Acoustic tagging of Sakinaw Lake sockeye salmon to investigate marine migratory behaviour and ocean survival: Results from 2005

prepared for the Pacific Salmon Commission

by

Chris C. Wood[1], David Welch[2],

and

Lyse Godbout[1]

[1] Fisheries and Oceans Canada, Science Branch, Pacific Biological Station, Nanaimo, B.C. V9T 6N7

[2] Kintama Research Coorportion, Centre for Shellfish Research, Bldg 373, Malaspina University-College, 900-5th Street, Nanaimo, B.C. V9R 5S5

INTRODUCTION

In 2004, Fisheries and Oceans Canada (DFO) began an experiment to track the marine migratory behaviour of Sakinaw Lake sockeye salmon using acoustic tags as part of the Pacific Ocean Shelf Tracking (POST) project. The experiment was continued in 2005 with additional financial support from the Pacific Salmon Commission (PSC). This report provides a summary of results from tagging in 2005, as required by the terms of a collaborative agreement with the PSC. The experiment had two principal objectives:

Objective 1: Determine adult migratory routes and timing

Marine mortality including mixed-stock fishing in Johnstone and Georgia Straits has been identified by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the Sakinaw Sockeye Recovery Team as one of the primary threats to the Sakinaw sockeye population. Additional information about migration routes and timing through these fisheries will help to focus fishing regulations to provide maximum protection to the Sakinaw stock and to avoid unnecessary disruption to fisheries. Although the timing of adult migration into Sakinaw Lake is known and monitored, efforts to reconstruct the migratory route and timing through mixed-stock fisheries have proven controversial because of the high cost of error. Sakinaw sockeye have been detected returning through Johnstone Strait in July and early August by scale analysis (single documented study of catch composition in 1975) and an adult tagging experiment (single tag recovery in 1925). Some fishermen have questioned the assumption that all Sakinaw sockeye return through Johnstone Strait as opposed to Juan de Fuca Strait, and many dispute the assumption that a significant portion of the run is vulnerable to fisheries in August. Abundance of Sakinaw sockeye is now too low to have any hope of detecting their presence using conventional tags or analyses of catch composition using scale patterns or DNA. The POST acoustic array provides an extraordinary technological opportunity to track individually identifiable acoustic tags that can be surgically implanted into large smolts.

Objective 2: Determine juvenile migratory routes and timing

Knowledge of atypical juvenile migratory behaviour will provide insight about likely sources of marine mortality, which has important implications for recovery planning, and the feasibility of recovery. Returns of Sakinaw sockeye were below expectation in 2004 suggesting that Sakinaw smolts, despite their large size, may have experienced higher marine mortality than expected for Chilko sockeye smolts. Poor marine survival (independent of fishing mortality) might account for the current critically endangered status of Sakinaw sockeye, but to date, no plausible mechanisms have been identified; one hypothesis is that Sakinaw sockeye migrate differently than Chilko sockeye smolts, perhaps with a prolonged residence in the Strait of Georgia, more like “southern inside” coho which have also experienced high marine mortality over the last decade.

Experience in 2004 and proposal for 2005

In 2004, 97 large (>17cm) Sakinaw sockeye smolts were released with acoustic tags into the ocean near the outlet of Sakinaw Lake. Of these, 39 (41%) were later detected as they crossed listening lines in Georgia Strait. Most (36) migrated quickly northwards (all but one through Malaspina Strait) and 17 (18% of those released) were detected entering Queen Charlotte Sound. Only 1 fish was detected leaving Georgia Strait via the Strait of Juan de Fuca; 2 fish were last detected in Howe Sound, and 1 fish was last detected in the Fraser River.

All smolts released in 2004 had been artificially reared at Rosewall Creek hatchery on Vancouver Island. They were genetically Sakinaw sockeye and were released at age 1+ (the typical age of smolting), but their fertilization, incubation and freshwater rearing experiences were entirely unnatural, and they had never experienced Sakinaw Lake. A second year of study using naturally reared smolts was proposed – partly out of necessity, as no artificially reared smolts were available in 2005, and partly by design, to confirm that results apply to wild Sakinaw sockeye.

