Fishery Data Series No. 98-32

Sockeye Salmon Escapement to Windfall Lake during 1997

by

Richard J. Yanusz

November 1998

Alaska Department of Fish and Game | Division of Sport Fish

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
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
ounce	oz
pound	lb
quart	qt
yard	yd

Spell out acre and ton.

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s

Spell out year, month, and week.

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
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
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

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	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
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.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
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
standard length	SL
total length	TL
variance	Var

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ABSTRACT

A weir was operated on Windfall Creek from 1 June through 17 August 1997, and the escapement was estimated to be 2,426 (SE = 39) sockeye salmon *Oncorhynchus nerka*. Age 1.3 sockeye salmon that averaged 586 mm (SE = 25 mm) mid-eye to tail-fork length composed 74% (SE = 1.5%) of the escapement, followed by sockeye salmon age 1.1 that averaged 349 mm (SE = 16 mm) in length that composed 11% (SE = 1.2%) of the escapement. Minimal numbers of sockeye salmon inspected at the weir exhibited scars that might be attributed to commercial fishing gear. A series of foot surveys in the index area during 1997 resulted in a peak count of 484 sockeye salmon, which represented only 22% of the escapement. In a previous study, 46% of the escapement was observed in the index area. A mark-recapture experiment was conducted independently of the weir operations, to test the feasibility of this method for escapement estimation. The estimated escapement of 4,228 (SE = 954) sockeye salmon was 73% greater than the weir count, in part because 28% of the tagged fish never migrated to the recapture site. Limnological sampling was conducted in Windfall Lake and the euphotic zone depth was estimated to be 3.1 m (SE = 0.01) and the mean seasonal biomass of macrozooplankton was estimated to be 103 mg/m^2 (SE = 3.8). Applying the limnological observations to a model of sockeye salmon production, it was estimated that the maximum annual production for Windfall Lake is 1,722 adult sockeye salmon.

Key words: sockeye salmon, *Oncorhynchus nerka*, weir, escapement, length, age, index, mark-recapture, limnology, euphotic zone, zooplankton, model.

INTRODUCTION

Sport fishing opportunities for sockeye salmon *Oncorhynchus nerka* are extremely limited on the Juneau road system. Windfall Creek has provided the only consistent sockeye salmon sport fishery in the Juneau area since 1982; it has received as much as 279 angler-days of effort annually (Mills 1990) and has yielded annual harvests ranging to 800 fish (Bethers and Glynn 1990). Since 1990, however, the fishery has been closed by emergency order, in response to high fishing pressure and low index counts (Bethers and Glynn 1990; Mark Schwan, Alaska Department of Fish and Game, Douglas, personal communication). A section of Slate Creek, tributary to Windfall Lake, is designated as the index area, and adult sockeye salmon here are counted by foot survey every summer. From 1987 to 1991, peak index counts averaged 1,344 fish, but from 1992 to 1995 averaged only 417 fish (Appendix A1).

Index counts did not rebound after closure of the sport fishery, however, except for one peak index count of 1,608 in 1996. Windfall Creek sockeye salmon stocks may also be harvested in commercial net fisheries in Lynn Canal. Or, the index counts may not accurately reflect the escapements, as the flow in Slate Creek has changed channels over time, and a series of beaver dams interrupt the creek before it enters Windfall Lake. These environmental changes may have decreased utilization of the index area by spawning sockeye salmon (Brian Glynn, Alaska Department of Fish and Game, Douglas, personal communication).

Also lacking is an escapement goal for sockeye salmon management in the Windfall system. In lieu of the multi-year sampling necessary for traditional spawner-recruit analysis, this year's study was used as an opportunity to collect one season of limnological data to estimate theoretical production capacity of Windfall Lake. The planned field operations also presented an opportunity to investigate the suitability of using a mark-recapture experiment to estimate sockeye salmon escapement to the Windfall system as a cheaper alternative to future weir projects.

Objectives of our research at Windfall Lake in 1997 were: (1) determine sockeye salmon escapement to the lake by use of a weir; (2) estimate age, sex, and length composition of sockeye salmon in the escapement; (3) compare peak counts of sockeye salmon in the index area to the escapement at the weir; (4) conduct a mark-recapture abundance experiment to estimate the escapement of adult sockeye salmon; (5) estimate the seasonal mean macrozooplankton abundance and the seasonal mean euphotic zone depth (light penetration) in Windfall Lake; and (6) estimate frequency and type of scars on sockeye salmon examined at the weir.

STUDY SITE

The Windfall system is located in northern Southeast Alaska, approximately 27 km northwest of Juneau, Alaska (Figure 1). Windfall Lake (Anadromous Waters Catalog [AWC] Number 111-50-10070-2004-3006-0010; ADF&G 1993) lies at 11 m elevation, has a surface area of 46 ha, and a maximum depth of approximately 4.5 m. The lake is heavily stained by tannin. Slate Creek (AWC Number 111-50-10070-2004-3006-4006) is the principal tributary of Windfall Lake and has relatively clear water (Figure 1). Windfall Creek (AWC Number 111-50-10070-2004-3006-4003), a low-gradient stream, flows about 1 km from Windfall Lake to the Herbert River, ranges from 6 to 12 m wide, and has numerous pools (to 2 m deep) and riffles (Bethers et al. 1995). From the Windfall Creek confluence, the Herbert River (AWC Number 111-50-10070-2004) continues about 4 km downstream to the Eagle River (AWC Number 111-50-10070), which continues another 2 km to enter salt water at Stephens Passage. Both Herbert and Eagle River are glacially occluded. The confluence of Windfall Creek and the Herbert River is an important holding area for sockeye salmon returning to the Windfall system, and it is the most popular sport fishing site in the drainage (Mark Schwan, Alaska Department of Fish and Game, Douglas, personal communication).

METHODS

WEIR

A weir was operated continuously on Windfall Creek from 1 June through 17 August 1997, located about midway between the Herbert River and Windfall Lake at the exact site of the 1989 weir (Figure 1). The weir was an aluminum bipod and picket design, with 18-mm-diameter pickets and a maximum gap between pickets of 31 mm. The entire upstream face of the weir was overlaid with 18 × 21 mm rectangular-opening plastic mesh (extruded polyethylene) to block passage of fish >150 mm long. The bottom and sides of the weir were sealed with landscaping cloth and sandbags. A 2.4-m square trap was placed on the upstream side of the weir to capture and hold all immigrating sockeye salmon for counting and sampling. A similar trap was placed on the downstream side to hold all downstream-migrating fish.

Every sockeye salmon captured at the weir was counted, marked according to one of three temporal strata (Table 1), and then released into the stream above the weir. Every second sockeye salmon captured during the period 1–19 June, and every fourth captured during 20 June–17 August, were also sampled for length, age, sex, and scars. Lengths were measured mid-eye to tail-fork (MEF), to the nearest 5 mm. Three scales were collected from the preferred area (ADF&G 1996), and presence of scars was noted (ADF&G 1990). Sampled scales were attached to a gum card, and age determinations were based on examination of the scales under 70× magnification. Criteria used to assign ages were similar to those of Moser (1968), and ages were reported in European notation (Koo 1962).

Scars found on sockeye salmon sampled at the weir were assigned to seven categories (Table 2) and noted as to whether fresh or healed. Scar categories 1 through 3 are thought to result from contact with fishing gear and the remaining categories thought to be from predators (Seibel et al. 1982; Taylor 1985). The proportion of the sockeye salmon run bearing each type of scar was calculated per equations 1 through 4.

AGE, SEX, AND LENGTH

Because the fraction of the immigration sampled each day changed on 20 June, the estimated proportion at age in each of the two temporal strata h sampled was computed by

$$\hat{p}_{a,h} = \frac{n_{a,h}}{n_h} \qquad (1)$$

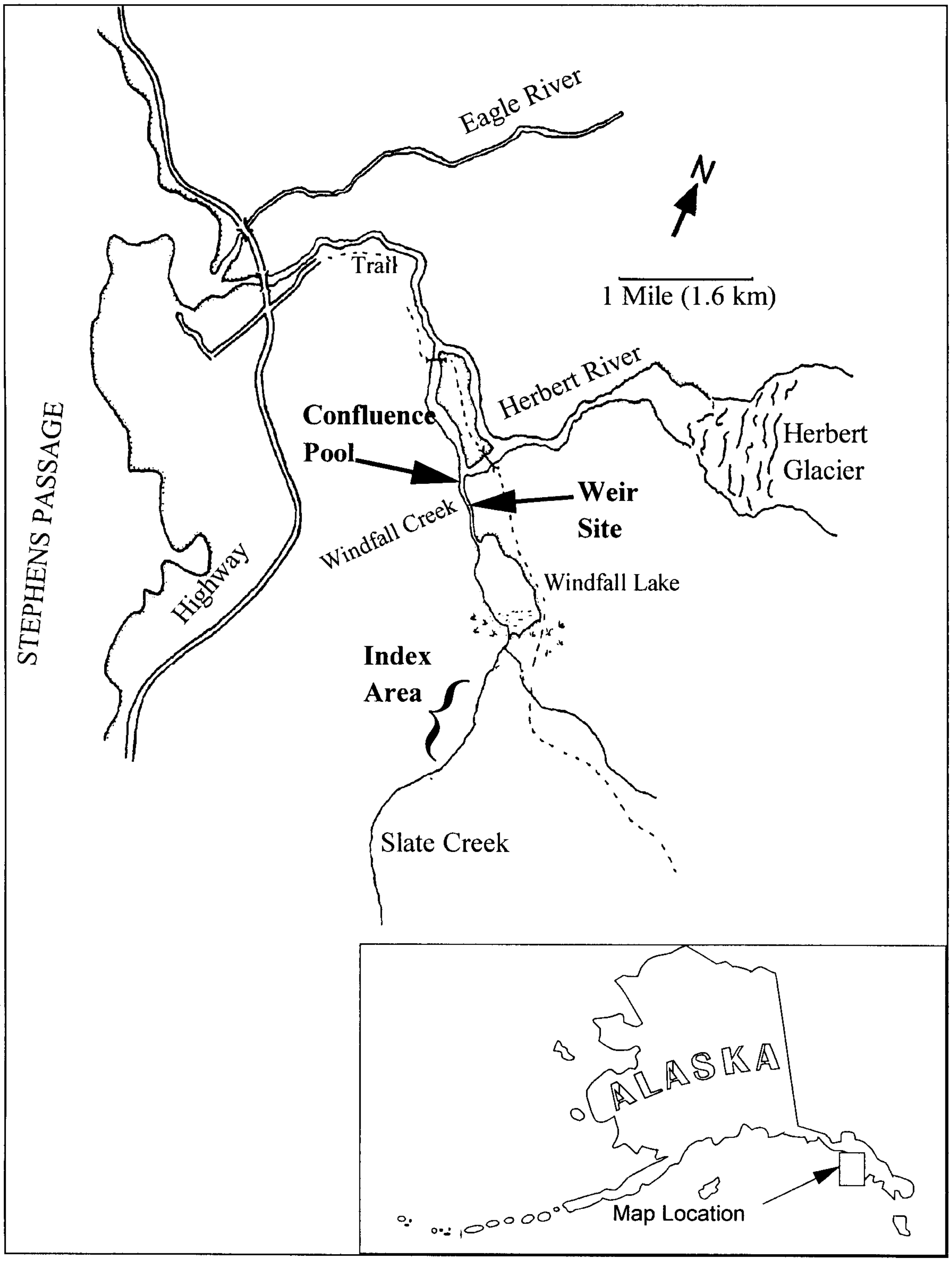

Figure 1.–Location of 1997 sampling sites in the Windfall Creek system, Southeast Alaska.

