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Assessment of Coquitlam Reservoir Salmon Migration Pathways

Project #05.Co.02, BC Hydro Fish & Wildlife Bridge Coastal Restoration Program

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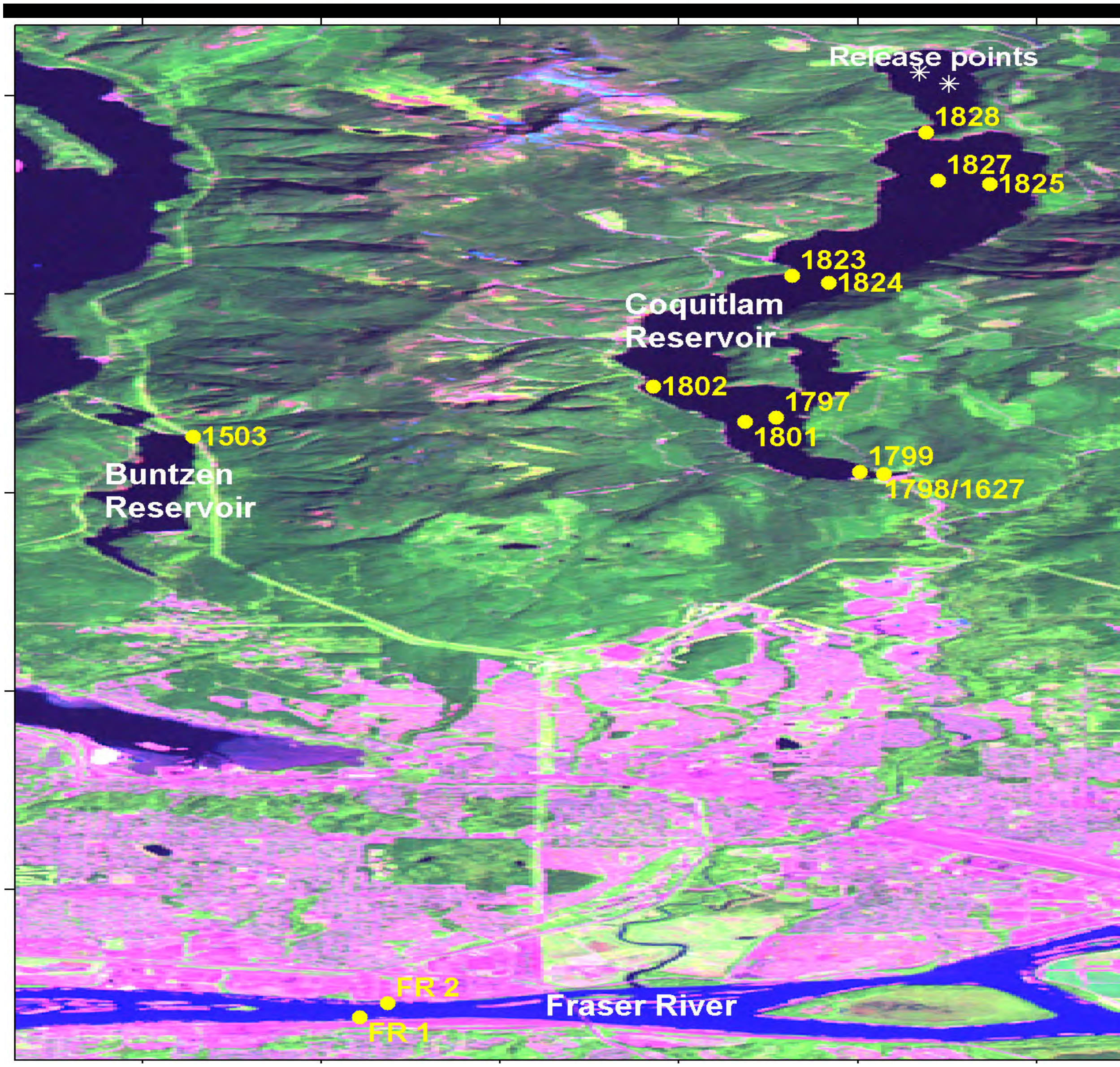

Cover Image: *Landsat 7 satellite image taken July 2000 (30m resolution). The location of the acoustic array used to track coho salmon smolts within the Coquitlam and Buntzen Reservoirs is overlaid. To the far left is Indian Arm (Burrard Inlet). The monitoring locations in the Fraser River are shown at the lower edge of this image.*

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Executive Summary

In 1904 the Coquitlam dam was constructed to supply drinking water and hydroelectric power to the city of Vancouver. Although initially provided with a fishway, the expansion of the dam in 1914 did not include a fishway, cutting off access to the spawning grounds and wiping out the native anadromous fish runs to the river, including the sockeye (Bengeyfield 2001). Extirpated sockeye populations are notoriously difficult to recover by transplanting exotic runs, presumably because of important differences in the life history of the different populations that can be used as seed stock. In the case of the Coquitlam River, there are additional difficulties created by the need to have the smolts migrate through the dam to reach the Coquitlam river, as either emigration via the Buntzen Lake diversion tunnel or the GVRD water supply would lead to those smolts failing to return as adults, and thus failing to restart the run.

Two essential elements must be met if restoration is to be successful: (1) the smolts used to restart the sockeye run must be able to find their way out of the reservoir and (2) their survival must be high enough to allow a reasonable return of adults. Bengeyfield (2001) commented on the possibility of restarting an anadromous run by noting that "…*juvenile fish seeking to migrate out of the reservoir would be attracted to the large flow volumes diverted to the other river system, and be less likely to locate the comparatively minor flow over the dam."* They judged that "*The intrabasin diversion factor alone suggested a reduced likelihood of successful re-introduction at… Coquitlam… reservoirs*" and concluded : *"The three reservoirs involved in significant interbasin diversions—Coquitlam, Alouette, and Carpenter—are considered impracticable candidates for anadromous re-introduction"*, primarily owing to the interbasin diversion of water.

Kintama Research was contracted in 2005 to assess what operating conditions promoted smolt out-migration at each of the three possible exit locations from Coquitlam Reservoir, with a view to maximizing smolts leaving via the Coquitlam River. To do so, we surgically implanted coho smolts with long-lived acoustic tags, and then determined their movements within the reservoir using an acoustic tracking array. Kintama is also constructing a compatible marine tracking array along the west coast of North America, a system that would also allow assessment of the survival of the tagged as they migrated through the Strait of Georgia.

The key aspects of this work in 2005 are as follows:

- Between April 15 and August 4, 2005, the movements of tagged coho smolts through the Coquitlam Reservoir were established using an array of acoustic listening receivers placed in the reservoir.
- Coho smolts were used as a proxy to the behaviour of sockeye smolts, as stipulated in the terms of reference for the study. Smolts with surgically implanted acoustic tags, as well as additional untagged smolts, were released into the reservoir in five groups between April 15 and May 13.
- Flow patterns at the reservoir outlets were altered several times during the study as a result of BC Hydro's pre-determined plan of operation, and the installed array was used to reconstruct smolt movements and out-migration patterns in order to establish how smolts left the reservoir and how BC Hydro operations affect emigration behaviour.

Main Findings:

- Of the 117 tagged smolts released, 94% were detected on the array, and 77% reached the south end of the reservoir at least once. The use of multiple listening lines made it possible to track fish with a good level of confidence.
- Smolt numbers declined at 4% per day (mortality + tag shedding + emigration), equivalent to 30% survival of tagged fish per month. As a result, there were substantial numbers of smolts available over an extended period of time, allowing observation of their behaviour and emigration over the study period
- There is excellent evidence that smolts use the entire reservoir. We did not find evidence that the majority of the fish remained near the 3 outlets from the reservoir.
- There are clear differences in the areas of the reservoir where the coho smolts prefer to spend their time, for example at the south end of the reservoir. We found evidence of extended residence by some fish.
- Fish make rapid repeated migrations the entire length of the reservoir, at speeds on the order of 1-2 body lengths per second. Speeds are similar for fish traveling north or south along the lake.
- We found *no* evidence that any of the smolts ever left the reservoir
- Neither fish distributions nor swimming speeds varied significantly with BC Hydro operations in 2005.

Recommendations:

- We recommend that future studies switch from coho to sockeye smolts if the latter are the primary rebuilding target
- Smolt releases should be timed relative to Hydro Operations in order to focus on behaviour of smolts at the Low Level Outlet (LLO) from the dam. Releases should be scheduled to ensure high numbers of fish are present in the vicinity of the LLO to the Coquitlam River prior to the time of peak outflow. This will maximize the chance of detecting behavioural differences under different hydro operations. During the 2005 experiment, only one fish was near the LLO intake at the time of maximum outflow, as high outflow operations to the Coquitlam River were terminated before several of the fish releases occurred.
- The data from the large array could be supplemented by operating a 3-D positioning system to establish the fine-scale movements of the tagged smolts near the mouth of the outlets, in order to establish whether the smolts are at least approaching the dam's LLO more closely under high outflow conditions.
- Some changes to the 2005 array configuration would improve system performance and strengthen the results obtained using the existing array:

    - A receiver could be added near the mouth of the Coquitlam R.
    - The number of receivers should be increased at the Port Mann detection site in the Fraser River by adding one or two mid-river receiver sites, or the site location changed.
    - To increase tracking performance in the reservoir, future studies should consider either switching to using the more powerful V8 tag in larger smolts (>14.5 cm), if possible, or adding additional receivers to some of the Coquitlam Reservoir lines
    - A second receiver should be added near the Buntzen Lake outlet to verify the lack of out-migration.

1. Introduction

Construction of the Coquitlam Lake Reservoir Dam early last century blocked anadromous salmonid passage and subsequent impoundment inundated some key salmonid habitats which historically supported sockeye (*Oncorhynchus nerka*), and coho (*O. kisutch*) populations (Bengeyfield, 2001; Koop 2001). Little data, save some anecdotal accounts, exist regarding historical run size, but, recently, stakeholders (BC Hydro, GVRD, community groups and the Kwikwetlem First Nation) have been investigating the possibility of reintroducing anadromous salmonids to habitat above the dam site. Bocking and Gaboury (2003) authored a report for the Bridge-Coastal Fish and Wildlife Restoration Program exploring the feasibility of reintroducing both sockeye and coho above the dam, and at present the Coquitlam Salmon Restoration Project (CSRP) is studying potential outmigration options for juvenile salmon in the Coquitlam watershed above the dam site.

