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The use of acoustic tags to monitor the movement and survival of juvenile chinook salmon in the Strait of Georgia

by

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Abstract

A total of 278 acoustic tags were placed in juvenile chinook salmon that were captured and released in the Strait of Georgia in 2007 and 2008. These tags could be detected at receiver arrays within the Strait of Georgia and at a receiver array at a northern exit point in Queen Charlotte Strait and a southern exit point in Juan de Fuca Strait. There were 83 (30%) of these fish detected at least once after they were released. Of the 100 fish tagged in September 23-24, 2007 only six fish were detected leaving the Strait of Georgia and all detections were at the southern exit point in Juan de Fuca Strait. Of the 30 fish tagged in the central Strait of Georgia in June 19-20, 2008, only one fish was detected leaving the Strait of Georgia through Queen Charlotte Strait. None were detected leaving the Strait of Georgia of the 78 fish tagged in the central Strait of Georgia in July 16-19, 2008. Only one was detected leaving the Strait of Georgia through Juan de Fuca Strait of the 40 fish tagged in the Gulf Islands area in July 14-15, 2008. None of the 30 tagged fish that were reared in the net pen and released in the Gulf Islands area were detected at any receiver. A tagging mortality and tag loss study indicated that the tagging procedures were an unlikely source of low detection rates of fish leaving the Strait of Georgia. It was also unlikely that the tagged fish remained in the Strait of Georgia over the winter and into the spring of the following year as trawl studies capture very few juvenile chinook salmon in the Strait of Georgia in the winter. Therefore, we concluded that there were large mortalities of the tagged fish which we interpret to indicate that the early marine mortality of chinook salmon within the Strait of Georgia is the major regulator of their brood-year strength.

Introduction

The marine survival of chinook salmon that enter the Strait of Georgia declined over the past two decades to below 1.5% (Beamish et al. 1995, Ruggerone and Goetz, 2004, PSC 2009). Although it is believed that a large percentage of this mortality occurs early in the marine residence, the magnitude and timing of this early marine mortality remains to be identified. Acoustic telemetry has been used to study juvenile Pacific salmon movements and can be used to study early marine survival (Chittenden et al., 2010, Steig 1999, Melnychuck et al. 2007, Welch et al. 2004). Chittenden et al. (2009) successfully tagged juvenile coho salmon in the Strait of Georgia in 2006 to determine when the juvenile salmon left the strait. Results of their studies supported their hypothesis that the juvenile coho salmon from the Strait of Georgia were rearing in the strait until after September and that this was the location and time when most marine mortality occurred and brood-year strength was determined. The study also demonstrated that the mortality of tagged fish between July and September was similar to the mortality estimated from trawl surveys for this same period. In addition to measuring the amount of mortality occurring between mid-July and mid-September, the coho salmon study showed that there was minimal effect from the tagging procedure on the behaviour and mortality of juvenile coho salmon.

A study of juvenile Pacific salmon in the Strait of Georgia over the past 13 years showed that there were moderate abundances of chinook salmon in July that originated from a relatively large number of stocks. In September, the abundances were either similar or only slightly smaller. However, the size of the juvenile chinook salmon in September was either similar to the sizes in July or moderately larger. The puzzle was that large abundances of smaller juvenile chinook salmon appeared later in the year and the juveniles that were present in July all but disappeared. Recent DNA analysis indicated that most of the juvenile chinook salmon in the September catches were from one area of the Fraser River drainage (Beamish et al. 2010a). This suggested that the chinook observed in July either left the Strait of Georgia, died or did both. In this study we use acoustic telemetry to estimate the early marine survival of the juvenile chinook salmon in our July and September surveys and to determine if the changes in juvenile chinook salmon stock composition are a mostly a result of movements out of the Strait of Georgia or mortalities.