Table 1.–Mark combinations and origins of marks found on sockeye salmon examined in the index area of Slate Creek on 6 August 1997.

MARK COMBINATION FOUND					
T-bar anchor tag	Left axillary appendage clip	Other	Origin of marks (location and period)	Number recovered in index area	Number released
Yes	Yes	Upper right opercle punch	Confluence	14[a]	378
Yes	Yes	Lower right opercle punch	Confluence	1	52[b]
			Confluence subtotal	15	430
No	Yes	Upper left opercle punch	Weir: early run (6/1–6/26)	63	1,040
No	Yes	Lower left opercle punch	Weir: mid-run (6/27–7/10)	28	428
No	Yes	Lower right opercle punch	Weir: late run (7/11–8/5)	40	504
No	Yes	Lower right opercle punch	Weir: after recapture event (8/6–8/17)	0	34[c]
			Weir subtotal	131	2,006
No	Yes	No	Weir: run segment unknown	2[d]	n/a
No	No	No	Passed weir uncounted	8	n/a
			Total	156	n/a

[a] Includes four fish which had lost their T-bar anchor tags.

[b] Wrong mark applied, should have been upper right opercle punch.

[c] These fish passed the weir after the index area was sampled on 8/6 and are presented here for completeness.

[d] Assumed to have been marked at the weir.

$$\text{var}(\hat{p}_{a,h}) = \left[1 - \frac{n_h}{N_h}\right] \frac{\hat{p}_{a,h}(1-\hat{p}_{a,h})}{n_h - 1} \quad (2)$$

$$\hat{p}_a = \frac{1}{N} \sum_h N_h \, \hat{p}_{a,h} \quad (3)$$

$$\text{var}(\hat{p}_a) = \sum_h W_h^2 \, \text{var}(\hat{p}_{a,h}) \quad (4)$$

where $\hat{p}_{a,h}$ is the estimated proportion of the population in age group a and temporal strata h, $n_{a,h}$ is the number of fish sampled in age group a and strata h, n_h is the number of fish successfully aged in strata h, N_h is the total number of fish passing the weir in stratum h, $W_h = N_h/N$, and $N = \sum N_h$. Because the counts were essentially complete over the entire emigration, a finite population correction factor $(1-n/N)$ was included in the estimator.

Mean lengths at age ($\bar{y}_{a,h}$) for the immigration were similarly estimated using the temporal counts N_h and the total seasonal immigration N,

$$\bar{y}_{a,h} = \frac{1}{n_{a,h}} \sum_i y_{a,h,i} \quad (5)$$

$$\text{var}(\bar{y}_{a,h}) = \left[1 - \frac{n_h}{N_h}\right] \sum_i \frac{(y_{a,h,i} - \bar{y}_{a,h})}{n_{a,h}(n_{a,h} - 1)} \quad (6)$$

$$\bar{y}_a = \frac{1}{N} \sum_h N_h \, \bar{y}_{a,h} \quad (7)$$

$$\text{var}(\bar{y}_a) = \sum_h W_h^2 \ \text{var}(\bar{y}_{a,h}) \qquad (8)$$

where i denotes an individual fish.

Mark-Recapture Experiment

A two-event, Petersen-style model was used to estimate the sockeye salmon escapement (Seber 1982). Sockeye salmon were captured and marked in a large pool located approximately 60 m above the Windfall Creek–Herbert River confluence (see Figure 1). On every fourth day from 3 June through 18 July, sockeye salmon were captured by blocking the lower end of the pool with a seine and then driving the fish from the pool into the seine, using a line of people with dip nets. Occasionally a second seine was used in the middle of the pool.

One seine was 20 m long × 2 m deep, with approximately 3-cm bar-measure mesh, and the second seine was 30 m long × 3 m deep, with approximately 4-cm bar-measure mesh. The capture process was repeated three to five times during each marking event. Each newly captured fish was measured for MEF, had a uniquely numbered T-bar anchor tag inserted into its dorsal musculature just below the dorsal fin, and was given two secondary marks (see Table 1) to enable detection of tag loss. Recaptured fish were recorded but did not receive additional marks, and all fish were released at site of capture.

On 6 August, sockeye salmon in the index area were captured by seine and dip net and examined for marks, both to detect the presence of any fish that had been missed at the weir and to complete the second sampling event of the mark-recapture experiment. This date was chosen because it was nearest the peak of sockeye salmon abundance in the index area. All fish captured were measured to the nearest 5 mm MEF and marked by excising the adipose fin to avoid double-counting. All captured fish were recorded, and all fish were released at the site of capture.

Chapman's modification was used to estimate abundance of sockeye salmon immigrating past

Table 2.–Description of scar types found on sockeye salmon (ADF&G 1990).

Category	Description
1	One or more fairly well delineated linear marks between the head and the dorsal fins, approximately perpendicular to the longitudinal body axis and encircling or partially encircling the body.
2	A series of approximately parallel marks or scrape lines over a substantial portion of the body; two or more series of such marks occurring at different angles may give an appearance of crosshatch marks.
3	A fairly well delineated scrape band generally occurring between the head and dorsal fin approximately perpendicular to the longitudinal body axis or angled slightly backward from the top to the bottom of the body and containing a nearly oval shaped open wound, normally in the upper portion of the body.
4	Extensive descaling of at least 25% or more of one or both sides of the body but with marks or wounds not well delineated.
5	Open, gaping wounds or puncture marks located anywhere on the body, either with no other marks and scrapes or with adjacent irregular 'scratch' or 'claw' marks, but none of the marks described in categories 1–4.
6	Any scars/marks not fitting descriptions in categories 1–5 and 7.
7	A fresh or healed appearing wound on either side of the body—usually a couple of inches in length, and angled dorsally and forward toward the head of the fish, from the anterior insertion of the dorsal fin to the front of the anal fin and behind the ventral fin. May also occur elsewhere on the fish, but the angle of cut is usually consistent with the ones described above. The fresh wound will have flesh exposed the whole length of the cut. The healed scar will have an 'indentation or pucker' type scar wherever it is located.

the pool and into the Windfall system (Seber 1982):

$$\hat{N} = \frac{(n_1+1)(n_2+1)}{(m_2+1)} - 1 \qquad (9)$$

$$\text{var}(\hat{N}) = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)} - 1 \qquad (10)$$

where $\hat{N}$ = the estimated number of fish, n_1 = number of fish marked, n_2 = total number of fish examined, and m_2 = number of fish examined with marks.

Index Counts

A count of the number of live and dead sockeye salmon in the index area (see Figure 1) was conducted on 30 July, and on 5 and 15 August. One person attempted to chase sockeye salmon out from beneath protective cover so that the second observer could count them more accurately. Observers then consulted each other to determine a count for that particular reach of stream.

Limnological Sampling

Limnological samples were collected from two sites in Windfall Lake once each month during 22 May–21 October (Figure 2). At each site, one vertical tow was made with a 0.5-m-diameter, 153-µ mesh, conical plankton net from 0.5 m above bottom to the surface, at a speed of about 0.5 m/s. Each tow was preserved separately in a 10% buffered formaldehyde solution. Macrozooplankton present were identified to the lowest convenient taxon (usually genus, sometimes species), counted, and body length measured at the ADF&G Limnology Laboratory in Soldotna. Zooplankter body lengths were converted to biomass using regression analysis (Koenings et al. 1987).

Light intensity in the water column was measured at the incident (above surface), subsurface (0.05 m), and every 0.5-m increment until <1% of the subsurface intensity was reached. A Protomatic submersible photometer with peak sensitivity in the 400–700 nm wavelength range (the range of photosynthetically active radiation) was used for measurement. The euphotic zone depth (EZD) is the depth at which remains 1% of the light that entered the water (Koenings and Burkett 1987); EZD was calculated by regressing (with a zero intercept) the log of the percent light at depth against the depth:

$$\ln(I_0 / I_z) = az \qquad (11)$$

where I_0 = light intensity (ft-candles) 5-cm deep, I_z = light intensity at depth z, a = constant, and z = depth. EZD is obtained by letting $\ln(I_0/I_z)$ = ln(100)—i.e., the 1% light value, and solving for z (Gary Kyle, Alaska Department of Fish and Game, Soldotna, personal communication). The volume of the lake down to the EZD was then calculated to yield the euphotic volume (EV, in $10^6 m^3$), which represents the volume of water receiving sufficient light to support primary production. Water clarity was also measured with a standard black and white 20-cm-diameter Secchi disk (Koenings et al. 1987).