The Coquitlam River watershed, located in the Greater Vancouver area in southwestern British Columbia, is a typical southwest coastal watershed. River flows are dominated by snowmelt during the spring months, with lower flows through the summer prior to elevated precipitation driven flows October through March. The watershed can be divided into three distinct components; Upper Coquitlam River, Coquitlam Lake Reservoir, and the Lower Coquitlam River.

Coquitlam Lake Reservoir is supplied by 193 km^2 of watershed, including the upper river, and has a surface area of approximately 12 hectares depending on reservoir elevation. The reservoir is utilized by two facilities both initiated near the turn of the twentieth century. One facility, with origins dating back to 1892, provides an intake for domestic water supply by the Greater Vancouver Regional District (GVRD) for the Greater Vancouver area. The other facility, BC Hydro's Coquitlam-Buntzen generation project, dates to 1903 and diverts water out of Coquitlam Lake Reservoir via a 3.9 km tunnel to Buntzen Lake Reservoir, where dual penstocks lead to powerhouses for electricity generation located in Indian Arm, Burrard Inlet .

The Lower Coquitlam River watershed covers an area of approximately 60 km^2 and has its source at the Coquitlam Dam located within the GVRD watershed boundary, and flows though the municipality of Port Coquitlam before entering the Fraser River. At present the lower watershed is impacted by gravel extraction, urbanization and altered flows due to domestic water use and power generation.

The original anadromous salmon runs to the Coquitlam River were wiped out with the construction of the dam on the Coquitlam River in 1914 (Bocking and Gaboury 2003). The restoration of an anadromous salmon run to the Coquitlam reservoir depends on the identification of a sockeye stock with suitable genetic characteristics to re-start the run, and possibly the modification of hydro operations to ensure smolt emigration from the reservoir via the dam, since this is the only viable exit route that will allow emigrating smolts to return as adults. The results reported in this document show that smolt losses via the GVRD and Buntzen Lake diversion tunnels are apparently negligible. This removes one major potential impediment to re-introducing anadromous runs to the Coquitlam Reservoir. The discovery in 2005 that kokanee smolts from the adjacent Alouette Reservoir will migrate of their own volition from the Alouette lake when provided with a surface outflow (Bocking, personal communication) suggests that a second major issue in restarting the Coquitlam run can be resolved fairly readily, because the transplant of exotic sockeye stocks is usually a failure. (Securing a transplant permit from regulatory authorities when land-locked sockeye are already present may be difficult).

Using Coquitlam kokanee as the seed stock to re-start an anadromous run is an attractive approach. However, their persistence for over a century in the reservoir without an ability to successfully return from the sea indicates that few kokanee currently migrate out of the reservoir of their own accord,. As a result, the key issue for the restoration of the Coquitlam sockeye run turns on establishing reservoir operations that will promote emigration of the existing smolts to the sea. There are two issues that must be established: (i) What modifications to existing hydro operations will promote emigration via the Coquitlam River?, and (ii) What is the survival of these smolts once they leave? If this run has genetic characteristics similar to that of the now endangered Cultus Lake sockeye stock, which likely collapsed in the 1990s because of poor ocean conditions, the likelihood of run restoration is remote. The success of restoration efforts therefore depends on establishing hydro operations that will promote (or force) emigration to the sea, and the choice of a sockeye stock that will have good survival until return as adults. The technological approach employed in the study reported here addresses the first component, but could also be used to address the second issue in the future.

2. Goals and Objectives

Two essential elements must be present if restoration of an anadromous salmon run is to be successful: (1) the smolts used to restart the run must be able to find their way out of the reservoir and (2) their survival must be high enough to allow a reasonable return of adults. Bengeyfield (2001) commented on the possibility of restarting an anadromous run by noting that "…*juvenile fish seeking to migrate out of the reservoir would be attracted to the large flow volumes diverted to the other river system, and be less likely to locate the comparatively minor flow over the dam."* They judged that "*The intrabasin diversion factor alone suggested a reduced likelihood of successful re-introduction at… Coquitlam… reservoirs*" and concluded : *"The three reservoirs involved in significant interbasin diversions—Coquitlam, Allouette, and Carpenter—are considered impracticable candidates for anadromous re-introduction"*, primarily owing to the interbasin diversion of water.

Given the Bengeyfield (2001) report, the key issue that needs to be addressed first concerns the identification of a method to promote smolt emigration to the Coquitlam River (i.e. via the lower level outlet through the dam). To address this issue, we installed an acoustic array within the reservoir to reconstruct the movements of free-ranging smolts throughout the system. To make the smolt's movements traceable, we surgically implanted an individually identifiable acoustic tag into each smolt, which allows us to establish the precise timing that the smolt's movements bring them near the elements of the array. By reconstructing the movements of the individuals throughout the array, we are able to describe how the animals move, whether they respond to different hydro operations (flow regimes), and what fraction of the smolts left by each possible outlet path.

To establish how smolts exit from the reservoir, coho smolts were surgically implanted with small acoustic tags. Each tag transmits a unique acoustic code, allowing the movements of each fish to be monitored. Motion of fish through the reservoir was tracked by a grid of acoustic receivers placed in the reservoir (described in Section 3.2), primarily placed as paired units forming listening lines or "acoustic curtains" at intervals down the length of the reservoir (Figure 1). The intent with this array was to form a series of listening lines that the tagged smolts must pass through when they swim down the reservoir. Receivers placed at the Buntzen tunnel, near the

GVRD inlet, and at the base of the dam were used to record fish arriving at each outlet. One receiver was placed near the outlet of the Buntzen tunnel in Buntzen Reservoir to detect smolts migrating through the tunnel. Two satellite-linked receivers were placed on either side of the Fraser River, downstream of the confluence with the the Coquitlam River (Figure 1), to detect any tagged smolts migrating down the Fraser River to the ocean.

3. Study Area and Methods

3.1. Study Area

This study followed the movements of coho smolts within the Coquitlam Reservoir, from release at two sites at the northern end of the reservoir to potential emigration via three outlets in the middle and southern portions of the lake (Figure 1):

1. Into the Greater Vancouver Regional District potable water intake

2. Down the tunnel connecting the Coquitlam and Buntzen Reservoirs, into the Buntzen Reservoir, and finally into Indian Arm

3. Through one of the fish valves leading from the lower level outlets (LLO) in the Coquitlam dam, then down the Coquitlam River and finally the Fraser River

Of these three exit options, only the third is viable for the establishment of an anadromous salmon run. The GVRD inlet, which is covered by a fine-meshed screen, would result in death if any fish enter it. Similarly, there is no safe route available for fish to enter the marine environment from the Buntzen Reservoir; furthermore, the Buntzen-Coquitlam tunnel does not permit return travel from the Buntzen Reservoir back to the Coquitlam Reservoir should any adults return.

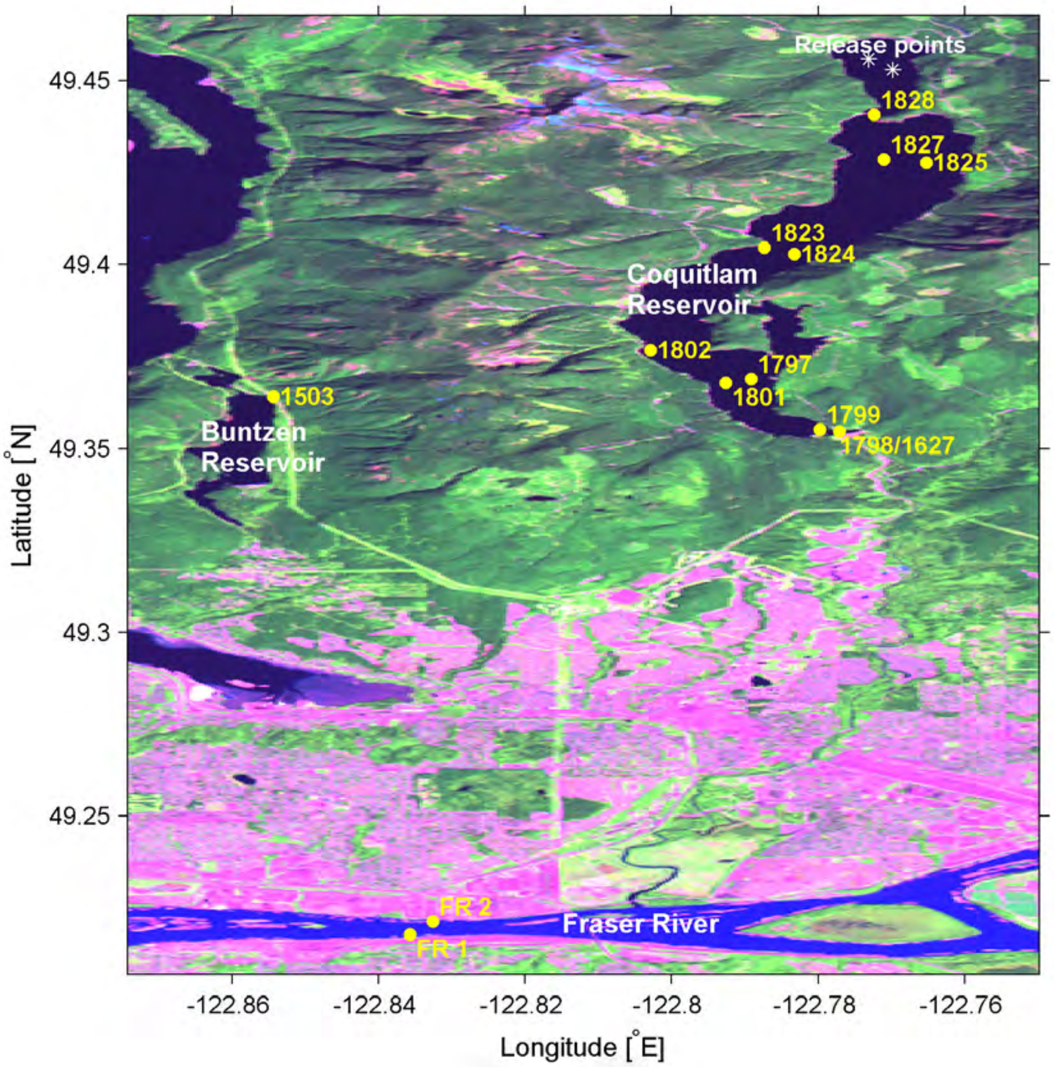

Figure 1. Layout of the acoustic tracking array used for the Coquitlam smolt migration study. Smolts were released at one of two sites at the north end of the reservoir (white stars in the figure). Locations of acoustic receivers are shown as filled yellow circles. Note the following key locations: Buntzen Reservoir tunnel (between receivers 1802 and 1503), GVRD water inlet (receiver 1799), and the Coquitlam Reservoir dam (receiver #s 1798/1627). The location of two acoustic receivers on the Fraser River, monitoring smolt movements downstream from the confluence of the Coquitlam River, is also shown. Background satellite image: © 2003, Government of Canada, with permission from Natural Resources Canada (http://geodiscover.cgdi.ca).

