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Effects of Habitat and Predator–prey Interactions on Stocked Sockeye Fry in Tatsamenie Lake

by

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and

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

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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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ABSTRACT

Tatsamenie Lake has been stocked with marked sockeye salmon fry since 1991, as part of a program initiated by the Pacific Salmon Commission to increase annual returns of sockeye salmon (*Oncorhynchus nerka*) to the Taku River system by 100,000 fish annually. However, the average annual commercial catch of stocked Tatsamenie sockeye salmon between 1995 and 2000 has been only about 2,000 fish. We conducted this study in 2001 and 2002, to ascertain whether predators were targeting stocked sockeye fry in the lake, and which species, if any, were responsible. Other questions we investigated included whether age-0 stocked sockeye fry were migrating prematurely from the lake, and whether differences in water chemistry between Tatsamenie Lake and the incubating hatchery were depressing stocked-fry survival rates. In 2001 and 2002, sockeye fry stocked in Tatsamenie Lake did not appear to suffer higher mortality than wild fry. Lake trout (*Salvelinus namaycush*) were probably the primary predators on sockeye fry, and were likely targeting the fry as they migrated into the limnetic zone in late summer. Tatsamenie Lake sockeye fry have a residence time in the littoral zone of up to 2 months or more, before migrating into the limnetic zone. Thus, food resources for sockeye fry in Tatsamenie Lake may be partitioned in time and space, into littoral and limnetic zones. If the carrying capacity of the littoral zone is considerably smaller than that of the limnetic zone, the littoral zone may be constricting the sockeye fry population. Predation may cause food resource partitioning in the lake, by confining emergent sockeye fry to littoral areas. While the results of the study do not conclusively support resource partitioning, we feel that the evidence is compelling enough to warrant further inquiry.

Key Words: sockeye salmon; *Oncorhynchus nerka*; Tatsamenie Lake; predator-prey; lake trout; *Salvelinus namaycush*; diet; survival; wildlife-habitat relationships; fry stocking

INTRODUCTION

Tatsamenie Lake, a large lake within the Taku River system, has been stocked with about 1.7 million sockeye fry (*Oncorhynchus nerka*) annually since 1991 (Table 1). Despite the intensive stocking, the number of returning adults from these stockings has been disappointingly low, about 2,000 fish annually (TTC *In press*). The Department of Fisheries and Oceans Canada, in conjunction with the University of York, Ontario, had conducted a 2-year study of the lake to ascertain possible reasons for the low stocked adult returns (Mathias 2000). Mathias concluded that sockeye fry stocked in Tatsamenie Lake suffered higher mortalities than wild fry, and that the probable cause for the differential mortality was predation on stocked fry. Our study was undertaken to determine the following: whether predation was causing the differential mortality between stocked and wild fry; which species of fish were targeting stocked sockeye fry; and, the time period the differential predation occurred.

HISTORICAL BACKGROUND

The Pacific Salmon Treaty of 1985 specified formal harvest sharing of salmon originating from the Stikine, Taku, and Alsek rivers (Mathias 2000). The sharing agreements between the U.S. and Canada expired after the 1986 fishing season and negotiations to extend sharing arrangements were very contentious and unsuccessful in 1987. In order to break the impasse, negotiators from the two nations agreed to a long-term plan to develop sockeye enhancement programs for the Taku, Alsek, and Stikine Rivers, and to develop underutilized rearing potential in several headwater lakes.

The goal of the proposed enhancement programs was to increase annual returns of adult sockeye salmon to each of the rivers by 100,000 fish. A feasibility study to determine the most appropriate enhancement programs was carried out under the auspices of the Transboundary Technical Committee of the Pacific Salmon Commission (TTC 1988). The Transboundary Technical Committee used the euphotic volume model (Koenings and Burkett 1987) and the zooplankton density model (Koenings and Kyle 1997) to assess the lakes as candidates for enhancement. After reviewing a number of lakes in the Stikine, Taku, and Alsek drainages, four lakes were chosen as candidates for enhancement in the Northern Boundary region: Tuya and Tahltan lakes in the Stikine River watershed, and Trapper and Tatsamenie lakes in the Taku River watershed (Figure 1). Tahltan and Tatsamenie lakes had resident populations of sockeye salmon while Tuya and Trapper lakes did not. The chosen enhancement strategy for all four lakes was to collect and fertilize eggs from wild spawning sockeye salmon, transport the eggs to a hatchery to be incubated over the winter, and to release fry into the lake the following spring. The Transboundary Technical Committee concluded that Tatsamenie Lake was capable of producing 390,000 adult sockeye salmon (TTC 1988).

Tatsamenie Lake was first stocked with sockeye fry in 1991 (TTC 1993). Sockeye salmon adults were collected at Little Tatsamenie Lake and artificially spawned by technicians. The fertilized eggs were transported to Snettisham hatchery for incubation over the winter. The resulting fry were then transported to Tatsamenie Lake, and released. All stocked sockeye fry were marked with a thermal otolith mark to distinguish them from wild fry using the RBr coding scheme described by Munk and Geiger (1998). The egg takes for Tatsamenie Lake were moved from Little Tatsamenie Lake to Tatsamenie Lake in 1994 (TTC 1998). The average catch of stocked sockeye salmon in the Taku River fisheries has been about 2,000 fish (TTC *In press*), considerably less than the stated goal of 100,000 stocked sockeye adults returning to the Taku River annually. Given that incubated eggs and emergent fry are protected from hazards in the early life stages, the stocked fry should have had a large survival advantage. Prior to 1999, mean egg-to-smolt survival rates in Tatsamenie Lake for stocked sockeye fry averaged about one-third that of wild fry (Mathias 2000).

The average annual adult sockeye salmon production for Tatsamenie Lake has been about 26,000 fish (TTC *In press*). In contrast, Chilkoot Lake – a deep, glacially impacted lake with about 40% of the volume of Tatsamenie Lake – produced an average of 233,000 sockeye salmon between 1976 and 1990 (Geiger and McPherson 2004).

STUDY SITE

Tatsamenie Lake (58 20’N. 132 20’W) is located within the Taku River watershed, approximately 220 km east of Juneau, Alaska, and 140 km west of Dease Lake, British Columbia (Figure 1). Tatsamenie Lake drains north and west into Tatsatua Creek, which in turn flows through Tatsatua Lake (also known as Little Tatsamenie), and empties into the Sheslay River, about 25 km north and east. The Sheslay River is a tributary of the Inklin River, which in turn drains into the Taku River. The Taku River flows into the ocean about 150 km downstream from Tatsamenie Lake. Tatsamenie Lake is about 17 km long and 1.5 km wide, and is at an elevation of 790 m. The lake has a surface area of 1,622 ha, and a volume of 890 million m^3. The lake’s littoral zone has a surface area of 114 ha. The maximum depth is 142 m and the mean depth is 53 m. The principal inlet stream at the south end of the lake is glacially fed, resulting in higher turbidity at that end of the lake. Due to wind mixing and the glacial inputs, the water is colder at the southern end of the lake. Tatsamenie Lake is covered with ice from December until May. The terrain surrounding Tatsamenie Lake is flat at the ends near the outlet and primary inlet streams, but is steep along the lake proper, especially on the western side of the lake (Mathias 2000). Beaches along the steep sides of the lake tend to be narrow, and composed of cobble, bedrock outcroppings, and boulders. The inlet streams have formed alluvial fans of much finer material, especially on the eastern side of the lake. The lake bottom drops off rapidly from a narrow littoral area to a depth of 70 to 120 m (Figure 2). Littoral shelving is more prominent at the north end of the lake. Tatsamenie Lake is 1 of 5 lakes in the Taku River watershed that have been documented as supporting populations of sockeye salmon (www.fishwizard.com). Other fish species or genera known to inhabit Tatsamenie Lake include Chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), kokanee (*O. nerka*), rainbow trout (*O. mykiss*), steelhead trout (*O. mykiss*), lake trout (*Salvelinus namaycush*), Dolly Varden (*S. malma*), bull trout (*S. confluentus*), mountain whitefish (*Prosopium williamsoni*), sculpin (*Cottus spp.*), and suckers (*Catastomus spp.*; Mathias 2000).

STOCK ASSESSMENT

Since 1983, the Alaska Department of Fish and Game (ADF&G) and Department of Fisheries and Oceans Canada (DFO) personnel have been monitoring harvests of Taku River sockeye salmon in the commercial and subsistence fisheries that specifically target these fish (McGregor 1986). Beginning in 1986, ADF&G and DFO began allocating the harvests to specific stocks of origin by scale pattern analysis (Jensen et al. 1993).

In U.S. waters, most of the fishing effort targeting Taku River salmon occurs in the District 111 gillnet fishery in Taku Inlet and in Stephens Passage, and in an Alaskan personal use and a subsistence fishery just below the U.S./Canada border on the Taku River (Figure 1). A Canadian combined inriver commercial fishery and aboriginal fishery also targets these fish just above the U.S. Canada border on the Taku River (TTC 1993).

The sockeye catches are classified to general stocks of origin via scale pattern analysis and presence or absence of brain parasites (Jensen 1999). In addition, otoliths are used to determine percentage and origin of hatchery fish in the commercial catch. ADF&G partitions the District 111 sockeye catch into 8 separate stocks or groups of stocks: Kuthai Lake, Little Tatsamenie Lake, wild Tatsamenie Lake, stocked Tatsamenie Lake, mainstem Taku, Crescent Lake, Speel Lake, and Snettisham hatchery (TTC *In press*). The Canadian commercial sockeye catch is partitioned into 5 separate stocks or groups of stocks: Kuthai Lake, Little Trapper Lake, wild Tatsamenie Lake, stocked Tatsamenie Lake, and mainstem Taku River (TTC *In press*). Speel Lake, Crescent Lake, and Snettisham hatchery sockeye stocks are dropped from this allocation, because they originate in Alaska and should not be present in the Canadian commercial catch.

ADF&G and DFO estimate overall escapement of sockeye salmon into the Taku River by a mark-recapture study, whereby fish are marked at a fish wheel at Canyon Island and released. Fish caught upstream of Canyon Island in the Canadian commercial fishery are examined for marks (Kelley et al. 1997). The overall escapement into the Taku River is calculated by subtracting the Canadian commercial catch from the mark-recapture estimate at Canyon Island. DFO also monitors sockeye escapements into several lakes and stream reaches using weirs and mark-recapture studies.

Since 1995, an adult sockeye weir has been operated at the outlet of Tatsamenie Lake to count the escapement into the lake. The weir also functions as a collection point for brood stock. The U.S./Canada Treaty allows up to 30% of the escapement to be used as brood stock. Usually, about 17% of the females are retained for brood stock and their offspring become the stocked fry (Hyatt et al. 2005).

Since 1996, DFO personnel have also been estimating Tatsamenie Lake sockeye smolt emigrations with a mark-recapture study during spring and early summer. Emigrating smolts are representatively sampled for age, length, and weight. The otoliths from these smolts are examined to determine if they are of wild or stocked origin. DFO personnel also monitor the fry population during that time by taking beach-seine samples at designated points along the shore. The fry in the samples are preserved, dissected, and classified as stocked or wild fry, based on examination of the otoliths for a thermal mark. During the fall, one or more hydroacoustic surveys are conducted. In the past, DFO personnel from Nanaimo, British Columbia conducted one survey in late August; the rest were conducted by local field personnel. Trawl net tows are made in association with the hydroacoustic surveys. The sockeye fry captured in the trawl tows are preserved, dissected, and classified as stocked or wild. The hydroacoustic echograms are sent to DFO in Nanaimo, British Columbia for analysis. The results are then used to estimate the size of fall fry population.

STOCKING HISTORY

Between 1991 and 2002, the average number of fry stocked annually into Tatsamenie Lake was 1.68 million (Table 1). From 1991 through 1996, sockeye fry were stocked into the limnetic zone (mid-lake) shortly after they had absorbed their yolk sacs. Fry-to-smolt survival rates for stocked fry during this period were very low (Mathias 2000).

In an effort to increase survival of stocked fry the Enhancement subcommittee of the Transboundary Technical Committee began to change the timing of stocking, assess fry transport and acclimation, change location of stocking (from offshore to onshore), and feed hatchery fry prior to their release (TTC 2001; Hyatt et al. 2005).

