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Kanalku and Sitkoh Lakes Subsistence Sockeye Salmon Project: 2004 Annual Report

by

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and

Margaret A. Cartwright

February 2007

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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February 2007

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ABSTRACT

In 2004, we estimated escapement of sockeye salmon (*Oncorhynchus nerka*) in two systems with important subsistence fisheries for the village of Angoon, continuing a series of annual estimates starting in 2001 for Kanalku Lake and 1996 for Sitkoh Lake. We used mark-recapture methods, visual surveys, and age, sex, and length sampling on the spawning grounds to estimate sockeye escapement and age composition in each lake. Estimated escapement in Kanalku Lake in 2004 was about 1,250 sockeye salmon, a substantial increase from extremely low escapements (200–300 fish) observed in 2003 and 2001, and comparable to the 2002 escapement of about 1,600 fish. Small (mean length 486 mm, mid eye to tail fork) age-1.2 sockeye salmon were the largest age class in the escapement. Despite low water in June through August 2004, sockeye salmon were observed successfully ascending the falls in the Kanalku outlet stream in late July and early August. In Sitkoh Lake the estimated escapement of about 3,700 sockeye salmon was the lowest in nine consecutive years. Age-1.2 fish made up 55% and age-1.3 fish made up 40% of the escapement. Extreme low water in the Sitkoh outlet stream in late July and early August may have created a temporary barrier to sockeye migration. Most Angoon residents continued to observe a voluntary conservation closure and refrained from fishing in Kanalku Bay in 2004. Some Angoon residents shifted their subsistence fishing effort to Sitkoh Bay, but not all were able or willing to do so. Kanalku Bay is still the preferred subsistence fishing area for most Angoon residents. These residents are very concerned about the effect of the closure on traditional subsistence activities, but are willing to participate in the effort to try and rebuild larger sockeye returns to this system.

Key words: sockeye salmon, *Oncorhynchus nerka*, subsistence, Kanalku Lake, Sitkoh Lake, escapement, mark-recapture.

INTRODUCTION

Since 2001, we have studied sockeye salmon spawning populations in two lake systems with long traditions of subsistence fishing by people from the village of Angoon. Kanalku Lake is the closest of the two lakes to Angoon, and is the system most village residents prefer for subsistence harvest of sockeye salmon. Sitkoh Lake is across Chatham Strait from Angoon, and fished somewhat less intensively by Angoon residents. We were alarmed at the small escapements in Kanalku Lake, less than 250 fish in 2001 (Conitz and Cartwright 2002) and only about 270 fish in 2003 (Conitz and Cartwright 2005). Because these escapements were several times lower than normal reported harvests since the late 1980s, we judged them to be abnormally low. Tradition and archaeology indicate that Angoon people have fished the Kanalku system continuously for at least 1,000 years (de Laguna 1960; Moss 1989; Goldschmidt et al. 1998). Modern villagers returning Alaska Department of Fish and Game (ADF&G) subsistence permits reported annual harvests of 1,000–2,000 fish in the 1990s, and we know from harvest surveys in other subsistence sockeye systems that the estimated totals from returned permits frequently underestimate actual harvest (Conitz and Cartwright 2005). In response to the apparent sharp decline in sockeye abundance, the Kanalku system was closed to subsistence and sport fishing starting in 2002 by a voluntary agreement between the Angoon community and ADF&G. In contrast, the Sitkoh Lake system, where subsistence fishing has been far less intense, supported estimated annual sockeye escapements of 6,000 to 17,000 fish during 1996–2003 (Conitz and Cartwright 2005, Appendix C). Reported subsistence sockeye harvests from Sitkoh Bay throughout this period averaged less than 150 fish annually (Conitz and Cartwright 2005, Appendix A). Although Sitkoh Bay is within the traditional territory of the Angoon Tlingit people (Goldschmidt et al. 1998), it is farther and more difficult to access from Angoon than Kanalku Bay, and reportedly more difficult to fish (M. Kookesh, retired biologist, Division of Subsistence, personal communication 2003). However, perhaps because of the voluntary fishing closure in Kanalku Bay, the number of Angoon residents who reported fishing for sockeye

salmon in Sitkoh Bay increased from under 10 permits annually during 1991–2000 to 20 permits in 2003 (Conitz and Cartwright 2005, Appendix A).

In 2002, the first year of the voluntary fishing closure in Kanalku Bay, the estimated sockeye escapement into Kanalku Lake was about 1,600 fish; ADF&G biologists and Angoon residents were encouraged that the closure was effective. However in 2003, due to personnel changes in both the ADF&G area management team and leadership positions in Angoon, the voluntary closure was not well publicized and Angoon residents began to disagree about whether the bay should be closed. Most Angoon residents upheld the fishing closure despite the confusion in 2003, but some residents and community leaders disagreed sharply over the extent of actual harvest (M. Kookesh, retired biologist, Division of Subsistence, personal communication 2004). The total harvest reported on ADF&G permits in 2003 was 90 sockeye salmon, which should be considered a minimum harvest estimate (Conitz and Cartwright 2005, Appendix C). The 2003 escapement estimate of just 270 sockeye salmon provided convincing evidence, after the fishing season, that the closure needed to be continued.

ADF&G management biologists held a preseason public meeting in Angoon in 2004, and village residents expressed a wide variety of concerns about the voluntary closure at that meeting. Participants in the meeting did not achieve resolution of the problems discussed, but the closure remained in effect by default. Although most residents agreed with the concept of the closure, many felt it created an unfair hardship, particularly for people with smaller boats who were unable to get across Chatham Strait to fish in other areas. Some people expressed the idea that their fishing rights in Kanalku are a matter of family heritage and custom and should not be subject to regulation. A few people questioned the need for a conservation closure at Kanalku Bay.

