Title

Movements of Radio-tagged sockeye salmon in Auke Lake

Introduction

(Spawning area placticity, energy directed to important commercial stocks, importance cumulatively of SE small stocks)

The objective of this paper is to describe sockeye salmon movements from time of release at the weir until death on the spawning grounds.

Study Area

Auke Lake -- a small (46.1 ha^2), round lake 19.2 km north of Juneau, Alaska (Figure 1)-- has two inlet streams and one outlet Auke Creek, which drains to saltwater. Visibility of the lake water is about 1 m, due to tannic runoff, however, the two tributaries and outlet are clear. A permanent tidewater weir permits a census of all fish entering or leaving the drainage (Taylor 1991). This sockeye salmon population has been monitored about 30 years and has both lake and stream spawners (S. G. Taylor, Auke Bay Fishery Laboratory, personal communication;

Bucaria 1968).

The majority of lake shoreline contains several varieties of macrophytes and sunken logs. Gravel (suitable for salmonid spawning) is plentiful and visible at both of the inlet creek deltas.

Methods

Radio transmitters identical to those used in Eiler (1990), were inserted through the mouth and placed into the stomach of sockeye salmon caught at the Auke Creek weir. The fish were tagged while in a neoprene cradle submerged in a tub of water without the use of anesthesia. Tagging occurred throughout 4-5 weeks beginning early July, 1991 and 1992. Each transmitter emitted a unique frequency in the 30-31 MHz range, and a steady base pulse rate of 60 or 90 beats per minute. The transmitters were equipped with a motion-sensitive mercury switch (motion sensor) that inserted additional pulses into the base pulse rate each time the tag moved (Eiler 1990). During each tracking session, fish's activity was classified as (1) stationary, if the transmitter pulsed at the base rate; (2) moving, if the transmitter signal included erratic pulses in addition to the base-rate pulses; and (3) dead if the transmitter pulse rate had doubled (contingent on repeated observations).

Movements of the tagged fish were monitored either every other day (1991) or daily (1992) from tagging until death. Usually two observers tracked the fish while in a small boat in the lake using a scanning receiver and a hand-held loop antenna to locate transmission signals. The outlet creek was surveyed by foot until all the tagged fish reached the lake. The lower 0.5 km of Lake Creek, the primary inlet and spawning area, was surveyed by foot daily during August both years.

I divided the lake drainage into 12 geographic zones and assigned transmitter signals to these zones according to the observer's perception of the maximum audio signal strength from the tags. In 1991, signal strength was recorded in every zone, and final assignment was made only after the signal had been heard in several adjacent zones. In 1992, reference tags were placed in all the zones to aid in evaluating signal strength and location. Tag signals were excluded from data analyses if the signal was recorded (1) intermittently (2) fewer than five times during the season or (3) as a continuous mortality signal immediately after entry into the lake.

The mixing of tagged and untagged fish in the drainage was evaluated daily in the creeks (visual association) and periodically in the lake by simultaneously locating a tagged fish with the receiver, and an untagged fish by sonar. Each monitoring effort in the lake consisted of precisely locating a radio-tagged fish by homing in to the audio signal without using the receiver antenna and then surveying the water column

A sockeye salmon showed "holding" behavior if the fish remained in one identifiable region of the lake for several consecutive days before moving to the area of mortality. A schooling cove was defined as a locale in Auke Lake where large (>10) aggregations of fish were consistently found. additionally with sonar.

Mortality date was assigned to the third day of five consecutive days that the transmitter registered a double base rate, or the date the fish was visually identified as dead. An attempt was made to visually locate and verify all radio-tagged carcasses in the creeks.

SCUBA observations of radio-tagged sockeye salmon, substrate composition, slope, were made in areas of Auke Lake. Two divers swam the nearshore areas where congregations of radio-tagged fish were located.