Stocking dates have changed several times during the course of the program. During 1991 and 1992, fry were stocked at the end of June. From 1993 to 1995, stocking dates were shifted to late July. In 1996 to 1998, stocking dates were shifted back to late June. In 1999, stocking dates were shifted to early June (Mathias 2000). Prior to 1998, stocking dates were a result of variations in hatchery protocol and transport availability. Between 1992 and 2002, fry were delivered from the hatchery at a median post emergence weight of 0.15 g (range between 0.11 and 0.17 g).

In order to reduce transport mortalities, all fry transports followed ADF&G aerial transport protocols. Fry were acclimated for 10 to 15 minutes if lake water and transport water temperatures were greater than 2.5 º C apart. In 1997 and 1999, a series of holding studies were conducted to examine long-term and short-term transport mortalities. Hyatt et al. (2005) concluded that fry transport and acclimation was not substantially contributing to the low survival of the stocked fry in Tatsamenie Lake.

Based on results of the fry-sampling program from 1991 to 1996, the Transboundary Technical Committee concluded that the wild sockeye fry congregated predominantly in the littoral zone in spring and early summer (Mathias 2000). The biologists hypothesized that fry stocked in deep water failed to orient themselves towards the littoral zone, and became more susceptible to predation and starvation. As a result, from 1997 to 2002, stocking sites were shifted from offshore to the nearshore littoral zone (TTC 2001; Hyatt et al. 2005). Following the shift, stocked fry-to-smolt survival rates increased, but not to the point where stocked fry survival equaled or exceeded wild fry survival.

In 1998 through 2002, net-pen feeding experiments were conducted by DFO to compare fry-to-smolt growth and survival of wild fry, unfed stocked fry, and stocked fry fed in a net-pen prior to release. In 1998 and 1999, under the aegis of the Transboundary Technical Committee, Mathias examined growth rates and egg-to smolt survival rates of wild fry, fed stocked fry, and unfed stocked fry into Tatsamenie Lake. The growth rates for all three treatment groups were similar. The egg-to-smolt survival rates of stocked fry were comparable to or slightly exceeded that of wild fry; unfed stocked fry had the lowest egg-to-smolt survival rates (Mathias 2000). Mathias (2000) analyzed these and other data and hypothesized that Tatsamenie Lake stocked fry were experiencing greater size-selective mortality than wild fry. Mathias stated that the possible causes for this mortality were size-selective success in feeding, disease, or predation. She concluded that predation was the most likely cause of the differential mortality.

In 2000, under direction of the Transboundary Technical Committee, DFO personnel conducted another experiment comparing fed stocked fry and wild fry. The egg-to-smolt survival was much higher for fed stocked fry than it was for wild fry, but wild fry had slightly higher growth rates (Hyatt et al. 2005).

In 2001, the Enhancement subcommittee of the Transboundary Technical Committee, in conjunction with DFO, ADF&G, and the Douglas Island Pink and Chum Aquaculture Corporation (DIPAC) began this study of Tatsamenie Lake stocked sockeye salmon and potential predators to further examine stocked fry survival issues. The Transboundary Technical Committee identified the following goals for our study: 1) to determine if and when size-selective predation was affecting survival of stocked fry relative to wild fry, and 2) to establish or rule out other factors that may be impacting survival of stocked sockeye salmon fry in Tatsamenie Lake. Results were to be used to optimize sockeye salmon production in the lake. In late 2001, the predator portion of the study was terminated one year early, because the Technical Committee concluded that the study could not provide quantitative information on predation.

OBJECTIVES

Our study was divided into several parts. One part involved monitoring Tatsamenie Lake sockeye fry populations more extensively to determine whether the stocked fry were suffering differential mortality relative to the wild fry, and whether stocked fry were leaving the lake prematurely. A second part involved examining potential predators to determine whether they were preying upon sockeye fry, and whether stocked fry were more vulnerable to predation. A third part of the study involved trying to establish whether water quality at Snettisham hatchery was responsible for the small stocked fry returns. To fulfill these goals, we developed the following objectives:

1. Monitor relative proportions of wild and stocked sockeye fry present in littoral zone of Tatsamenie Lake in June through September of 2001 and 2002.
2. Monitor relative proportions of wild and stocked sockeye fry present in the limnetic zone of Tatsamenie Lake in August, September and October of 2001 and 2002.
3. Determine whether time of stocking or feeding prior to stocking affected survival of stocked fry.
4. Determine whether sockeye fry were emigrating prematurely from the lake during the year they are hatched.
5. Determine whether water chemistry in Tatsamenie Lake and Snettisham hatchery was sufficiently different to depress survival rates of stocked fry.

METHODS

STOCKING

In 2001 and 2002, the stocked fry were divided into two separate treatment groups, to determine if feeding fry or time of release affected their survival rates. The first release group was to consist of unfed fry, while the second release group was to consist of fed fry. Due to weather delays in May and June, both of the 2001 release groups were fed. In 2002, the earliest release consisted of unfed fry, and the second release consisted of fed fry.

FIELD SURVEYS AND SAMPLING

Sockeye Fry Populations

In 2001 and 2002, a field crew, consisting of two technicians, took fry samples for our study. All sockeye fry samples were sent to the DFO otolith lab in Whitehorse for measurement, dissection, and classification as wild or stocked fry.

To sample the littoral zone, the field crew collected sockeye fry by beach-seining at previously selected sites, every 10 to 14 days, from June to October. The field crew took a representative subsample of their catch, and preserved the subsample in 95% ethanol for later dissection in the lab. A minimum of 10 sets was made at 5 sites, and sampling was usually accomplished in one day. The overall sampling goal for each period was a minimum of 200 fish. The beach-seine samples were used to monitor the relative abundance of the stocked fry, but not to develop estimates of overall population size. The same beach-seine sampling sites and methods were used in previous studies (Mathias 2000). This enabled us to compare the results from our study with those of previous studies.

The field crew deployed trawl nets to sample sockeye fry in the limnetic zone. The sampling by trawl nets was usually conducted in conjunction with four to six hydroacoustic surveys, between July 15 and late October. Surveys were conducted according to guidelines described by Hyatt et al. (1984). A portion of the trawl net catches was preserved in 95% ethanol. The sample goal for the trawl surveys was a minimum 100 sockeye fry, or as many as could be caught in 5 nights. The fry samples were sent to the DFO otolith lab in Whitehorse, for dissection and classification.

To determine whether stocked age-0 fry were prematurely migrating out of the lake, a fyke net was deployed at the outlet of the lake and checked daily from June through August of 2001.

Potential Predators of Sockeye Fry

In the summer of 2001, the field crew used a variety of capture methods to collect fish considered potential predators of juvenile sockeye salmon in Tatsamenie Lake. Various trap nets, gee traps, and fyke nets were set in littoral areas to capture shallow-water predators. Large fish in deep water were sampled using sinking gillnets. Angling was the primary method used to capture fish for examination of stomach contents. The technicians occasionally caught fish actively feeding on sockeye fry during beach-seine sets.

The captured fish were measured (tip of snout to fork of tail) and anesthetized. Their stomach contents were removed by gastral lavage, as described in Light et al. (1983). Gastral lavage was chosen over removal of stomachs, to avoid unnecessary killing of larger fish, and in accordance with restrictions placed on the project by the British Columbia Ministry of the Environment.

Stomach contents that could be identified as sockeye fry remains were preserved in 95% ethanol, and sent to the DFO otolith lab in Whitehorse for dissection and classification.

LAB PROCEDURES

Otolith Processing

Technicians at the DFO otolith lab in Whitehorse received the preserved sockeye fry and smolt samples, and weighed and measured the individual fish. The length measurement was from the tip of the snout to the fork of the tail, in millimeters, and the weight measurement was in grams. The DFO otolith lab in Whitehorse followed procedures documented in Hoyseth (1995), for dissection and classification of otoliths. Although preservation methods resulted in shrinkage of the length and weight of the fry (Shields and Carlson 1996), the consistency of preservation methods since 1991 allowed us to compare weights and lengths between and within years.

Water Chemistry

In 2001, DIPAC sent water samples from Snettisham hatchery, and Tatsamenie, Tuya, Tahltan, and Chilkat Lakes to Analytica Alaska, in Juneau, Alaska for analysis. The water quality measurements for the different samples were compared to hatchery water quality criteria developed for the American Fisheries Society and the U.S. Fish and Wildlife Service (Piper et al. 1982), DFO (Sigma Environmental Consultants Ltd. 1983), and ADF&G (McDaniel et al. 1994).

RESULTS

SOCKEYE FRY POPULATIONS

The 2001 and 2002 samples from beach-seine hauls were segregated by site as well as by day, instead of being combined into one large sample for the day, as in previous years. The hatchery fry were found to remain less than 1 or 2 km from their release sites for 30 to 50 days after release. This was contrary to the assumption (prior to 2001), that released fry distributed themselves randomly and mixed with wild stocks shortly after release. In both 2001 and 2002, percentages of stocked fry in beach-seine samples did not markedly or consistently decrease for at least 1 month following release. In 2001, the proportion of stocked fry in beach-seine samples trended down slightly after June 29, but was still usually above 30% of the samples through July 24, and became highly variable after August 13 (Table 2; Figure 3). In 2002, the stocked-fry percentages in the samples ranged between 30% and 43% until June 30, and then dropped to 15% on July 11 and ranged between 15% and 20% until July 31 (Table 3; Figure 4). After August 10, the percent of stocked fry in beach-seine samples plummeted to 5% or less.

Beginning in late July and early August, the trawl net samples contained increasing numbers of sockeye fry, evidence that the fry were migrating into the limnetic zone at that time. In the August 2001 trawl tows, the percentage of stocked fry in the samples was about 40% for the first samples collected, and plummeted to 10% or less in later samples (Table 4; Figure 5). In 2002, the percent of stocked fry in the samples was 17% in the initial trawl tows, but rapidly dropped to 6% or less for 8 of the 9 subsequent sample dates (Table 5; Figure 6). The 2001 and 2002 stocked-fry percentages in the September and October trawl samples were considerably lower than the age-1 stocked-smolt estimates for the following spring. The average stocked fry in 2001 and 2002 was larger than the average wild fry. Given the percentage of age-1 stocked fish in the following year’s smolt emigration (Table 6), the trawl samples underestimated the proportion of stocked fish in the fall fry population.

As a result of more intensive beach-seine sampling than in previous years, the field technicians noticed sac fry in the beach-seine samples until at least July 15 in the 2001 and 2002 samples. In 2001, a sizable proportion of the wild fry from all beach-seine samples and early trawl net samples consisted of individuals with weights below 0.17 g (Figures 7, 8 and 9). While one or two low-weight stocked fry were found in the samples, the stocked fry median weights continued to increase as the summer progressed.

The number of stocked smolts exiting the lake the following years (2002 and 2003) was not markedly higher than in previous years (Table 6). The estimated percentage of stocked smolts in 2002 was the highest recorded, but the total number of smolts was the second lowest recorded. The estimated number and percentage of stocked smolts in 2003 was at the median seen for all years of data.

The 2001 early fed fry release group had survival rates more than twice as large as the late fed-fry release group (Table 7). The two 2002 groups were released on schedule. The earliest release group was not fed, and the second release group was fed. The 2002 unfed fry release group – the earliest release group – had a higher fry-to-smolt survival rate than the later, fed fry release group.

The field crew deployed a fyke net in the outlet stream in June through August 2001, to sample for prematurely emigrating fry. No age-0 sockeye fry were captured in the fyke net.

POTENTIAL PREDATORS OF SOCKEYE FRY

Juvenile coho salmon, Dolly Varden, and sculpin were caught in gee traps and trap nets. Kokanee salmon, rainbow trout, suckers, and mountain whitefish were caught primarily with gillnets. Most of the fishing effort was expended on angling; of 936 fish caught, 583 were captured by angling. Out of these 583 fish, 578 were lake trout (Table 8).