RESULTS

Weir

We counted a total of 2,318 sockeye salmon at the weir between 1 June and 17 August (Appendices A2 and A6), and only six of these fish were mortalities. Some fish passed the weir uncounted during about four hours on 13 July when a weir modification accidentally created a hole. Fish were marked at the weir according to temporal strata; thus, total immigration in the late run (the affected stratum) was estimated by using simple mark-recapture methodology (equations 9 and 10) and the recapture data from the 6 August sampling in the index area. The recapture data was simplified for this purpose by ignoring fish marked during the first two strata, because all of those fish had been counted and marked. The number of sockeye salmon marked in the late run (11 July–5 August) was 619 fish (n_1 = 504 marked at the weir + 115 marked at confluence), the number recaptured

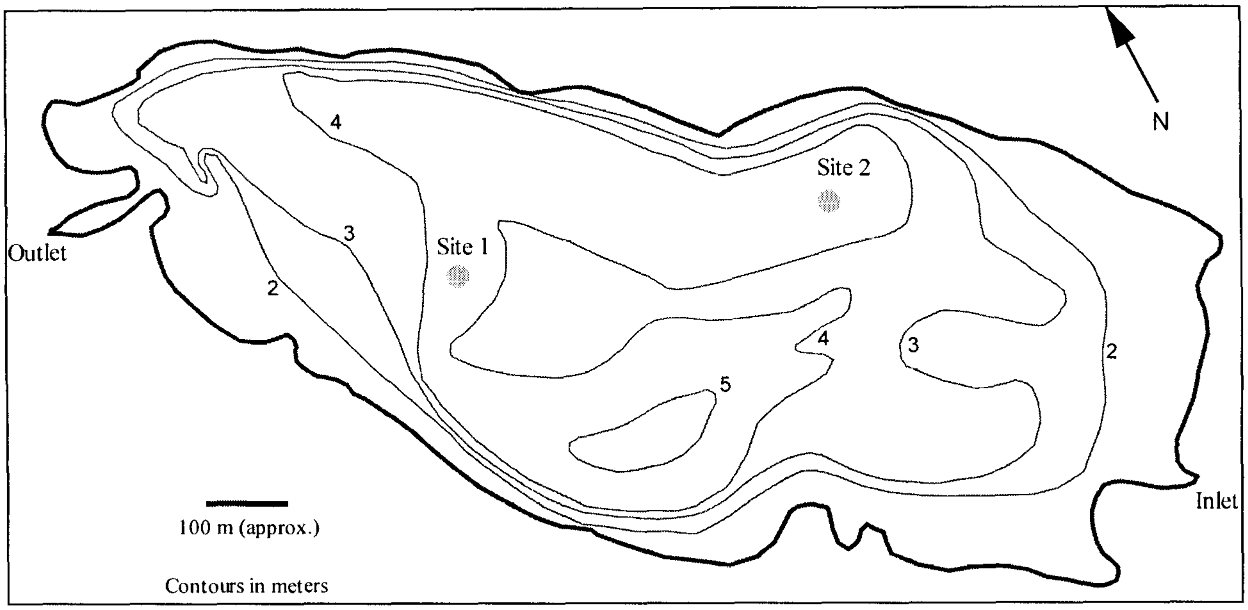

Figure 2.–Bathymetric map of Windfall Lake, showing location of 1997 limnological sampling sites.

in the index area from the late run was 45 fish (m_2 = 40 marked at the weir + 5 marked at the confluence), and the number inspected from the late run was 53 fish (n_2 = m_2 + 8 unmarked), assuming unmarked fish are from only the late run (see Table 1). Immigration during the late run was then estimated at 727 fish (SE = 39), 108 fish more than were counted. Thus, the total sockeye salmon escapement is estimated to be 2,426 fish (SE = 39), which comprises the sum of the weir counts from the first two strata (1,664 fish), the abundance estimate for the late run (727 fish, SE = 39), and the weir count from 6 to 17 August (35 fish). The absence of size-selective sampling is assumed by the mark-recapture method employed above, and lengths of sockeye salmon at the weir during the late run and those recaptured from that stratum in the index area were not significantly different (Figure 3; $P_{2\text{-tail}} = 0.0864$, $D_{max} = 0.2159$, $n_1 = 154$, $m_2 = 45$, K-S test).

The sockeye salmon run began on 1 June, reached its midpoint on 25 June, and appeared to be essentially completed by 15 August (Figure 4; Appendix A2). There was some correlation of stream height with the same day's weir count (r = 0.33, P = 0.005), whereas counts 1 or 2 d prior or later were less correlated.

Scars on sockeye salmon sampled at the weir were rare; only 4.8% showed scars of any type, and only one fish had multiple scars. Of the scars that did occur, type 6 were the most frequent (Figure 5). Healed scars were more common than fresh scars.

One adult coho salmon *O. kisutch* and 13 chum salmon *O. keta* were also counted upstream through the weir. Five of the chum salmon that passed the weir were sampled for otoliths to determine their origin. Otoliths from all five chum salmon collected bore the thermal banding pattern unique to the 1992 brood that the Douglas Island Pink and Chum Corporation released at Amalga Harbor (about 4 km from the mouth of the Eagle River; Kris Munk, Alaska Department of Fish and Game, Juneau, personal communication). Thirty-two (32) steelhead *O. mykiss* kelts (post-spawning adults) were passed downstream. The total count for cutthroat trout *O. clarki* was 42 downstream and 68 upstream, for Dolly Varden *Salvelinus malma*, 39 downstream and 3,891 upstream, for steelhead smolts, 43 downstream, and for apparently nonanadromous rainbow trout *O. mykiss*, 11 downstream and 58 upstream. Counts for cutthroat trout, Dolly Varden, rainbow trout, and steelhead smolt are minimums, because the

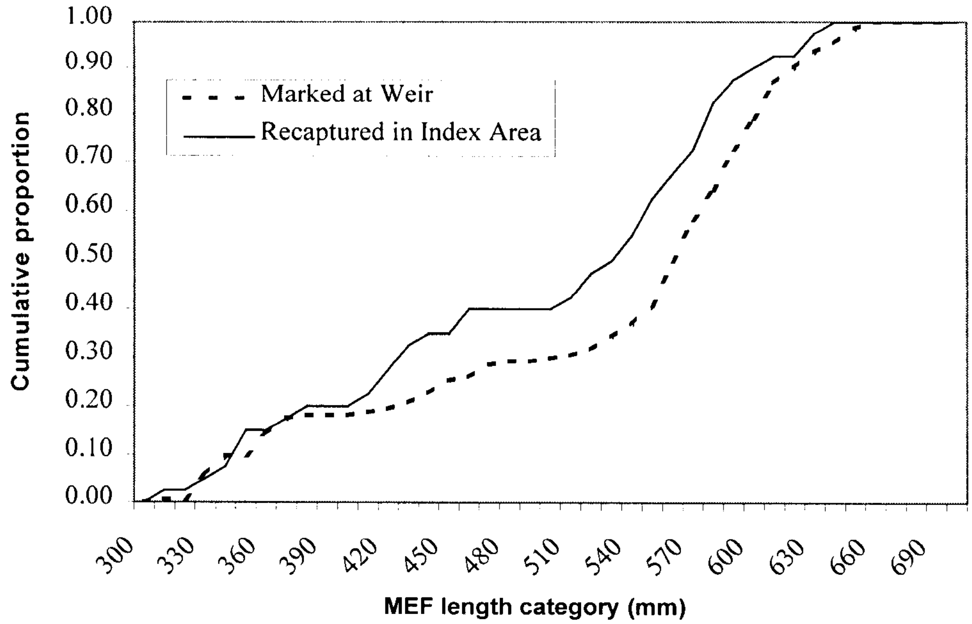

Figure 3.–Comparison of length distributions of sockeye salmon marked at the Windfall Creek weir and those recovered in the index area during the 1997 study. Data pertain to only those sockeye salmon marked at the weir 11 July–5 August 1997 and those sampled in the index area from that period, for the purpose of correcting the weir count for unseen fish. Length categories shown in 10-mm increments; vertical tick marks indicate starting value for each 10-mm increment.

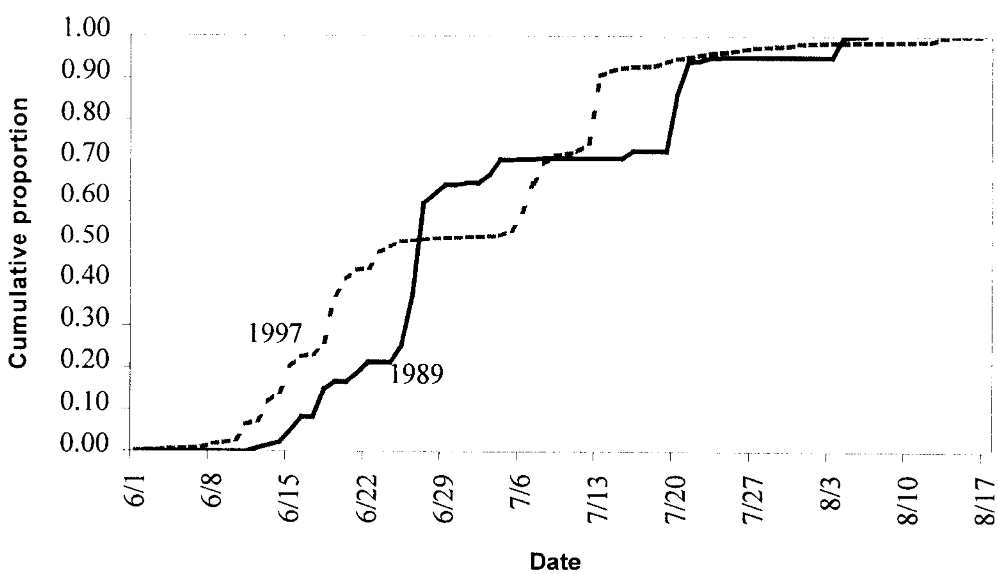

Figure 4.–Comparison of the cumulative proportion of the sockeye salmon escapement at Windfall Creek weir between 1997 and 1989. Data for 1989 are from Bethers and Glynn (1990).

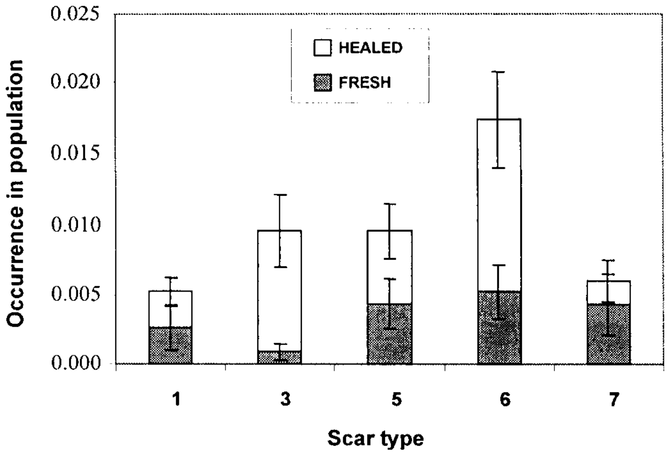

Figure 5.–Frequency of occurrence of different scar types observed on sockeye salmon sampled at the Windfall Creek weir during 1997. (See Table 2 for scar type definitions.) Error bars are ± one SE.

mesh on the weir's face was removed for two overnight periods to allow freshets to pass (Appendix A2), and fish of this size would have been able to fit between the pickets.

AGE, SEX, AND LENGTH

Age 1.3 sockeye salmon, the majority of which were females, dominated the age composition of sockeye salmon sampled at the weir (Table 3, Appendix A6). Age 1.1 and 1.2 sockeye salmon, both mostly male, were next highest in abundance. Mean MEF of all age 1.3 sockeye salmon was 586 mm, and males averaged 26 mm longer than females.

