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[Note]

The Use of Acoustic Tags to Determine the Timing and Location of the Juvenile Coho Salmon Migration out of the Strait of Georgia, Canada

C. M. CHITTENDEN*
Fisheries and Oceans Canada Centre for Aquaculture and Environmental Research, University of British Columbia, 4160 Marine Drive, West Vancouver, British Columbia V7V 1N6, Canada

R. J. BEAMISH, C. M. NEVILLE, AND R. M. SWEETING
Fisheries and Oceans Canada, Pacific Biological Station, 3190 Hammond Bay Road, Nanaimo, British Columbia V9T 6N7, Canada

R. S. MCKINLEY
Fisheries and Oceans Canada Centre for Aquaculture and Environmental Research, University of British Columbia, 4160 Marine Drive, West Vancouver, British Columbia V7V 1N6, Canada

Abstract.—The migration of juvenile coho salmon *Oncorhynchus kisutch* out of the Strait of Georgia in 2006 was investigated by means of acoustic telemetry. During July and September, 173 juvenile coho salmon were caught in the strait with a purse seine, surgically implanted with acoustic tags, and released the same day. In 2006, approximately 19% of the fish tagged in July and 52% of those tagged in September left the Strait of Georgia. Most of these fish did so in October and November through Juan de Fuca Strait and not by a northward migration through Queen Charlotte Strait. This movement was several months later than that observed for coho salmon migrating out of Puget Sound. A small number of coho salmon that moved out of the Strait of Georgia migrated south to areas off the coast of Washington and Oregon. The documentation of a movement out of the Strait of Georgia late in the year was important, as it shows that population changes of the juvenile coho salmon that enter the strait during spring and summer are a consequence of ecosystem-related effects within the strait.

The Strait of Georgia, British Columbia, (Figure 1) historically supported strong recreational and commercial fisheries for coho salmon *Oncorhynchus kisutch* (Beamish et al. 1999). Before the early 1990s, coho salmon were fished from early spring through to the fall when they returned to the rivers to spawn. However, the total marine survival of coho salmon declined from about 10% in the mid-1980s to about 2% in the mid-1990s (Beamish et al. 2000, 2004). This decline has continued, with an average marine survival for coho salmon of 1.4% between 1996 and 2004 (Beamish et al. 2008). Coho salmon within the Strait of Georgia exhibited major migratory changes in recent years. Beginning in about the mid-1990s, young coho salmon, which may have normally spent the marine portion of their life cycle entirely within the Strait of Georgia, left and did not return during the normal fishing times in the next year (Beamish et al. 1999). This change in behavior, along with the major declines in marine survival, essentially ended the once lucrative recreational fishery.

The marine survival of salmon has been correlated to changes in climate and ocean conditions (Beamish et al. 2000; Hare and Mantua 2000). Beamish et al. (2008) conducted a long-term study on the behavior and survival of juvenile coho salmon in the Strait of Georgia between 1997 and 2006. They used modified midwater trawls to examine the growth and distribution of the juveniles. The changes in the population dynamics that they reported depended on the juvenile coho salmon remaining in the Strait of Georgia through September. The determination that coho salmon remained in the Strait of Georgia was based on coded wire tag (CWT) recoveries within the strait and the lack of CWTs from Strait of Georgia hatcheries recovered during surveys in regions outside of the strait (Beamish et al. 2008). However, the numbers of CWT recoveries were small, resulting in an equivocal interpretation of the recent migration behavior. It was important to be certain that coho salmon remained in the Strait of Georgia past September because if juvenile coho salmon were rearing for extended periods in the Strait of Georgia, it would be the conditions within this area that were critical for their marine survival. The objective of this study was to use acoustic tags to obtain the specific dates and direction that coho salmon leave the Strait of Georgia.

Methods

Catch and release.—Juvenile coho salmon were caught in the Strait of Georgia (Figure 1) during July

* Corresponding author: cedar@interchange.ubc.ca

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and September 2006 to allow a comparison of early- and late-summer movements. A 150-m purse seine with a small mesh bunt (6 mm) was used to catch the fish, which were subsequently removed from the seine with a small mesh (8 mm) dip net. From 17–19 July and 11–13 September 2006, 94 and 79 coho salmon, respectively, were caught and tagged. To minimize scale loss and handling stress on the fish during fishing, surgery, and release, MS-222 (tricaine methanesulfonate; Syndel Laboratories, Vancouver) was used to anesthetize fish during handling. For species identification, the coho salmon were partially sedated in a seawater bath containing 20 mg/L MS-222. Once identified, the coho salmon were transferred to a tank with circulating seawater.