Results

Tagging

A total of 286 sockeye salmon were tagged, 168 in 1991 and 118 in 1992 (Table 1). In both years, fish were tagged during the 4-5 weeks beginning in early July, when 72 and 92%, respectively, of the total run returned. Tagged fish were 3 and 2% of the escapement during these years.

Radio-tagged fish resumed swimming almost immediately after tagging unless injured during handling. Known handling mortality was the only tagging stress observed and occurred within a day of tagging. This stress was immediately apparent because fish fell back to the weir and were necropsied. These deaths were caused by tags perforating the stomachs and accounted for 2 and 4% of the fish not tracked during 1991 and 1992, respectively (Table 1). Tagged and untagged fish showed no difference in milling or migration behavior in Auke Creek.

In 1991 and 1992, 146 and 108 sockeye salmon, respectively, were tracked into Auke Lake and its tributaries. Deaths from handling, predation, and unknown causes as well as transmitter regurgitation or failure accounted for 13 and 8% of the tagged fish in 1991 and 1992, respectively (Table 1). The only prespawning predation I observed was in 1991, when approximately 30 tagged and untagged fish migrating upstream to Auke Lake were attacked by eagles after being trapped in a pool during low water flow. The transmitters from the predations were all found on shore and were, therefore, distinguishable from regurgitated transmitters found in the creek near the weir.

Migration and Final Location

During both years the migratory behavior of the radio tagged sockeye salmon was similar. The fish entered Auke Lake from Auke Creek within 2-6 h of tagging, together with untagged fish. Nearly half (47%) of all radio-tagged sockeye salmon schooled together in a schooling cove (Figure 1) near the lake outlet for 5 - 30 consecutive days. Aggregations of tagged and untagged fish were monitored by sonar observation 8 times in 1991 and 12 times in 1992. Tagged and untagged fish schooled in groups of 5-20 in the schooling cove at 6-30 m depths; and these groups usually included only one tagged fish. Most tagged fish moved to the mouth of Lake Creek at the same time that untagged fish were aggregating by the hundreds directly off the delta; these aggregations remained at the mouth several days before migrating into the stream. Both tagged and untagged fish were substantially absent from the mouth of Lake Creek after the mid-August.

Three small schools (less than 15) of radio-tagged sockeye salmon were consistently located in three distinct areas ("holding area") of Auke Lake other than the schooling cove each season (Figure 1). These radio-tagged fish were never found in the schooling cove, arrived in their holding areas within a day of entry into the lake, were located in these holding areas during every survey, and did not ascend either tributary. This was consistent both seasons.

The terminal locations of tagged sockeye salmon were remarkably consistent both years (Figure 2). Lake Creek was the final location for 68% of the tagged sockeye salmon both years. In 1991, 28% of the tagged sockeye salmon remained in Auke Lake, whereas 31% remained in 1992. I did not find a significant difference in arrival time at the weir between fish that stayed in the lake versus those which went to the tributary creeks (chi-square $p > 0.05$) for either year.

Spawning Behavior

Spawning behavior (pairing, and redd construction or defense) was observed during daily surveys of the lower 1 km of Lake Creek from late July through early September each year. A total of 70 tagged fish were observed visually in Lake Creek at least once, always commingled with untagged fish, and were found paired on redds or milling among groups of 5-10 untagged fish along the bank. The carcasses of 20 tagged fish (8 females and 12 males) in Lake Creek were examined during the two seasons and all but one had spawned.

Sockeye salmon entered the Lake Creek tributary in different patterns each season. In 1991, fish entered the stream every day during the first two weeks of August. In 1992, two distinct groups separated, by 5 days in which no fish entered Lake Creek, pulsed onto the spawning grounds. The first group entered the stream from August 1st to 8th and the second from August 13th to 19th. All of the first group were spawned out and most dead when the second group arrived. Most fish during both seasons enter the stream at night except during flood conditions.