Seine surveys in Sakinaw Lake in October 2004 indicated a relatively large number of age 1+ to age 3+ sockeye (12-23 cm) resident in the lake. The abundance of resident fish was consistent with previous speculation that many yearling sockeye had failed to emigrate from the lake in 2004 because of atypical warm dry conditions. Two resident individuals captured were marked (missing adipose fin) confirming that they had been released as hatchery fry in previous years. We speculated that some of these fish would smoltify at age 2+ in 2005, and might be captured during routine smolt enumeration. Failing this, we proposed to seine resident fish from the lake, and release them into the ocean with acoustic tags. At the time, we had not yet ascertained whether non-anadromous sockeye ("kokanee") existed as a separate population, genetically distinct from anadromous sockeye in Sakinaw Lake. Genetic analysis of non-anadromous individuals was also completed during 2005.

METHODS

Seining in Sakinaw Lake on 26-27 May 2005 (Fig. 1) yielded 90 resident sockeye that appeared large enough to tag with acoustic transmitters. Fish were sedated with 0.2 ppm metomidate hydrochloride (Aquacalm) and transported to a holding pen tethered near the surface within a boathouse (for shade) near the lake's outlet. The pen was constructed of perforated stainless steel panels and measured approximately 1x1x2 m. Surface water temperature was 18°C. Six fish failed to recover fully from sedation during transport and died within 24 h, but the remainder (84) were all alive and vigorous when the tagging crew arrived on 30 May. Before tagging, the fish were sedated (with Aquacalm), measured for fork length, examined for lamprey marks and parasites, sampled for DNA (caudal fin clip), then anesthetized (with MS222) so that Vemco V8-1L acoustic tags could be surgically implanted within the body cavity. These tags are plastic cylinders about 10 mm in diameter and 250 mm long. A fork length of 170 mm was considered the threshold size for zero tagging mortality based on experience with hatchery-reared sockeye in 2004. After surgery, the fish were returned to the holding pen in the lake for recovery.

Figure 1. Seining resident sockeye salmon in Sakinaw Lake (photo: Jim Cameron).

The resident fish captured on 26-27 May had a median fork length of 182 mm (range 147-221) and most 67 (73%) exceeded 170 mm. As it turned out, however, most individuals exhibited an atypical proliferation of membranous tissue in the body cavity, apparently produced in reaction to a trematode parasite infection, and consequently, only 52 fish had enough room in the body cavity to accept the acoustic tags. Most fish carried copepod parasites on their gills and infestation was considered “heavy” in 72% of individuals larger than 170 mm. A few fish also had lamprey scars.

More seining was attempted on 30 and 31 May in an unplanned effort to bolster the sample size, resulting in 27 additional specimens (length ranging from 155-209 mm). Of these, only 10 captured on 31 May could be tagged. In sum, many fewer fish were tagged than planned, and in general, the smallest specimens - those most likely to be age 1+ “hold-over” smolts - could not be tagged.

In late afternoon of 31 May, the fish were sedated again, transported in garbage pails by truck to the same holding pen now anchored in a protected cove about 1 km from the outlet of Sakinaw Lake. Surface water temperature was 17°C; there was no source of fresh water nearby, so salinity would have been equivalent to Georgia Strait. Of the 62 fish being held, 25 died within 24 h, but the remaining 47 appeared healthy after 48 h and were released on the evening of 2 June.

Later inspection revealed that 90% of the fish captured, tagged, and transferred to seawater the same day (31 May) had died compared with only 16% of those captured on 26-27 May, tagged on 30 May, and transferred to seawater on 31 May, as originally planned. It remains unclear whether the additional mortality for fish collected on 31 May was due to excessive cumulative stress within a single day, including repeated sedation, or to insufficient time for surgical wounds to heal before the fish were transferred to seawater.