3.2. Instrumentation and Array Design

Acoustic telemetry is in principle similar to radio telemetry, but has the advantage that radio tracking will not work when the tags are in deep or highly conductive water; as a result, radio tracking is infeasible in estuarine or salt water. In contrast, acoustic telemetry can in principle provide a seamless system to monitor both movements and survival in both freshwater and the ocean. Kintama Research is developing the technical basis for a continental-scale permanent marine tracking array. As the Coquitlam smolts tagged in this study did not move out over the lower Fraser or Strait of Georgia array in 2005, these components of the array are not described here. An overview of the marine array can be reviewed at www.postcoml.org.

For the study reported here, an array was formed in the Coquitlam Reservoir of Vemco VR-2 acoustic receivers. These units are essentially waterproof data loggers, that detect the presence near the receiver of an acoustic tag. The units verify the accuracy of the received transmission and, if the detection passes a checksum test transmitted as part of the acoustic code, is logged to non-volatile flash memory along with the date and time of the detection. Because of the characteristics of the checksum encoded as part of the tag's transmission, the acoustic code is identified with high accuracy, and "false positives" (detection of an incorrect tag code) are very rare.

The original planned layout of the array is shown in Figure 2. The actual array placed in the reservoir differs chiefly because of the fine-scale geometry in the vicinity of the GVRD water intake and the lower-level outlet (LLO) at the dam; the forebay area of the dam is formed by a "dog-leg" in the reservoir that meant that smolts approaching the face of the dam would not be detected at the originally proposed location. As a result, during the actual deployment of the array the positions of the acoustic receivers were changed to better monitor movements of smolts near the lower-level outlet (see Fig. 1).

The purpose of the array in the reservoir was to form a series of five listening lines, each formed of one or two individual receivers, over which the tagged smolts must pass to reach the three possible outlets. To study the smolt movements, Vemco V7-2L acoustic tags (7 mm in diameter; 18.5 mm long; weighing 1.6 g in air) were surgically implanted into the smolt's abdominal cavity. These tags were programmed with the POST code map, an acoustic code map and associated transmission schedule developed by Kintama Research to allow highly efficient long term studies of the movements and survival of even small fish.

In principle, the array deployed in the Coquitlam Reservoir was expected to have a nearly 100% detection rate for tagged animals passing individual listening lines. In practice we found that these lines did not detect all passing smolts. The primary cause of this was probably the lower acoustic power output of the V7 tags, which was lower than the manufacturer's specifications. As a result, the detection range for the tags was lower than originally anticipated. This can be redressed in future years either by using the larger Vemco V8 acoustic tag (requiring the use of smolts $\geq$14.5 cms) or by placing more receivers in the lines.

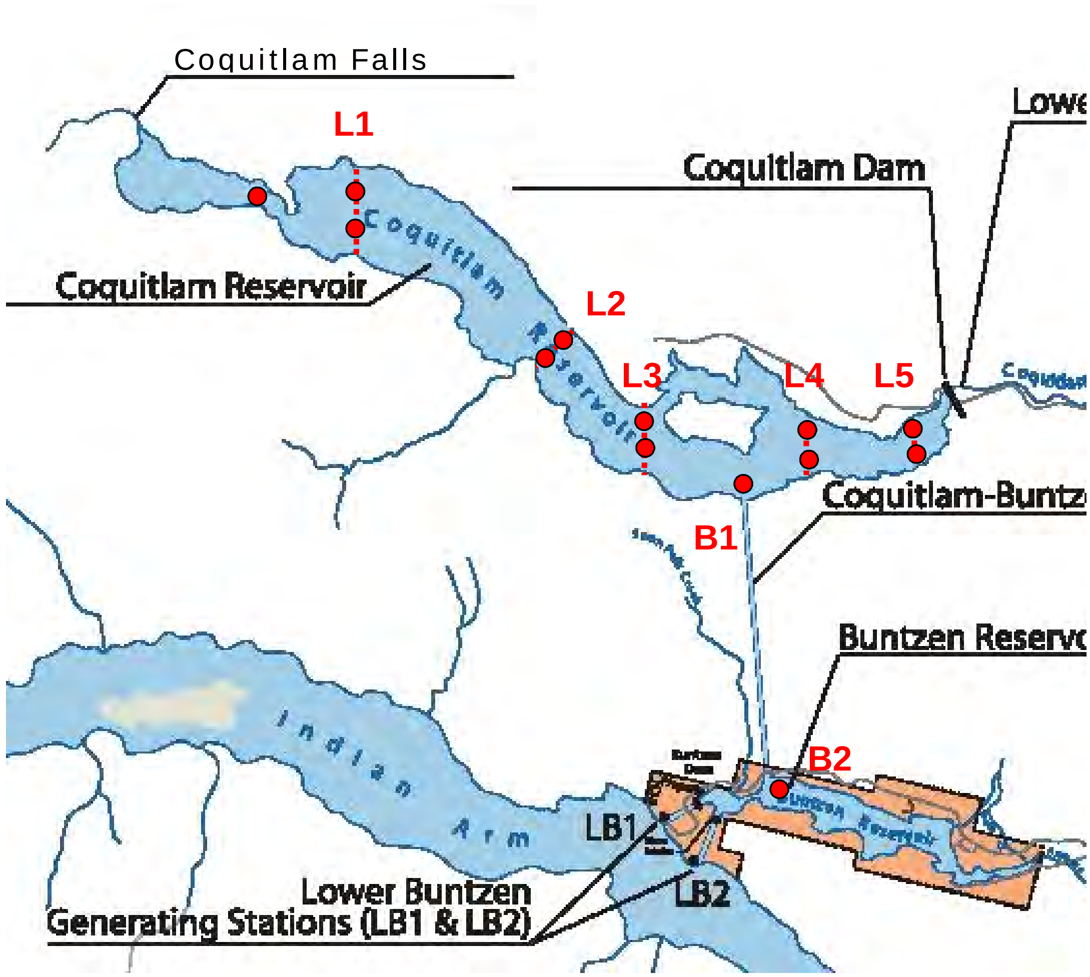

Figure 2. Location of the Coquitlam reservoir acoustic sub-array, as originally proposed. The additional listening line deployed in the Fraser River just downstream of the Coquitlam R is not shown. Line L5 was reconfigured as described in the text.

3.2.1. Tagging Operations & Release of Tagged Fish

Surgical procedures are detailed in Appendix 5. Fish were released in weekly intervals to ensure that sufficient numbers of tagged fish were available to monitor their movements in response to hydro operations. Tagged and untagged smolts were transported by truck in two aerated 80 litre containers filled with Coquitlam River water from the hatchery holding facility to the boat launch at the south end of the reservoir and transported by boat to the release site located at the extreme north end of the reservoir. The water temperature was continually monitored and the average transit time was about 45 minutes from the hatchery to final release.

- Three (of 120 tagged) smolts died during holding at the hatchery. Improving holding facilities and reducing fish holding time for future studies may help eliminate these mortalities.

- Fish were released at one of two release sites (see Figure 1). Because of some concern that the first release site was too near to two osprey nests, the subsequent releases were moved east to take advantage of deep water habitat in that portion of the reservoir.

Release group	*Release date (UTC)*	*Tag codes*	*Mean fork length (mm)*	*Number of tagged fish*	*Number of untagged fish*	*Release location*	*Reservoir water temperature (°C)*
1	15 Apr.	1151-1174	127	24	56	Northwest	6.5
2	22 Apr.	1175-1199	128	24	54	Northeast	10
3	29 Apr.	1200-1223	127	24	54	Northeast	10.5
4	06 May	1224-1247	126	23	56	Northeast	15
5	13 May	1249-1271	131	22	32	Northeast	19

Table 1. Release groups involved in the Coquitlam smolt migration study. Fish were tagged on April 10-11, 2005, at the Al Grist Memorial Fish Hatchery, and were released at one of the two sites shown in Figure 1. Note that additional, untagged fish were also released in an attempt to reduce possible initial predation mortality of tagged fish.

3.3. BC Hydro Operations

The rates of outflow through each of the three outlets listed in Section 3.1 are changed regularly as part of the operation of the Coquitlam Reservoir, depending on the needs of the GVRD and BC Hydro. These operations influence the overall flow fields experienced by fish in the reservoir, and have the potential to affect their choice of emigration routes. In order to assess the impact of these operations on the behaviour of newly released smolts, operations at the two BC Hydro outlets (Coquitlam/Buntzen tunnel and LLO) were changed simultaneously with the five releases of tagged smolts (see Table 2, also Table 6 of Appendix A3). This was done to ensure that tagged fish would be present in the reservoir during each operational cycle even if the previous release had already left the lake. After May 20 (one week after the last release), BC Hydro and the GVRD carried out normal operations, including a number of changes in flow rates (Table 2, Table 6); while these changes were carried out independently of the migration study, they offered additional opportunities to observe changes in behaviour in the smolts remaining in the reservoir.