SCUBA OBSERVIONS

A total of 14 dives were made in Auke Lake during the two seasons of 1991 and 1992. These dives attempted to assess substrate types in several areas where sockeye salmon were found. The bottom of Auke Lake is mostly soft mud, however areas of gravel/pebble/cobble (about 4 x 4 square meter) as well as bedrock ledges and boulder areas were found. Suitable types of spawning substrate were identified in 3 locations in the lake.

Three dead radio-tagged sockeye salmon females were retreived during SCUBA surveys. Two of these fish had not spawned and one had spawned. These fish were found in holding areas 1 and 2 (Figure 1).

Mortality Date

Mortality dates were estimated for 85 and 83% of the radio-tagged sockeye salmon in 1991 and 1992. Sockeye salmon in the Auke Lake system usually died during the third and fourth weeks of August (Figure 3). The exact date was visually observed for 64%(1991) and 38%(1992) of the total tagged fish during on surveys of Lake Creek spawners. The tagged and untagged fish in Lake Creek died during the same period.

DISCUSSION

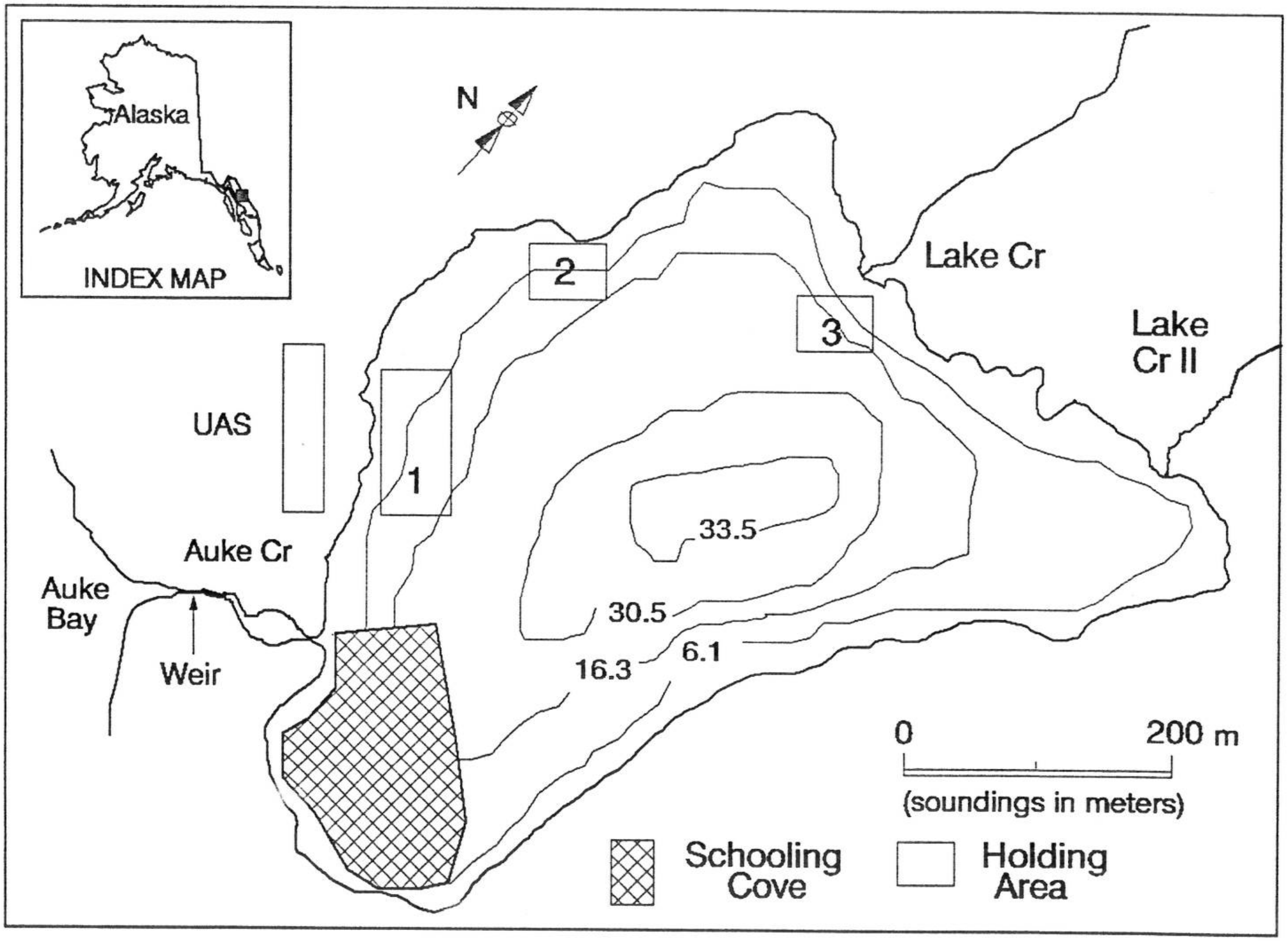
Behavioral differences between radio-tagged and untagged sockeye salmon were not evident. The distribution and migration of the tagged and untagged fish were indistinguishable: tagged sockeye salmon were always associated with untagged salmon in proportions consistent with the escapement; most tagged sockeye salmon died in Lake Creek, which is broadly consistent with previous observations for this population (Bucaria 1968); terminal location of the tagged sockeye salmon was nearly identical in 1991 and 1992; tagged sockeye salmon spawned successfully, always with untagged mates; and finally, most tagged fish did not die prematurely. These results are clearly not fortuitous, because more than 100 tagged sockeye salmon were successfully monitored and tracked each year of the study. Therefore, if the radio tags did affect sockeye salmon behavior, the consequent effects were not apparent in this study.