Faced with the Kanalku closure, some Angoon residents were able and willing to shift their subsistence sockeye fishing effort to other areas such as Sitkoh Bay. Sitkoh Bay was the site of a traditional fishery and associated settlements. From the early 1900s until the 1970s, both Angoon and Sitka Tlingit people worked and lived seasonally at the Chatham cannery in Sitkoh Bay, and harvested sockeye salmon returning to Sitkoh Bay for family use (Thornton et al. 1990). In the early 1980s, both Angoon and Sitka residents considered Sitkoh Bay a desirable subsistence fishing site because they found the sockeye runs to be consistent, predictable, and large enough to meet their needs. During that time, many subsistence users from Angoon were also active in commercial fisheries, and commercial fishing vessels were used to travel to and fish in Sitkoh Bay. Annual subsistence harvests of 1,000–5,000 sockeye salmon were reported for the period 1979–1984. After the mid-1980s, however, subsistence effort and harvest in Sitkoh Bay declined to very low levels, in response to perceived or actual declines in sockeye returns (Thornton et al. 1990). Also, the number of commercial fishing permits and boats in Angoon declined, leaving mainly a fleet of small skiffs for subsistence fishing, many of which were unsuitable for crossing the exposed waters of Chatham Strait. Reported harvests in 1985–2003 ranged from zero to just under 700 fish, but the annual totals since 2000 have increased, perhaps in response to the closure at Kanalku Bay (Conitz and Cartwright 2005).

The general impression that Sitkoh Lake sockeye runs have been consistent and stable is supported by information, although limited, from previous years of study. In 1982, about 7,200 sockeye salmon were counted through an adult escapement weir in the outlet creek (Cook 1998). This count, which should be considered a minimum estimate of escapement because it was not verified with a mark-recapture experiment, was nevertheless within the range of annual sockeye

escapements between 6,000 and 17,000 fish, estimated in 1996–2003. In 1996, an escapement weir in conjunction with a mark-recapture study yielded a reliable escapement estimate of about 16,000 (the weir count was about 9,500; Cook 1998), again within the observed range of escapements. Biological evidence from Sitkoh Lake also supports the idea of moderate and stable sockeye production at least since the 1980s. Among adult spawners sampled in 1982–2003, we observed that most fish had spent only one year in the lake as juveniles (Conitz and Cartwright 2005), an indication that sockeye fry populations are not limited by food resources in the lake. Secondary production in Sitkoh Lake was high in 2001 and 2002, with seasonal mean biomass estimates of about 600–700 $mg \cdot m^{-2}$, compared with an average of 200–300 $mg \cdot m^{-2}$ for 14 sockeye-producing lakes in Southeast Alaska (Conitz and Cartwright 2005). Sitkoh Lake also supports large populations of cutthroat trout (*O. clarki* spp.), Dolly Varden char (*Salvelinus malma*), and steelhead trout (*Oncorhynchus mykiss*), in comparison with other lakes in the region (Brookover et al. 1999; Jones and Yanusz 1998; Yanusz 1997).

Overall, recent Sitkoh Lake sockeye returns appear to be sustainable and capable of supporting at least the limited level of subsistence harvest observed since the mid-1980s. However, an unknown factor in the management and biology of the Sitkoh sockeye stock is the level of commercial harvest. Sockeye salmon are harvested incidentally in purse seine fisheries in Chatham Strait, and these fisheries have expanded to target increased hatchery production since the 1990s. For example, annual harvests of 1,000–10,000 sockeye salmon were documented in most years since the 1980s in management sub-district 113-51, adjacent to Sitkoh Bay (Conitz and Cartwright 2005). The timing of maximum commercial fishing effort appears to coincide with maximum sockeye abundance in northern Chatham Strait (B. Van Alen, presentation to the Southeast Regional Advisory Council, October 2005). However, the stock composition of sockeye salmon in these harvests is unknown, so we have no way of knowing how many, or even if any, Sitkoh Lake sockeye salmon were harvested in commercial fisheries.

The primary focus of this study was to continue estimating annual sockeye escapements in Kanalku and Sitkoh Lakes, to provide fisheries management biologists a basis with which to compare the sizes of future harvests and escapements. We estimated the sockeye spawning population in each lake using mark-recapture studies and visual surveys on the spawning grounds. We also collected biological data from samples of the sockeye spawning populations in Sitkoh and Kanalku Lakes to estimate the age, sex, and length composition of these populations. These estimates will continue time series of escapement and age distribution estimates started in 1996 for Sitkoh Lake and in 2001 for Kanalku Lake. We also reconstructed the returning spawners from three brood years, 1996–1998, for which returns (in the escapement only) of all age classes were complete in 2004.

OBJECTIVES

1. Estimate annual sockeye escapement into Kanalku and Sitkoh Lakes, using mark-recapture methods and observer counts on the spawning grounds, so the estimated coefficient of variation is less than 15%.
2. Estimate the age, length, and sex composition of the sockeye salmon in the escapement at each lake, with coefficient of variation no greater than 10% for the two major age classes.

METHODS

STUDY SITES

Kanalku Lake

Kanalku Lake (ADF&G stream no. 112-67-58/60; lat 57° 29.22'N long 134° 21.02'W) is about 20 km southeast of Angoon (Figure 1) and lies in a steep mountainous valley within the Hood-Gambier Bay carbonates ecological subsection (Nowacki et al. 2001). The U-shaped valley and rounded mountainsides are characterized by underlying carbonate bedrock and built up soil layers supporting a highly productive spruce forest, especially over major colluvial and alluvial fans. The watershed area is approximately 32 km^2, with one major inlet stream draining into the east end of the lake. The lake elevation is about 28 m. The lake surface area is about 113 hectares, with mean depth of 15 m, and maximum depth of 22 m (Figure 2). The outlet stream, Kanalku Creek, is 1.7 km long and drains into the east end of Kanalku Bay. In addition to sockeye salmon returning to the lake, large numbers of pink salmon (*O. gorbuscha*) spawn in the lower part of the outlet creek and intertidal area. A few coho (*O. kisutch*) and chum salmon (*O. keta*) spawn in the Kanalku system, and resident populations of cutthroat trout, Dolly Varden char, and sculpin (*Cottus sp.*) are found in Kanalku Lake. A waterfall, approximately 8–10 m high and about 0.8 km upstream from the tidewater, forms a partial barrier to migrating sockeye salmon. In 1970, ADF&G, working with the U.S. Forest Service, blasted resting pools and a small channel in the falls bedrock to assist the migrating salmon.