Table 3.–Age and sex composition and mean length-at-age (mm) of sockeye salmon sampled at Windfall Creek weir during 1997. $\hat{p}_a$ = proportion per age and sex class a; n = sample size; and $\hat{N}$ = total number in the population.

		AGE							
		1.1	1.2	1.3	1.4	2.1	2.2	2.3	All
		COMPOSITION							
Male	n	62	46	185	5	2	1	22	323
	$\hat{p}_a$	0.110	0.067	0.232	0.007	0.004	0.002	0.027	0.447
	SE	0.012	0.009	0.014	0.003			0.005	0.017
	$\hat{N}$	266	161	562	16	10	5	66	1085
Female	n	3	8	377	4	0	0	15	407
	$\hat{p}_a$	0.003	0.009	0.509	0.007			0.025	0.553
	SE	0.001	0.003	0.017	0.003			0.006	0.0170
	$\hat{N}$	6	22	1235	16	0	0	61	1341
All	n	65	54	562	9	2	1	37	730
	$\hat{p}_a$	0.112	0.076	0.741	0.013	0.004	0.002	0.052	1.00
	SE	0.012	0.009	0.015	0.004	0.002	0.002	0.008	
	$\hat{N}$	273	184	1797	32	10	5	126	2426
		LENGTH-AT-AGE (mm)							
Male	n	62	46	185	5	2	1	22	323
	mean	349	466	604	625	353	410	613	520
	SE	16	31	31	20	18		29	29
Female	n	3	8	377	4	0	0	15	407
	mean	345	512	578	564			574	576
	SE	13	47	20	19			17	17
All	n	65	54	562	9	2	1	37	730
	mean	349	471	586	601	353	410	593	550
	SE	16	33	25	29	11	0	27	65

MARK-RECAPTURE EXPERIMENT

Over the course of 11 days of marking, 430 sockeye salmon were marked with tags and finclips at the confluence and released alive (Tables 1 and 4). The number of sockeye salmon captured at the confluence during each marking event was significantly correlated with the sum of the weir counts for the period 2–5 d after the marking event ($r = 0.61$, $P = 0.047$), and this indicates that marking occurred in rough proportion to the overall run. Further, the proportion of each week's weir count that bore tags from the confluence showed no trends while tags were being applied (Figure 6). Also, sockeye salmon tagged in the first half of the run were recaptured just as frequently as those tagged in the second half of the run ($P = 0.42$, χ^2 test, df = 1, Table 5). Marking ceased on 18 July, when 93% of the run was complete. Except for one fish, the movement of tagged sockeye salmon through the weir was complete by 29 July (Appendix A2), which suggests that essentially all tagged sockeye salmon above the weir should have had sufficient opportunity to reach the index area before the sampling on 6 August.

The proportion of tagged sockeye salmon found in the index area (15/156 or 10%; Table 1), was not significantly different ($P = 0.17$, χ^2 test, df = 1) from the overall proportion of tagged sockeye salmon through the weir (312/2,318 or 13%; Appendix A2), which suggests that marked and unmarked fish experienced similar mortality and behaved similarly in the lake. Tag loss in the index area was substantial, at 27% (4/15), but was compensated for by using the persistent mark (finclips) in the abundance calculation.

Size-selectivity between the marking and recapture events must be evaluated to determine if size stratification of the population estimate is necessary. Considering only fish germane to the mark-recapture experiment, length distributions of marked and recaptured sockeye salmon were not significantly different ($P_{2\text{-tail}} = 0.80$, K-S test, $D_{max} = 0.1588$, $n_{n1} = 432$, $n_{m2} = 15$; Figure 7). However, length distributions of marked sockeye salmon and all sockeye salmon sampled in the index area were significantly different ($P_{2\text{-tail}} = 0.0001$, K-S test, $D_{max} = 0.2023$, $n_{n1} = 432$, $n_{n2} = 156$; Figure 7).

Table 4.–Number of sockeye salmon observed and captured at the confluence of Windfall Creek and the Herbert River, 3 June–18 July 1997.

		Categories of sockeye salmon caught			
Date	Confluence pool count	Previously marked [a]	Mortalities	New fish	Total caught
6/3/97	0	0	0	3	3
6/7/97	not done	0	0	15	15
6/11/97	not done	1	0	31	32
6/15/97	80	2	0	89	91
6/19/97	75	0	0	48	48
6/23/97	8	3	0	23	26
6/27/97	12	0	0	8	8
7/1/97	100	0	2	57	59
7/6/97	0[b]	10	3	95	108
7/10/97	150	6	1	55	62
7/14/97			not done–water too high		
7/18/97	0	0	0	6	6
	Total	22	6	430	458

[a] Previously marked sockeye salmon are those captured and marked in earlier marking events at the confluence pool (i.e., recaptured fish, but not germane to the mark-recapture experiment).

[b] Very poor visibility, glacial water intruding.

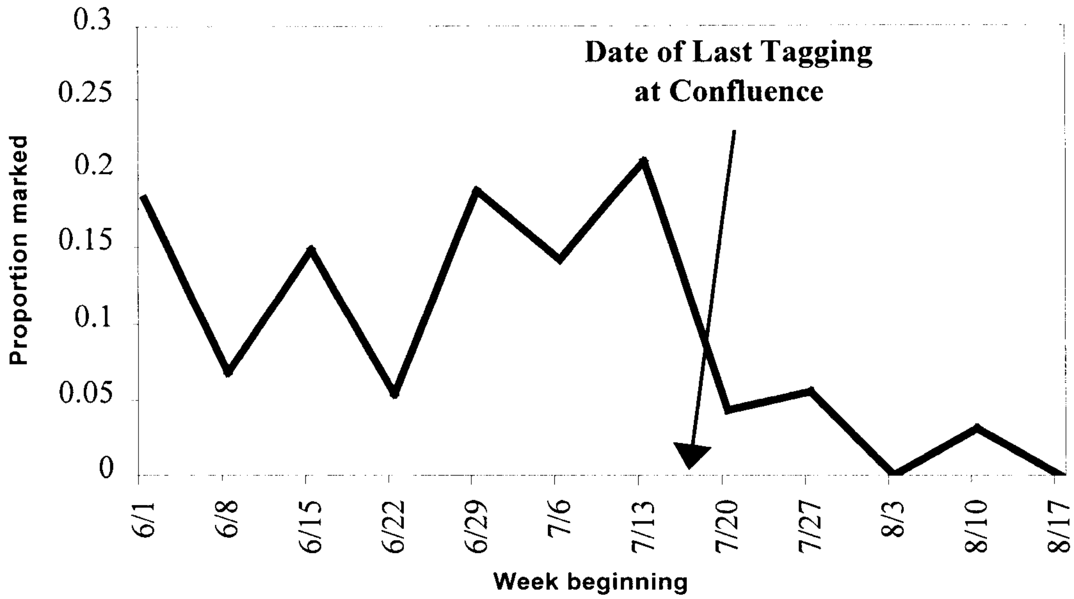

Figure 6.–Weekly proportion of sockeye salmon observed at the weir from 1 June to 17 August 1997 bearing tags applied at the confluence pool.

These circumstances indicate that only the marking event was size-selective, so fish of all lengths were pooled for the escapement estimate (Bernard and Hansen 1992). Thus, the escapement estimate from the mark-recapture experiment was 4,228 fish (SE = 954, relative precision of the 95% CI = 44.2%, n_1 = 430, n_2 = 156, m_2 = 15), much higher than the 2,426 (SE = 39) sockeye salmon that passed through the weir. Since the entire immigration was passed by the weir, the mark-recapture experiment was significantly biased high ($\alpha < 0.05$). An obvious bias with the mark-recapture estimator occurs, because only 72% (310/430) of the sockeye salmon marked at the confluence were passed through (and stayed above) the weir and had the opportunity to reach the index area where the recapture event occurred. Failure to recognize tagged fish at the weir was not the cause of this bias, for the finclips revealed that only 1.3% (4/312) of sockeye salmon had lost their tags before reaching the weir. Because only the marking event was size-selective, sockeye salmon lengths from the index area were used to estimate the length distribution of the escapement in the mark-recapture experiment. The length distributions of all sockeye salmon sampled in the index area and those sampled at the weir were significantly different ($P_{2\text{-tail}}$ = 0.0001, K-S test, D_{max} = 0.2043, n_{weir} = 578, n_{index} = 156; Figure 8).

Table 5.–Sockeye salmon marked at the confluence and recaptured in the index area on 6 August 1997.

Tag number	Date marked	Date through weir	Confluence residence (days)
9911	6/7/97	not noted	
9981	6/15/97	7/13/97	28
9968	6/15/97	6/19/97	4
9971	6/15/97	7/8/97	23
9723	6/27/97	7/13/97	16
9761	7/1/97	7/3/97	2
9614	7/6/97	7/13/97	7
9647	7/6/97	not noted	
9654	7/6/97	7/13/97	7
9636	7/6/97	not noted	
9656	7/6/97	7/13/97	7
		Mean	12
		Median	7

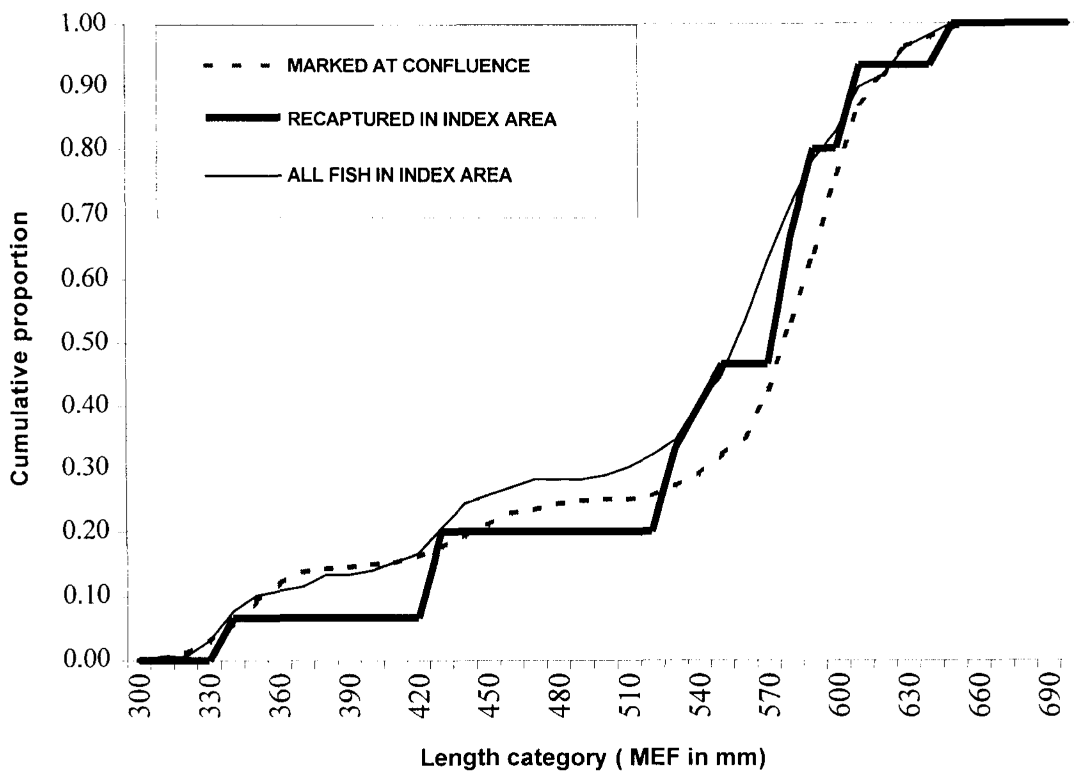

Figure 7.–Comparison of length-frequency distributions of sockeye salmon in the 1997 mark-recapture experiment. Length categories shown in 10-mm increments; vertical tick marks indicate starting value for each 10-mm increment.