Methods

Juvenile chinook salmon were tagged from three areas: central Strait of Georgia (September 23-24, 2007, June 19-20, 2008 and July 16-19, 2008), the Gulf Islands (July 14-15, 2008) and Cowichan Bay (July 22, 2008, Figure 1). The timing of the tagging was selected to sample both ocean and stream type chinook salmon.

The chinook salmon from the Strait of Georgia and the Gulf Islands were collected using a small mesh purse seine (129m X 19m purse seine with 6mm mesh in bunt) fished from a 12 m vessel. Fish were transferred from the seine directly into live tanks on board the vessel using a small mesh dip net. Twenty-litre totes filled with sea water were used for sorting. Juvenile chinook salmon were transferred into 20L holding totes with aerated sea water. Temperature and dissolved oxygen were monitored in these tanks.

The chinook salmon from Cowichan Bay (Figure 1) were hatchery reared salmon from the Cowichan River hatchery. They had been transferred directly from the hatchery to a net pen in Cowichan Bay. The chinook salmon were released from the net pen on July 2, 2008. Approximately 100 chinook salmon were retained in the net pen for our study. These fish were fed in the net pen for approximately 3 weeks to ensure adequate size for tagging.

DNA collected from the tagged fish was analyzed in the molecular genetics laboratory at the Pacific Biological station to determine the stock origin. The DNA baseline for chinook salmon from British Columbia and Washington State includes over 400 stocks and the use of this technique is a valuable method of assessing the origin of ocean caught fish (Beacham et al., 2003, Trudel et al. 2004). Results were summarized into major production regions contributing chinook salmon to the Strait of Georgia. These were the East Coast Vancouver Island and the Fraser River, including the South Thompson.

We used the procedures of Chittenden et al. (2009) for all tagging. A chinook salmon was sedated in an anaesthetic bath of 60 ppm MS222 (Syndel Laboratories). The anaesthetic bath was aerated and temperature and dissolved oxygen was monitored. Vidalife (Syndel Laboratories) was added to bath to reduce scale loss. When temperature varied more than 3^{o}C from the holding tank, the anaesthetic water was replaced. In general this occurred between sets or following 8-10 surgical procedures, whichever occurred more frequently. Fish remained in the anaesthetic bath for 1-3 minutes or until fully sedated (no opercular movement, no swimming, fish on side). Fish was measured, weighed and species identification was confirmed. Only fish larger than 120mm were tagged (Chittenden et al. 2009).

The surgical areas used in the study were clean of non essential equipment and was used for surgical procedure only. Surgical instruments, suture material and new tags were cleansed prior to and between surgeries using Ovodine (Dynamic Aqua Supply, Canada) followed by two rinses in sterile distilled water. For surgery, the fish was placed ventral side up on a surgical platform that supported the fish. The platform was covered in a sea water moistened towel that was regularily sprayed with Vidalife to help reduce scale loss. The fish was irrigated with flowing sea water and 30 ppm MS222 by a tube that was placed in the mouth of the fish. The head of the fish was also covered with a dampened towlette to reduce visual stimulation during surgery. A small incision (11-12mm) was made along the ventral midline of the fish anterior to the pelvic fins. A Vemco V7-2L tag (7 x 20mm, 1.6 g in air, 0.7 g in water) was inserted through the incision. The tag was positioned in the body cavity to ensure that the posterior end of the tag was posterior to the incision. This ensured that neither end of the tag was putting pressure on the surgical incision following surgery. The incision was closed with two simple interrupted sutures (Ethicon Moncoryl Y513 reverse cutting 4-0, 1.5metric, 45 cm, PS-2 19mm, 3/8 circle needle). The two sutures were approximately the same distance apart as they were from either end of the incision. The incision was examined to ensure no gaping. If required, a third suture was added. Following surgery the fish was removed from the table and, when present, the adipose was clipped and stored in 95% ethanol for DNA analysis. The tagged fish was placed in a 20-40L recovery tank.