For each fish released, the tissue sample obtained during surgery was later assayed by a RFLP technique to determine its mitochondrial DNA (mtDNA) haplotype at cytochrome b and ND1 genes; these data were then compared with known samples collected from spawning anadromous and non-anadromous individuals (C.C. Wood, unpublished data).

The acoustic tags had been programmed to remain active for the first 60 days (sufficient to track juvenile migration - objective 2), then to switch off for 665 d (to preserve battery life) until the expected time for return migration (in summer/fall of 2007). A sample of 6 "surplus" tags were retained under refrigeration as a control to confirm that the programmed tags perform as intended. Each tag is individually-identifiable so that when a tag crosses a POST listening line, the position, time and date are recorded uniquely for each fish (Fig. 2). Preliminary detection data were provided by the POST Secretariat in fall 2005.

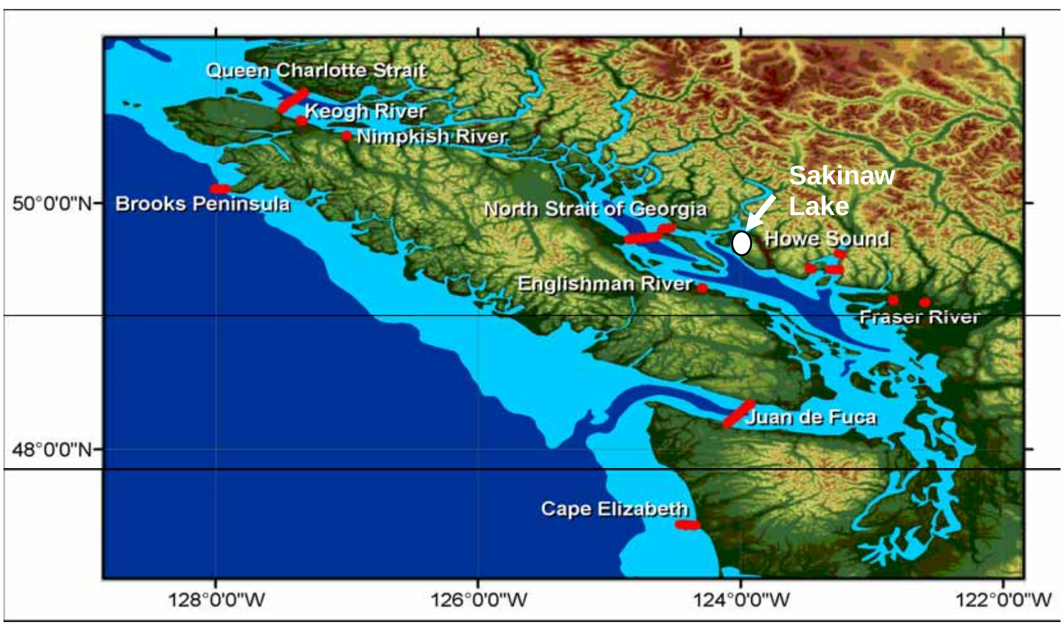

Figure 2. Location of Sakinaw Lake and POST listening arrays (shown in red).

RESULTS AND DISCUSSION

Composition of tagged fish at release

The median length of released fish was 191 mm (range 171-213). Three mtDNA haplotypes (female lineages, designated #1, #3, and #5) occurred in the tagged fish in the following proportions: 29%, 42% and 29%. The same haplotypes also occurred, but in very different proportions, in spawning samples of known anadromous (16%, <1%, and 83%) and non-anadromous fish (37%, 27% and 36%) (Fig. 3). The highly significant difference in haplotype proportions indicates that anadromous and non-anadromous sockeye are reproductively isolated within Sakinaw Lake, and that the non-anadromous sockeye should be considered as a separate "kokanee" population. MtDNA haplotype composition of tagged fish was not significantly different from that of the kokanee sample ($p=0.244$), but it was highly significantly different from that of the sockeye sample ($p<0.000$). Haplotype #3, virtually absent in sockeye (<1%) but common in kokanee (27%), was the predominate haplotype in the released group (42%). Thus, it is statistically most probable that the released group comprised only kokanee. This conclusion is consistent with the fact that, in the end, only the largest resident fish could be tagged, and that most of these were probably entering their fourth year (age 3+); age 3+ individuals could not be "holdover sockeye" that failed to smolt in 2003 due to anomalous weather. There was no significant difference in mean length among haplotypes ($p=0.83$) within the release group, and thus no indication that the smaller fish were sockeye.