The proportion of sockeye salmon that spawn in Lake Creek is probably estimated more accurately and precisely in this study than in the only previous study available for comparison (Bucaria 1968). Bucaria estimated that 90% of Auke Lake system sockeye salmon spawn in Lake Creek, based on visual observations of Lake Creek and snorkeling along the adjacent shore of Auke Lake during a single year.

SCUBA divers found suitable spawning gravel in all of the locations where sockeye salmon were found holding or died in the lake. Divers recovered one spawned out radio tagged salmon in the lake that was never recorded in either tributary stream. However, it is not clear that all of the fish that did not ascend the tributaries spawned because divers also recovered two dead radio tagged, unspawned females in Auke Lake. It is unlikely that the 2 fish recovered that did not spawn were adversely affected by the radio tags because an additional 7 unspawned dead females were recovered floating in the lake that had not been radio tagged.

The only difference in movement patterns of radio-tagged sockeye in Auke Lake observed over the two seasons was their entry into the Lake Creek spawning areas. Two factors may have contributed to this difference: the water levels in the creek and the arrival time of pink salmon into Lake Creek. In 1991, the majority of sockeye salmon (both tagged and untagged) spawning in Lake Creek were spawned out and dead by the time the pink salmon arrived in mid-August. The water levels remained high enough for the sockeye to enter the creek throughout the spawning time, the first two weeks of August. In 1992, however, the pink salmon began to arrive and congregate at the mouth of Lake Creek in early August along with the sockeye salmon. Both species entered the creeks together and constructed redds in the same locations. The second pulse of sockeye salmon in 1992 entered the stream a week later than the first, and spawned on top of existing sockeye and pink salmon redds. The water levels in the spawning creek dropped very low between the two pulses of spawning sockeye salmon which could have prevented the second group from entering the stream, although many of those second pulse fish arrived at the creek mouth with the fish that went into the stream during the first pulse.

The significance of these findings is that estimates of escapement calculated from a one time stream count only, could inadvertently not evaluate the spawning population size accurately. Several small sockeye salmon populations in Southeast Alaska have been assessed by a one time visit to the system. It is apparent that a significant portion of a small population may remain in the nursery lake to spawn and that the spawners may enter the grounds continuously or in discrete groups.