Tagged chinook salmon were held in recovery tanks for a minimum of 1 hour prior to release. Fish that did not return to normal swimming performance, had excessive bleeding or had other issues of concern were euthanized in MS222. The tag was sterilized and used in an alternate fish (~5%). The fish were released in groups of five or more in the same general location they were collected.

The POST receiver arrays (Welch et al. 2004) located in the central Strait of Georgia, Juan de Fuca Strait and Queen Charlotte Strait were used to monitor movements of the tagged fish within the Strait of Georgia and out of the Strait of Georgia (Figure 1). Data from these receivers were retrieved twice yearly during our study (fall and spring). The guaranteed battery life of the tags used in the study was 120 days or approximately 4 months from the day they were activated. Tags were activated on the day of surgery.

Acoustically tagged juvenile chinook salmon were held in net pens in the Strait of Georgia in 2008 and 2010 to determine tag loss and tagging mortality for juvenile chinook salmon. The study was conducted in the Cowichan Bay net pen in 2008 and in net pens located in Nanaimo Harbour at the Pacific Biological Station and in Hidden Harbour in Campell River in 2010 (Figure 1). In each study 30 fish were tagged with dummy acoustic tags that matched the size and weight of the VEMCO V7-2L tags used in our telemetry studies. An additional 30 fish were used as a control and were treated with the anaesthetic but had no surgical procedure. In 2010 the two study groups also had 30 fish that underwent surgery but had no tag implanted. In all studies, fish were held post surgery in the net pens for two weeks and fed daily.

Results

There were 278 juvenile chinook salmon tagged in the five tagging events. There were 79 of these fish (28%) detected at the receiver line in the Strait of Georgia (Figure 1). Three of these fish were detected at the southern exit point and one at the northern exit point of the Strait of Georgia. There were four fish that were not detected within the Strait of Georgia that left through the southern exit point. Thus, there were 83 (30%) of the 278 fish that were detected after they were tagged and released. Thus, there were 8 (3%) of the 278 tagged fish that left the Strait of Georgia and 4 (5%) of the 79 fish that were detected at least once within the Strait of Georgia that left the Strait of Georgia (Table 1).

One hundred juvenile chinook salmon were tagged on September 23-24, 2007 at the tagging site in the central Strait of Georgia. The average size of these fish was 163 mm (Figure 2A). There were 33 of the tagged fish detected within the Strait of Georgia by the end of December (Table 1). Three of these fish also were detected leaving the Strait of Georgia at the southern exit point. Three fish that were not detected in the Strait of Georgia also left through the southern exit point. All of these six tagged chinook salmon were detected leaving the Strait of Georgia between October 11 and November 24, 2007. One of the six fish was also observed at Willipa Bay off Oregon on November 11, 2007 (Figure 1). There were no fish from this tagging event observed leaving the Strait of Georgia at the northern exit point in Queen Charlotte Strait. There also were no detections between the end of December and the end of May 2008.

There were 13 distinct stocks in the sample of 98 fish used for DNA analysis with the majority of these fish originating from rivers in the South Thompson drainage (76%, Figure 3A). There were 36 of the tagged Chinook salmon detected at least once at any of the receivers, and these fish originated from eight distinct stocks. The majority of these fish were also from rivers in the South Thompson drainage (74%). The remaining 23% and 3% were from Vancouver Island and the Fraser River, respectively (Figure 3B). All tagged fish that left the Strait of Georgia were from the South Thompson drainage.

Thirty juvenile chinook salmon were tagged in the central Strait of Georgia on June 18-19, 2008. The average size of these fish was 170 mm (Figure 2B). A total of 18 (60%) of these fish were detected within the Strait of Georgia between the tagging date and August 24 (Table 1). The first detection was on July 12 and some fish were detected multiple times. Only one of these fish was detected leaving the Strait of Georgia at the northern exit point. It was detected multiple times between August 2 and August 21, 2008. No tissues were available for DNA analysis.