Of the 7 species captured and examined, only 4 species had a sample size over 30 fish (Table 9). The field crew examined 33 sculpin, 57 Dolly Varden, 167 young-of-the-year coho salmon, and 641 lake trout. Dolly Varden had the highest incidence of sockeye fry in the stomach contents, 39%. About 8% of the coho juveniles had readily identifiable sockeye salmon in their stomachs, as did 8% of the lake trout, and 3% of the sculpin. When identifiable fry were present in the stomach contents, usually only one or two were found. Occasionally predatory fish were caught actively feeding on sockeye fry. One lake trout caught in a beach-seine had 28 sockeye fry in its stomach and 7 partially digested small fish that were probably sockeye fry.

Only a fraction of the fish in the stomach contents could be identified as sockeye fry. The percentage of stocked fry for all species was over 50% (Table 10). Some individual fish exerted undue influence over the summary statistics, such as the single lake trout that contained 28 fry (of which 82% were stocked fry). Angling and trapping effort was proportionately higher at the northern half of the lake, where all the stocked fry releases occurred.

Trap nets caught both sockeye fry and potential predators – with the net mesh being too small to allow the sockeye fry to escape. Larger fish would eat the fry in the trap net. In addition, the trap net that captured the largest number of sockeye predators was also situated near one of the release sites for sockeye fry.

The percent of coho salmon and Dolly Varden that contained confirmed fry, or sockeye fry plus unidentified fish remains decreased as the summer progressed (Tables 11 and 12; Figure 10). In

2001, there was no concomitant decrease in the percentage of stocked fry in the beach-seine samples during the periods of highest fry consumption by these predators.

The percent of lake trout stomach contents containing sockeye fry increased over the summer (Table 13; Figure 10). In June, 4% of the lake trout sampled contained identifiable sockeye fry, increasing to 8% in July, and 19% in August. These percentages were indicative of very recent feedings, because sockeye fry remain identifiable for only a few hours after ingestion. If we included partially digested unidentifiable fish in the calculation, 20% of the lake trout caught in June contained probable sockeye fry remains, which increased to 33% for fish caught in July, and 55% of the fish caught in August. The highest percentage of sockeye fry found in lake trout stomachs over the summer of 2001 coincided with the migration of sockeye fry into the limnetic zone.

Interestingly, virtually all species of potential predators sampled in 2001 were highly dependent on shallow water invertebrates. Aquatic insects and snails were the most frequent prey items found in lake trout, Dolly Varden, and coho salmon juveniles.

WATER CHEMISTRY

The water chemistry analyses did not show either presence of toxic compounds in detectable amounts at Snettisham hatchery, or large differences in mineral content between Snettisham hatchery water, and Tatsamenie Lake water (Appendix A). The other lakes sampled had comparable water chemistry to Tatsamenie Lake; yet the sockeye salmon that were stocked into these lakes from Snettisham hatchery had much higher survival rates than at Tatsamenie Lake.

DISCUSSION

The stated goal for the Taku River Enhancement Project was to increase the Taku River adult sockeye return by 100,000 fish. Assuming a smolt-to-adult-survival rate of 5% and an average wild smolt emigration of 370,000 fish (approximations based on previous years' estimates of smolt emigrations and adult returns), the Tatsamenie stocked fry project would have had to increase the annual Tatsamenie sockeye smolt abundance to about 2.4 million fish, of which 85% would have been stocked smolts. Except for one outlier of 2.5 million smolts in 1998 (15% of which were stocked smolts), Tatsamenie Lake smolt emigration estimates have not exceeded 550,000. The median percentage of stocked smolts seen in samples is 13% for all documented years.

At the beginning of the Tatsamenie Lake predator study, we assumed both the stocked and wild fry would migrate into deep water quickly and that predation pressure would lessen as a result (Burgner 1991). We also hypothesized that the fry faced heavy predation pressure in littoral areas, that predators would target stocked fry immediately upon stocking, and that the percentage of stocked fry would drop precipitously within the first 2 weeks to 1 month following stocking (Cartwright et al.1998).

In Tatsamenie Lake, neither the sockeye fry populations nor the potential predator populations behaved as expected. The wild sockeye fry had a much longer emergence period than expected. Both stocked and wild sockeye fry had a much longer littoral zone residence time than expected, causing a later-than-expected offshore movement of sockeye fry. Predators did not appear to target stocked sockeye fry immediately following stocking, and the stocked-fry percentages remained stable until early August.

The fry stocked in 2001 and 2002 were as large as or larger than the wild fry in virtually all samples taken (Tables 2–5). The difference between wild and stocked fry became greater as the season progressed. In contrast, fry stocked in 1997 and 1998 were initially smaller than wild fry in the samples and became roughly equal in size as the season progressed (Mathias 2000). The addition of smaller more recently emerged wild sockeye fry served to hold down the overall average size of the wild sockeye fry as the season progressed, even as the size of individual fish increased.

If predators were targeting stocked fry immediately after release, then we should have seen a marked drop in percentage of stocked fry in beach-seine samples immediately after stocking. We expected some drop due to the addition of late emergent wild fry. Even so, the stocked-fry percentages in 2001 and 2002 beach-seine samples remained relatively stable for weeks following stocking. The August decline in beach-seine samples was probably due to offshore movement of stocked fry and early emergent wild fry into the limnetic zone. The beach-seine surveys in Mathias (2000) exhibited similar trends over time, whereby percentage of stocked fry in seine and trawl samples did not markedly decrease until after July 24 (Figures 11 and 12). Therefore, littoral zone predators such as Dolly Varden and coho salmon juveniles probably did not cause differential mortality in stocked sockeye fry populations.

The stocked-fry percentages declined in the trawl surveys in the 2001 and 2002, as well as in the trawl surveys documented in Mathias (2000). In studies on lakes in southern British Columbia, after fry attained a threshold length of about 40 mm, they began to swim fast enough to avoid the trawl net (Hyatt et al. 2005). By early August of 2001 and 2002, the average stocked fry had surpassed that threshold size. Because the fry stocked in 2001 and 2002 had a larger average size than the wild fish, stocked fish were probably underrepresented in the trawl surveys. This hypothesis is buttressed by the fact that the 2002 and 2003 stocked-smolt percentages (at the smolt weir) were considerably higher than the stocked-fry percentage in the previous summers' trawl surveys. In the Mathias (2000) study, the stocked fish were smaller initially, and the stocked-fry percentage in the last trawl survey of the season tracked closely with the following year's stocked-smolt percentage at the smolt weir. Thus in Mathias's study, the declines in stocked-fry percentages in the trawl samples were likely reflecting actual declines in stocked fry, relative to wild fry.

In 2001 and 2002, the percentage of lake trout containing sockeye fry increased over the summer, and the highest percentage in the samples coincided with the migration of sockeye fry into the limnetic zone, in late summer. By comparing the declining stocked-fry percentages in trawl samples after July 15 in Mathias (2000), with the increasing percentage of lake trout preying on sockeye fry over the summer of 2001, we concluded that lake trout were probably the principal predators affecting the sockeye fry, and the heaviest predation probably occurred as fry migrated into the limnetic zone.

While the 2001 and 2002 stocked fry did not appear to suffer higher mortalities than wild fry, the 1997 and 1998 stocked fry may have done so, because of their initial smaller size (Mathias 2000). However, despite possible differential mortality, the fry stocked in 1997 did very well; an estimated 364,000 of them left the lake as smolts in 1998, more than 4 times of the second largest stocked-smolt estimate. The concurrent wild-smolt component was equally successful; an estimated 2,138,000 exited the lake.

The littoral zone constitutes only 7% of the total surface area of Tatsamenie Lake. Given that Tatsamenie Lake sockeye fry can spend up to 2 months or more in the littoral zone, it is apparent they do not feed exclusively on zooplankton. We did not analyze stomach contents of fry in 2001 or 2002. However, stomach analysis of beach-seined fry was performed during a previous study in 1998 and in 1999. In 1998, dipteran larvae composed approximately 70% of the stomach contents by volume, with zooplankton comprising 30% (number of wild fry examined equaled 30; number of stocked fry examined equaled 10). In 1999, the most common prey items found in sockeye fry stomachs were dipteran larvae and pupae, and Thysanoptera adults (number of wild fry examined equaled 26, number of stocked fry examined equaled 26; Mathias 2000). We assume that the sockeye fry switch to zooplankton during their limnetic zone residence time, because of the paucity of other food sources in the limnetic portion of Tatsamenie Lake.

Some sockeye stocks in the Chignik River system exhibit similar feeding strategies to Tatsamenie Lake sockeye salmon. Sockeye fry emerging in Black Lake feed heavily on aquatic insects. The Black Lake sockeye fry then emigrate from Black Lake into Chignik Lake and feed on zooplankton, thereby competing with sockeye stocks indigenous to Chignik Lake. Finkle (2004) concluded that Black Lake was too shallow to provide a refugium for sockeye fry during periods of high temperatures, thereby forcing an emigration of Black Lake sockeye fry late in the summer. In addition, Black Lake is too shallow to provide overwintering habitat for sockeye fry (Bowens and Finkle 2003). The bathymetry of Tatsamenie Lake is so dissimilar to that of Black Lake, that the factors forcing changes in location and feeding strategies of their respective sockeye stocks are completely different.

If Tatsamenie sockeye fry are feeding heavily on insects during their littoral zone residence, and feeding primarily on zooplankton during their limnetic zone residence, the different food resources likely have been partitioned in time and space. If the first partitioned space (littoral zone) has fewer resources than the second partitioned space (limnetic zone), then the size of the fry population is determined within the first partition, and food resources in the second partition may never be used to full capacity. Under such a scenario, littoral zone invertebrate populations would be the primary factor limiting the smolt production. Interestingly, the highest documented smolt emigration in 1998 coincided with very high chironomid biomass estimates, and higher than average zooplankton biomass estimates in 1997 (TTC 2002). Chironomids have been mentioned as a primary food source for emergent fry, when zooplankton are not available (Burgner 1991).

If partitioning of food resources actually exists in Tatsamenie Lake, predation may be the causative agent, by confining emergent fry to shallow water areas to avoid being eaten (Walters and Juanes 1993). The relative size of the emigrating smolt at Tatsamenie Lake is similar to that of other transboundary lakes (TTC 1998, 2002), indicating that food availability for surviving sockeye fry is not an issue. Limited food resources in the littoral zone may not be a direct cause of mortality, but may be pivotal in terms of predator–prey interactions. Predation pressure is likely to increase as sockeye fry move into the transition zone between the littoral and pelagic areas. If food resources in relatively safe regions are limited, fry that are surplus to carrying capacity could be forced into the deeper water to feed, and incur much heavier predation losses as a result. Individual fry may be faced with an energetic versus predation tradeoff: migrate to the limnetic zone early and face a high probability of being eaten; or postpone migration to reduce the chance of being eaten, but rely on scarcer food resources for a longer period of time.

If a sockeye fry is to survive a migration into the limnetic zone, it may need to reach a critical size and swimming speed prior to making the migration. Predation on smaller, newly emerged sockeye fry is probably greater than on larger, faster fry. Therefore a minimum size threshold may be a trigger for fry to migrate into deep water.

Another factor to consider in the food resource partitioning hypothesis is the length of dark periods in the diurnal cycle. Because Tatsamenie Lake is at a high latitude, periods of complete nighttime darkness will be very short for weeks before and after the summer solstice. If predation is confining sockeye fry to the littoral zone, the fry may need to migrate in darkness to substantially decrease their chances of being eaten. The number of hours of nighttime darkness may be more critical to the timing of migration to deeper water than the attainment of a minimum size threshold.

If predator-driven habitat restrictions have been in place for a long time, littoral zone residence times may be genetically imprinted on the sockeye fry. In 2000, about 350,000 stocked sockeye fry were fed for 3 weeks in a net pen, and then released into the limnetic zone of Tatsamenie Lake, at a mean size of 0.46g. This stocking strategy was discontinued in part because some portion of the release group migrated into the littoral zone, instead of remaining in the limnetic zone following release (DFO Whitehorse, *Unpublished data*).