Acoustic transmitters, VEMCO V7–2 L (7 × 19 mm) and V9–6 L (9 × 21 mm), were surgically implanted in the body cavity using methods further described in Chittenden et al. (2008). The V7 transmitters were used for fish that were too small to tag with V9 transmitters ($n = 37$ in July, $n = 1$ in September). In this study V7 and V9 transmitters were implanted in coho salmon having a minimum fork length (FL) of 12 and 17 cm, respectively, as previous tag-effect trials had shown no change in survival, growth, swimming performance, or physiology of coho salmon of these sizes with these tags (Chittenden et al. 2009). For tagging, coho salmon were anesthetized in 60 mg/L MS-222. The presence (mostly wild fish) or absence (all hatchery fish) of adipose fins on the coho salmon was recorded for all fish tagged; however, there was no attempt to tag a specific number of any one rearing type. Following surgery, each fish was allowed to recover in a tank containing circulating seawater until normal swimming behavior was resumed. The tagged fish were released the same day (a minimum of 3 h postsurgery) in the Strait of Georgia, near to where they had been collected. The tags were estimated to be active until at least February 2007, and were programmed to stop transmitting 1 year after initialization.

Receiver arrays.—The Pacific Ocean Shelf Tracking (POST) project has established a number of receiver arrays in the vicinity of the Strait of Georgia (Figure 1; Welch et al. 2004). These arrays are maintained by POST and provide detection information to researchers using acoustic tag technology in their research. The POST arrays were designed to have as close to 100% detection efficiency as possible. Melnychuk et al. (2007) reported that marine detection rates of the VEMCO V8SC-6 L acoustic tags (20 × 9 mm) implanted into out-migrating juvenile steelhead *O. mykiss* (14–22 cm) ranged from 91.2% to 100% (average, 95.8%) in 2004 and from 84.6% to 97.5% (average, 91.6%) in a replicate study in 2005. These detection probabilities were calculated as the number of tagged fish detected at point *A* divided by the total number of tagged fish known to have passed by that receiver (i.e., the number of fish detected later, at point *B*). Although there may be slight deviations from this probability range, the results from Melnychuk et al. (2007) were applied to this study resulting in an average detection rate of 92% to 96%.

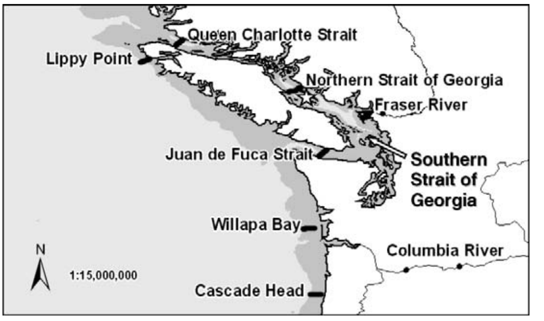

FIGURE 1.—The study area and the locations of the three major Pacific Ocean Shelf Tracking array lines (Queen Charlotte Strait, northern Strait of Georgia, and Juan de Fuca Strait). The locations of arrays in the southern Strait of Georgia and on the West Coast are also identified. The catch-and-release area in the Strait of Georgia is denoted by a star.

Three major arrays in the Strait of Georgia completely transect the waterways and provide information on the movement of fish into and out of the strait. In this study these major arrays are referred to as "lines." The Juan de Fuca Strait line transects the Juan de Fuca Strait approximately 340 km (shortest distance by water) to the southwest of our release site (Figure 1). Fish detected at this line left the Strait of Georgia to the south and west. The Queen Charlotte Strait line is located in Queen Charlotte Strait, 280 km from the release site at the northern tip of Vancouver Island (Figure 1). The Queen Charlotte Strait line marked the northern exit point for this study. The third listening line in the northern Strait of Georgia at Texada Island (Figure 1) was located north of our tagging site. In addition, there were receiver arrays located in the southern Strait of Georgia and at the Vancouver Aquarium and Marine Science Center–Fraser River (Figure 1; for exact locations, see www.postcoml.org). These additional receivers did not completely transect any waterway. However, they did provide information and added verification on general directional movements of some of the tagged coho salmon during the study. Detections of fish at these additional arrays along with the northern Strait of Georgia line are all reported as Strait of Georgia detections. The POST receiver arrays on the west coast of Vancouver Island, Washington, and Oregon were used to obtain informa-