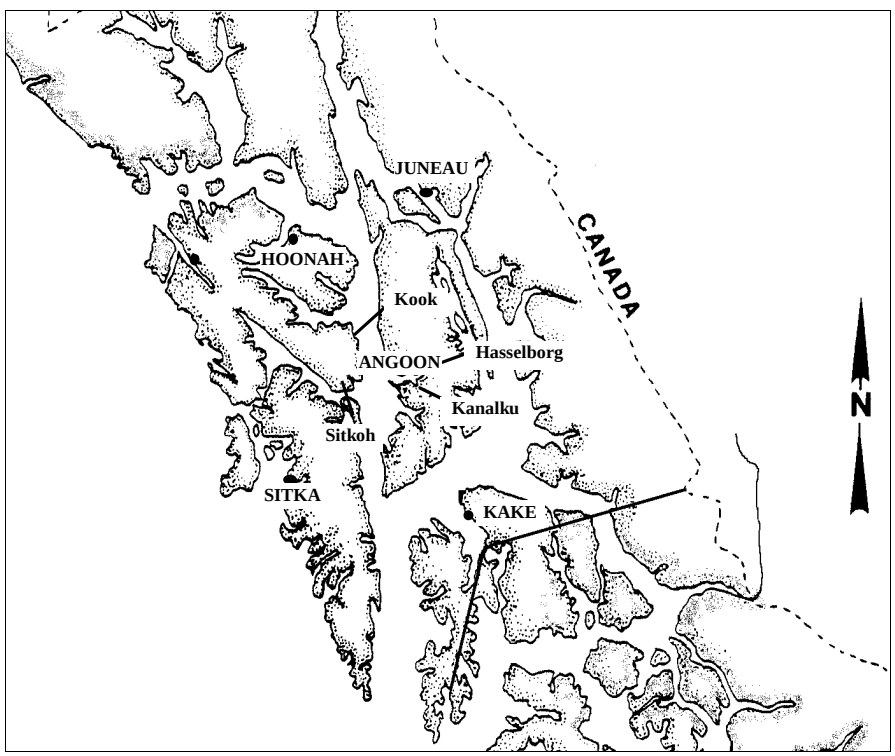

Figure 1.–Map of Southeast Alaska showing location of Kanalku and Sitkoh Lakes, and the village of Angoon.

Figure 2.–Bathymetric map of Kanalku Lake, showing 5 m depth contours and the mark-recapture study area.

Sitkoh Lake

Sitkoh Lake (ADF&G stream no. 113-59-005; lat 57°30.89'N, long 135°2.52'W) is located on the southeastern tip of Chichagof Island, about 30 km from Angoon, and drains east into Sitkoh Bay (Figure 1). Situated between Chatham and Peril Strait, the Sitkoh Lake drainage lies within the Peril Strait granitics ecological subsection, while the outlet stream and the bay are part of the Kook Lake carbonates subsection to the east (Nowacki et al. 2001). Continental ice sheets covering this area left rounded and heavily scoured mountains. Sitkoh Lake and its outlet stream lie in a broad, U-shaped valley that nearly bisects the peninsula at the tip of Chichagof Island. The Sitkoh Lake watershed area is about 31 km^2; the lake is situated at an elevation of about 59 m. Its surface area is 189 hectares, the average depth is 20 m, and the maximum depth is 39 m (Figure 3). Several steep-gradient inlet streams enter the lake on the north and south sides, ending in productive alluvial fans on the lakeshore; the outlet stream is about 6 km long with at least two tributaries. The lake supports runs of sockeye, coho, pink, and chum salmon. It also supports a run of as many as 50,000 anadromous Dolly Varden char, several thousand sea-run cutthroat trout and a smaller number of summer resident cutthroat trout, and one of the region's largest steelhead runs (Yanusz 1997; Jones and Yanusz 1998; Cook 1998; Brookover et al. 1999). The Sitkoh drainage was extensively clear-cut between 1969 and 1974.

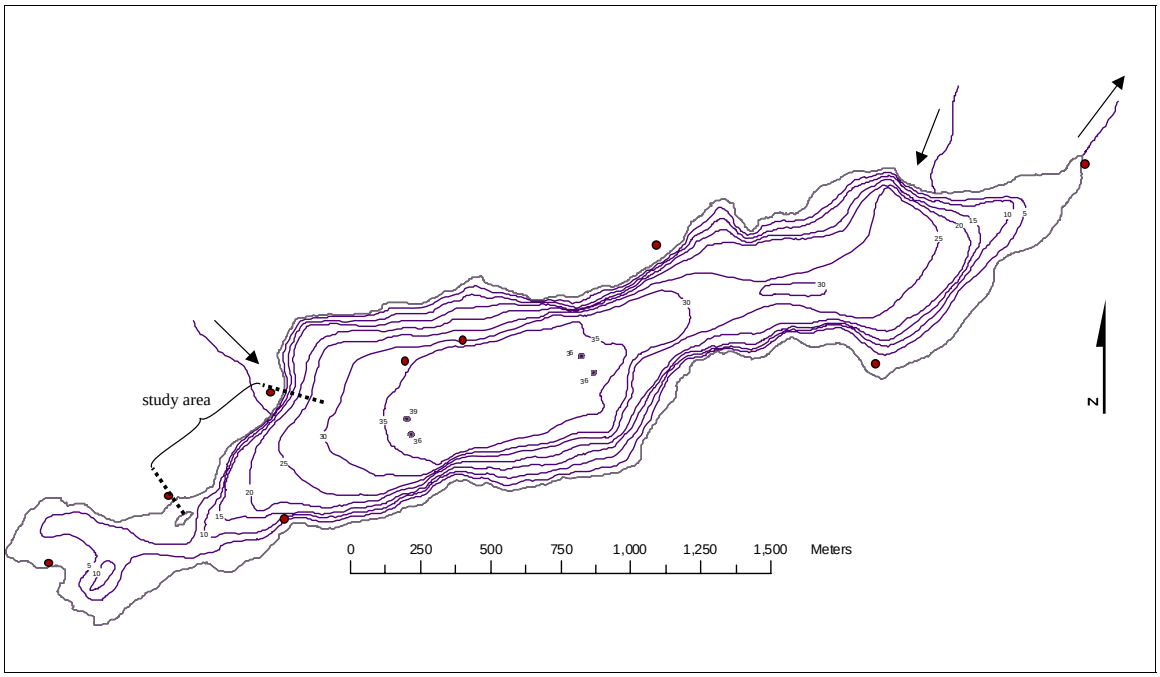

Figure 3.–Bathymetric map of Sitkoh Lake, showing 5 m depth contours and the mark-recapture study area.