Operation Label	*Dates*	*Description*
A	15-22 Apr. 05-13 May 25 May–17 Jun 22-29 June 18 Jul–4 Aug.	Buntzen Reservoir tunnel closed Coquitlam dam fish valves open
B	29 Apr–5 May 13-25 May 17-22 June 14-18 July	Buntzen Reservoir tunnel opened Coquitlam dam fish valves open
C	22-29 Apr.	Buntzen Reservoir tunnel closed Coquitlam dam fish valves + lower level outlet open
------	29 June-14 July	Special operations during gate maintenance: Coquitlam dam fish valves closed, flow maintained via pumping

Table 2. BC Hydro operations during the Coquitlam smolt migration study. The locations of the Buntzen and Coquitlam Reservoirs are shown in Figure 1. Note that changes BC Hydro operations between 15 April and 20 May correspond to the release dates shown in Table 1. Further details are provided in Table 6 in Appendix A3.

3.4. Data Analysis

Data from all receivers in the Coquitlam and Buntzen Reservoirs were recovered in June and again on August 4, 2005 when the array was removed. The ASCII files stored on the receivers by the VEMCO data acquisition software (including system status data and tag detection data) were downloaded shortly after retrieval of the instrumentation.

Quality control was carried out on all data files. System data recorded in the file header were reviewed, and the data files checked for gaps or inconsistencies. Only one such issue was found, resulting from premature failure of receiver number 1798 and its subsequent replacement with receiver number 1627; as a result, there is a two-week gap (between June 30 and July 12) during which no detection data were collected at the dam (see Figure 2). Finally, all records of tag detections were checked against a list of known tags codes used in the Coquitlam study (Table 1), in order to ensure that no false detections would be included in data analysis.

Additional details regarding data analysis and manipulation are described in Section 4 below.

4. Results and Discussion

4.1. Line Performance

The layout of the acoustic array was originally designed to provide 100% detection of tagged fish moving through the reservoir, based on the specified power output of the acoustic tags and on the range-dependent sensitivity of the acoustic receivers. However, a number of factors can reduce this detection rate, including the following:

- Incomplete coverage by listening lines (i.e., sections of the line are outside the effective listening range of the receivers)
- Environmental noise (e.g., machinery, heavy rainfall, wind creating waves, interference between two or more tag transmissions)

- Acoustic absorption due to high levels of particulates in the environment
- Low power on the acoustic tags (the small 7mm tags newly available in 2005 had lower acoustic power than the manufacturer's original specification)

If a tag transmission arriving at an acoustic receiver meets certain criteria, the tag code is recorded by the data acquisition firmware; otherwise, internal counters are incremented to record how many possible transmissions were received, but the transmission itself is not recorded. A key point to note is that all component pulses must be received in order for the tag to be detected; a drop out of even one pulse is sufficient to cause the receivers to reject the transmission from a tagged fish. A substantial amount of effort went into designing Kintama's array geometry and tag transmission scheduling in order to allow that high detection rates were possible while ensuring a long tag life and relatively low amounts of equipment deployed in the array.

As discussed below, some fish were not detected passing individual detection lines. Although the overall performance of the array that we describe below was quite satisfactory, and provided a good picture of smolt movements in the lake, array performance was somewhat below our expectations. We attribute this mainly to the lower acoustic power output of the V7 tag, compared to its designed power output. The V7 tag is a new tag first released this year, and which we used because it was smaller than the V8 tag we have used in the past. We chose to use this tag to avoid having to rear the smolts to a larger size, since the movement data for larger smolts released unusually late might not be comparable. However, in testing this production tag we found that the acoustic power output was lower than projected, so that the detection range was accordingly lower. In future years we could either switch to larger smolts tagged with the more powerful V8 tag or deploy a larger array in the lake.

Receiver number	Line description	Number of sync pulses received	Number of pulses received (average # pulses per sync pulse)	Total number of tag transmissions detected (% of sync pulses received)	Number of checksum errors (% of total transmissions)
1828	Northern "neck"	22,977	163,620 (7.1)	10,989 (48%)	275 (2.5%)
1827	Line 1	673	5,317 (7.9)	308 (46%)	1 (0.3%)
1825	Line 1	12,327	97,351 (7.9)	7,983 (65%)	90 (1.1%)
1823	Line 2	142,220	930,730 (6.5)	89,780 (63%)	3062 (3.4%)
1824	Line 2	567	4132 (7.3)	270 (48%)	0 (0%)
1802	Buntzen Tunnel inlet	16,469	181,636 (11.0)	6733 (41%)	42 (0.6%)
1503	Buntzen Tunnel outlet	1349	3,011 (2.2)	0 (0%)	1
1801	Line 3	2787	20,680 (7.4)	1,373 (49%)	13 (0.9%)
1797	Line 3	5545	42,852 (7.7)	2,488 (49%)	159 (6.4%)
1799	GVRD inlet	122,873	872,518 (7.1)	95,970 (78%)	3631 (3.8%)
1798	Dam (09 Apr. to 30 Jun.)	269,533	1,862,952 (6.9)	148,168 (55%)	32,473 (21.9%)
1627	Dam (12 Jul. to 04 Aug.)	38,982	274840 (7.1)	29,497 (76%)	1286 (4.4%)

Table 3. Number of sync pulses, all pulses, detections, and checksum errors at each of the acoustic receivers used in the Coquitlam Reservoir study. Sync pulses mark the beginning of a ping transmission, regardless of whether or not it represents a complete, valid ping, and are followed by 6 additional pulses for a valid tag transmission. The number of tag transmissions indicates the number of valid transmissions received, and may include multiple transmissions from a single tag. Checksum errors are invalid transmissions rejected by the acoustic receiver. Receiver locations are shown in Figure 1, and are listed north to south. Note that receiver #1798 failed partway through the study, and was replaced by #1627. Detailed data are not yet available from the satellite linked VR-3 units in the Fraser River, as the satellite transmissions contains only a summary of the detection data.

While most receivers in the Coquitlam/Buntzen array fit this pattern of relatively high detection rates for in-range tags, three receivers appear to have been located in unique environments:

- Receiver #1798, at the Coquitlam dam: This receiver recorded an unusually high number of checksum errors. This is consistent with numerous tag collisions, which would be explained by the large number of fish present simultaneously at this site during the first part of the study (see Section 4.3). Note that the numbers of fish had declined significantly by the time this receiver was replaced with # 1627 (see Section 4.2).
- Receiver #s 1802 and 1503, at the ends of the Buntzen tunnel: Despite fairly typical numbers of checksum errors, the ratio of sync pulses to the total number of pulses is very unusual for both of these sites. Tag collisions are a less likely source of noise here, particularly in the Buntzen Reservoir, where no complete transmissions were observed, and the average length of the “fragments” observed is very low. While the data cannot indicate the source of these “fragments”, one possibility is that environmental noise at frequencies near those at which the receivers operate (e.g., water falling into the reservoir from the tunnel mouth, fish finders in the Buntzen Reservoir) caused these results..

As discussed above, the proportion of tag transmissions recorded by a receiver is not as significant to the tracking of fish movements as is the detection of the tagged *fish* that are present. The numbers of fish detected on each receiver in the array are shown in Table 4(a). Of the 117 fish released into the reservoir, 110 (94%) were detected at least once on the acoustic array. Detection rates on individual lines vary between 62% and 80%, with more than three-quarters of the fish (77%) released into the reservoir detected at the face of the dam. While there is some variability in overall detection rates across release groups, there is no trend toward either higher or lower detection rates for later groups of fish.

More detailed information on the frequency with which fish avoid acoustic detection may be obtained by following the motions of individual fish southward through the reservoir. Table 4(b) lists the numbers of fish which arrived at a given listening line without being detected first on the line immediately to the north of it, during their first southward traverse of the reservoir. Line performance varies considerably, but does not appear to be systematically higher for later release groups. The highest detection rates occurred at the single receiver in the northern “neck” of the reservoir and at the line immediately north of the Buntzen tunnel (Table 4(b), Figure 1); note that both lines were located in relatively narrow portions of the reservoir. In contrast, the lowest detection rates occurred at line 1 (immediately south of the “neck”) and at the receiver near the GVRD inlet (Figure 1), with non-detection at Line 3 only slightly lower.

(a) Number of unique fish detected on each listening line (% of tagged)						
Line	*Group 1, Oper. A*	*Group 2, Oper. C*	*Group 3, Oper. B*	*Group 4, Oper. A*	*Group 5, Oper. B*	*All groups*
Northern "neck"	22 (92%)	23 (96%)	21 (88%)	18 (78%)	20 (91%)	104 (89%)
Line 1	15 (63%)	22 (92%)	15 (63%)	11 (48%)	9 (41%)	72 (62%)
Line 2	20 (83%)	20 (83%)	19 (79%)	16 (70%)	19 (86%)	94 (80%)
Line 3	18 (75%)	17 (71%)	17 (71%)	13 (56%)	15 (68%)	80 (68%)
GVRD inlet	18 (75%)	17 (71%)	19 (79%)	16 (70%)	17 (77%)	87 (74%)
dam	19 (79%)	16 (67%)	18 (75%)	18 (78%)	19 (86%)	90 (77%)
Entire array	23 (96%)	24 (100%)	22 (92%)	19 (83%)	22 (100%)	110 (94%)
(b) Number of "novel" fish, not first heard on the previous, up-lake line (% of line total)						
Line	*Group 1, Oper. A*	*Group 2, Oper. C*	*Group 3, Oper. B*	*Group 4, Oper. A*	*Group 5, Oper. B*	*All groups*
Northern "neck"	-----	-----	-----	-----	-----	-----
Line 1	0 (0%)	2 (9%)	0 (0%)	1 (9%)	0 (0%)	3 (4%)
Line 2	12 (60%)	9 (45%)	14 (74%)	10 (63%)	16 (84%)	66 (70%)
Line 3	1 (6%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (1%)
GVRD inlet	14 (78%)	8 (47%)	12 (63%)	7 (44%)	10 (59%)	54 (62%)
dam	17 (89%)	10 (63%)	13 (72%)	11 (61%)	18 (95%)	71 (79%)

Table 4. Summary of line statistics, by release group (see Table 1, Table 3 (line descriptions), and Figure 1); the BC Hydro operation in place at the time of release is also indicated (see Table 2). (a) The number of fish detected on a given listening line is expressed both in numbers of fish and as a percentage of the total number of tagged fish in a given release group (24 fish for groups 1-3, 23 and 22 for groups 4 and 5, respectively). (b) The number of "novel" fish on a line is calculated using only the first southward movement of fish across the reservoir, from the release point to the dam, and is expressed both as a number of fish and as a percentage of the total number detected on the same line (from (a)). A large percentage indicates a large number of fish were not detected on the previous, up-lake listening line.