There were 78 juvenile chinook salmon tagged in the central Strait of Georgia area on July 16 -19, 2008. This was a mixture of ocean and stream type chinook salmon as indicated by a bimodal length distribution with mean lengths at 132mm and 167mm (Figure 2C, Beamish et al. 2010a). The average length for all fish was 146mm. There were 28 (36%) of the tagged fish detected within the Strait of Georgia between the tagging dates and the end of September (Table 1). None of the 78 fish were detected leaving the Strait of Georgia. DNA stock identification of 74 fish indicated that 80% originated from the east coast of Vancouver Island and 20% from the Fraser River (Figure 4A). There were no South Thompson chinook salmon. The stream type chinook salmon originated primarily from four stocks in the Fraser River. The DNA analysis indicated that the 28 fish that were detected after tagging had a stock distribution similar to the fish that were tagged (Figure 4B).

Forty juvenile chinook salmon were tagged in the Gulf Islands region in July 14-15, 2008. The average size of the tagged fish was 135mm (Figure 2D). Of the 40 fish tagged, 18 (45%) had an adipose fin clip and a CWT. These tagged fish were larger (143mm) than the non-clipped chinook salmon that were tagged (128mm). The 22 fish with their adipose fin intact were sampled for DNA analysis. Ninety-five percent were identified as originating from Vancouver Island and most of these (73%) were from the Cowichan River (Figure 5). A purse seine survey was conducted in the Gulf Islands from June 20-27, 2008 and 96% of the 36 chinook salmon recovered with CWTs were from the Cowichan River hatchery. Therefore, we expected that the majority of the fish that had a CWT and an acoustic tag would be from the Cowichan River hatchery. Only 1 (2.5%) of these 40 chinook salmon was detected at the southern exit point in Juan de Fuca Strait on August 12 (Table 1) and was 137 mm at the tagging date.

Thirty chinook salmon were tagged on July 22, 2008 from the net pen located in Cowichan Bay. These were all chinook salmon from the Cowichan River hatchery and their average size was 136mm (Figure 2E). None of these fish were detected at any receiver.

There was no mortality or tag loss of the 30 fish at the Campbell River site in 2010. At the Nanaimo location in 2010, one fish lost its tag through the incision location and none died. At the Cowichan Bay net pen location in 2008, four (13%) of the 30 fish tagged lost their tag and died over the two week study period. There was no mortality in any of the control studies at any of the three sites.

Discussion

Only 8 of the 278 tagged chinook salmon were detected leaving the Strait of Georgia. This represents an early marine survival of 3%. If only the 79 fish that were detected within the Strait of Georgia at least once after tagging were used to estimate survival, the estimated early marine survival was approximately 5%. Juveniles tagged later in the year in September 2007 had a higher detection rate or survival of 6% at the exit points as would be expected. Also, all but one of the eight fish detected leaving the Strait of Georgia, left through Juan de Fuca Strait. We propose that the 3% of the tagged fish we observed leaving the Strait of Georgia is representative of the early marine survival of all chinook salmon populations that enter the Strait of Georgia in the spring.

Detection efficiencies for the V7-2L tags at the receiver arrays may be about 80%. If we correct for the undetected tags we would only be increasing our estimate to 4% migration of juvenile chinook salmon out of the Strait of Georgia. There is also a possibility that there were some missed detections due to the four-month life expectancy of the tags. However, with the exception of the June 2008 tagging event, this would indicate that most migrations out of the Strait of Georgia would occur after mid-November. Trawl surveys have indicated that there are very low numbers of juvenile chinook salmon in the Strait of Georgia at this time. In addition, DNA analysis from this study and from Beamish et al (2010a) demonstrate that the stocks of chinook salmon in the Strait of Georgia in June and July are only present in small numbers by September (Figures 3, 4) indicating that most juvenile chinook salmon in July have left the Strait of Georgia or died. Therefore, we suggest that a very small percentage of juvenile chinook salmon survived to leave the Strait of Georgia.