ADULT ESCAPEMENT ESTIMATES

Spawning Grounds Mark-Recapture and Visual Survey

Mark-recapture methods were used to estimate portions of the sockeye salmon spawning populations in Kanalku and Sitkoh Lakes. Mark-recapture sampling was conducted only within designated study areas, established in 1997 for Sitkoh Lake and in 2001 for Kanalku Lake (Figures 2 and 3). We used a study design based on the methods described in Schwarz et al. (1993) for estimating salmon escapements and further modified for estimating spawning populations in beach spawning sockeye systems (Cook 1998). Specifically, we used a simple Petersen estimator (Seber 1982) to estimate the number of spawners present at each sampling event, and a modified Jolly-Seber model to estimate the super population, or total number of fish entering the study area throughout the season (Seber 1982; Schwarz et al. 1993; Cook 1998; J. Blick former ADF&G, personal communication 1998). We give details in the data analysis section below.

Visual Survey Counts of Sockeye Spawners

The study areas were established in most highly concentrated spawning areas, encompassing about half the total spawning population in Sitkoh Lake and about 90% of the spawning population in Kanalku Lake (Figures 2 and 3). We used mark-recapture methods to estimate the total number of sockeye salmon spawning within these designated study areas. However, our objective was to estimate the total sockeye escapement in each lake. Therefore, we also determined the proportion of the total spawning population within the study area for each lake using visual survey counts. Just before each sampling event, at least three observers counted

sockeye spawners from a skiff that was motored slowly around the lake perimeter. Observers counted sockeye salmon within the study area and in all other areas outside the study area, and summed these counts for a total lake count. The main inlet stream in Kanalku Lake was checked for presence of fish, but we have never observed sockeye spawners in this stream. Sitkoh Lake has no spawning tributaries. After each survey, we divided the mean count (between all observers) for the study area by the mean count for the whole lake, to estimate the proportion of fish within the study area at that sampling event. The proportion of fish in the study area over the entire season was estimated by taking the mean of proportions in the study area at each sampling event, weighted by the estimated total spawning population size at each event.

Mark-Recapture Methods for Beach Spawning Populations

Each sampling event consisted of two consecutive days of sampling. On each day, the crew captured sockeye salmon on the spawning grounds with a beach seine. They first inspected each sockeye salmon for previous marks, then marked the fish with an opercular punch or pattern of punches identifying the sampling event and day, and released it with a minimum of stress. The crew leader recorded the total sample size, the number of new fish marked, and the number of recaptured fish with each type of mark. Sampling in these small populations continued until the number of same-day recaptures exceeded the number of new fish caught. Left opercular punches used to identify each sampling event were: first event—round, second event—triangle, third event—square, fourth event—two round. A right opercular punch was given each fish caught on the second day of each event to indicate the fish had already been caught and should not be recounted during that event. In order to generate a simple Petersen estimate for each event, fish were marked on one day and examined for marks the next day. For the super population estimate, fish marked on both days of a given event were counted, and on subsequent sampling events, recaptures of these marks were recorded. We used the number of recaptures from each previous event and the Petersen estimates of abundance from each event to generate the super population estimate.

Data Analysis

We used Chapman's form of the Petersen mark-recapture estimator to estimate the number of sockeye spawners within the study area at each sampling event (Seber 1982, p. 60). For a given sampling event, i, we let K_i denote the number of fish marked on the first day of the event in a random sample from a population of size N_i. We let C_i denote the number of fish sampled and examined for marks on the second day of event i, and let R_i denote the number of fish in the second day's sample with a mark. The estimated number of fish in the population at event i, $\hat{N}_i$, was calculated by,

$$\hat{N}_i = \frac{(K_i + 1)(C_i + 1)}{(R_i + 1)} - 1 .$$

In developing the total population estimate, we used only the point estimates $\hat{N}_i$. However, if an estimate of precision was needed for these, we used the coefficient of variation (CV). We estimated the variance of $\hat{N}_i$ as,

$$\mathrm{var}(\hat{N}_i) = \frac{(K_i + 1)(C_i + 1)(K_i - R_i)(C_i - R_i)}{(R_i + 1)^2 (R_i + 2)} .$$

Then, we estimated the coefficient of variation as,

$$CV = \frac{\sqrt{\mathrm{var}(\hat{N}_i)}}{\hat{N}_i}.$$

Using the Petersen estimates of spawner abundance at each event, and the number of recaptures from previous events, we estimated the super population, or total spawning population within the study area, N^*. Given s sampling events, we let $\hat{N}_i$ denote the Petersen estimate from each sampling event i ($i=1,...,s$). The $\hat{N}_i$ values were used in place of the usual Jolly-Seber derived parameter estimates of the number of animals alive in the system at each sampling event (J. Blick ADF&G, personal communication 1998; Cook 1998). We let n_i represent the number of unmarked fish and fish marked in previous events, caught at sampling event i, and we let m_i represent the number of fish marked in previous events, caught at sampling event i.

We also defined the parameters (Schwarz et al. 1993; J. Blick ADF&G, personal communication, 1998; Cook 1998):

> M_i = number of marked fish alive at time i (i=1,…,s; M_1=0),
>
> ϕ_i = probability that a fish alive at time i is also alive at time i+1 (i=1,…,s-1; *i.e.* the survival rate),
>
> B_i = number of fish that enter the system after event i and are still alive at event i+1 (i=1,…,s-1; *i.e.* immigration), and B_0 = number of fish that entered the population before the first sample and are still alive at the time of the first sample,
>
> N^* = total number of animals that enter the system before the last sampling event.