We have no conclusive proof that resource partitioning is occurring. However, the long littoral residence times for sockeye fry seen in this study, coupled with the results of the small dietary study conducted by Mathias (2000) provide circumstantial evidence that resource partitioning may indeed be taking place. Some classic diet and energetics study designs can be applied to this question. However, such a study would take many years, and given the size of the lake, would be very expensive to conduct. Stable isotope analysis of aquatic insects, zooplankton, and sockeye fry is an alternative avenue of research. While it will not provide conclusive proof for a population bottleneck from resource partitioning, it can provide evidence of the degree to which the sockeye fry population is consuming upon aquatic insects during its littoral zone residence.

If food-resource partitioning exists in Tatsamenie Lake, it has profound implications for management practices. If littoral zone food resources are limiting sockeye smolt numbers, stocking fry in the littoral zone only increases competition for food, and increases the density dependent mortality. Stocked sockeye fry might exhibit higher survival rates than wild fry, but the total number of smolts produced would not increase. Hyatt et al. (2005) noted that 17% of the females counted in the escapement were used for enhancement brood stock; their offspring constituted 15% of the emigrating smolts. Stocking fry offshore might bypass a littoral zone bottleneck. However, for offshore stocking to be successful, the fry may have to be reared for 2 or 3 months, to circumvent an apparent tendency to migrate back into the littoral zone. Long-term rearing would impose much higher costs, in transportation, fish food, and losses due to disease.

If the Pacific Salmon Commission decides to stock fed fry off-shore in late summer, it should reinvestigate the carrying capacity of Tatsamenie Lake. Originally, the Pacific Salmon Commission relied on the euphotic zone and zooplankton density models to predict the carrying capacity of the lake (Koenings and Burkett 1987; Koenings and Kyle 1997). The models have fallen out of favor at ADF&G; many of the stocking projects initiated on the predictions of these models have failed. For example, stocking projects at Pass and Esther Passage lakes in Prince William Sound and Chilkat Lake in Southeast Alaska were carried out because the euphotic volume and zooplankton density models predicted large increases in sockeye salmon production from stocking (Edmundson et al. 1993; Holder and Riffe 2004). The lakes were stocked at about 50% of the carrying capacity predicted by these models. In all 3 lakes, the zooplankton populations collapsed or underwent severe restructuring because of excessive predation by sockeye fry. A bottleneck resulting from the littoral zone residence may have prevented excessive predation on Tatsamenie zooplankton populations. Late stocking of fry into the limnetic zone could result in excessive predation on zooplankton populations if the release group size is too large. Given the harsh environmental conditions in the lake, recovery of collapsed or severely restructured zooplankton populations might take upwards of a decade.

RECOMMENDATIONS

Successfully increasing Tatsamenie Lake sockeye production has been much more difficult than originally thought, because of the complexity of the underlying biological processes. In order to make informed decisions on stocking and management, the Transboundary Technical Committee should ascertain whether food resource partitioning is actually occurring. A study of stable isotope ratios for Tatsamenie Lake aquatic insects, zooplankton, and sockeye fry may provide much of the necessary information, in less time and for less cost than a classic diet and energetics study.

At least as important, the Transboundary Technical Committee should investigate whether excess carrying capacity actually exists in Tatsamenie Lake. Since the euphotic zone and zooplankton density models used in the original feasibility study have failed at other sockeye systems, a feasible estimate of carrying capacity of Tatsamenie Lake does not exist. Food resource partitioning, if it occurs, negates all historical stocking and assessment data for empirical estimation of carrying capacity in the limnetic zone.

The Transboundary Technical Committee should continue monitoring limnological conditions and aquatic insect populations. Productivity of Tatsamenie Lake may be more variable than previously thought, so continuing or increasing the monitoring of limnological conditions, zooplankton populations, and aquatic insect populations is important. The streams flowing into Tatsamenie Lake may be the primary producers of aquatic insects in the lake, and can be greatly affected by droughts or other prevailing weather conditions. Zooplankton populations can change in response to changes in glacial inputs. Whether or not the Transboundary Technical Committee changes its enhancement program, monitoring of lake limnology, zooplankton, and aquatic insects can provide early information about the onset of shifts in productivity.

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FIGURES AND TABLES

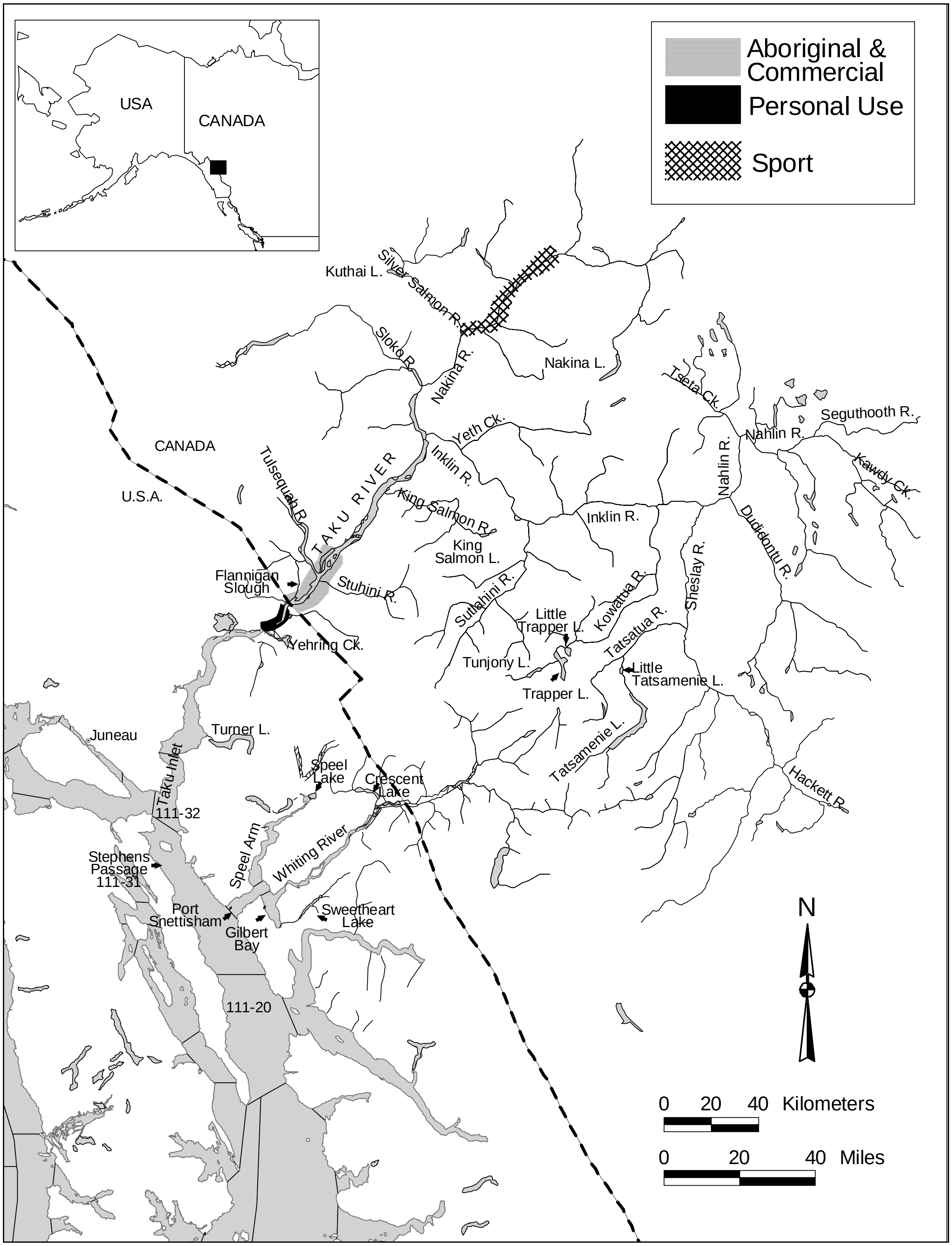


Figure 1.–Taku River watershed and location of fisheries targeting Tatsamenie Lake sockeye salmon.

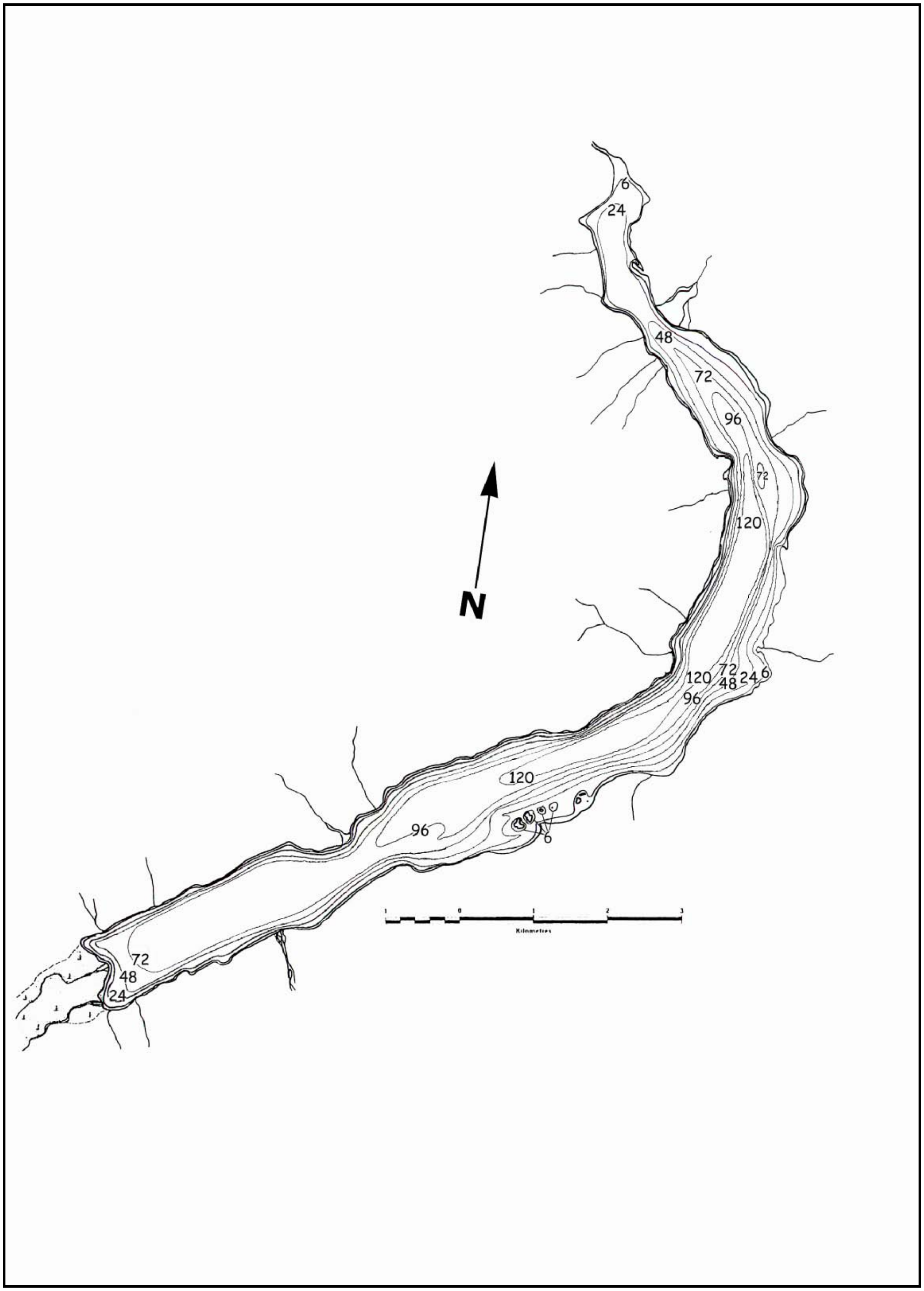


Figure 2.–Bathymetric map of Tatsamenie Lake. Depths are in meters.