TABLE 1.—Percentages of coho salmon tagged and released in July and September 2006 that were last detected in the Strait of Georgia (SOG), Juan de Fuca Strait (JDF), or Queen Charlotte Strait (QCS) lines at the end of each subsequent month. Individuals that were never detected (29.8% for July and 17.7% for September) were included in the SOG group, as that was their last known location. None of the fish tagged in September were detected at the Queen Charlotte Strait line.

Month of detection	SOG	QCS	JDF
July releases			
Jul	95.7	2.1	2.1
Aug	92.5	4.3	3.2
Sep	92.5	4.3	3.2
Oct	90.4	4.3	5.3
Nov	84.0	4.3	11.7
Dec	79.8	4.3	14.9
Jan and after	79.8	4.3	14.9
September releases			
Sep	100.0		0.0
Oct	86.1		13.9
Nov	63.3		36.7
Dec	49.4		50.6
Jan and after	48.1		51.9

tion on fish movement outside the Strait of Georgia. The Cascade Head line offshore of Oregon was 750 km from the release site, and the Willapa Bay line offshore from the Washington coast was 560 km from the release site (Figure 1). The Lippy Point line was offshore from the northwest coast of Vancouver Island and was 780 km from the release site (Figure 1). These outer receiver lines extended from the shoreline to the continental shelf.

Data analyses.—The data were first checked for false detections that may have occurred due to tag collisions or ambient noise. Detections were excluded as false if (1) they occurred only once on a receiver line within an hour, (2) one or more other tags were heard on the same receiver within 1 min of the suspect detection, and (3) the suspected tag was not detected at any other time.

Results

Early- and Late-Summer Releases

The last detected location, including the Strait of Georgia line (SOG), the Juan de Fuca Strait line (JDF), and the Queen Charlotte Strait line (QCS) is shown in Table 1. Fish that were never detected were included in the Strait of Georgia totals, as it was possible that they remained undetected. The mean ± SD FL of the fish tagged in July and September was 190 ± 26 mm and 253 ± 25 mm, respectively. Six of the 94 coho salmon tagged in July were missing their adipose fin, indicating that they were of hatchery origin. In July, the average length of the fish with an intact adipose fin was significantly smaller (189 ± 27 mm; *t*-test: $P <$ 0.01) than the fish with their adipose removed (201 ± 13 mm). In September, 18 of the 79 coho salmon tagged were missing their adipose fin indicating they also were hatchery fish. The average length of the fish with an intact adipose fin in September (248 ± 21 mm) was again significantly smaller than the fish with their adipose fin removed (263 ± 13 mm; *t*-test: $P < 0.05$).

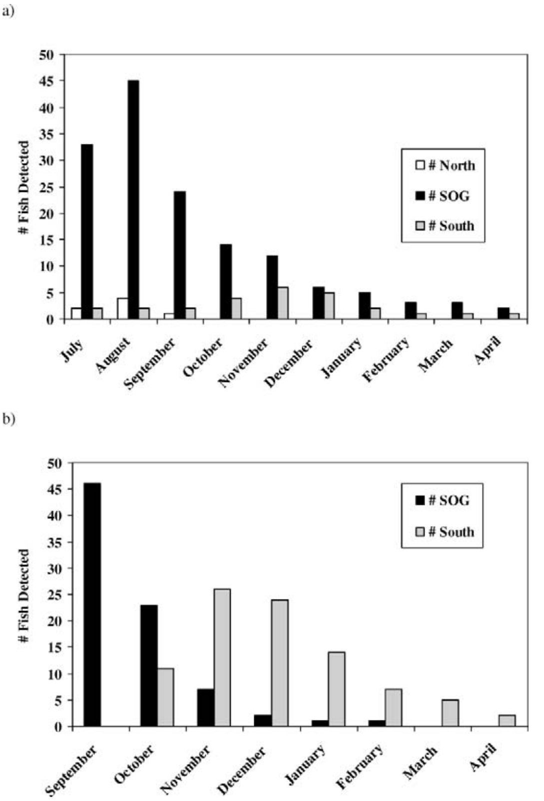

FIGURE 2.—The number of coho salmon from the **(a)** July and **(b)** September release groups detected in the Strait of Georgia (SOG) and Queen Charlotte (north) and Juan de Fuca straits (south) during 2006 and 2007, by month.