M_i was estimated as $\hat{M}_i = m_i \hat{N}_i / n_i$ (M_1=0);

ϕ_i was estimated as $\hat{\phi}_i = \hat{M}_{i+1} / (\hat{M}_i - m_i + n_i)$;

B_i was estimated as $\hat{B}_i = \hat{N}_{i+1} - \hat{\phi}_i \hat{N}_i$.

Seber (1982:204) recommended that m_i should be greater than 10 for satisfactory performance of these bias-adjusted estimators.

We assumed the interval between the last (s^{th}) sampling event, and the next-to-last (s-1th) sampling event was so short that the number of fish entering the population during this interval was negligible. Furthermore, we assumed that sampling extended to a time when immigration had ended, and the number of fish entering the population was negligible. Escapement can be estimated as the sum of the $\hat{B}_i$, estimated numbers of fish that entered the population between sampling events. However, the $\hat{B}_i$ are numbers of fish that entered the population after sampling event i and were alive at sampling event i+1. These estimates exclude those fish in the escapement that entered after sampling event i but died before sampling event i+1. Consequently, Jolly-Seber estimates of B_i underestimate spawning recruitment, except when all fish are known to survive from their entry to the next sampling event. To account for those fish that entered the system after sampling event i but died before sampling event i+1, we adjusted

$\hat{B}_i$ by a probability distribution approach (Schwarz 1993). Let B_i^* denote the total number of new fish entering the population between sampling events (including those that die before the next sampling event). When recruitment and mortality are assumed to occur uniformly between sampling events, the maximum likelihood estimator (MLE) for B_i^* is

$$\hat{B}_i^* = \hat{B}_i \frac{\log(\hat{\phi}_i)}{\hat{\phi}_i - 1}.$$

$\hat{B}_0$, $\hat{B}_1$, and $\hat{B}_{s-1}$ are confounded parameters and cannot be estimated without further assumptions (Schwarz et al. 1993). However, we assume recruitment has virtually ended before the last sampling event, so we set $\hat{B}_{s-1}$ to zero. The number of fish alive in the population on the second sampling event, N_2, can be estimated as,

$$\hat{N}_2 = \hat{B}_0 \phi_1 + \hat{B}_1.$$

So a reasonable estimate of the number of fish that enter the system before the first sampling event and between the first and second sampling events, including those that enter the system and die before and between these sampling events, is,

$$\hat{N}_2 \frac{\log(\hat{\phi}_1)}{\hat{\phi}_1 - 1}$$ (Schwarz et al. 1993).

We then estimated the super population, or total escapement, as

$$N^* = \hat{N}_2 \frac{\log(\hat{\phi}_1)}{\hat{\phi}_1 - 1} + \sum_{i=2}^{k-1} \hat{B}_i^*.$$

A parametric bootstrap method (Buckland 1985 and 1984) was used to construct a confidence interval for the population estimate. Let each bootstrap step be indexed by j (j=1...G; for our purposes G=1,000). The parametric bootstrap distribution for $\hat{N}_i$ was developed by drawing G bootstrap observations of a hypergeometrically distributed random variable (that is, r_i) using parameters based on the observed values of C_i, K_i, and $\hat{N}_i$ at each sampling event i. At each step the Petersen estimate $\hat{N}_i(j)$ is developed as previously described. Denote each bootstrap observation in the Petersen estimation process as the pair of $r_i(j)$ and $\hat{N}_i(j)$, for j=1...G. Before proceeding on to simulation of the modified Jolly-Seber estimation process, the variance of the number of recaptures across all bootstrap replicates was calculated and denoted sb_i, for each sampling event i (*i.e.*, $\mathrm{Var}_j(r_i(j)) = sb_i$). Note that this standard deviation is calculated from the bootstrap distribution of just second day recaptures at each sampling event. To simulate the Jolly-Seber portion, for each bootstrap step, a bootstrap observation, $m_i(j)$, was drawn from a normal distribution with the mean determined from the actual observed value of m_i, and the standard deviation given by sb_i. Because this standard deviation is based on the simulated variability only from second day recaptures in a given sampling event, it may tend to understate the sampling variability of m_i, which is the number of recaptures from all previous marking events. Even so, this assumption should provide a sensible approximation. We conditioned on the sample size, which we assumed to be fixed and not a random variable, so that $n_i = n_i(j)$, for

all j bootstrap observations. We then estimated $\hat{M}_i(j)$, $\hat{\phi}_i(j)$, and so on, as previously described, for all j=1, ...G. The confidence interval for each parameter was found from the quantiles of the bootstrap distribution (Rice 1995) for that estimate.

Adult Sockeye Salmon Population Age and Size Composition

At each lake, about 600 length, sex, and scale samples were collected during mark-recapture sampling of adult sockeye salmon to describe the size and age structure of the population by sex. Length of each fish was measured from mid eye to tail fork, to the nearest millimeter (mm). Sex of the fish was determined by length and shape of the kype or jaw. Three scales were taken from the preferred area of each fish (INPFC 1963), and prepared for analysis as described by Clutter and Whitesel (1956). Scale samples were analyzed at the ADF&G salmon aging laboratory in Douglas, Alaska. Age classes were designated by the European aging system where freshwater and saltwater years are separated by a period (e.g. 1.3 denotes a five-year-old fish with one freshwater and three ocean years; Koo 1962). The proportion of each age-sex group was estimated along with its with associated standard error, using standard statistical techniques assuming a binominal distribution, described in common references, such as Thompson (1992).

RESULTS

ADULT ESCAPEMENT ESTIMATES

Spawning Grounds Mark-Recapture and Visual Survey

Kanalku Lake

Mark-recapture sampling and visual surveys were conducted in Kanalku Lake between 24 August and 29 September 2004. No sockeye salmon were observed in the lake on 24 August (Table 1). The greatest abundance of sockeye salmon in the study area and in the lake was on 15 September; however, the survey and sampling event scheduled for 9 September were missed, leaving a gap of two full weeks between the previous and next event.