Marking fish at the confluence led to some other observations on sampling techniques and fish movements. First, it was found that sampling by beach seine at the confluence was not size-selective compared to the weir ($P_{2\text{-tail}}$ = 0.162, K-S test, D_{max} = 0.0700, n_{weir} = 578, $n_{confluence}$ = 432; Figure 9), and it appeared that all sizes of marked fish passed the weir. Second, the distribution of residence times at the confluence pool was highly skewed, showing a median residence time of 4 d (Figure 10). Third, visual counts conducted while sampling the confluence pool were well correlated with the sum of the weir counts 2–5 d later (r = 0.83, P = 0.011 for the natural logarithm transformation; Figure 11). The 2–5 d period was chosen because it gave the highest correlation.

Index Counts

Totals (live plus dead) of 484, 367, and 144 sockeye salmon were observed in the index area on 30 July, 5 August, and 15 August 1997, respectively. Survey conditions during all surveys were very good, with relatively low and clear water in Slate Creek.

Limnological Sampling

The seasonal mean abundance of macro-zooplankton in Windfall Lake was estimated at 69,100 individuals/m^2 (SE = 3,500) and seasonal mean biomass at 103 mg/m^2 (SE = 3.8; Appendix A3). Bosmina usually dominated the numbers and biomass; *Daphnia longiremis* and Holopedium were occasionally dominant. Copepods were very rare. The seasonal mean EZD in Windfall Lake was 3.1 m (SE = 0.01); for the Secchi disk it was 2.0 m (SE = 0.01), and K_d (the light extinction coefficient) was 1.56 (SE = 0.001; Appendix A4). We applied the following model of sockeye salmon production (Stan Carlson, Alaska Department of Fish and Game,

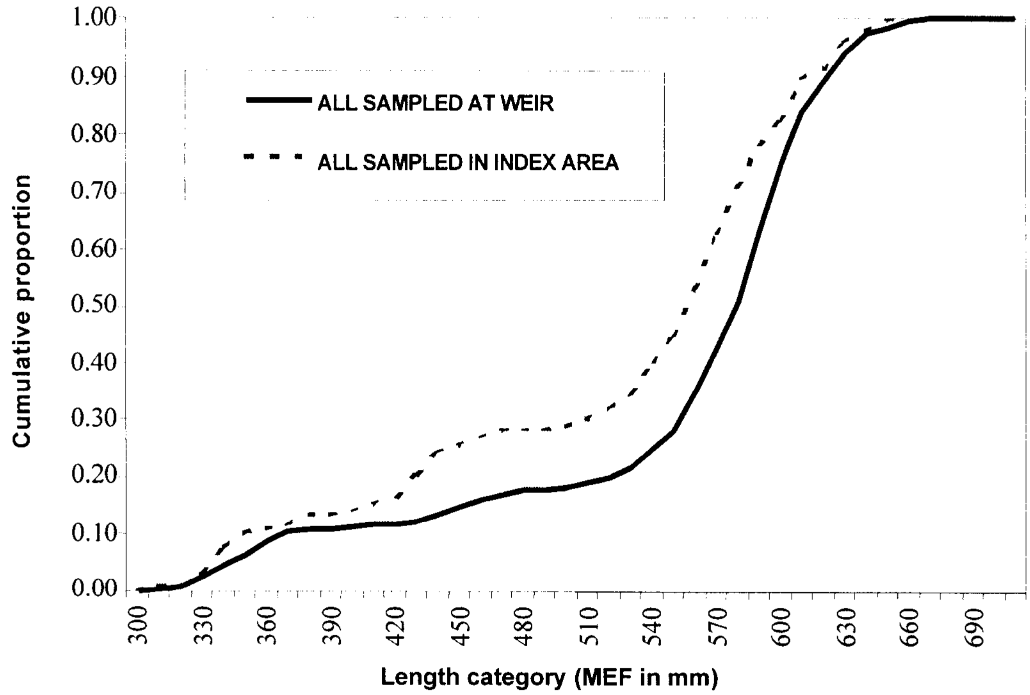

Figure 8.–Comparison of length distributions of sockeye salmon sampled in the index area and at the weir during 1997, showing size-selectivity between the mark-recapture experiment and the weir.

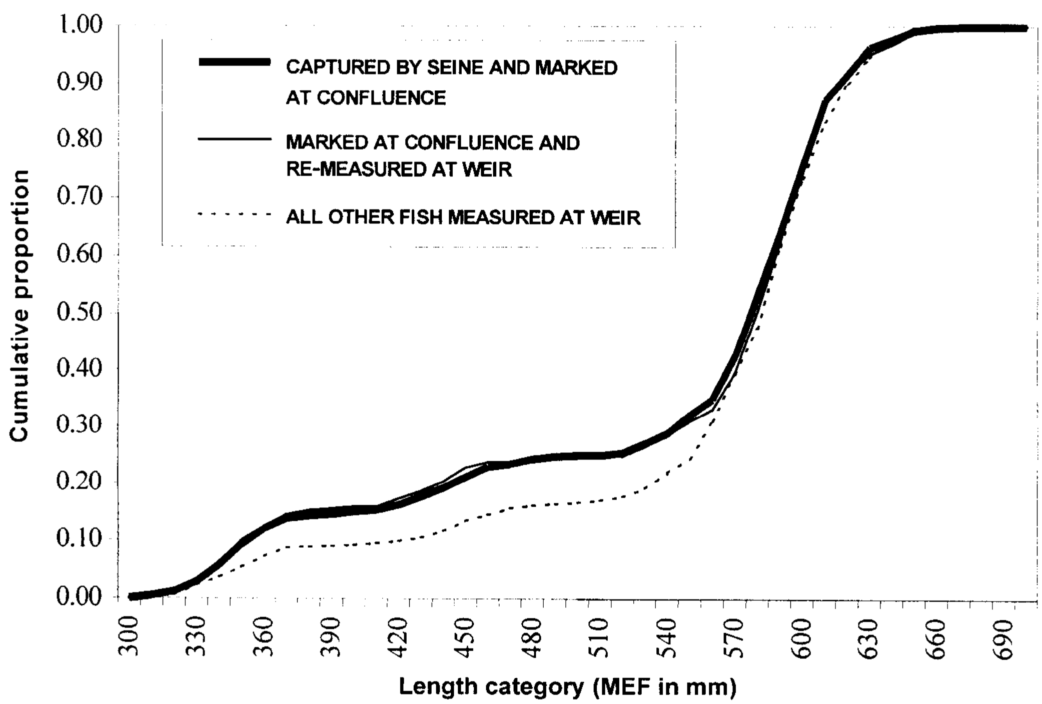

Figure 9.–Comparison of length-frequency distributions of sockeye salmon sampled by seine and those sampled at the weir during 1997. Length categories shown in 10-mm increments; vertical tick marks indicate starting value for each 10-mm increment.

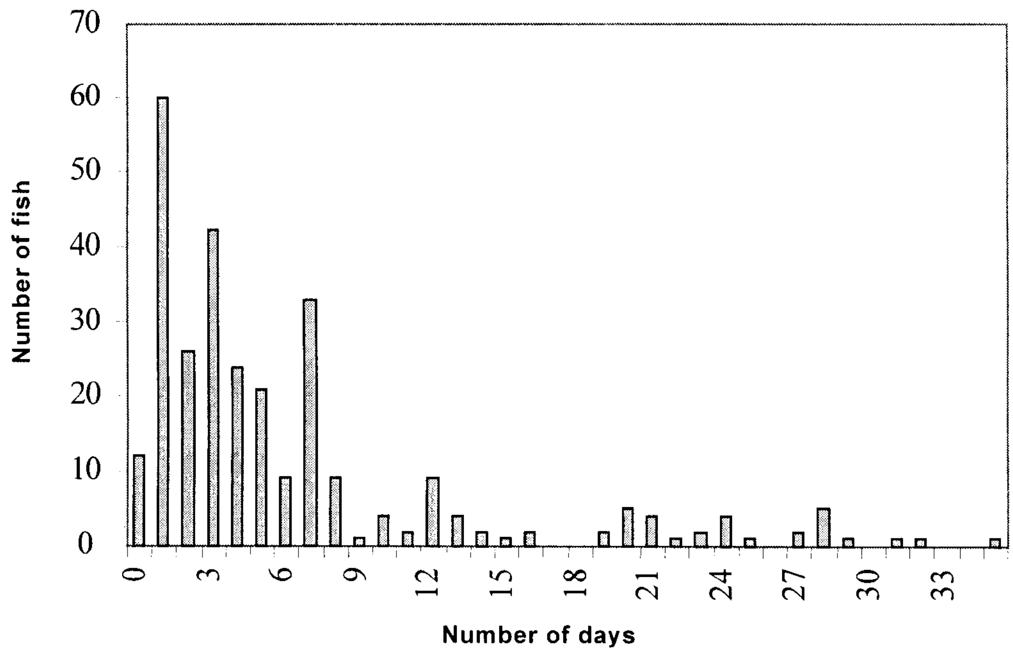

Figure 10.–Estimated residence time of tagged sockeye salmon in lower Windfall Creek in 1997. Values are the number of days elapsed between the day a particular sockeye salmon was tagged at the confluence pool and the day that same fish was passed through the weir.