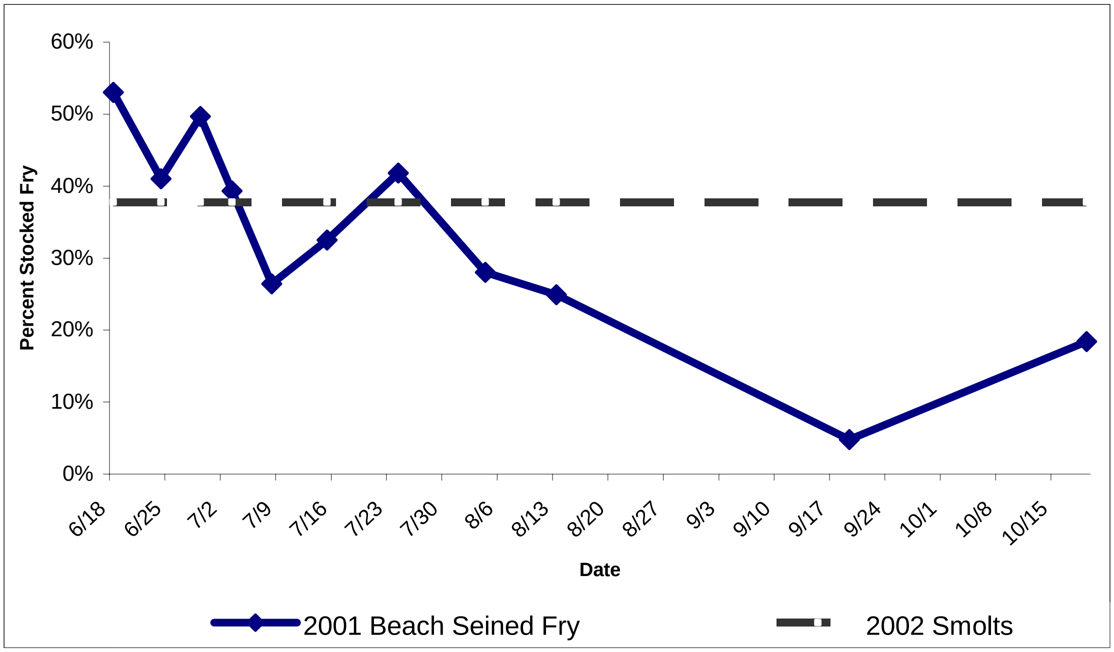


Figure 3.–Percentage of stocked sockeye fry from successive beach-seine samples taken at Tatsamenie Lake in 2001, and percentage of stocked fry in 2002 smolt emigration.

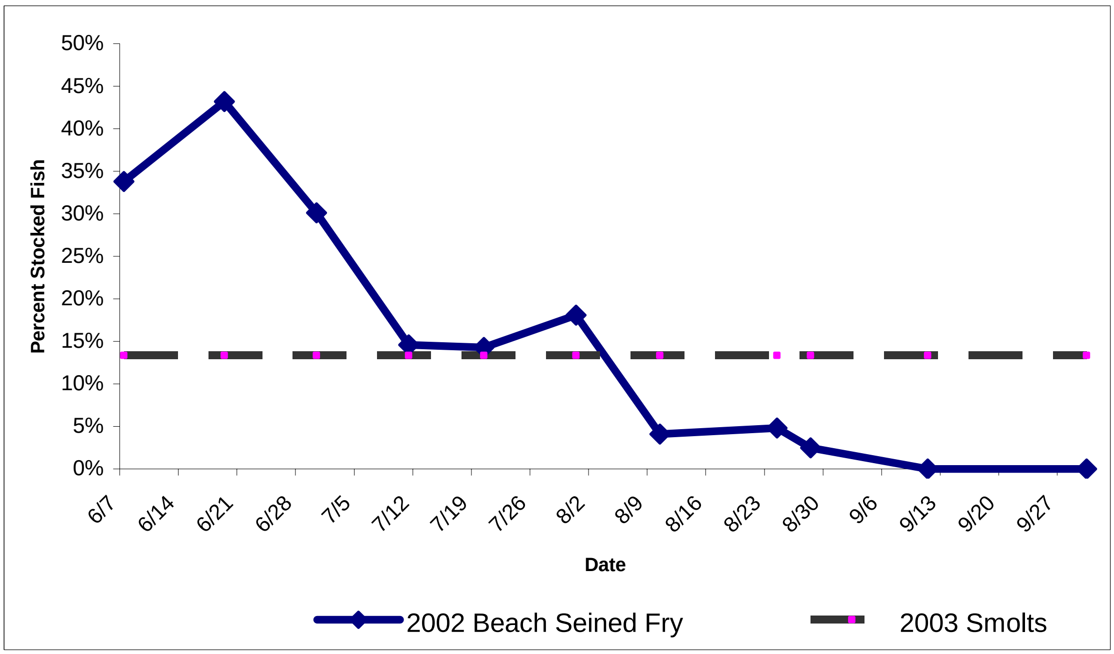


Figure 4.–Percentage of stocked sockeye fry from successive beach-seine samples taken at Tatsamenie Lake in 2002, and percentage of stocked fry in 2003 smolt emigration.

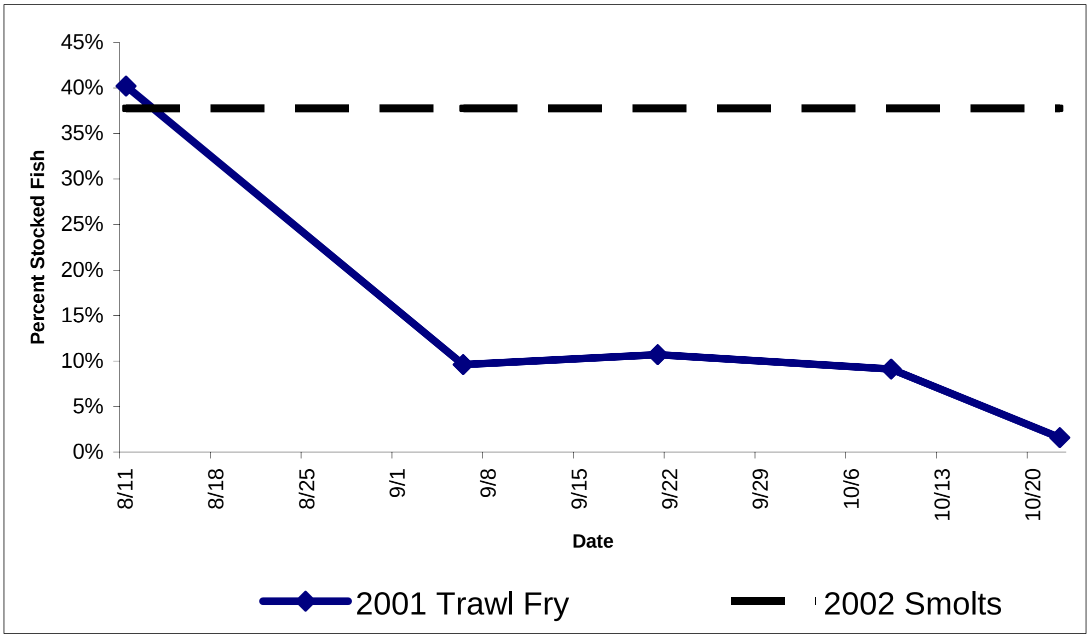


Figure 5.–Percentage of stocked sockeye fry from successive trawl net samples taken at Tatsamenie Lake in 2001, and percentage of stocked fry in 2002 smolt emigration.

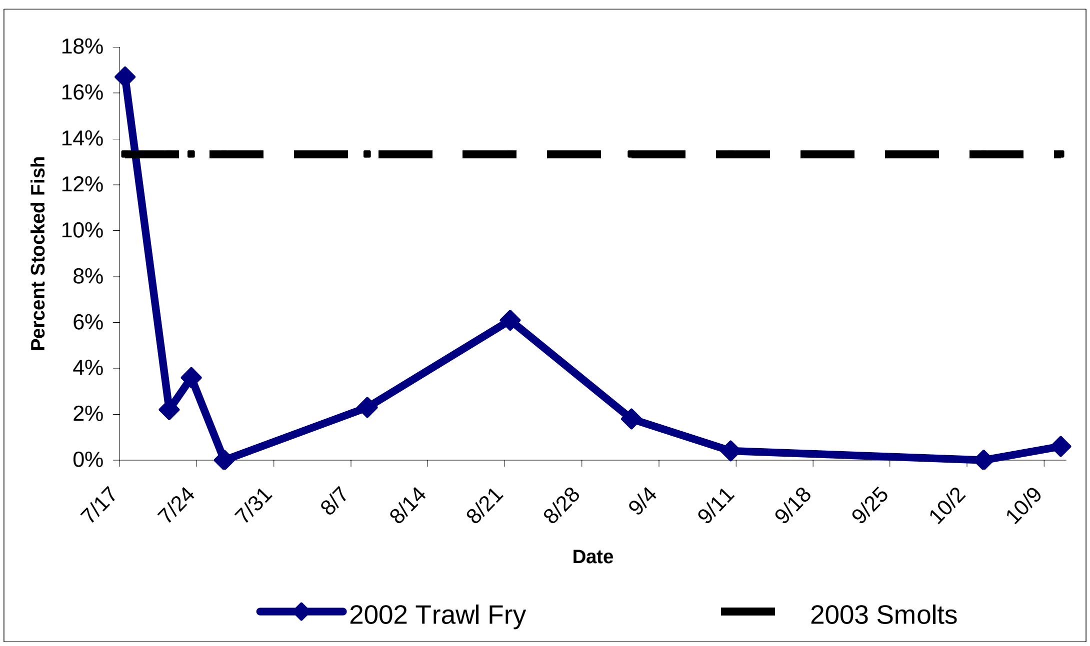


Figure 6.– Percentage of stocked sockeye fry from successive trawl net samples taken at Tatsamenie Lake in 2002, and percentage of stocked fry in 2003 smolt emigration.

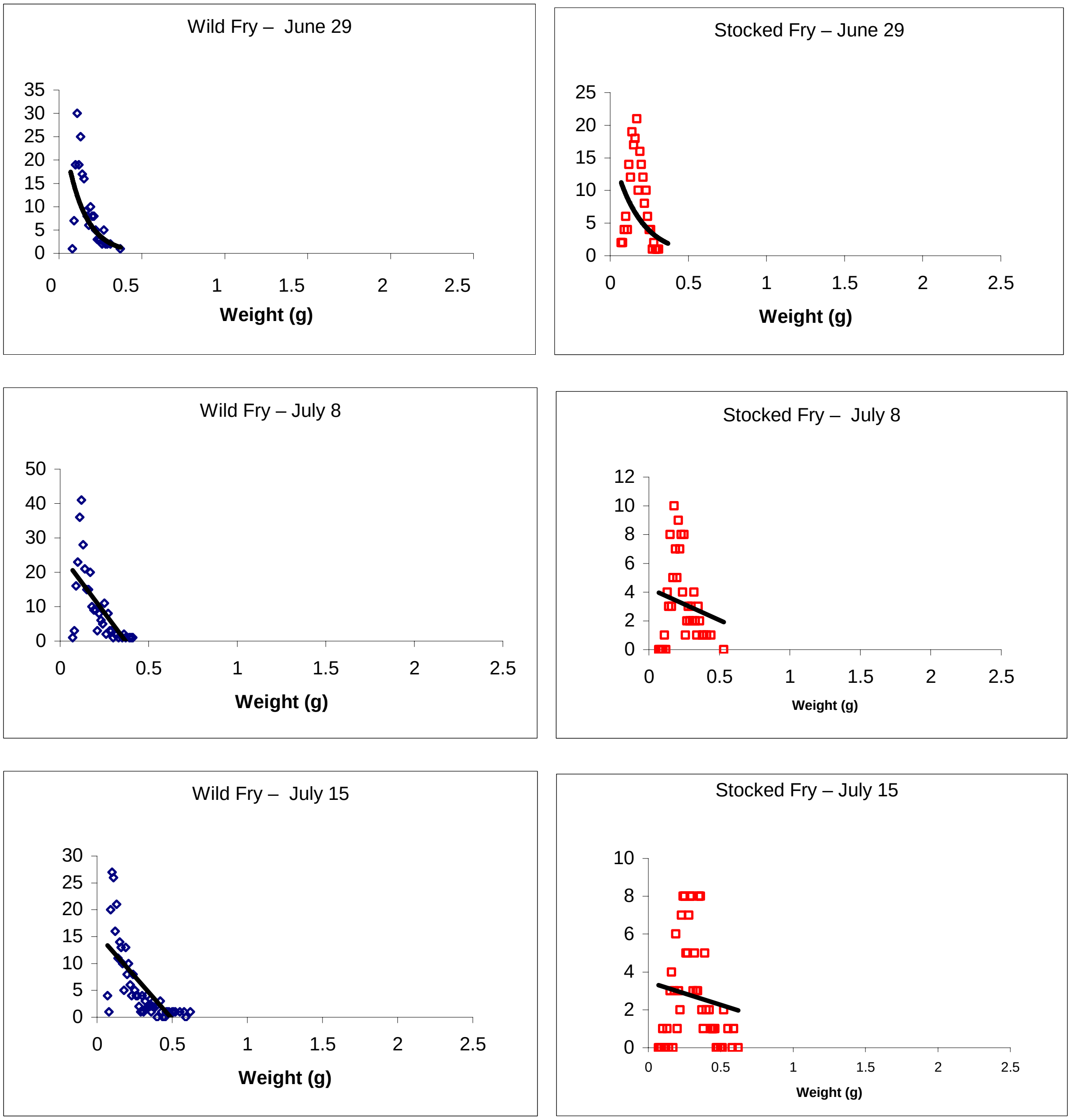


Figure 7.–Weight frequency distributions and associated trend lines for wild and stocked sockeye fry collected in beach-seine samples at Tatsamenie Lake, between June 29 to July 15, 2001.