Table 1.–Visual counts of sockeye spawners in Kanalku Lake, 2004, comparing numbers counted inside designated study areas with total counts for the lake. Counts are averages between three observers.

Date	Average count within study areas	Average count for whole lake	Proportion in study area
24 Aug	0	0	na
1 Sep	120	121	0.99
9 Sep	no survey or sampling	-	-
15 Sep	414	597	0.69
23 Sep	sampling only, no visual survey		-
28 Sep	77	87	0.88

Estimated abundance in the study area on 1 September was 170 (CV=16%) sockeye spawners. Out of 92 fish released with marks on that event, only three were recaptured in subsequent events (Table 2). We assumed that most of the first group of spawners died between 1 and 15 September and the spawners present on 15 September were mostly new immigrants to the spawning grounds. We decided that, because of the very small recapture numbers from the 1 September sampling event, including this event in the overall season escapement estimate could lead to unacceptable high bias in the estimate. Therefore, we decided to exclude the 1 September sample data and designate the 15 September sampling event as the first sampling event. We

recognized that excluding the 1 September sample most likely caused the estimate to be low, because fish that entered the study area and died before the 15 September sampling event would not have been included. However, the estimate does include fish that entered the study area any time before 15 September and were still alive on 15 September. Therefore, we assumed the magnitude of underestimation caused by dropping the 1 September sample was not much larger than the estimated abundance on 1 September (170 fish). We estimated about 820 sockeye salmon (CV=5%; 95% CI 750–920) spawned within the study area after 15 September. The weighted mean proportion of spawners in the study area was about 76% during this period, so the total escapement was roughly 1,080. To this number we added the 170 spawners estimated in the study area on 1 September (99% of sockeye salmon observed in the whole lake on that date), giving a total escapement estimate of about 1,250 sockeye spawners.

Table 2.–Sample sizes and numbers of recaptured fish in the Kanalku Lake study area in 2004. For the Petersen (first stage) estimate, we marked and released fish the first day and conducted recapture sampling on the second day of each sampling event, to estimate spawner abundance at that date. For the Jolly Seber (second stage) estimate, we counted all fish released with marks denoting the event on both days of a given sampling event, and also counted all recaptures of fish with marks from previous events.

First Stage: Petersen			
Date	**Number marked (1st day)**	**Number sampled (2nd day)**	**Number recaps from 1st day**
1 Sep	51	58	17
15 Sep	350	347	186
23 Sep	140	155	77
29 Sep	33	17	14

Second Stage: Jolly Seber				
		Recaptures from previous marking event		
Date	**Number of marks released**	**1 Sep**	**15 Sep**	**23 Sep**
1 Sep	92	-	-	-
15 Sep	511	2	-	-
23 Sep	218	1	28	-
29 Sep	36	0	0	23

Sitkoh Lake

Mark-recapture sampling and visual surveys were conducted in Sitkoh Lake between 21 August and 30 October 2004. No sockeye salmon were seen on the first sampling event, starting 21 August, or the last sampling event, starting 30 October (Table 3).

Table 3.–Visual counts of sockeye spawners in Sitkoh Lake, 2004, comparing numbers counted inside designated study areas with total counts for the lake. Counts are averages between three observers.

Date	Average count within study areas	Average count for whole lake	Proportion in study area
21 Aug	0	0	na
6 Sep	149	277	0.54
17 Sep	244	412	0.59
1 Oct	241	442	0.55
15 Oct	68	108	0.63
30 Oct	0	0	na

Based on mark-recapture sampling between 6 September and 15 October (Table 4), we estimated a total of about 2,100 sockeye spawners (CV=9%; 95% CI 1,900–2,600) within the study area. We estimated that fish sampled in the study area represented just under 60% of the total lake spawning population over the 2004 season, so a total estimate of sockeye escapement for Sitkoh Lake was about 3,700.

Table 4.–Mark and recapture sample sizes and numbers of recaptured fish in the study area of Sitkoh Lake, 2004.

First Stage: Petersen			
Date	**Number marked (1st day)**	**Number sampled (2nd day)**	**Number recaps from 1st day**
6 Sep	134	94	53
17 Sep	186	179	86
1 Oct	232	190	121
15 Oct	71	45	19

Second Stage: Jolly Seber				
Date	**Number of marks released**	**Recaps from previous marking event**		
		6 Sep	**17 Sep**	**1 Oct**
6 Sep	175	-	-	-
17 Sep	279	13	-	-
1 Oct	301	0	20	-
15 Oct	97	0	0	27

Adult Sockeye Salmon Population Age and Size Composition

Kanalku Lake

As in previous years, the age composition of the Kanalku Lake sockeye escapement in 2004 was very simple. Over three-quarters of the sampled fish were age-1.2, and almost all (99%) were fish with only one freshwater year (Table 5). Age composition estimates were based on analysis of scale samples from 329 Kanalku Lake sockeye salmon, out of a total sample of 464 fish. In part because so few fish were present on the first and last sampling events, we did not meet our sampling goal of 600 fish.

Table 5.–Age composition of adult sockeye salmon sampled in the Kanalku Lake escapement by sex, 2004.

Brood year	**2000**	**1999**	**1999**	
Age	**1.2**	**1.3**	**2.2**	**All aged**
Male				
Sample size	123	69	2	194
Percent	37.4%	21.0%	0.6%	59.0%
Std. error	2.7%	2.2%	0.4%	2.7%
Female				
Sample size	126	6	2	134
Percent	38.3%	1.8%	0.6%	40.7%
Std. error	2.7%	0.7%	0.4%	2.7%
All fish				
Sample size	250	75	4	329
Percent	76.0%	22.8%	1.2%	100.0%
Std. error	2.4%	2.3%	0.6%	

Fish in the dominant age-1.2 class in Kanalku Lake were small, averaging 486 mm in mideye to fork length. Age-1.3 fish that had spent one additional year at sea, predominantly males in this sample, were 60 mm larger on average (Table 6). Only four fish sampled in the Kanalku escapement were age-2.2; they were intermediate in size between the other five-year-old (age-1.3) fish and the four-year-old (age-1.2) fish.