The poorer detection rates at these locations is likely due to the wider separation of the two receivers making up each line; as a result, tagged fish could migrate over a line at a greater distance from the receivers than on other lines. While this is clearly not the case at the GVRD receiver, "misses" on this line are distinct from those observed elsewhere in the lake in that fish usually appear in the record from the GVRD receiver within hours of their detection at the dam; in contrast, the average lag is typically on the order of a few to several days for other pairs of lines in the lake. As the two southernmost receivers are only 200 m apart, but acoustically invisible to each other because of the geometry of the dam face, most of the "misses" on the GVRD line may not in fact be very significant.

Note that no fish were detected at the Buntzen Reservoir receiver, or at either of the Fraser River receivers deployed about 1 km downstream of the Port Mann bridge. Detailed line avoidance data are not available for these locations (due to the lack of downstream lines), although detailed experimental work carried out in the Fraser River suggests that detection rates at the Fraser River line was poor for the V7 tag compared to the in-reservoir performance (this is probably due to a high sediment load in the Fraser river attenuating the sound signal). However, even assuming that these three receivers performed no better than the worst lines in the Coquitlam Reservoir, it is unlikely that significant numbers of fish could have migrated past these detection lines without producing even one tag detection. This result is supported by our results for 19 Allouette sockeye smolts tagged with the V7 tag in July 2005; despite their much lower numbers, 4 were detected passing the Port Mann line. As a result, while we cannot rule out the possibility that some fish left the reservoir, it appears likely that the numbers must be very low.

4.2. Survival of Tagged Fish

As discussed in Section 3.2, tagged fish were released into the reservoir in five groups of approximately 24 fish, at intervals of one week. For each release group, the number of unique fish detected on the acoustic array per day initially increased with time as fish left the northern basin and dispersed throughout the reservoir, reaching a maximum after a few weeks to a month (Figure 3, Figure 4). As a result, the total number of unique fish detected per day increased for the first month of the study, reaching a peak of almost 80 fish shortly after the release of the fifth group of tagged fish (Figure 5(a)). After this initial peak, numbers declined as a result of tag loss, fish mortality, and possibly emigration from the reservoir; note that unless fish are detected outside the reservoir, these forms of loss cannot be distinguished.

The average "mortality" (fish loss) for all groups may be estimated by fitting an exponential curve to the declining portion of the curves in Figure 3-Figure 5(a), once all curves have been plotted as a function of days since release; the result is shown in Figure 5(b). The rate of decline calculated in this way is approximately 4% per day, or a survival rate of 30% per month (Figure 5(b)). As a result, almost half the fish originally released into the reservoir have disappeared a month and a half into the study (Figure 5), and no fish would be detected after slightly more than four months (assuming that this rate of mortality does not change with time). While this is a fairly high mortality rate, it provides ample time for smolts to leave the reservoir, and leaves a large enough population of fish through at least the first part of the study (up till the end of June) to support observations of migration pathways and responses to changes in BC Hydro operations. (The projected battery life of the tags exceeds 4.5 months, so tag lifespan is ample for the purposes of the study)

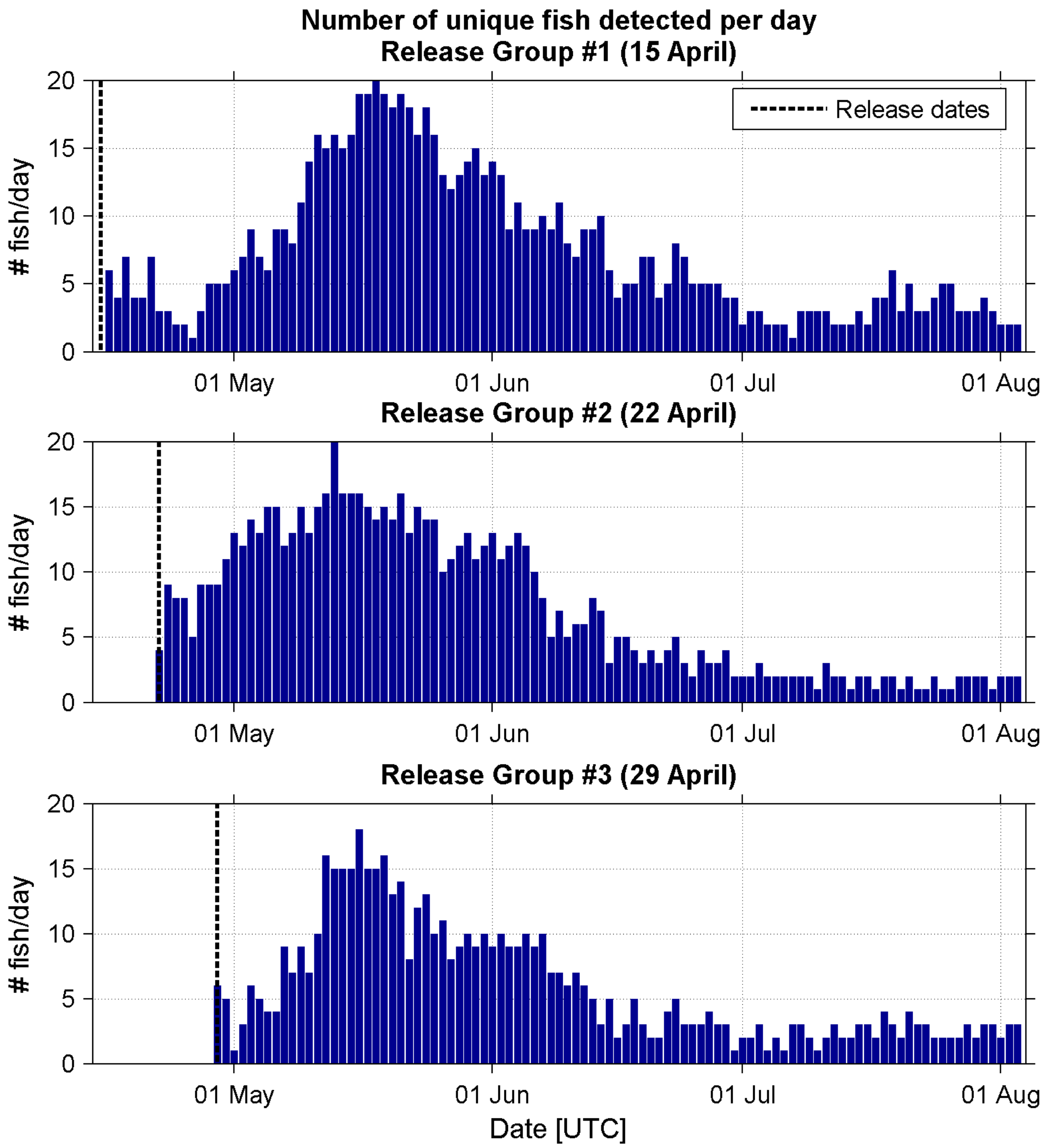

Figure 3. Number of unique fish (tags) detected on the Coquitlam Reservoir acoustic receiver array per day, as a function of time. The first three release groups are shown; 24 tagged coho smolts were released in each. The first group was released at the western release site (see Figure 1); groups 2 and 3 were released at the eastern site, as this site was further from an osprey nest. Each release group also included roughly twice as many untagged smolts (see Table 1), in order to reduce initial predation risk. *For each release group, the number of unique fish detected per day initially increases as the fish leave the release area and spread throughout the lake, then decreases as numbers decrease through a combination of mortality, emigration, and tag loss.*