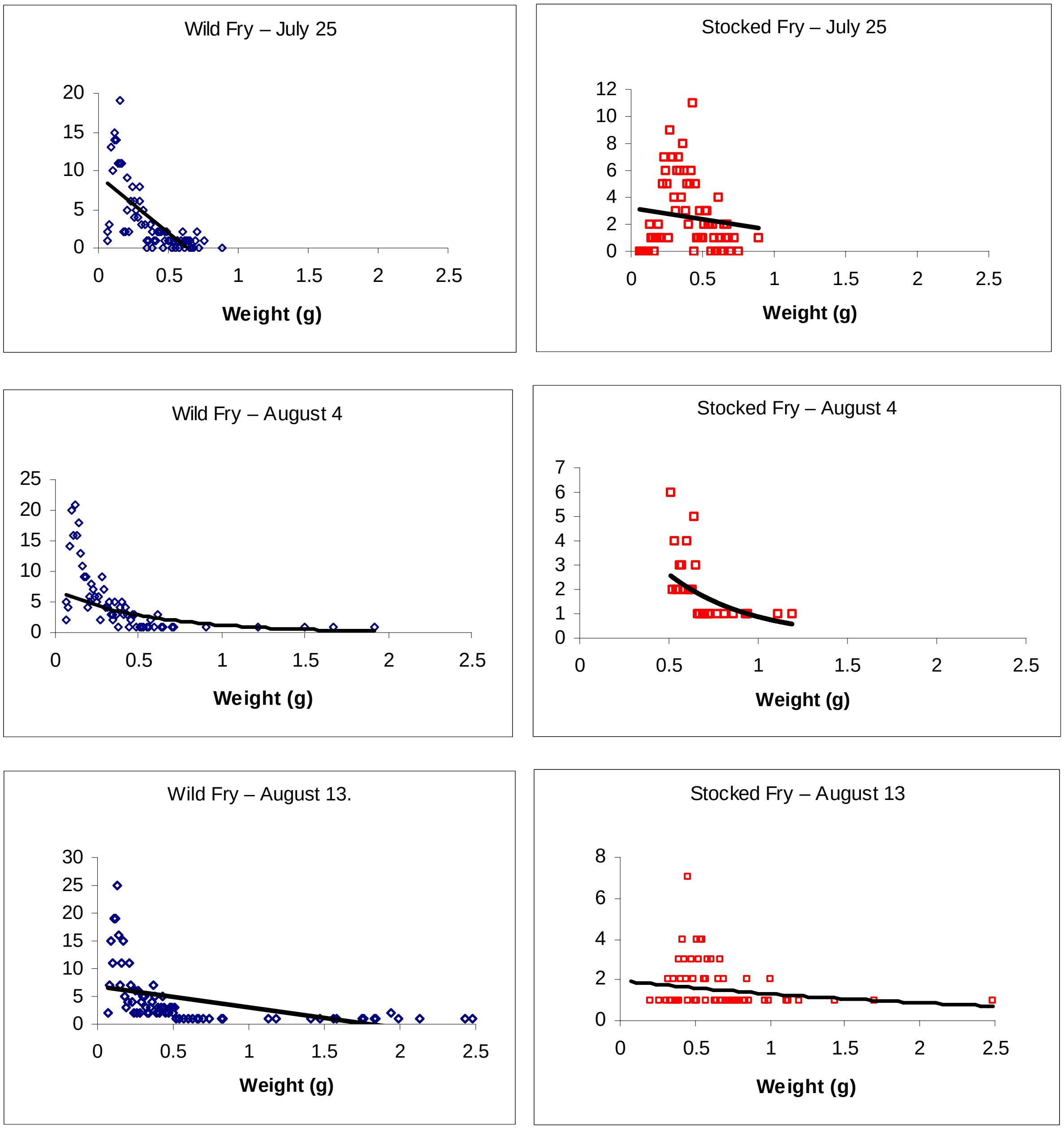
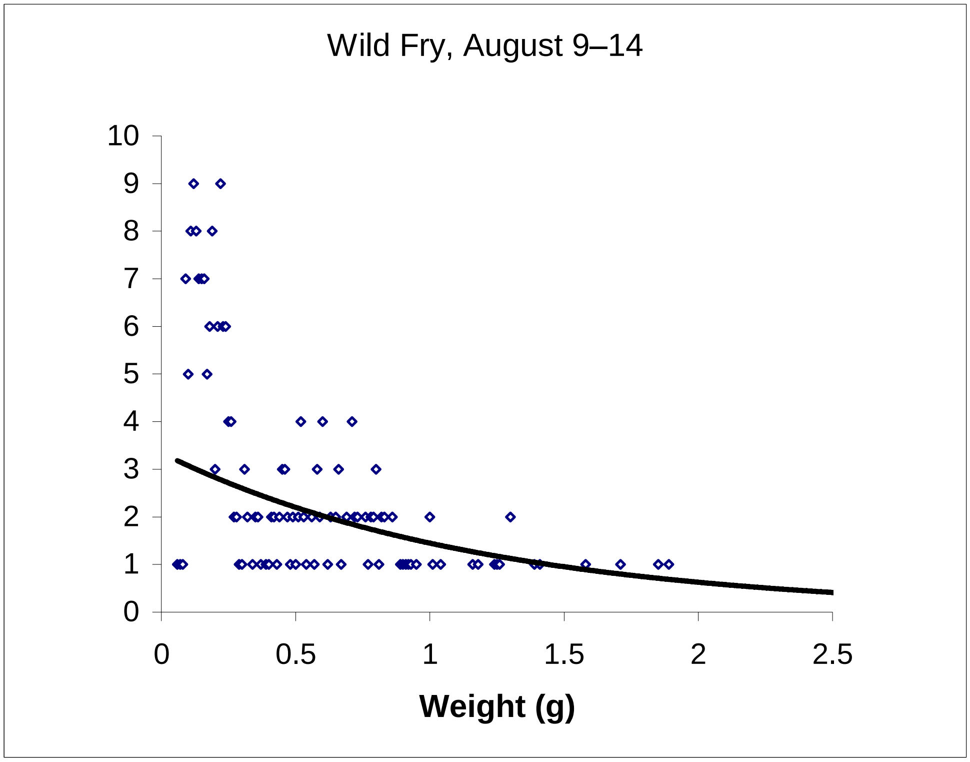


Figure 8.–Weight frequency distributions and associated trend lines for wild and stocked sockeye fry collected in beach-seine samples at Tatsamenie Lake, between July 25 to August 13, 2003.



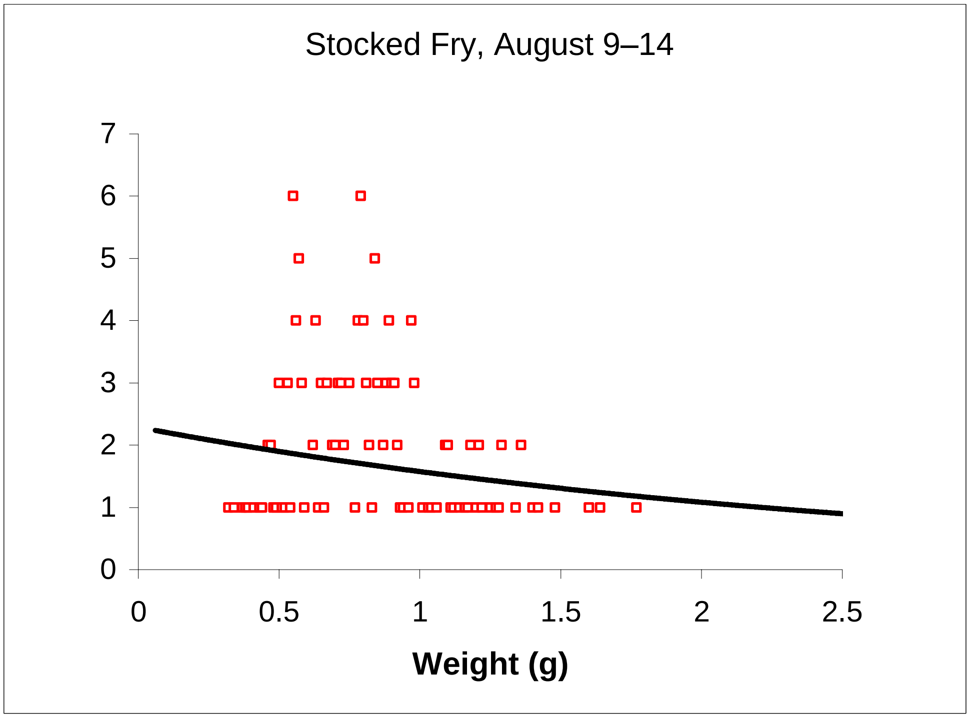


Figure 9.–Weight frequency distributions and associated trend lines for wild and stocked sockeye fry collected in trawl net samples at Tatsamenie Lake, between August 9 and 14, 2001.

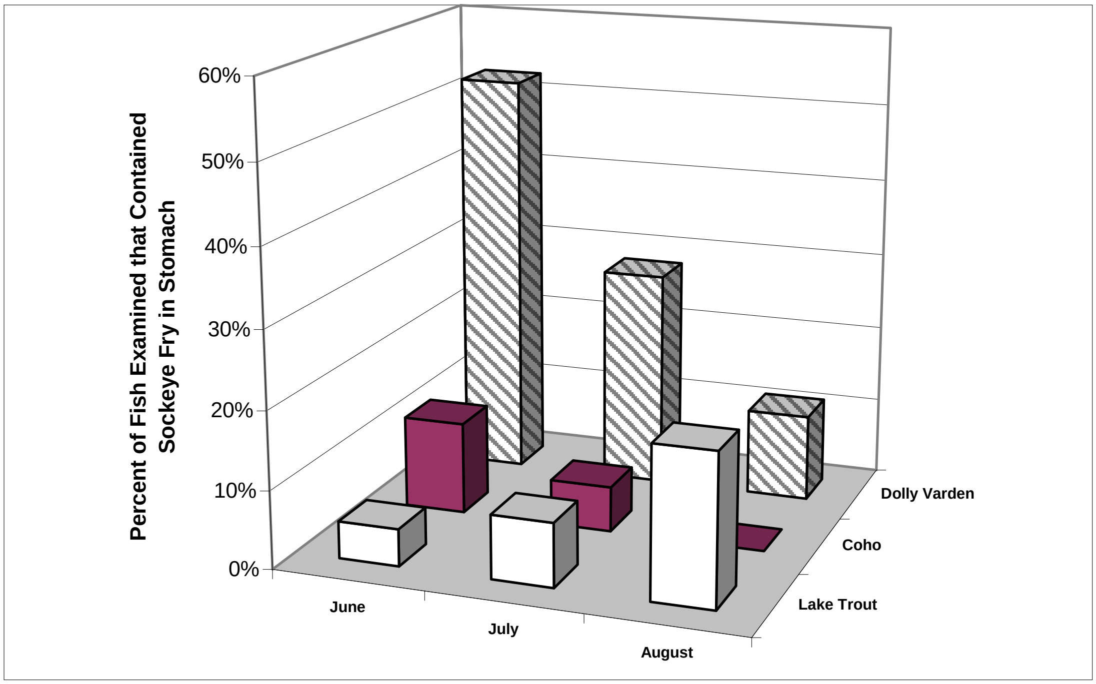


Figure 10.–Percent of lake trout, juvenile coho salmon, and Dolly Varden stomach samples, by month, that contained sockeye salmon fry, in 2001 Tatsamenie Lake predator study.