Table 6.–Mean fork length (mm) of adult sockeye salmon in the Kanalku Lake escapement by sex and age class, 2004.

Brood year	**2000**	**1999**	**1999**	
Age	**1.2**	**1.3**	**2.2**	**All fish**
Male				
Avg. length (mm)	488	548	523	510
Std. error	1.3	2.0	2.5	2.3
Sample size	123	69	2	194
Female				
Avg. length (mm)	484	527	510	487
Std. error	1.5	3.3	10.0	1.6
Sample size	126	6	2	134
All fish				
Avg. length (mm)	486	546	516	500
Std. error	1.0	2.0	5.5	1.7
Sample size	250	75	4	329

Sitkoh Lake

An estimated 95% of the Sitkoh Lake sockeye spawners were fish with one freshwater year, with slightly more four-year-old (age-1.2) fish than five-year-old (age-1.3) fish (Table 7). A few age-1.1 and -2.1 jacks were sampled. Age composition estimates were based on analysis of scale samples from 528 Sitkoh Lake sockeye salmon, out of a total sample of 642 fish.

Table 7.–Age composition of adult sockeye salmon sampled in the Sitkoh Lake escapement by sex, 2004.

Brood year	**2001**	**2000**	**1999**	**2000**	**1999**	
Age	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**All ages**
Male						
Sample size	9	170	131	1	10	321
Percent	1.7%	32.2%	24.8%	0.2%	1.9%	60.8%
Std. error	0.6%	2.0%	1.9%	0.2%	0.6%	2.1%
Female						
Sample size		120	79		7	206
Percent		22.7%	15.0%		1.3%	39.0%
Std. error		1.8%	1.6%		0.5%	2.1%
All Fish						
Sample size	9	290	211	1	17	528
Percent	1.7%	54.9%	40.0%	0.2%	3.2%	100.0%
Std. error	0.6%	2.2%	2.1%	0.2%	0.8%	

Not surprisingly, fish that spent two years in the ocean (age-1.2) were about 50 mm smaller, on average, than fish that spent three years in the ocean (age-1.3; Table 8). The few age-2.2 fish, which, like the age-1.3 fish were also five years old, were smaller than either of the other age classes (not including jacks).

Table 8.–Mean fork length (mm) of adult sockeye salmon in the Sitkoh Lake escapement by sex and age class, 2004.

Brood year	**2001**	**2000**	**1999**	**2000**	**1999**	
Age	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**All fish**
Male						
Avg. length (mm)	347	498	549	370	489	514
Std. error	5.8	1.5	1.8		5.1	2.4
Sample size	9	170	131	1	10	321
Female						
Avg. length (mm)		489	536		488	507
Std. error		2.0	1.4		5.5	2.1
Sample size		120	79		7	206
All Fish						
Avg. length (mm)	347	494	544	370	488	511
Std. error	5.8	1.2	1.3		3.6	1.7
Sample size	9	290	211	1	17	527

DISCUSSION

The escapement of 1,250 sockeye salmon into Kanalku Lake in 2004 was a substantial increase from the extremely low escapement of 270 sockeye salmon in 2003, and was comparable to the escapement of about 1,600 sockeye salmon in 2002. We are confident that our mark-recapture sampling, combined with visual surveys of the lake, was adequate to provide a reliable estimate of total spawning escapement. Although the crew missed the second scheduled sampling trip in to Kanalku Lake, data collected on the three trips between 15 and 30 September were adequate to yield an estimate that met our objective for precision. We accounted for the missed second trip by adding the number of spawners estimated on the first trip to the total season escapement, and assuming any new immigrants in the intervening period were already incorporated in the estimate. As observed in previous years, the spawning period in Kanalku Lake was brief, lasting only about four weeks in September. As in previous years, most of the sockeye spawning population was found within the study area. Those few fish we have observed outside the study area were generally not spawning, but were either staging to spawn elsewhere or had already spawned.

Although estimation of subsistence sockeye harvests was not part of this study, we considered reported harvests and anecdotal information to help gauge the effectiveness of the Kanalku closure and the relationship between harvest and escapement sizes. Some Angoon residents continued to harvest sockeye salmon in Kanalku Bay and Kanalku Creek despite the voluntary closure, but opinions differed as to the size of harvests and the number of participants (M. Kookesh, retired biologist, Division of Subsistence, personal communication 2004; W. Jack, Angoon Mayor, personal communication 2004). Subsistence permit holders reported harvesting 14 sockeye salmon in 2002, 90 sockeye salmon in 2003, and 60 sockeye salmon in 2004 (Conitz

and Cartwright 2005; ADF&G Division of Commercial Fisheries database 2006). We have demonstrated in other subsistence sockeye fisheries that permit holders tend to under-report their true harvests, although the degree of under-reporting varies (Cartwright et al. 2005). In this case, the possibility that harvests in 2002–2004 were larger than reported must be considered in light of the very low escapements in 2001 and 2003. Suppose, for example, that actual subsistence harvest in 2003 was twice as large as the reported number, or about 200 fish. Although this would have been a small harvest in comparison with reported harvests in the 1990s, for example, it would have represented almost 50% of the total sockeye return, excluding any commercial harvest, in 2003. It appears that without universal observance of the voluntary closure, this measure may not adequately protect very small sockeye runs.

The crew surveyed Kanalku Bay and the outlet stream up to the lake once or twice per week from 30 June through 17 August 2004 (Table 9). The purpose of the surveys was to provide ADF&G fisheries management biologists with a rough assessment of early season escapement into the lake and document any subsistence fishing activity. The crew observed peak numbers of sockeye salmon entering the outlet stream in mid to late July, and peak numbers ascending the falls later, in early August. They observed relatively large concentrations of sockeye salmon in the pool below the falls during most of the season. Like many previous observers, they noticed evidence, such as removals by bears and unsuccessful attempts by sockeye salmon to ascend the falls, that the falls present a partial barrier to sockeye migration. However, even with low water in the stream, the crew observed that some sockeye salmon were successfully negotiating the falls, with the largest numbers of fish above the falls from 27 July to 10 August. Beyond the top of the falls, the crew observed few fish, so we surmise that, after successfully ascending the falls, sockeye salmon moved quickly into the lake. The crew observed no fishing activity in the bay or stream during any of their surveys.