All detections of chinook salmon tagged in September 2007 and in June and July of 2008 were made in the first two months post surgeries. Of these fish there were 37% that were detected on multiple days at the same receiver line suggesting that the fish was remaining in the general area during that time period. The longest detection period occurred for a chinook salmon tagged in September 2007. It was first detected on September 28, 2007 and had a final detection date at the same receiver array on December 30, 2008. The timing of the chinook salmon detected leaving the Strait of Georgia ranged from 17 to 62 days post surgery in September 2007 and 18 to 45 days for the June and July 2008 tagging events.

The tagging procedure used in this study was virtually identical to the procedure used for coho salmon by Chittenden et al. (2009) including the two person surgical team. Two control studies in 2010 indicated little to no effect of the tags and surgery on the chinook salmon (0-3% tag loss). The control study in Cowichan Bay in 2008 did indicate that there was some impact with 13% mortality associated with the tagging. The mortality observed in these controls was lower than the mortality observed by Hall et al. (2009) using the same size and type of tag. They observed just over 20% mortality during the first 10 days post surgery in their tagged chinook salmon. They also observed low levels of mortality in both their control group and their surgery only group. However, Hall et al. (2009) tagged fish with a minimum size of 110 mm which was 10 mm smaller than our minimum size. Frost et al. (2010) and Adams et al. (1998) both tagged similarly sized juvenile chinook salmon with acoustic tags in freshwater. Neither study showed mortality as a result of tagging although there was a slight impact on growth. Adams et al. (1998) demonstrated that this impact on growth was not apparent by 54 days post surgery.

We know that the total survival of chinook salmon from the Cowichan River is low with less than 1% of the chinook salmon returning to the river to spawn (Figure 6). The total survival of chinook salmon from some of the other rivers in the region including

Chilliwack, Puntledge, Quinsam, and Big Qualicum rivers varies from 1.5% to less than 1% (PSC 2009). We have demonstrated from other studies conducted in the Gulf islands and Strait of Georgia that a large percentage of the mortality for the Cowichan River stock occurs in the first four months in the ocean. Beamish et al. (2010b) estimated that the survival of Cowichan River chinook salmon during this four month period could be 1.3% for hatchery fish and 8.8% for wild chinook salmon. In this study we tagged a number of chinook salmon from the Cowichan River. Some of these fish were from the hatchery and some were wild. None of the approximately 66 fish from the Cowichan River were ever detected after they were released. These observations corroborate the estimates of very high early marine mortality reported by Beamish et al (2010b).

In another study (Beamish et al. 2010a) we show that juvenile chinook salmon from the South Thompson watershed enter the Strait of Georgia in July, later than all other chinook salmon. These populations are also surviving better than other chinook salmon. Our acoustic tag study showed that juveniles from the South Thompson leave through Juan de Fuca Strait between mid October and the end of November. We tagged 76 of these South Thompson chinook salmon in September 2007 and 8% of these were detected leaving through the southern exit point. Even though this survival is higher than observed for other populations tagged in July, it still indicates that the early marine period is a major source of mortality for chinook salmon in the Strait of Georgia. Thus, the mortality of chinook salmon that is occurring during the first few months in the Strait of Georgia indicates that it is virtually during this period that their brood-year strength is determined.