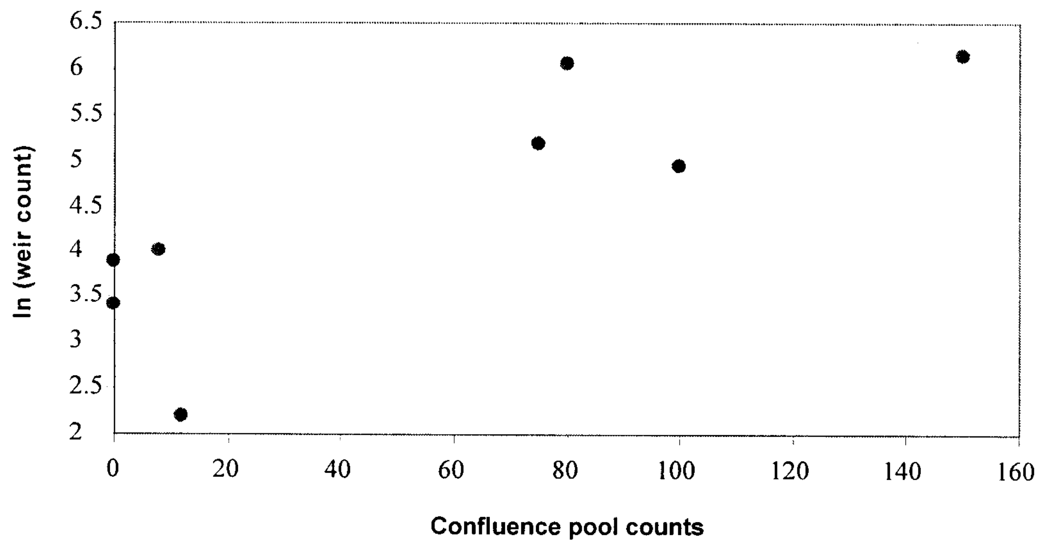

Figure 11.–Relationship between visual counts of sockeye salmon at the confluence pool during 3 June–18 July 1997 and the sum of the weir count 2–5 days later (natural log transformed). Correlation coefficient (r) = 0.83.

Soldotna, personal communication):

$$\text{Smolt Biomass (kg/km}^2\text{)} = -183 + 1.95(\text{Macrozooplankton Biomass, mg/m}^2) + 15.5(\text{EZD, m}) \quad (12)$$

to arrive at an estimate for maximum annual production in Windfall Lake of 31.31 kg of smolt (68.07 kg/km^2 total x 0.46 km^2 surface area).

On 7 August, a YSI™ Model 57 meter with a submersible probe was used to measure temperature, dissolved oxygen, and conductivity in the water column at each site in Windfall Lake during the probable peak of thermal stratification. Although surface temperatures were near the upper limits for salmonids, there was a strong thermocline between 0.5 and 2.0 m, such that hypolimnetic temperatures and dissolved oxygen concentrations were well within tolerance limits for salmonids (Appendix A5).

DISCUSSION

The total sockeye salmon escapement through the weir of 2,426 was estimated with very high precision (SE = 39) and negligible, if any, bias. For comparability to 1989 weir counts, when the weir was not covered with plastic mesh and sockeye salmon jacks (one marine annulus and small enough to pass between the pickets) could pass uncounted (Bethers and Glynn 1990), the 1997 escapement estimate must be reduced by 11% (the age 1.1 and 2.1 components; Table 3) in order to represent the "non-jack" portion of the escapement, which is 2,159 fish. Thus, the proportion of the escapement observed in 1997 during the peak count in the index area was 22% (484/2,159), very different from the proportion of 46% in 1989 (Bethers and Glynn 1990).

The great disparity in these proportions (>2:1) suggests more than simple random variation in the counts, if the assumption of no difference in sockeye salmon behavior is true. Historical records do not indicate any operational problems with the weir during 1989, so the escapements estimated in each year should be accurate and comparable when adjusted for jacks in 1997. Although the index counts during 1997 did not "bracket" the peak count, they were conducted during the historical period of peak counts (Appendix A1), so it is likely the peak count in 1997 was at or near the peak of abundance in the index area. Thus, it is reasonable to conclude that the proportion of the sockeye salmon escapement present in the index area during 1997 was truly lower than during 1989.

A possible mechanism for high interannual variation in the proportion of the sockeye salmon escapement in the index area is the large and rapid fluctuation in Slate Creek's discharge each summer. I and other ADF&G biologists have observed that Slate Creek can cease to flow during periods of low precipitation, usually in July or August, and actually becomes a series of disconnected pools that block all sockeye salmon movement. When heavy precipitation increases its discharge, sockeye salmon are observed spawning in areas of Slate Creek that were dry only days before (Mark Schwan, personal communication, Alaska Department of Fish and Game, Douglas). Precipitation levels during the two summers of weir operation were vastly different: 4.9 inches of rainfall was recorded at the Juneau International Airport (about 17 km away) during June and July 1989 versus 13.87 inches during June and July 1997. Total precipitation during June and July of the survey years ranged from 3.59 inches to 13.87 inches, so 1989 was a very dry summer, whereas 1997 experienced record-high precipitation. Thus, the proportion of escapement observed in the index area each year may have reflected strong, opposing states of habitat availability, and the mean of the two years may be a relatively unbiased estimate. Environmental correlates (e.g., stream height or precipitation during a defined period) may explain some of the variation in proportions, but this approach cannot be evaluated without more data. Estimation of a linear regression model with a constant would require at least two more years of weir, index counts, and rainfall data.

If the differing proportions are due to interannual variation, then the mean of the proportions from the two study years (34% of observed escapement) may be a better estimate. If this were the case, then the index counts would represent a smaller proportion of the escapement than previously thought, meaning that the peak index counts should be expanded by a factor of 2.94 (100/34) instead of 2.17 (100/46, based solely on 1989 data) to estimate the escapement excluding jacks.

In contrast to some of the above arguments, ADF&G biologists have noticed dramatic natural changes in the course of Slate Creek in recent years and suspect the overall quantity or quality of spawning habitat in Slate Creek has been significantly reduced (Mark Schwan, personal communication, Alaska Department of Fish and Game, Douglas). Thus, the difference in the two annual proportions counted could be caused by a shift to a new mean proportion, not just by interannual variation or environmental effects. Again, more years of data would be required to strengthen arguments for either cause.

Comparing other population characteristics, we found the escapement estimate in 1997 (excluding jacks) to be only 56% (2,159/3,864) of the 1989 escapement of 3,864 sockeye salmon (Bethers and Glynn 1990). Salmon escapements naturally vary greatly, and the 1997 escapement was not considered to be so low as to present a conservation concern for a system as small as Windfall. Other assessments of the age composition of Windfall sockeye salmon were done in 1987 and 1989, and age 1.3 sockeye salmon were more dominant in both years, at 95% and 92%, respectively (Bethers and Glynn 1990). Adjusting the 1997 age composition by again excluding jacks increases the proportion of age 1.3 sockeye salmon from 74% to 83% and makes the difference between years slight. The age composition of salmon returns also can be highly variable, and many environmental and biological conditions could cause the observed differences between years. The large proportion of age-1. sockeye salmon may be an indicator of excellent freshwater rearing conditions. Population-density studies in juvenile sockeye salmon have found that older smolt become more prevalent as rearing capacity is exceeded (Foerster 1968, Koenings and Burkett 1987, Kyle et al. 1988). The run timing in both years was very similar (Figure 4).

Because the confluence of Windfall Creek and the Herbert River is the most popular sport fishing site, the residence period of fish at the confluence is of interest to fishery managers. The high correlation between visual counts of sockeye salmon at the confluence and the sum of weir counts 2–5 d later, and the short residence times determined from the marking study (median 4 d) suggest that most fish reside only a few days at the confluence pool. However, it must be noted that residence times are biased low because of the nature of the experimental design; i.e., our measurement does not include the time between when fish first arrive at the pool and when they were captured and tagged. Also, the abundant precipitation in 1997 may have shortened residence times and made these results unique to this year (assuming stream height affects fish movement in Windfall Creek).

The weir operation in 1997 offered a rare opportunity to perform a mark-recapture experiment on a known population. Logistically, adequate numbers of fish could be marked and recaptured in the areas chosen. A larger number of sockeye salmon could have been sampled in the index area if repeated visits had been made, and the precision of population estimate would have been improved. We appeared to have sampled about 50% of the sockeye salmon present on the day we visited, which met our expectations, but the numbers of sockeye salmon present in the index area declined as time went on, which led us to the conclusion that the additional effort would have increased precision only marginally. Petersen-style abundance models require either that all fish have an equal probability of marking or recapture, or that all fish mix equally (Seber 1982). It appears that both conditions were met (see Table 5 and Figure 6). Tag loss did occur, but was fully accounted for through the use of secondary marks.

Although length distributions of sockeye salmon sampled in the mark-recapture experiment and those of sockeye salmon sampled at the weir were significantly different, the difference is biologically negligible. The full range of lengths are represented in both distributions, difference in mean length between the distributions is only

12 mm, and large sample sizes made this particular comparison very powerful. Most of the difference may be due to the timing of the samples. We observed that fish had begun to deteriorate from age by the time the recapture event took place, but were in prime condition when measured several weeks earlier at the weir. This effect can be seen in Figure 8, where lengths of sockeye salmon sampled in the index area are shown to be systematically shorter than lengths at the weir. Where only fresh fish are compared, sockeye salmon lengths from sampling at the confluence are similar to those at the weir (Figure 9). In either case, length and age compositions in the mark-recapture experiment should be accurate in a practical sense.

Because many (28%) sockeye salmon marked at the confluence were not observed at the weir, and hence had no chance of reaching the index area, the mark-recapture methodology employed has little utility for estimating escapement to the Windfall system. Possible causes for this are removal of fish (by predators or poachers), high mortality for marked fish, significant spawning below the weir, or a high downstream emigration rate of marked fish from the confluence pool.

The sport fishery for sockeye salmon was closed on Windfall Creek during 1997, so there was no known removal of tagged fish. Mortality during the marking event appeared low, but the water temperature in Windfall Creek reached 20°C during the early July marking dates at the confluence. Sockeye salmon sampled on these dates showed stress by tiring quickly and recovering slowly. A 10°C recovery bath was created by mixing cold Herbert River water with Windfall Creek water, and it appeared to speed fish recovery in the short term. The opaque, swift water of the Herbert River prevented locating mortalities after marking events, and abundant scavengers such as bears and eagles kept carcasses from remaining in the open very long.