Of the 94 coho salmon tagged in July, 4 were detected at the Queen Charlotte Strait line (Table 1; Figure 2a) between 25 July and 11 September 2006. None of the 79 fish tagged in September were detected at the Queen Charlotte Strait line (Figure 2b). Fifty-five of the tagged coho salmon were detected at the Juan de Fuca Strait line primarily from October to December 2006 (Figure 2b). Fish that were tagged in July had an earlier mean date of travel out of Juan de Fuca Strait (9 November 2006) compared with the fish tagged in September (2 December 2006), and spent less time near the Juan de Fuca Strait line (6 ± 12 d compared with 36 ± 44 d).

The number of tagged fish detected at least once was

66 (70%) for the July group and 65 (82%) for the September group. Of the 37 fish tagged with V7–2 L (7 mm) tags in July, 24 (65%) were detected. Of the 57 fish tagged with V9–6 L (9 mm) tags, 42 (74%) were detected. There were 48 fish from the July tagging and 24 fish from the September tagging (a total of 72 fish) that were detected within the Strait of Georgia, but did not leave. There were 28 fish from the July tagging and 14 fish from the September tagging that were never detected. A total of 114 (66%) of the total number of tagged coho salmon were either last detected in the Strait of Georgia, or never detected. Of the 72 fish that were last detected in the Strait of Georgia, 65 (90%) were last detected before 31 December 2006. Of the seven fish that were last detected in the Strait of Georgia during 2007, two were last recorded in January 2007, one in February 2007, two in March 2007, and two in April 2007.

Local Movements

Coho salmon that were detected in the Strait of Georgia, the Juan de Fuca Strait, and the Queen Charlotte Strait were recorded for periods of 33 ± 48 d, 28 ± 40 d, and 16 ± 19 d, respectively. The average first and last detection dates at the northern Strait of Georgia detection area were 20 August and 30 September 2006 for the July release group ($n = 49$), and 18 September and 11 October 2006 for the September release group ($n = 39$). The average first and last detection dates at the Juan de Fuca Strait line were 6 November and 12 November 2006 for the July releases ($n = 16$), and 14 November and 19 December 2006 for the September releases ($n = 41$).

Long-Range Movements

Seven of the fish that left the Strait of Georgia through Juan de Fuca Strait (three from the July release group and four from the September release group) were detected on the outer coast. One was at Lippy Point 23 d after the last detection on the Juan de Fuca Strait line (26 December 2006), and five were at Willapa Bay (near the Columbia River in Washington State) between 24 and 103 d (21 January to 15 April 2007) after departing the Juan de Fuca Strait (Figure 1). The seventh fish, which was tagged in July, was detected at the Cascade Head line in Oregon (Figure 1) from 31 January to 1 February 2007; however, it was neither detected at the Juan de Fuca Strait line nor at the Queen Charlotte Strait line. The fish detected at Lippy Point took 23 d to travel approximately 360 km, or 16 km/d. One of the fish detected at Willapa Bay (22–25 January 2007) was recorded 33 d later back at the Juan de Fuca line (27–28 February 2007). The average time taken to travel the 220 km between the Juan de Fuca Strait line and the Willapa Bay line was 57 ± 28 d, or 4 km/d ($n = 6$).