Alaska
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1
2
3
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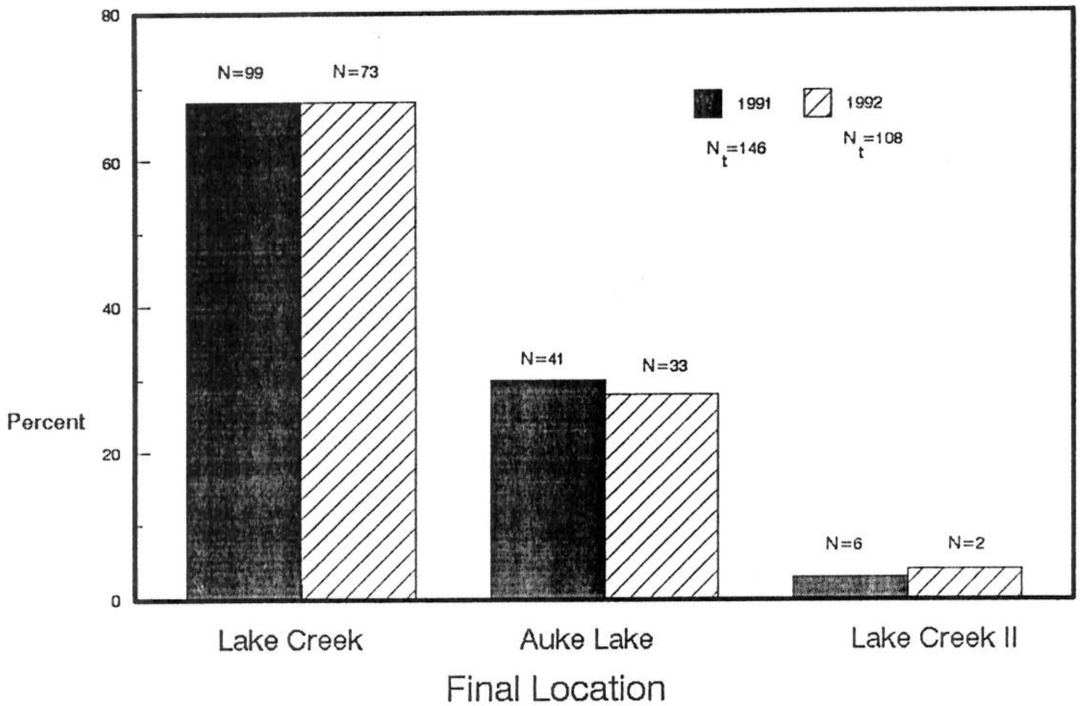
(soundings in meters)
Schooling Cove
Holding Area