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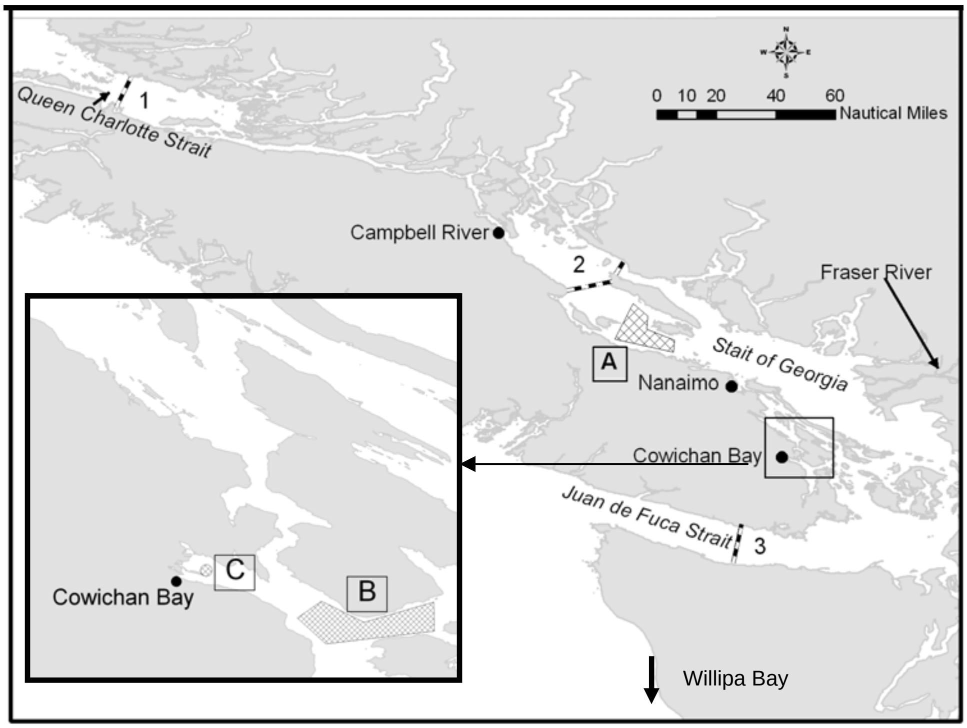

Figure 1. Location of POST receiver arrays (dashed lines) in (1) Queen Charlotte Strait (2) northern Strait of Georgia and (3) Juan de Fuca Strait. The locations where acoustic tagging was conducted are shown at (A) Purse seine, September 23-24, 2007, June 19-20, 2008 and July 16-19, 2008; (B) Purse seine, July 14-15, 2008; and (C) Net pen, July 22, 2008.

