several more years with the intention of obtaining a foot survey calibration that better reflects the annual variation that inevitably enters any fish population estimation that is based on visual counts.

The 2006 telemetry study was the first attempt to study fish movement in the lake and examine the assumption that there is no lake spawning at McDonald Lake. The organically stained water and steep sides of McDonald Lake limited the observers' ability to detect fish visually to less than three meters below the surface. During the two years of this study we did not visually detect any congregations of sockeye salmon in the littoral zones, nor did we track radio tagged fish to areas where we would expect lake spawning. Radio telemetry studies have been used successfully to locate Lake Trout and other salmonid species spawning in deep or poor visibility water (Eiler 1990, Viavant 1997, Wuttig and Evenson 2002). Based on radio tracking observations, we concluded that there was little, if any, beach spawning sockeye salmon at McDonald Lake in 2006. Since we only had a total of 70 radios, we obviously cannot conclude that there was absolutely no beach spawning. However, if beach spawning was even 10% of the spawning escapement, we expect the probability of detecting at least one radio in a littoral beach spawning area to be well over 90% (i.e., 1-0.10(1-0.1)70).

The low percentage of 1.3 sockeye salmon in the 2006 escapement was a reflection of the poor 2001 brood year escapement of 43 thousand, which was the lowest escapement recorded at McDonald Lake at that time (Johnson et al. 2005). The fry production from the poor 2001 escapement was also the lowest recorded to that point: the 2002 fall hydroacoustic estimate was 1.1 million rearing fry, which is approximately half of the average estimate (2.1 million) from 1983–2001. Although the proportions of jacks in the age composition were relatively low in 2005 and 2006, they were still the highest recorded since sampling started in 1981. The apparent increase in jack abundance is likely explained by the change in our sampling techniques. Prior to 2005, scales were sampled at the weir and from carcasses on the spawning grounds, where jacks would have been less likely to be sampled. In 2005 and 2006, all of the scale samples were taken from live fish captured in the fyke net at the outlet of McDonald Lake. Jacks are probably more susceptible to capture in the passive fyke net and thus would be sampled at a higher rate than sampling at a weir or from carcasses on the spawning grounds.

These results have implications in several different fora. We previously noted that McDonald Lake statistics are an important component of an international sockeye run reconstruction (English et al. 2004). Obviously, if McDonald Lake escapement statistics were far too low, then this may affect some aspects of the run-reconstruction output. At the very least, our results are justification for a careful sensitivity analysis of the run reconstruction, and a careful review of how sensitive the model is to errors in the McDonald Lake escapement estimates. The current escapement goal is in the units of the scaled foot counts, and the goal has been missed, in these units, several of the last few years (Johnson et al. 2005). The fact that the current escapement measure may be scaled to the wrong level should have no bearing, one way or another, as to whether or not McDonald Lake will be categorized as a stock of concern before the next Board of Fisheries meeting. That designation will be based on whether the escapement goal is reached or not over a several-year period—again, the current escapement goal is expressed in units of the scaled foot survey. Although the McDonald Lake escapement goal will need to be reexamined before the next Alaska Board of Fisheries meeting, we have no recommendations for changing the escapement goal at this time.

RECOMMENDATIONS

1. We recommend that a minimum of three more years of mark-recapture estimates be conducted to support the two preliminary estimates from this study, before using mark-recapture estimates to recalibrate the escapement series. That recommendation is based on the fact that the current calibration factor seems to have been based on too few years of observation.
2. In future telemetry studies we recommend having at least one stationary tracking tower at the mouth of the spawning stream and another located in the outlet stream. The stationary tracking station at the inlet would allow us to know exactly when a fish entered the inlet stream (passed the tower), and continuous monitoring would allow us to estimate average stream life, an essential part of the area-under-the curve technique of escapement estimation. A tracking tower at the outlet would allow us to determine if some of the unaccounted for tagged fish dropped out of the system.

3. Additionally, an obvious oversight in 2006 was that we failed to document the lake depth to which the radio tags were undetectable, both in the "live" and in the "mortality" modes. We think that most of the unaccounted for radio tags were likely lost by sinking to the bottom of the lake to depths where the radio signals were not detectable on the surface. This could have been easily tested in 2006. We recommend that this determination be made every year that radio tags are deployed at McDonald Lake.

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