Discussion

Most of the coho salmon that left the Strait of Georgia migrated out through the Juan de Fuca Strait from October to December 2006. Only 4% of the fish that were last detected in the Strait of Georgia were recorded after December 2006, which indicates that most of the tagged juvenile coho salmon left the Strait of Georgia before winter, or died. The conclusion that most coho salmon left the Strait of Georgia late in the year or died is consistent with the results of trawl studies (Beamish et al. 2008) that showed very few juvenile coho salmon were in the Strait of Georgia after the winter of their first ocean year. As part of these studies, a total of 159 trawl sets during February 1997, 1998, 2005, and 2008 resulted in a total catch of 24 coho salmon (0.15 fish/set). In comparison, 336 sets in July during the same years resulted in an average catch of 2,931 (8.72 fish/set). This clearly indicates that the abundance of coho salmon in February is considerably less than in July. The change in behavior is also illustrated by the recreational fishery. During the 1980s there was a small but important recreational fishery for coho salmon in the Strait of Georgia in February indicating that coho salmon were present. For example, in February of 1988, approximately 7,600 coho salmon were recorded in the recreational fishery (Fisheries and Oceans Canada 2009). These observations are consistent with the interpretation of Beamish et al. (1999) that there was a change in behavior of juvenile coho salmon during the mid-1990s that resulted in virtually all coho salmon leaving the Strait of Georgia. We now know from what this study shows that most of these fish leave the Strait of Georgia late in the year through the Juan de Fuca Strait.

The number of fish that were detected leaving the Strait of Georgia was smaller in the July tag group than in the September tag group, probably indicating a higher mortality within the July tag group. Beamish et al. (2008) showed that the mortality of juvenile coho salmon from the time of entry into the Strait of Georgia to mid-September 2006 was approximately 90%. We could not determine the reason why about 30% of all fish tagged in July were not detected, but it is probable that these fish remained resident in the strait until they died. The few fish from the July tagging that were detected at the Queen Charlotte Strait line moved there shortly after they were tagged (within 17 d). They may have been migrating north when captured, or it is possible that the tagging stimulated the migration, as has been observed in other telemetry studies (e.g., Walker et al. 2000). Approximately 19% of the fish tagged in July survived to leave the strait, compared with 52% of the fish tagged in September. Thus, substantial coho salmon marine mortality probably occurred between July and September. If the detection rates were between 92% and 96%, as indicated previously, then a small percentage may also have been undetected.

The detections of fish at the POST arrays along the Washington and Oregon coastlines are consistent with previous reports that indicate that about 10% of Strait of Georgia hatchery coho salmon were recovered in fisheries in this region (Weitkamp et al. 1995; Walker et al. 2000). One fish that was detected at the Cascade Head line near the Columbia River (Figure 1) was not previously detected crossing the Juan de Fuca Strait line or the Queen Charlotte Strait line. This could be either an error in detection at the Cascade Head line or a missing detection at the other two lines.

Our observations that juvenile coho salmon remained in the Strait of Georgia late into the year and then left through Juan de Fuca Strait just before winter identifies a migratory pattern of coho salmon that differs from those in Puget Sound (Beamish et al. 2008). Coho salmon in Puget Sound virtually all leave in August and migrate out through the Juan de Fuca Strait. From 1997 to 2006, there were 110 trawl sets in July and 126 sets in September in Puget Sound (Beamish et al. 2007). There were 7,220 juvenile coho salmon captured in July resulting in a catch per hour of 217 fish. This compares with a catch of 684 coho salmon or 15 fish per hour in September, representing a decrease in a catch rate of 93% from July to September in Puget Sound. The dramatic decline in catch of coho salmon in Puget Sound between the July and September surveys most probably indicates substantial movement out of Puget Sound. A study similar to ours conducted in Puget Sound could verify that most coho salmon in Puget Sound leave during the summer. The reasons for the different timing of migration are not known, but may relate to the rates of marine growth and physiological condition of the salmon (Beamish and Mahnken 2001). Understanding why the migration timing is different may help identify the factors that regulate migration and that affect marine survival.

The information in our study is important to an understanding of why the marine survival of coho salmon is declining in the Strait of Georgia (Beamish et al. 2008), because it confirms that processes within the strait are causing the declines. Although this was a 1-year study, we propose that it is representative of recent behavior of coho salmon in the Strait of Georgia because very few juvenile coho salmon with CWTs from Strait of Georgia hatcheries are recovered outside of the Strait of Georgia in the summer and fall (Beamish et al. 2007). However, it would be important to repeat the study to confirm our interpretation. The reasons for the change in behavior in the mid-1990s were thought to be related to climate and ocean effects (Beamish et al. 1999). However, the mechanisms remain to be discovered. It is possible that there have been stock composition changes resulting in the population of coho salmon in the Strait of Georgia consisting of a larger percentage of stocks that had a tendency to migrate out of the Strait of Georgia late in their first marine year. An acoustic-tagging study combined with DNA stock identification would be an excellent study to determine whether there are stock-specific differences in coho salmon movement.

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