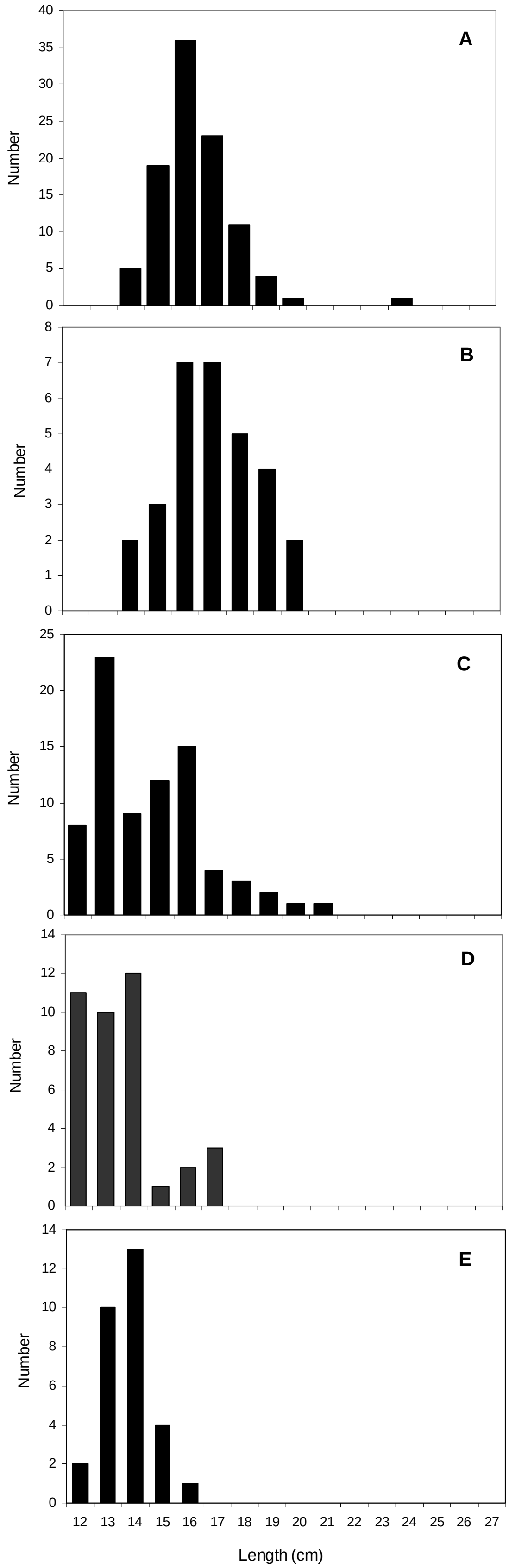

Figure 2. Length frequency of chinook salmon tagged in the Strait of Georgia on (A) September 23-24, 2007, n = 100; (B) June 18-19, 2008, n = 30; (C) July 16-19, 2008, n = 78; (D) in the Gulf Islands on July 14-15, 2008, n = 40; and (E) in Cowichan Bay on July 22, 2008, n = 30.

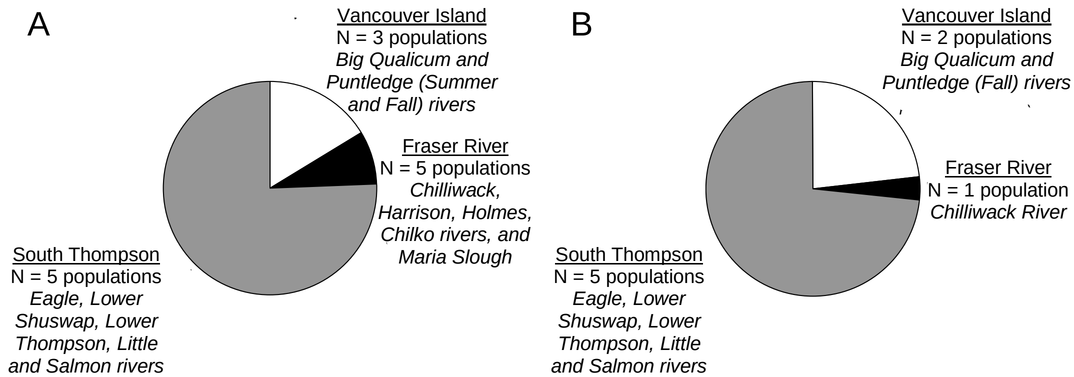

Figure 3. Stock composition of (A) 98 of the tagged juvenile chinook salmon September 23-24, 2007 examined for DNA, and (B) 33 tagged chinook salmon observed at the receiver array in the Strait of Georgia.

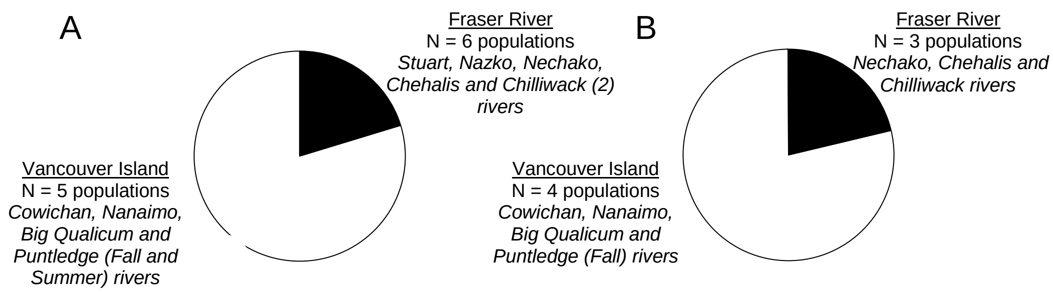

Figure 4. Stock composition of the (A) chinook salmon tagged in the Strait of Georgia July 16-19, 2008 (n = 74), and (B) tagged chinook salmon detected at the receiver array in the Strait of Georgia.