Table 9.–Foot survey counts of sockeye salmon from Kanalku Bay along the outlet stream to Kanalku Lake in 2004.

	Sockeye counts by location along stream					
Date	**Bay**	**Intertidal**	**Treeline to Falls**	**Falls**	**Above Falls**	**Lake at outlet**
30-Jun	600	30	0	na	na	na
6-Jul	500	32	24	150	15	0
10-Jul	na	35	5	7	8	0
13-Jul	some	39	4	7	na	0
16-Jul	some	150	1	75	na	0
21-Jul	some	100	1	100	na	na
27-Jul	0	100	1	150	50	0
6-Aug	some	150	na	200	50	na
10-Aug	0	8	na	150	50	na
13-Aug	na	10	na	150	na	na
17-Aug	na	40	na	100	3	0

The estimated sockeye escapement into Sitkoh Lake in 2004 was the lowest observed since monitoring began in 1996 (Conitz and Cartwright 2005, Appendix C). The spawning period was also shorter, beginning in early September and ending in mid-October. In previous years, sockeye salmon appeared on the spawning grounds as early as 17 August and remained into the first week of November. Most of the sockeye salmon in the 2004 escapement apparently

migrated into the lake during the very early season. Crew at a steelhead weir in Sitkoh Creek counted 2,257 sockeye salmon passing between 9 and 24 June 2004, or more than half the total number of spawners later estimated in the lake (D. Love ADF&G Division of Sport Fish, unpublished data 2004). Dry weather and low water during the summer migration period may have caused some pre-spawning mortality in the 2004 escapement. During aerial surveys in August, ADF&G biologists observed dry stretches along the outlet stream which may have prevented fish from getting to the lake (K. Monagle ADF&G Division of Commercial Fisheries, personal communication 2004).

We expected to see strong returns of age-1.3 and -1.2 fish from the 1999 and 2000 brood years in the 2004 escapement, because escapements were high (10,000 and 17,000 fish, respectively) in those two brood years, relative to other recent years. However, the 2004 escapement, which was the lowest in nine years, did not reflect strong production or survival from the 1999 or 2000 brood years. Age-1.3, or five-year-old, fish are usually dominant in the Sitkoh Lake escapement, but in 2004, four-year-old age-1.2 fish made up the largest proportion of the escapement. We could not complete reconstructions of brood year returns (in the escapement) from the 1999 and 2000 brood years until the 2005 and 2006 escapements were known, but we could estimate the numbers of fish that returned from the 1996–1998 brood years, by age class (Table 10; see also Conitz and Cartwright 2005:30). The six-year-old offspring from the 1998 brood year would have returned in 2004; however, none were found in the escapement samples. The parents in the 1996 brood years roughly replaced themselves in the escapement, and the 1997 brood year produced more than one (1.4) returning offspring per spawner in the escapement. Returns from the 1998 brood year were lower, with less than one (0.9) returning offspring per spawner. However, without estimates of the number and age composition of Sitkoh Lake sockeye salmon harvested in commercial fisheries, we cannot estimate the true number of recruits per spawner for this stock.

Table 10.–Returns from the 1996–1998 brood years estimated from Sitkoh Lake escapements and age compositions, 1999–2004. Numbers do not include fish from any subsistence, sport, or commercial harvest.

Brood Year	Number of parents	Number of offspring returning to spawn, by age class						Number of offspring
		0.2	1.1	1.2	1.3	2.2	2.3	
1996	16,300		126	2,982	13,074		83	16,265
1997	5,984	68	187	763	7,268	155		8,442
1998	6,649		212	4,277	1,579	17		6,086

Thirty-two permit holders reported a total subsistence harvest of 1,055 sockeye in 2004 for Sitkoh Bay (ADF&G Division of Commercial Fisheries database 2005). This harvest was the largest reported on permits to date (Conitz and Cartwright 2005, Appendix A), and the actual harvest may have been even larger. Nevertheless, the reported harvest was still less than one-third the size of the estimated escapement, in a year with low escapement. If future escapement sizes return to the middle or upper part of the range observed in previous years, the increased level of harvest would most likely still allow for sustainable sockeye production in Sitkoh Lake.

Continued accurate annual escapement estimates for Kanalku Lake are critical because of the extremely low escapements documented in two recent years (2001 and 2003) and the voluntary subsistence fishing closure. If more very low sockeye escapements are seen in this system, or sockeye salmon continue to be harvested in Kanalku Bay despite the voluntary closure, stronger

measures may be needed to curtail harvest. Some subsistence users and biologists responsible for managing federal subsistence fisheries have begun to demand that we consider the level of commercial sockeye harvest, and possibly restrict commercial fishing, before further restricting subsistence fishing on the Kanalku Lake stock. Sitkoh Lake sockeye runs could provide an alternate source of subsistence fish for Angoon residents, but not all residents are willing or able to take advantage of them. Furthermore, subsistence fishing has been very light in Sitkoh Bay since the mid-1980s and we don't know how this stock would respond to increased fishing. The Sitkoh Lake sockeye escapement was lower than we expected in 2004, and was below the previously observed range of escapements in Sitkoh Lake. In light of the possibility that Sitkoh sockeye runs may be declining, or that subsistence fishing effort in Sitkoh Bay may increase in response to the closure in Kanalku Bay, we need to continue estimating sockeye escapement into Sitkoh Lake. Sitkoh Lake has historically provided for important commercial and sport, as well as subsistence fisheries, and can continue to do so in the future provided fisheries managers have adequate scientific information about its fish abundance. If escapements continue to be low and additional fishing restrictions are needed, accurate estimates of escapement will be required to justify and assess the effectiveness of management actions. Likewise, biologists and users of the resource should expect management of the fishery to be based upon knowledge of typical sockeye run sizes and accurate escapement estimates for each year, even if no further restrictions are required.

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