2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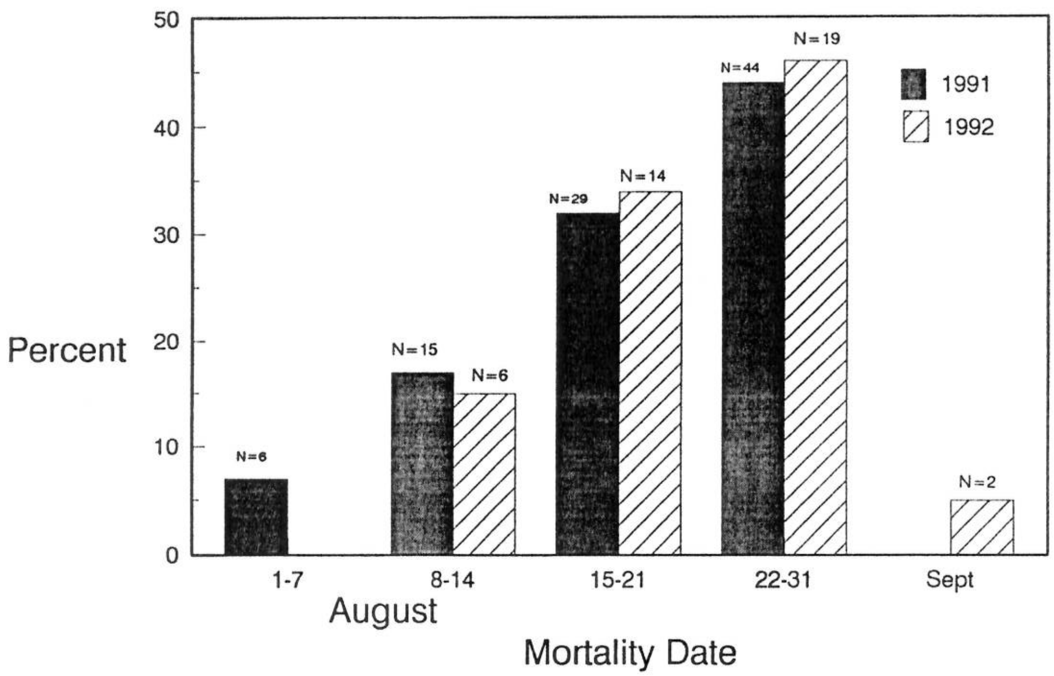
Auke Lake
Lake Creek II
Final Location



50
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1991
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1-7
8-14
15-21
22-31
Sept
August
Mortality Date

Figure 3 Percent of radio-tagged sockeye salmon in Auke Lake and thenumber of days the fish were consecutively found in a designated holding area near the outle of Auke Lake in 1991-92.

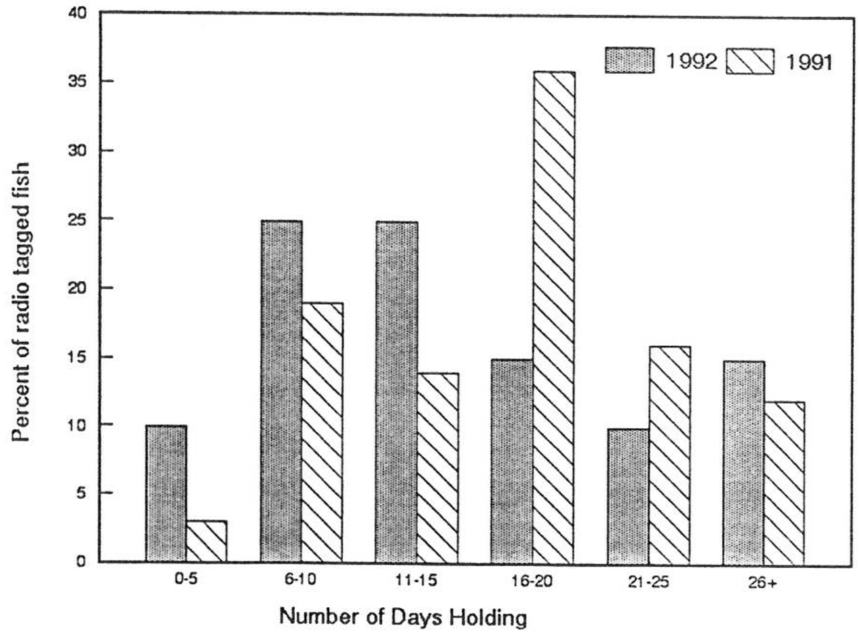

Table 1.--Fate of radio-tagged sockeye salmon in Auke Lake, Alaska, 1991 and 1992.

Fate	Year 1991	1992	Total
Total tagged	168	118	286
Total tracked	146	108	254 (89%)
Handling mortality	4	5	9 (03%)
Predation	11	0	11 (04%)
Regurgitation	2	1	3 (01%)
Other[a]	5	4	9 (03%)

[a]Transmitter failure or unknown cause of mortality within a week of tagging in Auke Lake.