Table 1.–Brood year, release year, number released, location of release, and treatment group of sockeye salmon fry incubated at Snettisham hatchery and released annually into Tatsamenie Lake, from 1990 to 2001.

Brood-Year	Year of Release	Number of Fry Released	Location	Treatment/Release Group	Number of Fry in Treatment/Release Group
1990	1991	673,000	offshore	unfed	673,000
1991	1992	1,232,000	offshore	unfed	1,232,000
1992	1993	909,000	offshore	unfed	909,000
1993	1994	521,000	offshore	unfed	521,000
1994	1995	898,000	offshore	unfed	898,000
1995	1996	1,724,000	offshore	unfed	1,724,000
1996	1997	3,945,000	nearshore	unfed	3,202,000
1997	1998	3,597,000	nearshore	unfed	3,203,000
			nearshore	fed at lake	394,000
1998	1999	1,769,000	nearshore	unfed	751,000
			nearshore	fed at lake	1,018,000
1999	2000	350,000	nearshore	fed at lake	350,000
2000	2001	2,320,000	nearshore	fed early release	1,054,000
			nearshore	fed late release	1,266,000
2001	2002	2,233,000	nearshore	unfed, early	727,000
			nearshore	fed late release	1,506,000
Average		1,680,917			1,194,800

Table 2.–Mean length, mean size, number and percentage of wild and stocked sockeye salmon fry sampled using beach-seines at Tatsamenie Lake in 2001.

	Wild Fry				Stocked Fry			
Date	Mean Length (mm)	Mean Weight (g)	No. in Sample	Percent of Sample	Mean Length (mm)	Mean Weight (g)	No. in Sample	Percent of Sample
14-Jun		0.20	50	100%			0	0%
18-Jun	31.1	0.12	167	47%	32.5	0.15	189	53%
24-Jun	31.2	0.13	229	58%	33.5	0.17	164	41%
29-Jun	32.2	0.15	211	50%	33.3	0.17	211	50%
3-Jul	31.8	0.23	245	61%	33.8	0.19	159	39%
8-Jul	32.2	0.16	309	74%	35.2	0.23	111	26%
15-Jul	30.5	0.18	130	68%	37.2	0.29	130	33%
24-Jul	34.5	0.23	240	58%	39.3	0.37	173	42%
4-Aug	34.8	0.25	302	72%	42.5	0.51	119	28%
13-Aug	35.9	0.31	299	60%	44.9	0.61	99	25%
19-Sep	48.3	0.84	178	95%	61.9	1.92	9	5%
19-Oct	48.4	0.89	120	82%	62.4	1.9	27	18%

Table 3.–Mean length, mean size, number and percentage of wild and stocked sockeye salmon fry sampled using beach-seines at Tatsamenie Lake in 2001.

	Wild Fry				Stocked Fry			
Date	Mean Length (mm)	Mean Weight (g)	No. in Sample	Percent of Sample	Mean Length (mm)	Mean Weight (g)	No. in Sample	Percent of Sample
7-Jun	31.7	0.14	149	66%	32.0	0.14	76	34%
19-Jun	32.6	0.17	223	56%	32.8	0.18	179	43%
30-Jun	34.4	0.22	272	70%	35.6	0.25	117	30%
11-Jul	34.7	0.26	368	85%	38.9	0.39	63	15%
20-Jul	34.7	0.26	336	86%	41.4	0.50	56	14%
31-Jul	41.0	0.54	316	82%	47.9	0.76	70	18%
10-Aug	39.2	0.56	353	96%	51.4	1.07	15	4%
24-25 Aug	42.0	0.57	138	95%	53.0	1.53	7	5%
28-Aug	40.2	0.56	77	97%	45.0	0.68	2	3%
11-Sep	31.2	0.16	16	100%	---	---	0	0%
30-Sep	32.9	0.23	33	100%	---	---	0	0%

Table 4.–Mean length, mean size, number and percentage of wild and stocked sockeye salmon fry sampled using trawl nets at Tatsamenie Lake in 2001.

	Wild Fry				Stocked Fry			
Date	Mean Length (mm)	Mean Weight (g)	No. in Sample	Percent of Sample	Mean Length (mm)	Mean Weight (g)	No. in Sample	Percent of Sample
9–14 Aug	39.2	0.61	238	59.8%	49.0	0.82	160	40.2%
2–10 Sept	39.7	0.39	178	90.4%	59.3	1.55	19	9.6%
20–22 Sept	45.4	0.69	192	89.3%	62.5	1.99	23	10.7%
9–Oct	44.6	0.55	20	90.9%	65.0	2.37	2	9.1%
20–23 Oct	47.1	0.67	62	98.4%	67.0	2.05	1	1.6%

Table 5.– Mean length, mean size, number and percentage of wild and stocked sockeye salmon fry sampled using trawl nets at Tatsamenie Lake in 2002.

	Wild Fry				Stocked Fry			
Date	**Mean Length (mm)**	**Mean Weight (g)**	**No. in Sample**	**Percent of Sample**	**Mean Length (mm)**	**Mean Weight (g)**	**No. in Sample**	**Percent of Sample**
17-Jul	32.7	0.19	10	83%	42.5	0.58	2	17%
21-Jul	33.4	0.26	171	98%	37.8	0.39	4	2%
22–23 Jul	32.7	0.22	53	96%	40.5	0.51	0	4%
26–27 Jul	36.6	0.38	44	83%	42.9	0.66	9	17%
6–8 Aug	35.6	0.32	382	98%	45	0.75	9	2%
20–22 Aug	38.1	0.45	352	94%	50.9	1.22	23	6%
1-Sep	40.2	0.54	379	98%	58	1.91	7	2%
10-Sep	42.4	0.63	476	100%	47	0.90	2	0%
3-Oct	46.1	0.83	42	100%	---	---	0	0%
10-Oct	49.5	1.43	177	99%	67	2.23	1	1%

Table 6.–Estimates of total emigration and percent by age class, of wild and stocked sockeye smolts exiting Tatsamenie Lake, from 1996 to 2003.

			Wild Smolts				Stocked Smolts				
			Percent		Estimate		Percent		Estimate		
Sample Year	**Total Smolts**	**n**	**1+**	**2+**	**1+**	**2+**	**1+**	**2+**	**1+**	**2+**	**Percent Stocked**
1996	513,000	n/a	84%	16%	415,000	79,000	63%	37%	12,000	7,000	4%
1997											
1998	2,502,000	475	97%	3%	2,068,000	70,000	100%	0%	364,000	0	15%
1999	777,000	498	66%	34%	455,000	237,000	96%	4%	82,000	3,000	11%
2000	191,000	503	55%	45%	87,000	71,000	91%	9%	30,000	3,000	17%
2001	71,000	393	44%	56%	27,000	35,000	100%	0%	9,000	0	13%
2002	233,000	564	100%	0%	145,000	0	100%	0%	88,000	0	38%
2003	540,000	324	98%	2%	458,000	10,000	100%	0%	72,000	0	13%
Average	690,000		78%	22%	522,000	72,000	93%	7%	105,000	2,000	16%
Median	513,000		84%	16%	415,000	70,000	100%	0%	72,000	0	13%

Table 7.–Estimated numbers, by release group, of eggs and fry used in the Tatsamenie Lake enhancement project, from egg-take through smolt emigration, for stocking years 2001 and 2002, as well as percent composition and survival estimates of wild and stocked sockeye smolts from stocking years 2001 and 2002.

	Estimate	
	Year Fry Emerged or were Stocked	
Statistic	**2001**	**2002**
Number of eggs taken for first release group.	1,371,000	1,845,000
Number of eggs taken for second release group.	1,200,000	1,655,000
Number of fry stocked in first release group.	1,265,000	727,000
Number of fry stocked in second release group.	1,054,000	1,506,000
Number of stocked fry in the latest fall hydroacoustic survey	807,000	1,913,000
Number of stocked first release smolt in the following year	69,000	31,000
Number of stocked second release smolt in the following year	19,000	35,000
Number of other stocked smolt (other years or unknown)	0	6,000
Total number of stocked smolt in the following year	88,000	72,000
Number of wild smolt	125,000	467,000
Total number of emigrating smolt	233,000	540,000
Percent of stocked smolt in year following release	38%	13%
Number of stocked smolt 2 years following release	0	0
Fry-to-smolt survival of first release group of stocked fry	5.5%	4.3%
Fry-to-smolt survival of second release group of stocked fry	1.8%	2.3%
Egg-to-smolt survival of first release group of stocked fry	5.0%	1.7%
Egg-to-smolt survival of second release group of stocked fry	1.6%	2.1%
Egg-to-smolt survival of wild fry	0.9%	1.1%

Table 8.–Fish captured for analysis of stomach contents, by species and method of capture, in the Tatsamenie lake predator study, 2001.

Method of Capture	Kokanee	Rainbow Trout	Mountain Whitefish	Sculpin	Dolly Varden	Coho Juveniles	Lake Trout	Total
Angling								
No. Examined	1	1	0	0	3	0	578	583
No. with salmon fry	0	0	---	---	0	---	43	43
Beach-seine								
No. Examined	0	0	0	0	8	5	2	15
No. with salmon fry	---	---	---	---	2	0	1	3
Gillnet								
No. Examined	1	7	19	0	3	0	53	83
No. with salmon fry	0	0	0	---	1	---	6	7
Trap Net								
No. Examined	0	7	0	15	43	123	8	196
No. with salmon fry	---	0	---	1	19	14	0	34
Gee Trap								
No. Examined	0	2	0	18	0	39	0	59
No. with salmon fry	---	0	---	0	---	0	---	0
Total								
No. Examined	2	17	19	33	57	167	641	936
No. with salmon fry	0	0	0	1	22	14	50	87

Table 9.–Number of fish, by species and method of capture, that were examined in Tatsamenie Lake predator study and contained sockeye salmon fry, as well as number and percentage of stocked and wild sockeye fry retained from stomach contents, in 2001.

Method of Capture	Sculpin	Dolly Varden	Coho Juveniles	Lake Trout	Total
Gee Trap					
Number of sockeye fry retrieved from stomachs	0	---	0	---	0
Angling					
Number of sockeye fry retrieved from stomachs	---	---	---	26	26
Number of stocked sockeye fry	---	---	---	13	13
Percent of stocked sockeye fry	---	---	---	50%	50%
Number of wild sockeye fry	---	---	---	13	13
Percent of wild sockeye fry	---	---	---	50%	50%
Beach-seine					
Number of sockeye fry retrieved from stomachs	---	0	---	28	28
Number of stocked sockeye fry	---	---	---	23	23
Percent of stocked sockeye fry	---	---	---	82%	82%
Number of wild sockeye fry	---	---	---	5	5
Percent of wild sockeye fry	---	---	---	18%	18%
Gillnet					
Number of sockeye fry retrieved from stomachs	---	4	---	29	33
Number of stocked sockeye fry	---	2	---	22	24
Percent of stocked sockeye fry	---	50%	---	76%	73%
Number of wild sockeye fry	---	2	---	7	9
Percent of wild sockeye fry	---	50%	---	24%	27%
Trap Net					
Number of sockeye fry retrieved from stomachs	2	143	12	3	160
Number of stocked sockeye fry	1	80	8	1	90
Percent of stocked sockeye fry	50%	56%	67%	33%	56%
Number of wild sockeye fry	1	63	4	2	70
Percent of wild sockeye fry	50%	44%	33%	67%	44%
Total					
Number of sockeye fry retrieved from stomachs	2	147	12	86	247
Number of stocked sockeye fry	1	82	8	59	150
Percent of stocked sockeye fry	50%	56%	67%	69%	61%
Number of wild sockeye fry	1	65	4	27	97
Percent of wild sockeye fry	50%	44%	33%	31%	39%

Table 10.–Number and percent of wild and stocked sockeye fry found in stomachs of fish examined in the 2001 Tatsamenie Lake predator study. Results are listed by predator and method of capture.