Figure 3. Relative frequency of mtDNA haplotypes in fish released with tags (n=47) and known samples of non-anadromous kokanee (n=70) and anadromous sockeye (n=116).

Composition of tagged fish that were later detected by the POST array

Of the 47 fish released, 25 were later detected by the POST array. Detected fish were not significantly larger or smaller, on average, than undetected fish ($p=0.27$). Haplotype composition was not significantly different among detected and undetected groups ($p=0.73$). Thus, neither size nor female lineage affected survival or migratory behaviour in a way that biased probability of detection.

Migratory behaviour determined by detections within 60 d of release

Tagged fish were detected crossing POST listening arrays in 29 separate events, excluding detections where the same fish crossed the same line multiple times. These events included 13 at the Northern Strait of Georgia line (NSOG), 10 in Juan de Fuca (JF), 3 in Queen Charlotte Strait (QCS), 2 in Howe Sound (HS) and 1 in the Fraser River (FR). One of the 10 fish leaving Georgia Strait via Juan de Fuca had previously been detected at NSOG moving north (Fig. 4). Note that the 3 tags that were last detected by the HS and FR lines may have been carried there by predators such as chinook salmon or harbour seals.

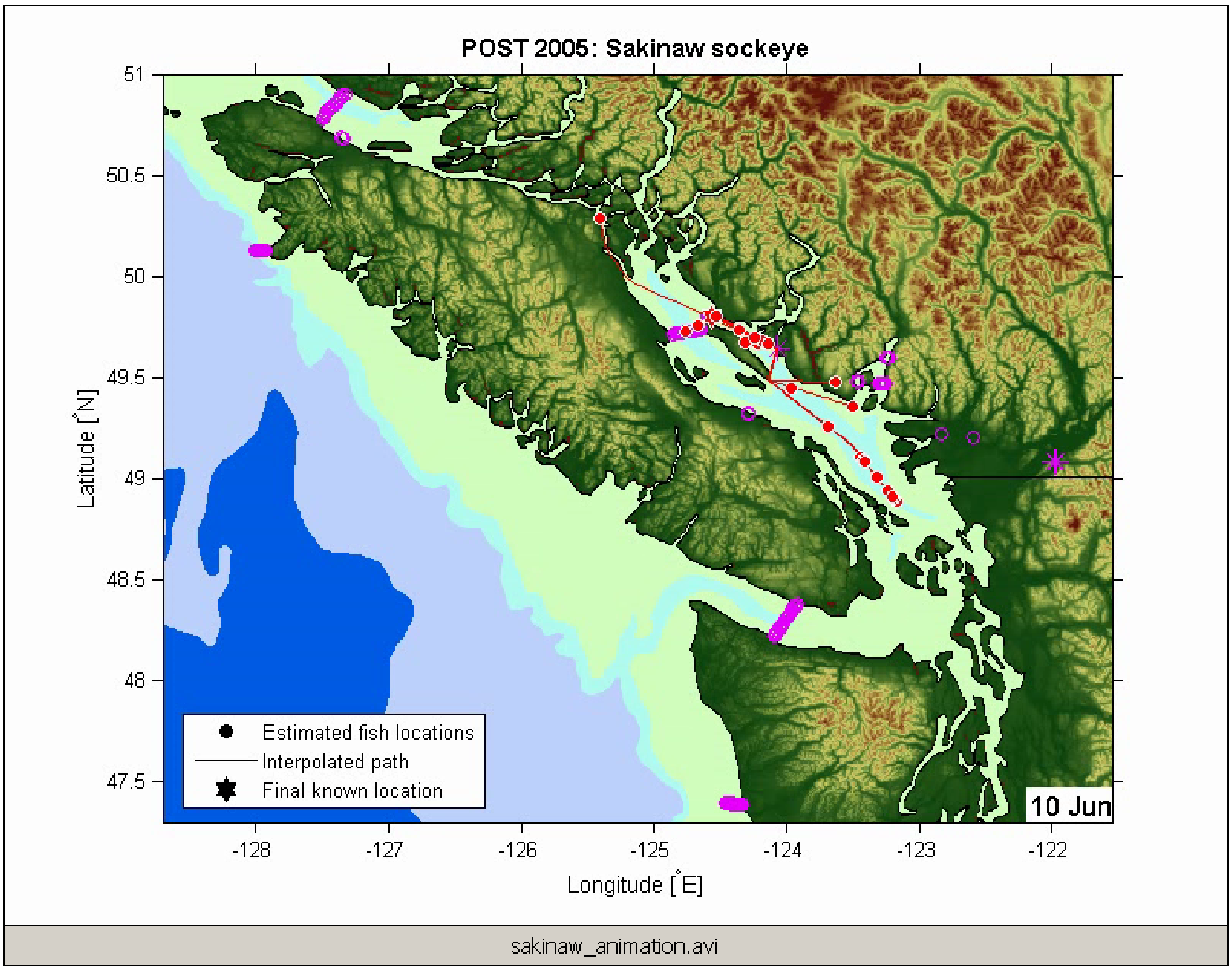

Figure 4. Animation of inferred migration of resident sockeye released from the outlet of Sakinaw Lake in 2005. Click on picture to start animation.