There was evidence that the capturing and marking may have had some effect on the fish, as tagged fish took a median 7 d to reach the weir (Table 5), versus 4 d for all fish. However, the constant proportion of marked fish through the weir argues against mortality coming from one or two stressful marking events.

Rather, the Herbert and Eagle rivers are large, complex drainages with small, clearwater tributaries and beaver ponds, such that abundant alternative locations exist for spawning sockeye salmon. Beaver-pond, side-channel, and mainstem spawning and rearing by sockeye salmon in glacial rivers is well known, and returning adult fish "backing out" of systems to salt water also has been documented (Eiler et al. 1992). There were no incidental reports, though, of tagged sockeye salmon found elsewhere in the Herbert or Eagle river drainages or at sea. One rotary-wing, aerial survey of the upper Herbert River was conducted on 18 August to look for signs of sockeye salmon spawning (fish, carcasses, or presence of scavengers), but none were seen. Lower Windfall Creek has suitable flows and substrates to allow salmon spawning, but the field crew never observed any spawning activity there. However, no regular surveys of the lower creek were done, and the tannin-stained water limited visibility into the water. I believe the loss of tagged fish from throughout the run suggests a steady attrition to alternative spawning sites in lower Windfall Creek or the Herbert and Eagle river drainages.

The Windfall Lake EZD is relatively shallow, even for tannin-stained lakes (Koenings and Edmundson 1991, Kyle 1996). The zooplankton biomass is also relatively low, compared to other sockeye salmon lakes (Kyle 1996, Koenings and Kyle *In press*). In Southeast Alaska, high annual precipitation and subsequently high flushing rates, along with hardrock drainages that contribute few nutrients, tend to make most lakes in the region highly oligotrophic (Dave Barto, Alaska Department of Fish and Game, Douglas, personal communication). The macrozooplankton taxa present are commonly consumed by juvenile sockeye salmon, but the sizes of Bosmina, the most abundant, are marginally small (Koenings and Burkett 1987, Kyle et al. 1988). Thus, Windfall Lake appears relatively unproductive.

The limnological model predicts sockeye salmon production in kilograms of smolt. Converting that into numbers of adult sockeye salmon requires assumptions about the size of each smolt. To estimate the maximum number of smolt possible, I assumed a threshold size for smolt of about 2.0 g/smolt (Koenings and Burkett 1987), which converts to 15,655 smolt (31.31 kg/0.002 kg/smolt). Estimating the escapement needed to produce these 15,655 smolt requires assumptions about the sex ratio of the escapement, the number of eggs each female sockeye salmon produces, and the survival rates to fry, smolt, and adult life stages. If we use Koenings and Kyle's (*In press*) assumptions of 50% females in the escapement, 3,000 eggs/female, 10% egg-to-fry survival, 21% fry-to-smolt survival, and 11% smolt-to-adult survival, then we can estimate that the 15,655 smolt predicted by the model will require an escapement of only 497 fish. Also, if 15,655 smolt are produced, and they have an ocean survival of 11% (Koenings et al. 1993), then 1,722 adults should return. This means that if only 497 adult sockeye salmon are necessary for escapement, then 1,255 fish remain for harvest.

As with any model, the specific application must be carefully considered. Windfall Lake is so small and shallow that it falls outside the range of lake sizes used in the development of the model. The extensive shoal areas of Windfall Lake and the numerous beaver ponds along its tributaries provide additional, complex habitat for juvenile sockeye salmon (possible insectivorous), whereas the model is based on limnetic (open-water), planktivorous populations of juvenile sockeye salmon. Also, the availability of zooplankton to juvenile sockeye salmon can be reduced if the plankters are too small or use elusive behavior (Kyle 1996). Further, the model was largely derived from systems at or near carrying capacity, either because of density-dependent (competition) or density-independent (water temperature) factors. As such, the resulting predictions are maximums, and are most appropriate for systems near carrying capacity (Stan Carlson, Alaska Department of Fish and Game, Soldotna, personal communication). Nonetheless, this model was developed empirically from a wide range (physical, chemical, and geographical) of Alaskan sockeye salmon systems, and its parameters and results have proven useful in other sockeye salmon management decisions (Kyle et al. 1988, Geiger and Koenings 1991). Knowledge of the true size of Windfall Lake smolt and of survivals between life stages would allow more appropriate conversions. For instance, if smolt were larger than assumed above, the predicted biomass would convert to fewer smolt numbers, but survivals would likely be higher and offset some of the reduction in smolt numbers.

Estimates of abundance from the weirs conflict with production estimates from the limnological model. The weir counts from 1997 and 1989 exceed, and several peak index counts approach, the predicted maximum annual production of 1,722 adult sockeye salmon, which would imply that escapements are already too large. However, the preponderance of age 1. adult sockeye salmon in the historical as well as 1997 data shows that juvenile sockeye salmon easily achieve sufficient growth to become smolt after only one year in Windfall Lake, and that finding suggests Windfall Lake was below carrying capacity (Foerster 1968, Koenings and Burkett 1987, Kyle et al. 1988). Again, better estimates of survival and fecundity might improve the fit.

Another explanation for the discrepancy in escapement estimates is that the Windfall system is spawning-limited, because of the dynamic flows in Slate Creek or insufficient spawning area in general, such that the effectively spawning escapement is much lower than the apparent escapement (through poor egg deposition or egg-to-fry survival). Whereas poor egg deposition or egg-to-fry survival would decrease the number of fry rearing in Windfall Lake, the decrement might be offset by reduced intra-specific competition and increased survivals in subsequent life stages. This hypothesis is supported by the fact that 1997's run was relatively strong at 2,426 fish, but the majority of the run (74% age 1.3) was from the 1992 brood year, which had the lowest peak index count ever recorded (assuming the index count was a valid indicator of the total escapement) (Appendix A1).

Other factors could certainly be significant in the sockeye salmon life cycle, such as predation by the Dolly Varden (about 30,000 migrants in 1997) and cutthroat trout (about 600 migrants in 1997) that overwinter in Windfall Lake (Jones and Harding *In prep.*), or competition from the juvenile Dolly Varden, cutthroat trout, and coho salmon that also rear in the lake. It does not appear that water temperature and dissolved oxygen are limiting factors, at least during mid-summer. While the limnological model results are open to questions of appropriateness and to assumptions regarding survivals, the overall indication is that the total carrying capacity of Windfall Lake is not large and that any unutilized capacity is likely minimal. Other habitats, such as beaver ponds, may be significant to sockeye salmon production.

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APPENDIX A

Appendix A1.–Historical counts of sockeye salmon observed during foot surveys of the index area (except as noted) of Slate Creek, 1987–1997. Data from Mark Schwan (Alaska Department of Fish and Game, Douglas, personal communication).

Date	Total Fish	Visibility	Level	Observer	Comments
6/24/87	0	excellent	high	MB	Lake outlet, outside index area
7/2/87	12	excellent	normal	MB	
7/7/87	11	excellent	low	MB	
7/13/87	24	excellent	low	MB	
8/10/87	1,724	excellent	low	MB	From lake to marked tree
8/12/88	925	normal	normal	MB	
7/27/89	386	excellent	low	MB	Spawning just started
8/1/89	1,128	excellent	low	JM	
8/10/89	1,766	excellent	low	SC	
8/17/89	956	excellent	low	SC	
7/19/90	0	excellent	normal	BG,PS	
7/23/90	10	excellent	low	BG	900 below dam, 225 below index area
8/7/90	810	normal	normal	BG	
8/13/90	1,433	excellent	normal	MB	
7/25/91	161	excellent	normal	BG,CLS	350 below beaver dam, poor visib. there
8/7/91	871	excellent	normal	BG,CLS	
8/15/91	501	excellent	low	CLS,BG	
7/31/92	189	excellent	normal	MB,BG	
8/11/92	330	excellent	low	BG,CLS	
8/4/93	100	excellent	low	MD	Below beaver dam, outside index area
8/18/93	0			MD	Fish at beaver pond, outside index area
8/25/93	475			MD	Heavy rain weekend before
7/14/94	0	excellent	normal	BG/MB	Lower half of creek, outside index area
7/28/94	349	excellent	normal		
8/3/94	0	normal	normal	BG	Lake inlet and swamp, outside index area
7/26/95	268				
8/1/95	510				
8/7/95	516				
8/16/95	243				
7/23/96	0				
7/31/96	0				
8/10/96	1,608				
7/30/97	484				
8/5/97	367				
8/15/97	144				

Appendix A2.–Daily observations at the Windfall Creek weir, 1 June–17 August 1997. Included are water depth, water temperature, and number of fish passed in either direction. Mortalities and tags up are included in the total number of fish for that day.

	Depth	Temper-ature	Dolly Varden char		Cutthroat trout		Steelhead trout Kelts	Steelhead trout Smolt	Sockeye salmon Total	Sockeye salmon Tags	Chum salmon	
Date	cm	°C	Down	Up	Down	Up	down	down	up	up[a]	Up	Comments
6/1/97	66	12	1	0	5	0	1	1	1	0	0	
6/2/97	68	13	0	0	1	0	0	2	6	0	0	
6/3/97	66	13	1	0	1	0	0	0	1	0	0	
6/4/97	66	13	4	0	1	0	1	2	5	1	0	
6/5/97	63.5	12	3	0	0	1	1	3	2	1	0	
6/6/97	63.5	12	0	0	0	0	4	2	2	1	0	
6/7/97	61	13	1	0	0	3	2	0	5	1	0	
6/8/97	61	13	0	0	1	2	1	3	21	3	0	
6/9/97	62	13	5	0	5	0	3	1	7	0	0	
6/10/97	63.5	13	7	0	3	5	0	1	13	0	0	
6/11/97	63.5	14	0	0	0	0	2	0	88	5	0	
6/12/97	63.5	14	0	0	5	0	0	0	20	3	0	
6/13/97	65	12	3	0	5	0	0	5	104	9	0	
6/14/97	75	12	9	1	10	3	13	23	54	1	0	
6/15/97	72.5	12	0	0	0	0	4	0	141	6	0	
6/16/97	67.5	12	0	0	0	0	0	0	57	19	0	
6/17/97	63.5	13	0	0	0	0	0	0	12	1	0	
6/18/97	61	12	0	0	0	0	0	0	66	7	0	
6/19/97	66	13	0	1	0	4	0	0	261	25	0	
6/20/97	67.3	12	0	3	0	0	0	0	87	35	0	
6/21/97	63.5	14	2	0	3	0	0	0	50	6	0	
6/22/97	62.2	16	0	0	0	2	0	0	9	0	0	
6/23/97	61.5	17	0	1	0	0	0	0	92	5	0	
6/24/97	61	17	3	1	2	5	0	0	29	2	0	
6/25/97	59.5	17	0	0	0	2	0	0	34	3	0	
6/26/97	60	18	0	9	0	15	0	0	7	0	0	