	Method of Capture																			
	Angling				Beach-seine				Gillnet				Trap Net				Total			
	Wild		Stocked		Wild		Stocked		Wild		Stocked		Wild		Stocked		Wild		Stocked	
Species	No	Percent	No	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Coho juveniles	---	---	---	---	---	---	---	---	---	---	---	---	4	33%	8	67%	4	33%	8	67%
Dolly Varden	---	---	---	---	---	---	---	---	2	50%	2	50%	63	44%	80	56%	65	44%	82	56%
Lake Trout	13	50%	13	50%	5	18%	23	82%	7	24%	22	76%	2	67%	1	33%	27	31%	59	69%
Sculpin	---	---	---	---	---	---	---	---	---	---	---	---	1	50%	1	50%	1	50%	1	50%
Totals	13	50%	13	50%	5	18%	23	82%	9	27%	24	73%	70	44%	90	56%	97	39%	150	61%

Table 11.–Number of juvenile coho salmon examined by month and capture method, and number and percentage of examined fish containing sockeye fry and partially digested fish remains in stomach contents, for 2001 Tatsamenie Lake predator study.

	Month			
Method of Capture	**June**	**July**	**August**	**Total**
Beach-seine				
Fish sampled	3	2	0	5
Fish containing sockeye fry	0	0	---	0
Percent of fish containing sockeye fry	0%	0%	---	0%
Fish with sockeye fry or fish remains	0	0	---	0
Percent of fish containing sockeye fry or fish remains	0%	0%	---	0%
Gee Trap				
Fish sampled	26	13	0	39
Fish containing sockeye fry	0	0	---	0
Percent of fish containing sockeye fry	0%	0%	---	0%
Fish with sockeye fry or fish remains	4	1	---	5
Percent of fish containing sockeye fry or fish remains	15%	8%	---	13%
Trap net				
Fish sampled	30	87	6	123
Fish containing sockeye fry	7	7	0	14
Percent of fish containing sockeye fry	23%	8%	0%	11%
Fish with sockeye fry or fish remains	10	47	0	57
Percent of fish containing sockeye fry or fish remains	33%	54%	0%	46%
Total				
Fish sampled	59	102	6	167
Fish containing sockeye fry	7	7	0	14
Percent of fish containing sockeye fry	12%	7%	0%	8%
Fish with sockeye fry or fish remains	14	48	0	62
Percent of fish containing sockeye fry or fish remains	24%	47%	0%	37%

Table 12.–Number of Dolly Varden examined by month and capture method, and number and percentage of examined fish containing sockeye fry and partially digested fish remains in stomach contents, for 2001 Tatsamenie Lake predator study**.**

	Month			
Method of Capture	**June**	**July**	**August**	**Total**
Angling				
Fish sampled	1	2	0	3
Fish containing sockeye fry	0	0	---	0
Percent of fish containing sockeye fry	0%	0%	---	0%
Fish with sockeye fry or fish remains	0	1	---	1
Percent of fish containing sockeye fry or fish remains	0%	50%	---	33%
Beach-seine				
Fish sampled	0	3	5	8
Fish containing sockeye fry	---	1	1	2
Percent of fish containing sockeye fry	---	33%	20%	25%
Fish with sockeye fry or fish remains	---	1	1	2
Percent of fish containing sockeye fry or fish remains	---	33%	20%	25%
Gillnet				
Fish sampled	3	0	0	3
Fish containing sockeye fry	1	---	---	1
Percent of fish containing sockeye fry	33%	---	---	33%
Fish with sockeye fry or fish remains	1	---	---	1
Percent of fish containing sockeye fry or fish remains	33%	---	---	33%
Trap net				
Fish sampled	17	22	4	43
Fish containing sockeye fry	12	7	0	19
Percent of fish containing sockeye fry	71%	32%	0%	44%
Fish with sockeye fry or fish remains	10	9	0	19
Percent of fish containing sockeye fry or fish remains	59%	41%	0%	44%
Total				
Fish sampled	21	27	9	57
Fish containing sockeye fry	13	8	1	22
Percent of fish containing sockeye fry	62%	30%	11%	39%
Fish with sockeye fry or fish remains	11	11	1	23
Percent of fish containing sockeye fry or fish remains	52%	41%	11%	40%

Table 13.–Number of lake trout examined by month and capture method, and number and percentage of examined fish containing sockeye fry and partially digested fish remains in stomach contents, for 2001 Tatsamenie Lake predator study.

	Month			
Method of Capture	**June**	**July**	**August**	**Total**
Angling				
Fish sampled	246	269	63	578
Fish containing sockeye fry	8	22	13	43
Percent of fish containing sockeye fry	3%	8%	21%	7%
Fish with sockeye fry or fish remains	43	88	35	166
Percent of fish containing sockeye fry or fish remains	17%	33%	56%	29%
Beach-seine				
Fish sampled	0	2	0	2
Fish containing sockeye fry	---	1	---	1
Percent of fish containing sockeye fry	---	50%	---	50%
Fish with sockeye fry or fish remains	---	1	---	1
Percent of fish containing sockeye fry or fish remains	---	50%	---	50%
Gillnet				
Fish sampled	45	4	4	53
Fish containing sockeye fry	5	0	0	5
Percent of fish containing sockeye fry	11%	0%	0%	9%
Fish with sockeye fry or fish remains	14	3	2	19
Percent of fish containing sockeye fry or fish remains	31%	75%	50%	36%
Trap Net				
Fish sampled	2	6	0	8
Fish containing sockeye fry	1	0	---	1
Percent of fish containing sockeye fry	50%	0%	---	13%
Fish with sockeye fry or fish remains	1	1	---	2
Percent of fish containing sockeye fry or fish remains	50%	17%		25%
Total				
Fish sampled	293	281	67	641
Fish containing sockeye fry	14	23	13	50
Percent of fish containing sockeye fry	5%	8%	19%	8%
Fish with sockeye fry or fish remains	58	93	37	188
Percent of fish containing sockeye fry or fish remains	20%	33%	55%	29%

APPENDIX

Appendix A.–Results of water quality study performed on water from Snettisham hatchery, Tuya Lake, Tahltan Lake, Tatsamenie Lake, and Chilkat Lake, in 2001.

		Water Quality Criteria								
Parameter	**Units**	**USFWS (a)**	**ADF&G (b)**	**DFO (c)**	**Snett. Treated**	**Snett. Untreated**	**Tuya Lake**	**Tahltan Lake**	**Tatsamenie Lake**	**Chilkat Lake**
Alkalinity (as CaCO3)	Mg/L	10 – 400		>15	3.9	3.9	30.0	93.0	65.0	56.0
Aluminum	Mg/L	<0.01	<0.01	0.1	0.089	0.190	0.028	0.007	0.034	0.044
Ammonia (as NH3)	Mg/L	<0.0125	<0.0125	<0.05	ND	ND	ND	ND	ND	ND
Arsenic	Mg/L	<0.05	<0.05		--	--	--	--	--	--
Barium	Mg/L	<5	<5		--	--	--	--	--	--
Cadmium (d)	Mg/L	<0.0004	<0.0005	0.0003	ND	ND	ND	ND	ND	ND
Calcium Carbonate	Mg/L	4-160			--	--	--	--	--	--
Carbon Dioxide	Mg/L	0-10	<1	<10	--	--	--	--	--	--
Chloride	Mg/L	<0.03	<4		--	--	--	--	--	--
Chlorine	Mg/L		<0.003		--	--	--	--	--	--
Chromium	Mg/L	<0.03	<0.03	<0.04	ND	ND	ND	ND	ND	ND
Copper (d)	Mg/L	<0.006	<0.006	<0.002	0.00033	0.00024	0.00023	0.00037	0.00086	0.00091
Dissolved Oxygen (inflow)	% saturation	95–100	90	>95	--	--	--	--	--	--
Dissolved Oxygen (outflow)	Mg/L		7		--	--	--	--	--	--
Fluoride	Mg/L	<0.5	<0.5		--	--	--	--	--	--
Hardness (as CaCO3)	Mg/L	10-400		>20	50	n/a	28	110	83	76
Hydrogen cyanide	Mg/L	<0.01			--	--	--	--	--	--
Hydrogen sulfide	Mg/L	<0.0001	<0.003	<0.002	--	--	--	--	--	--
Iron	Mg/L	<0.15	<0.1	0.3	0.087	0.19	0.068	ND	ND	0.058

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Parameter	Units	Water Quality Criteria			Snett. Treated	Snett. Untreated	Tuya Lake	Tahltan Lake	Tatsamenie Lake	Chilkat Lake
		USFWS (a)	ADF&G (b)	DFO (c)						
Lead	Mg/L	<0.03	<0.02	0.004	ND	ND	ND	ND	ND	0.00049
Magnesium	Mg/L	Needed	<15		--	--	--	--	--	--
Manganese	Mg/L	<0.01	<0.01	0.1	0.0064	0.0090	0.0041	0.0031	0.0019	0.0039
Mercury	Mg/L	<0.0002	<0.0002	0.0002	ND	ND	ND	ND	ND	ND
Nickel	Mg/L	<0.01	<0.01	0.045	ND	ND	ND	0.00064	0.00087	0.00092
Nitrate (as N03)	Mg/L	0-3	<1		--	--	--	--	--	--
Nitrite (as N02)	Mg/L	<0.1	<0.01	<0.015	ND	ND	ND	ND	ND	ND
Nitrogen	% saturation	<100	<103							
pH	pH units	6.5-8.0	6.5-8.0	7.2-8.5	6.9	7.3	7.7	8.2	8.1	8.2
Potassium	Mg/L	<5	<5		--	--	--	--	--	--
Salinity	ppt	<5	<5		--	--	--	--	--	--
Selenium	Mg/L	<0.01	<0.01	0.05		ND	ND	ND	ND	ND
Settleable solids	Mg/L	<80	<80		--	--	--	--	--	--
Silver	Mg/L	<0.003	<0.003	0.0001	ND	ND	ND	ND	ND	ND
Sodium	Mg/L	<75	<75		--	--	--	--	--	--
Strontium	Mg/L				0.025	0.015	0.027	0.066	0.097	0.060
Sulfate	Mg/L	<50	<50		--	--	--	--	--	--
Sulfur	Mg/L	<1			--	--	--	--	--	--
Total Dissolved Solids	Mg/L	10-1000	<400		--	--	--	--	--	--
Total Suspended solids	Mg/L	<80		<3	ND	6.2	ND	ND	ND	ND
Uranium	Mg/L	<0.1			--	--	--	--	--	--
Vanadium	Mg/L	<0.1			--	--	--	--	--	--
Zinc	Mg/L	<0.03	<0.005	0.015	0.0045	0.0036	0.0034	0.0029	0.0036	0.0059
Zirconium	Mg/L	<0.03			--	--	--	--	--	--

a Piper, R. G., I. B. McElwain, L. E. Orme, J. P. McCraren, L. G. Fowler, and J. R. Leonard, editors. 1982. Fish hatchery management. U.S. Fish and Wildlife Service, Washington, D.C.

b McDaniel, T. R., K. M. Pratt, T. R. Meyers, T. D. Ellison, J. E. Follet, and J. A. Burke. 1994. Alaska sockeye salmon culture manual. Alaska Department of Fish and Game, Commercial Fisheries Division, Special Publication No. 6. 31 pp.

c Sigma Environmental Consultants Ltd. 1983. Summary of water quality criteria for salmonid hatcheries, Prepared for Fisheries and Oceans Canada. 163 pp.

d Criterion is for waters with alkalinity <100 mg/L.