Fish moving north initially (n=13) did not differ significantly in size (p=0.22) from those moving south initially (n=12). Within the sample, fish from the haplotype#3 (almost exclusively kokanee) lineage were more likely to have moved north than south, but this difference was not statistically significant (p=0.10). Similarly, the 3 fish exiting Georgia Strait to the north (across the QCS line) did not differ significantly in size (p=0.42) or haplotype composition (p=0.10) from the 10 fish exiting Georgia Strait to the south (across the JF line).

Median time from release to first detection was 6 days (range 3-51) at the NSOG line, 20 days (range 17-52) at the JF line, and 33 days (range 17-32) at the QCS line. Median travel time for individual fish was 10 days (range 10-38, n=3) between the NSOG and QCS lines, and 47 days (n=1) between the NSOG and JF lines.

A total of 13 fish were detected leaving Georgia Strait within the 60 d window of tag activity. This implies a survival rate of at least 28%, excluding fish that might have remained within Georgia Strait without crossing listening lines within 60 d of release. It is noteworthy that none of the fish detected by the JF line were detected later crossing the Brooks Peninsula line on the northwestern coast of Vancouver Island.

Comparison of results in 2004 and 2005

A higher proportion of fish survived to be detected in 2005 (28%) than in 2004 (18%), despite the problems with mortality immediately after capture and surgery, and a shorter initial period of tag activity (60 versus 120 d). In fact, this detection rate was the highest observed among all sockeye tagged in the POST project in both years (Fig. 5).