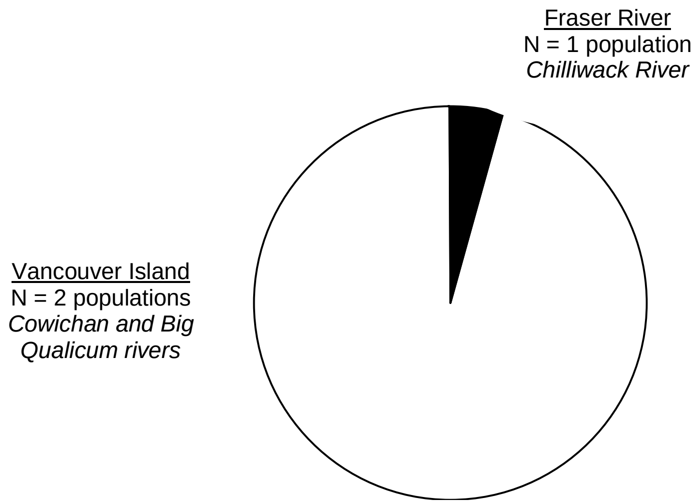

Figure 5. Stock composition from chinook salmon tagged in the Gulf Islands July 14-15, 2008 (n = 21).

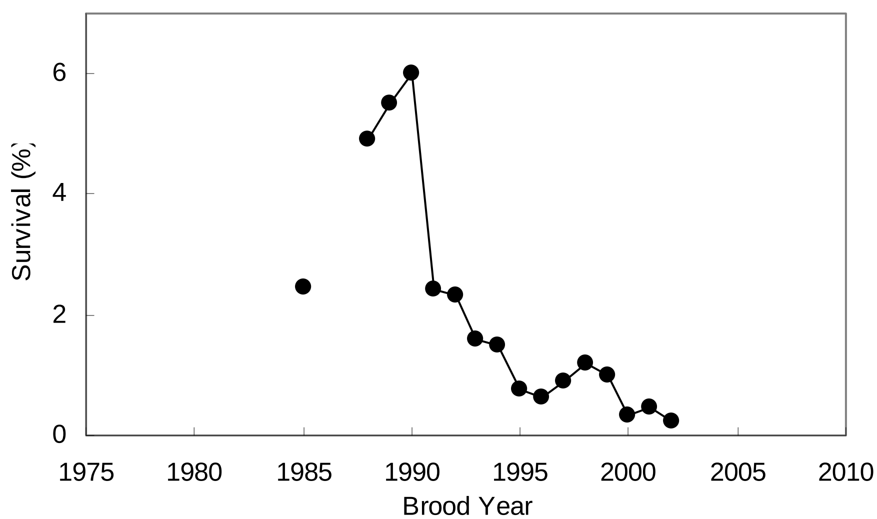

Figure 6. Marine survival of Cowichan River chinook salmon, by brood year 1985-2002, or ocean entry year 1986-2003 and return year 1989-2006, using coded wire tag (CWT) information from hatchery fish, reported in Tompkins *et al*. (2005). Note that there were no data for 1986 and 1987.

Table 1. Summary of the dates and location of tagging events and the number of fish detected at each receiver array.

Date	Area	Number tagged	Number of detections		
			Strait of Georgia	Juan de Fuca (south)	Queen Charlotte Strait (north)
September 23-24, 2007	Strait of Georgia	100	33	6*	0
June 18-19, 2008	Strait of Georgia	30	18	0	1**
July 16-19, 2008	Strait of Georgia	78	28	0	0
July 14-15, 2008	Strait of Georgia (Gulf Islands)	40	0	1	0
July 22, 2008	Strait of Georgia (Cowichan Bay)	30	0	0	0
Total		278	79	7	1

* Three of these fish were also detected within the Strait of Georgia.

** This fish was also detected within the Strait of Georgia.