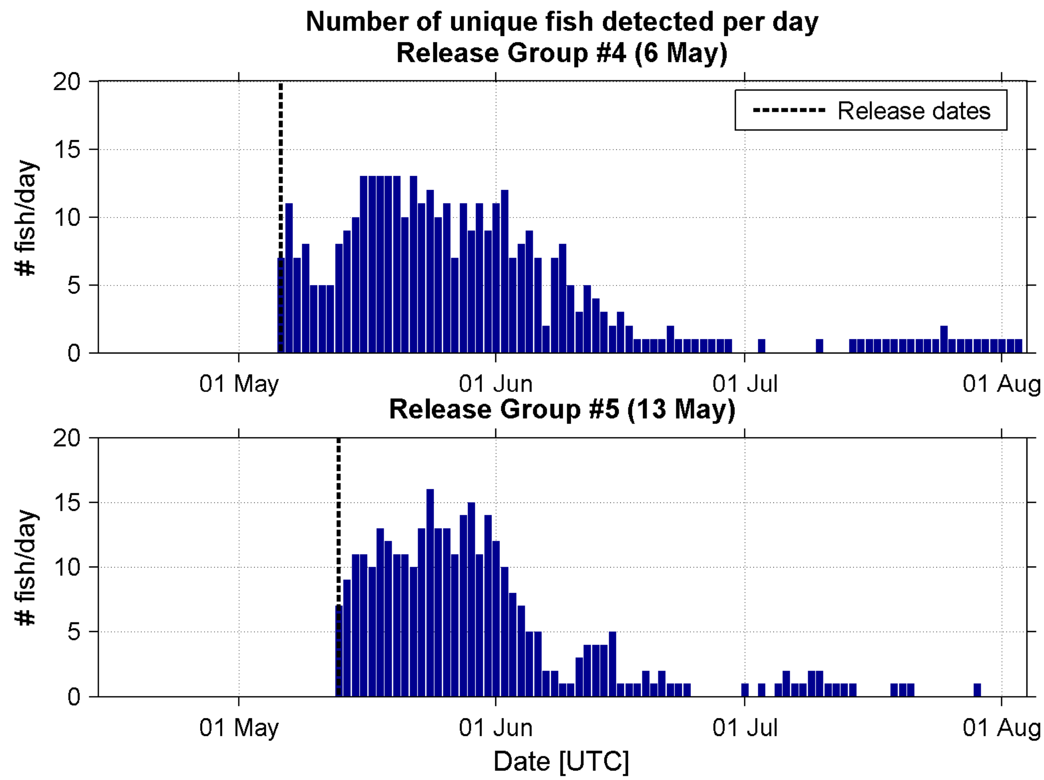

Figure 4. Number of unique fish (tags) detected on the Coquitlam Reservoir acoustic receiver array per day, as a function of time. The last two release groups are shown; 23 and 22 tagged coho smolts were released on 6 and 13 May, respectively. All were released at the eastern release site (see Figure 1). Each release group also included a roughly twice as many untagged smolts (see Table 1), in order to reduce initial predation risk. *For each release group, the number of unique fish detected per day initially increases as the fish leave the release area and spread throughout the lake, then decreases as numbers decrease through a combination of mortality, emigration, and tag loss.*

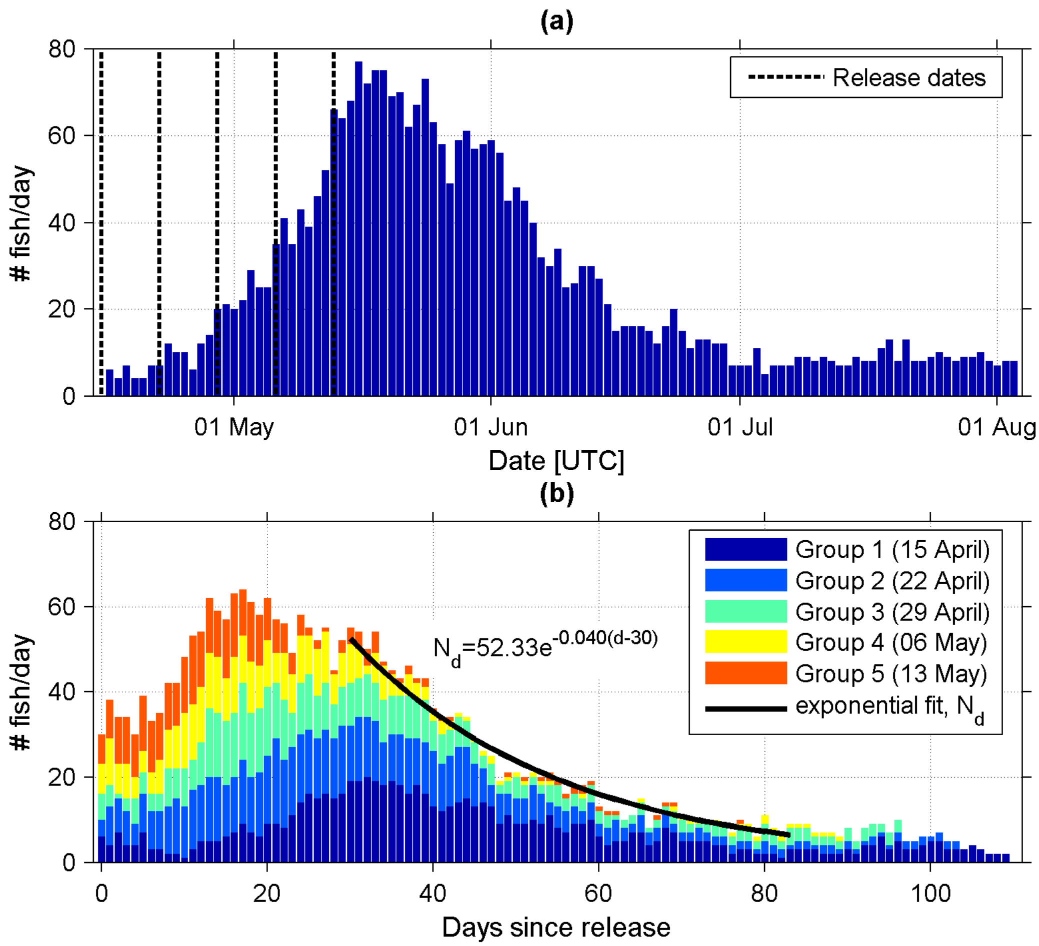

Figure 5. Number of unique fish (tags) detected on the Coquitlam Reservoir acoustic receiver array per day. (a) Number of unique fish detected per day, combining all 5 release groups plotted in Figure 3 and Figure 4. (b) Number of unique fish detected per day, as a function of the numbers of days since the fish were released into the reservoir. The black line represents an exponential fit to the portion of the plot between day 30 (by which time all groups had started declining) and day 83 (the receivers were retrieved 83 days after the last release). *After an initial peak (produced as fish spread throughout the lake), the number of fish detected on the array declines at a rate of 4% per day (survival rate of 30% per month).*

4.3. Fish Distributions

The tag detection data recorded by the receivers on the Coquitlam array may be manipulated in several ways to provide information on how fish use the reservoir. The numbers of unique fish detected on each receiver reflect preferred migration pathways, if they exist, and any tendency for fish to cluster. For example, Figure 6 shows the distribution of unique detections as a function of release group. Note that while the fish use the entire length of the lake (i.e., significant numbers of fish are detected everywhere within the reservoir), there appears to be a tendency for fish to favour one or another end of some lines, such as the eastern end of line 1 (south of the "neck" of the reservoir) and the western end of line 2 (north of the Buntzen inlet). However, the distributions are similar for all five release groups. Considering the distributions of the fish as a function of time (Figure 7), we see that while the numbers of unique fish detected on each receiver increase as more fish are released into the reservoir during the first five weeks of the study, the relative distributions do not appear to change in response to changes in BC Hydro operations (Figure 7). This suggests that fish are not changing their routes or distributions in response to the changing flows.

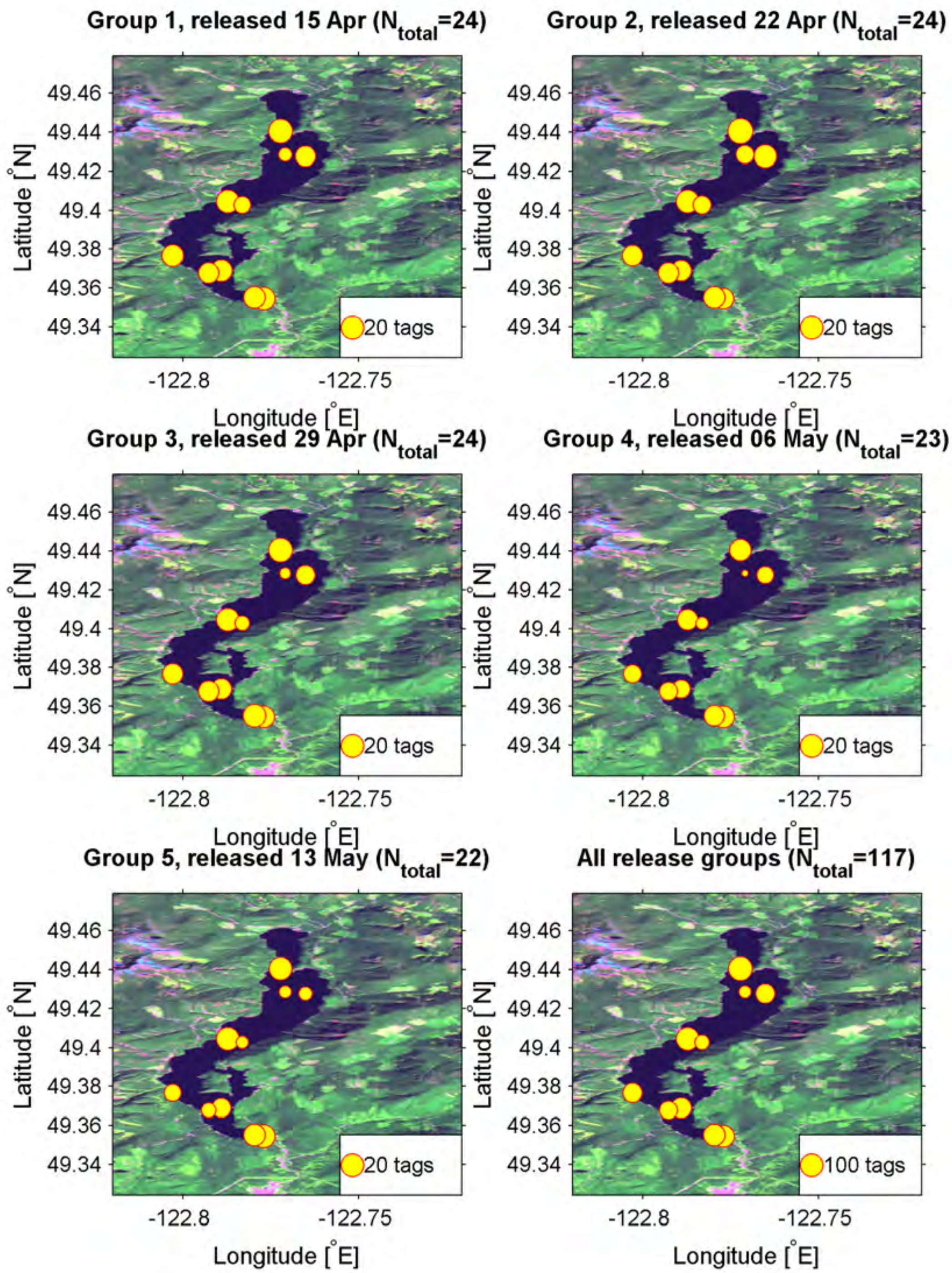

Figure 6. Number of unique fish detected at least once on each Coquitlam Reservoir acoustic receiver between April 15 (the first date for the release of Coho smolts) and August 4 (receiver retrieval), for each release group listed in Table 1. The area of each circle is proportional to the number of unique fish detected at the receiver located at the centre of the circle. Note that no Coquitlam Reservoir coho were detected at either the Fraser River receivers or the Buntzen Reservoir receiver (locations shown in Figure 1). The release date and total number of tagged fish in each release group is shown at the top of the corresponding panel. *The average distribution of tagged fish was similar for each of the five groups of fish released into the reservoir.*