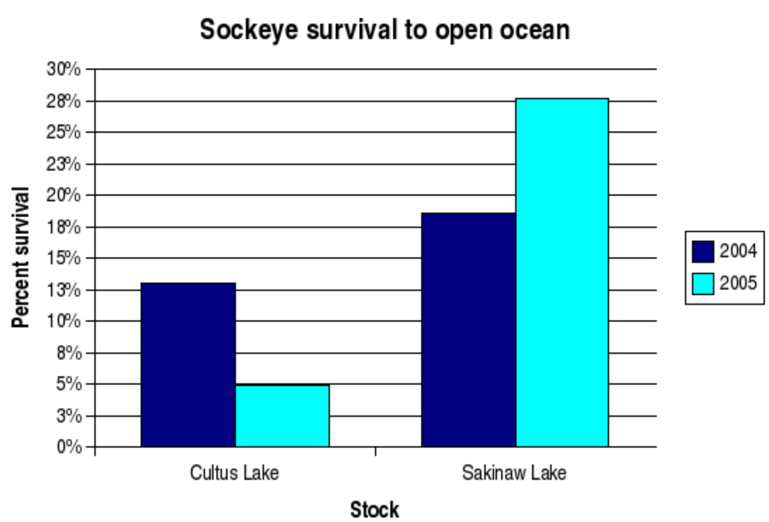

Figure 5. Minimum estimates of survival from release to the open ocean for Cultus and Sakinaw Lake sockeye. Estimates are the sum of detections at the QCS and JF lines, as a percentage of the total numbers of tagged fish that were released.

The most surprising result in 2005 was that a much larger proportion of tagged fish exited Georgia Strait to the south across the JF line (10 of 13) than to the north across the QCS line (3 of 13). Although most fish detected in 2005 also moved northwards across the NSOG line, few continued past the QCS line. In contrast, almost all (17 of 18) Sakinaw sockeye that left Georgia Strait in 2004 did so to the north. Similarly, in both 2004 and 2005, Cultus sockeye were detected leaving Georgia Strait via Queen Charlotte Strait but not the Strait of Juan de Fuca.

Median travel times from release to the NSOG line were almost identical (about 6 d) in 2004 and 2005. In both years, all but one fish moved northward through Malaspina Strait following the coastline and remaining east of Texada Island. Median travel time to the QCS line was less in 2004 (<20 d) than in 2005 (33 d) but the difference was not statistically significant.

Given that tagged Cultus sockeye migrated similarly in 2004 and 2005, the different marine migratory behaviour of Sakinaw fish in 2005 can probably be attributed to the fact that these fish were almost certainly kokanee, and mostly older fish (age 2 + and 3+) than tagged in 2004. It remains unclear whether the difference was caused by provenance or age, or both.

Anticipated results

Tags released in 2005 will become active again in the summer of 2007 and remain active until the batteries fail, likely in late fall of 2007. A sample of tags kept under refrigeration as a control will serve to indicate the time of battery failure. Any fish migrating past arrays during the active period in 2007 will be detected, providing additional information on return migration routes and timing (objective 1). However, because fish tagged in 2005 were likely age 2+ and age 3+ (older than those tagged in 2004), they will probably mature and return to spawn in 2005 or 2006. Even so, it should be possible, by deploying a portable acoustic receiver in 2007, to detect whether any of these fish survived to return to Sakinaw Lake. Both sockeye and kokanee spawn at depth within Sakinaw Lake, and after death, tags will likely remain detectable submerged within the spawning habitat.

Although the objective of the project was to determine migratory behaviour of Sakinaw sockeye salmon rather than kokanee, these results have provided an unexpected opportunity to address other issues relevant to the recovery of Sakinaw sockeye. We now know that non-anadromous sockeye (kokanee) spawners in Sakinaw Lake are part of a separate population and should not be used indiscriminately with anadromous sockeye for captive breeding purposes. Even so, the ability of kokanee to migrate seaward (now confirmed) and to return to spawn in Sakinaw Lake (awaiting confirmation), suggests that kokanee could still be an important genetic resource for reducing inbreeding during captive breeding of sockeye or for restoring an anadromous sockeye run to Sakinaw Lake should the existing population be lost.

ACKNOWLEDGEMENTS

Special thanks to Jim Cameron and Jim Irvine for assisting with the arduous collection of resident sockeye from Sakinaw Lake, and to Melinda Jacobs and Adrian Ladouceur who performed the surgery. We also thank Grant McBain for providing the holding pen, the Sechelt Indian Band for assistance transporting and releasing fish, and John Nelson for molecular genetic analyses.