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	Depth	Temper-ature	Dolly Varden char		Cutthroat trout		Steelhead trout		Sockeye salmon		Chum salmon	
							Kelts	Smolt	Total	Tags		
Date	cm	°C	Down	Up	Down	Up	down	down	up	up[a]	Up	Comments
6/27/97	59	17	0	2	0	5	0	0	6	0	0	
6/28/97	59	16	0	4	0	3	0	0	8	0	0	
6/29/97	58.5	17	0	8	0	2	0	0	3	1	0	
6/30/97	57.5	17	0	7	0	0	0	0	2	1	0	
7/1/97	56	16	0	2	0	0	0	0	2	1	0	
7/2/97	54	17	0	10	0	2	0	0	2	1	0	
7/3/97	54	17	0	13	0	1	0	0	4	2	0	
7/4/97	53	18	0	3	0	0	0	0	2	0	0	
7/5/97	53	17	0	19	0	0	0	0	33	3	0	
7/6/97	53	18	0	7	0	0	0	0	101	4	0	
7/7/97	67	17	0	94	0	1	0	0	166	16	0	
7/8/97	65	18	0	101	0	2	0	0	107	22	0	
7/9/97	61	16	0	2	0	0	0	0	47	11	0	
7/10/97	57	17	0	98	0	1	0	0	7	0	0	
7/11/97	54	16	0	109	0	0	0	0	15	7	0	
7/12/97	64	16	0	667	0	0	0	0	44	9	0	
7/13/97	104	14	0	396	0	1	0	0	378 [b]	74	0	mesh off @14:00
7/14/97	95	13	0	1	0	0	0	0	27	9	0	
7/15/97	71.5	13	0	34	0	0	0	0	15	2	0	mesh on @10:30
7/16/97	68	14	0	17	0	0	0	0	7	2	0	
7/17/97	66	14	0	31	0	0	0	0	3	2	0	
7/18/97	65	14	0	65	0	1	0	0	1	0	0	
7/19/97	96	12	0	72	0	0	0	0	21	5	1	
7/20/97	90	12	0	53	0	0	0	0	19	1	1	
7/22/97	72	13	0	91	0	0	0	0	10	1	0	
7/21/97	80	13	0	41	0	2	0	0	8	0	0	
7/23/97	75	12	0	89	0	0	0	0	12	0	1	

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		Temper-	Dolly Varden char		Cutthroat trout		Steelhead trout		Sockeye salmon		Chum salmon	
	Depth	ature					Kelts	Smolt	Total	Tags		
Date	cm	°C	Down	Up	Down	Up	down	down	up	up[a]	Up	Comments
7/24/97	76.5	12	0	108	0	0	0	0	5	0[c]	0	mesh off @20:30
7/25/97	110	11	0	11	0	0	0	0	6	0[c]	0	
7/26/97	82	12	0	51	0	0	0	0	9	1	4	mesh on @19:30
7/27/97	72	12	0	186	0	1	0	0	10	1	3	
7/28/97	66	15	0	88	0	1	0	0	3	0	3	
7/29/97	63	14	0	149	0	1	0	0	4	1	0	
7/30/97	60.5	14	0	107	0	1	0	0	1	0	0	
7/31/97	60	14	0	230	0	0	0	0	13	0	0	
8/1/97	59	15	0	182	0	0	0	0	3	0	0	1 coho up
8/2/97	58	14	0	156	0	1	0	0	2	0	0	
8/3/97	57	17	0	82	0	0	0	0	1	0	0	
8/4/97	56	16	0	17	0	0	0	0	0	0	0	
8/5/97	55.5	15	0	66	0	0	0	0	2	0	0	
8/6/97	57	16	0	0	0	0	0	0	0	0	0	
8/7/97	54.5	16	0	44	0	0	0	0	0	0	0	
8/8/97	54	15	0	16	0	0	0	0	0	0	0	
8/9/97	53	15	0	24	0	0	0	0	3	0	0	
8/10/97	52.5	17	0	30	0	0	0	0	0	0	0	
8/11/97	53	16	0	20	0	0	0	0	1	0	0	
8/12/97	52	16	0	17	0	0	0	0	0	0	0	
8/13/97	73	16	0	16	0	0	0	0	22	1	0	no flow- Herbert high
8/14/97	90	16	0	139	0	0	0	0	7	0	0	
8/15/97	62	16	0	71	0	0	0	0	2	0	0	
8/16/97	58	17	0	24	0	0	0	0	0	0	0	
8/17/97	56	17	0	5	0	0	0	0	0	0	0	last day
Total			39	3,891	42	68	32	43	2,318	312	13	

[a] T-bar anchor tags applied at the confluence of Windfall Creek and the Herbert River.

[b] An additional 108 sockeye salmon passed the weir uncounted on this day.

[c] One tagged sockeye went downstream.

Appendix A3.–Monthly density, biomass, and size of macrozooplankton taxa sampled at two sites in Windfall Lake during 1997.

Genus			Date					
(or species)	Site	Parameter	5/22/97	6/23/97	7/18/97	8/19/97	9/15/97	10/21/97
Bosmina	1	Density, no./m^2	153	4,075	30,310	206,994	65,800	127
		Biomass, mg/m^2	0.1	4	33.7	155	60.6	0.2
		Size, mm	0.29	0.33	0.35	0.29	0.32	0.38
	2	Density	341	22,245	235,866	12,583	98,996	209
		Biomass	0.3	19.2	189.7	8.7	91.2	0.3
		Size	0.31	0.31	0.3	0.28	0.32	0.38
Ovigerous	1	Density		255	204	25,471	13,839	326
Bosmina		Biomass		0.6	0.3	23.5	15.4	0.4
		Size		0.5	0.41	0.32	0.35	0.38
	2	Density	20	170	2,038	5,145	11,717	576
		Biomass	0	0.2	3	5.4	12.3	0.7
		Size	0	0.36	0.4	0.34	0.34	0.37
Chydorinae	1	Density	20					31
		Biomass	0.012					0.023
		Size	0.27					0.29
	2	Density	5				340	41
		Biomass	0.0175				0.3	0.1
		Size	0.6				0.31	0.37
Ovigerous	1	Density						5
Chydorinae		Biomass						0
		Size						0
Daphnia	1	Density	71	2,547	3,464	1,698	3,991	311
longiremis		Biomass	0.1	4.4	4.5	1.7	3.9	0.4
		Size	0.55	0.64	0.56	0.49	0.49	0.58
	2	Density	255	3,991	16,811	2,242	1,868	535
		Biomass	0.3	8.2	28.4	2.2	1.5	0.5
		Size	0.57	0.69	0.63	0.49	0.45	0.5
Ovigerous	1	Density	82		509	1,358	1,528	219
Daphnia		Biomass	0.1		1.7	2.5	3	0.4
longiremis		Size	0.64		0.86	0.65	0.68	0.67
	2	Density	122	679	764	458	1,019	204
		Biomass	0.2	2.5	2.1	0.8	1.8	0.4
		Size	0.66	0.91	0.79	0.64	0.64	0.65
Holopedium	1	Density	3,627	21,141	204			
		Biomass	3.7	176.4	3			
		Size	0.37	0.88	1.11			
	2	Density	4,381	6,113	1,274			
		Biomass	3.3	68	17.5			
		Size	0.33	0.99	1.08			

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Genus (or species)	Site	Parameter	Date 5/22/97	6/23/97	7/18/97	8/19/97	9/15/97	10/21/97
Holopedium	1	Density	3,627	21,141	204			
		Biomass	3.7	176.4	3			
		Size	0.37	0.88	1.11			
	2	Density	4,381	6,113	1,274			
		Biomass	3.3	68	17.5			
		Size	0.33	0.99	1.08			
Ovigerous Holopedium	1	Density		18,849	102			
		Biomass		277.2	2.2			
		Size		1.11	1.31			
	2	Density		2,717	1,019			
		Biomass		40	17.8			
		Size		1.11	1.19			
Cyclops	1	Density			153			
		Biomass			0.2			
		Size			0.65			
	2	Density				51	170	10
		Biomass				0.049	0.2	0.009
		Size				0.54	0.55	0.51
Ergasilus	2	Density		0		102	170	
		Biomass		0		0.1	0	
		Size		0.63		0.46	0	
			All dates combined					
			Mean	SE				
All	All	Density	69,136	3,507				
		Biomass	103.25	3.8				

Appendix A4.–Monthly readings of euphotic zone depth (EZD), the light extinction coefficient (K_d), and the Secchi disk depth in Windfall Lake during 1997.

	EZD (m)		K_d (m^{-1})		Secchi Disk (m)	
	Site		Site		Site	
DATE	1	2	1	2	1	2
5/22/97	3.5	3.5	1.3	1.3	2.2	2.1
6/23/97	4.2	4.1	1.1	1.1	2.6	2.9
7/18/97	3.0	3.0	1.5	1.5	1.9	1.9
8/19/97	2.7	2.6	1.7	1.8	1.9	1.9
9/15/97	2.3	2.4	2.0	1.9	1.4	1.4
10/21/97	2.8	2.7	1.7	1.7	1.9	1.8
Mean	3.1	3.1	1.56	1.56	2.0	2.0

Appendix A5.–Water column variables measured at sampling sites in Windfall Lake on 7 August 1997.

	Temperature, °C		Dissolved Oxygen, mg/ml		Conductivity, µmho/cm	
	Station		Station		Station	
Depth, m	1	2	1	2	1	2
0.05	17.3	17.8	9.3	9.5	35	35
0.5	17.2	17.8	9.8	9.7	35	35
1.0	14.0	16.2	9.8	9.5	35	40
1.5	12.9	14.0	9.9	9.4	38	39
2.0	11.9	12.0	9.8	8.8	35	35
2.5	11.3	11.1	9.3	8.3	33	34
3.0	10.7	10.9	8.1	7.6	35	33
3.5	10.2	10.2	7.0	6.8	35	35
4.0	9.9	9.8	4.2	4.3	38	40
4.5 (bottom)						

Appendix A6.–Description of electronic data files used to create this document and archive all field data collected. Files are stored at the Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services Section, in Anchorage, Alaska, and with the author.

File name	Format	Contents
DATA	Microsoft Word 97	Brief explanation of the data found in each section of the file WF97DATA.XLS below.
WF97DATA	Microsoft Excel 5.0	Raw data for this report, i.e. tag numbers, lengths, ages, and scars for individual sockeye by location, zooplankton densities and lengths, weir counts, confluence counts, index counts, and scar definitions.