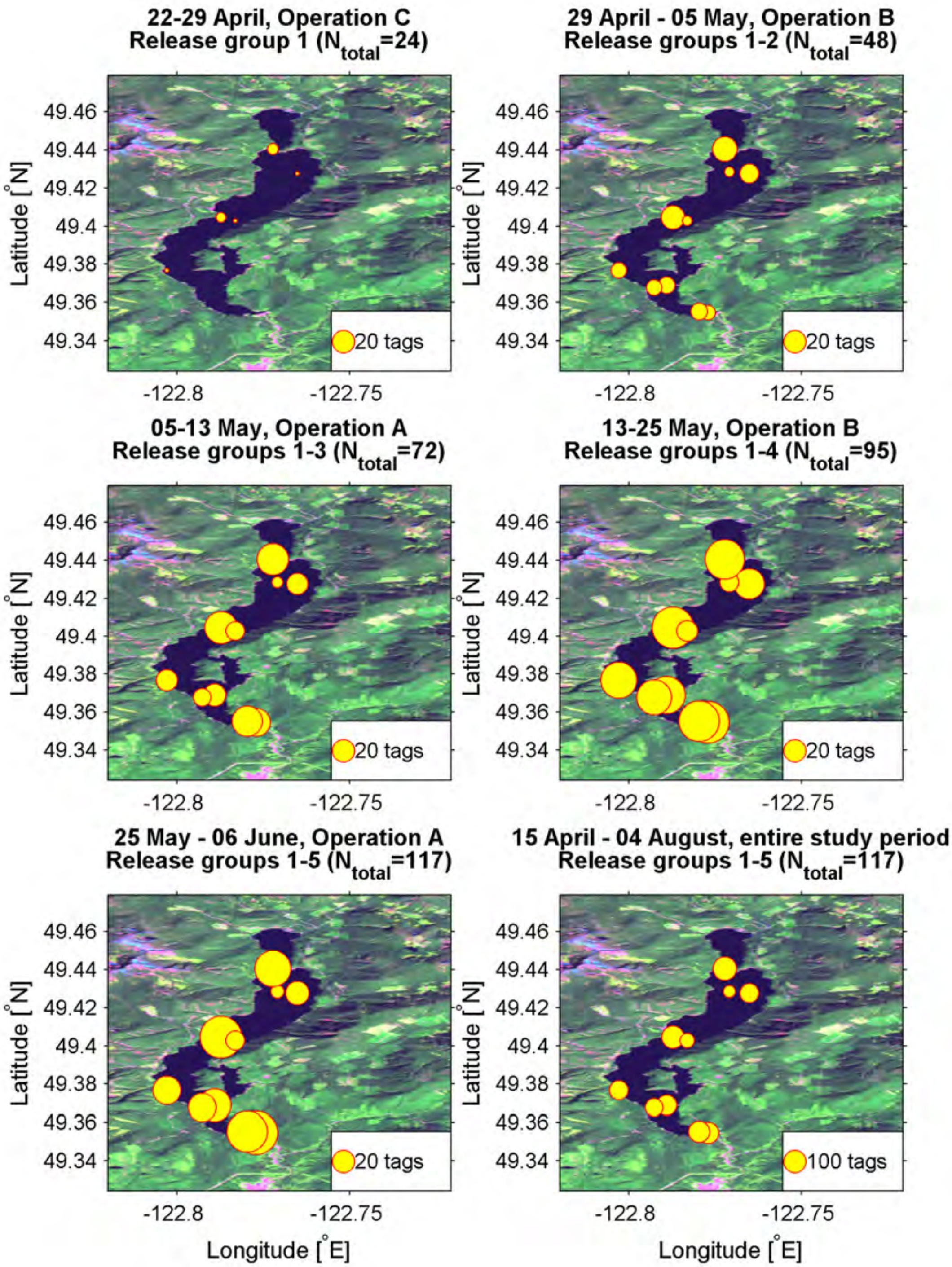

Figure 7. Number of unique fish detected at least once on each Coquitlam Reservoir acoustic receiver during each of 5 different BC Hydro operations (see Table 2), and during the entire study period. The area of each circle is proportional to the number of unique fish detected at the receiver located at the centre of the circle. For each panel, all release groups except the one released at the start of the current BC Hydro operation (if applicable) are included; see Table 1. Note that no Coquitlam Reservoir coho were detected at either the Fraser River receivers or the Buntzen Reservoir receiver (locations shown in Figure 1). *The relative distribution of tagged fish in the Coquitlam Reservoir did not change significantly in response to changes in BC Hydro operations.*

Another approach is to consider the total number of valid tag transmissions recorded at each receiver. This measure cannot be strictly interpreted as the number of fish present at a site times the number of minutes each fish spent there, due both to the issues discussed in Section 4.1 and to the disproportionate contribution that may occur if a tag is rejected or a fish dies within the range of a receiver. However, if these limitations or kept in mind, the number of tag transmissions recorded at each receiver can be used as a rough indication of the amount of time fish spent in that area. For example, from Figure 8 and Figure 9, it can be seen that fish preferred to spend their time in a few areas of the reservoir, including near the GVRD inlet and dam, as well as near the middle of the lake. While there were a small number of questionable detections at each of these sites, which were recorded almost continuously and only at a single location after mid-May to early June, (Figure 8), the numbers of transmissions recorded at each of these sites are significantly greater than those observed at the remaining Coquitlam receivers even once the questionable tag codes have been excluded. Once again, significant changes are not seen when comparing BC Hydro operations A (Buntzen tunnel closed) and B (tunnel open) (Figure 9). For example, fish did not spend significantly more time near the Buntzen tunnel inlet when Operation B was in effect. Unfortunately, only one fish reached the south end of the lake during the time that Operation C (highest flow through the LLO) was in operation (first panel of Figure 9), hence it is not possible to evaluate whether or not fish would respond any differently to this operation.

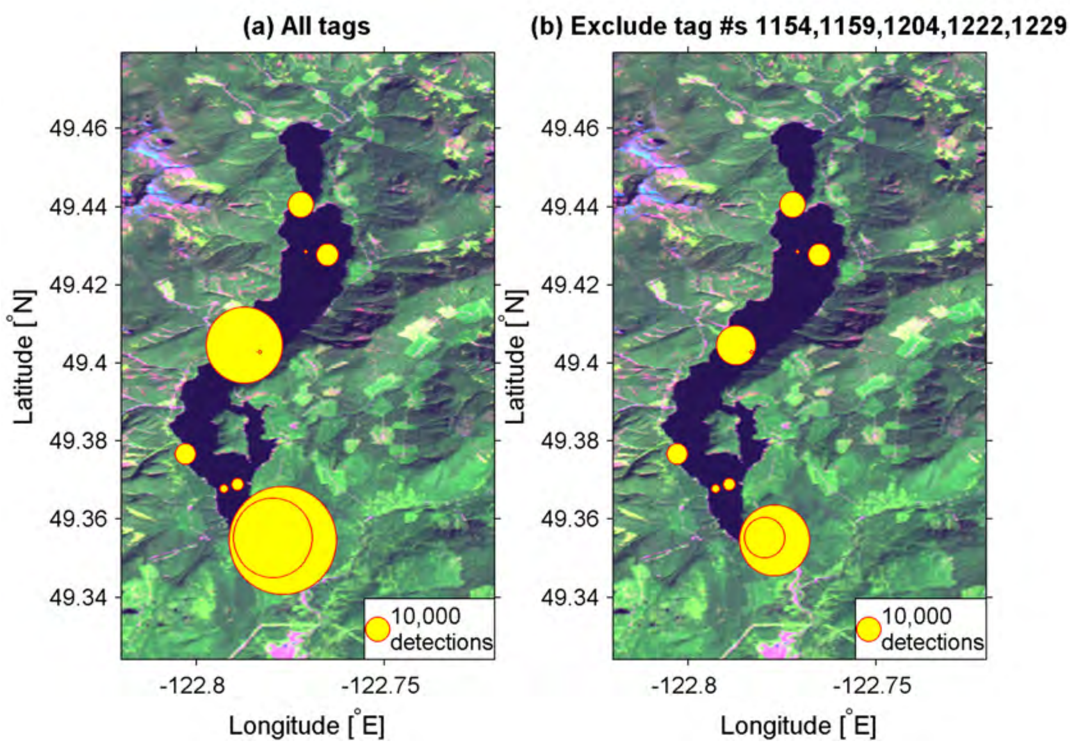

Figure 8. Number of tag transmissions recorded at each Coquitlam Reservoir acoustic receiver between April 15 and August 4, from all tagged fish released into the reservoir (a) and from all but 4 tags that are suspected to have died in the vicinity of receivers (b). The area of each circle is proportional to the number of pings detected by the receiver located at the centre of the circle, and is approximately indicative of relative habitat use at that location. Resident fish or tag loss near a receiver will result in an average one transmission per minute (i.e., 1440 transmissions per day); five such occurrences explain a portion of the very large numbers of tag transmissions at the two southernmost receivers and at receiver # 1823 (Figure 1). *Coho smolts preferred to spend their time in a few areas of the reservoir; in particular, some fish appeared to take up residence near the GVRD inlet and dam.*

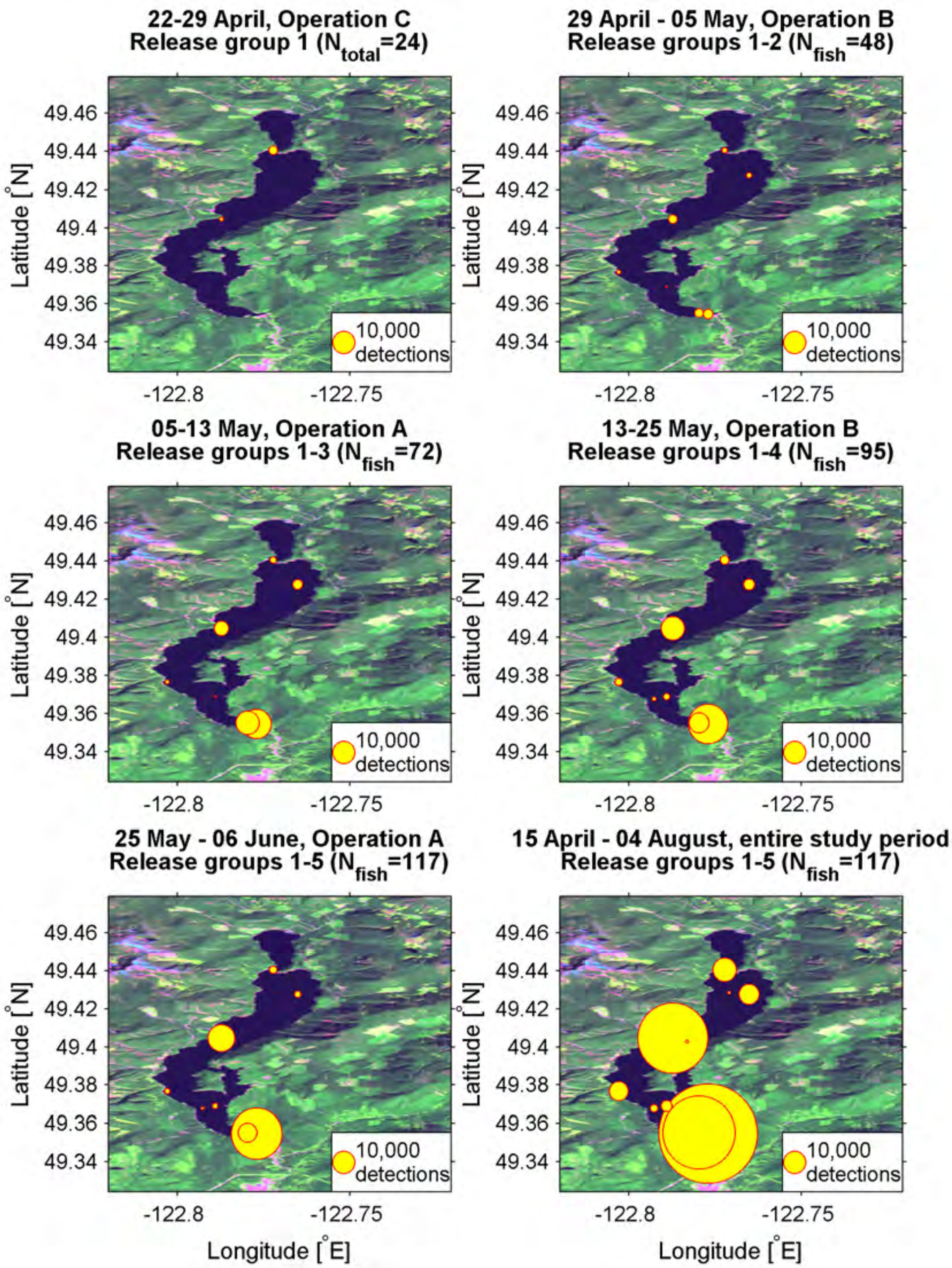

Figure 9. Number of tag transmissions recorded at each Coquitlam Reservoir acoustic receiver during the periods of time shown. The area of each circle is proportional to the number of pings detected by the receiver located at the centre of the circle, and is approximately indicative of relative habitat use at that location. For each panel, all release groups except the one released at the start of the current BC Hydro operation (if applicable) are included; see Table 1. Note that the very large number of transmissions at some receivers was partly due to a few resident tags (see Figure 8). No Coquitlam Reservoir coho were detected at either the Fraser River receivers or the Buntzen Reservoir receiver (locations shown in Figure 1). *Coho smolts preferred to spend their time in a few areas of the reservoir; in particular, some fish appeared to take up residence near the GVRD inlet and dam. This was not significantly affected by changes in BC Hydro operations.*

4.4. Movement of Fish through the Reservoir

By extracting all occurrences of a given tag code on the acoustic listening array, it is possible to track the movements of individual fish through the reservoir. The most straightforward way to view the result is via animations such as those described in Appendix A4; these simultaneously show the routes taken by the smolts and the rates at which they travel along those routes. (Files containing these animations are included in the CD-ROM attached at the back of paper copies of this report). Alternatively, the pathways and final known detection locations can be illustrated statically, as shown in Figure 10 through Figure 14 for all groups of smolts released into the Coquitlam Reservoir. While individual paths vary somewhat, the following general patterns may be observed:

- Fish make repeated excursions over the entire length of the reservoir.
- Last known detections may occur at any of the listening sites; there is no evidence for preferred aggregation near the outlets.
- Neither pathways nor end points appear to be affected by the date on which fish were released; all groups of smolts behave similarly.

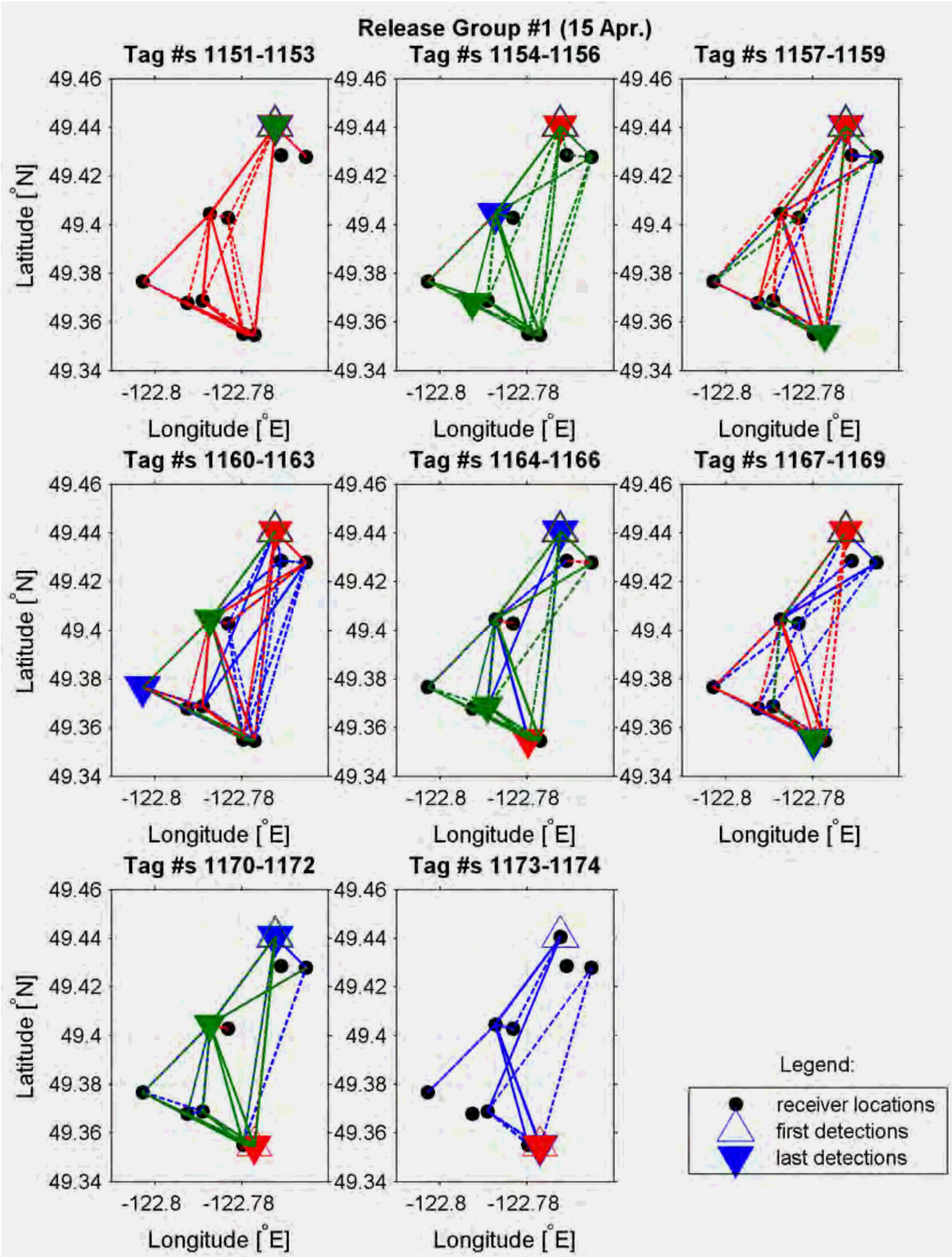

Figure 10. Motions of all tagged coho smolts released on April 15, 2005, through the Coquitlam Reservoir. Black dots mark the locations of the Coquitlam Reservoir receivers (see Figure 1); dashed lines connect successive fish detections (solid lines occur where two or more lines overlap); empty and filled triangles indicate first and last detections, respectively. Each panel shows the movements of three fish (two fish in the last panel), each plotted in a separate colour. *Repeated excursions over the entire length of the reservoir are evident for most fish from the first release group, demonstrating extensive use of the reservoir, and no evidence for preferred aggregation near the outlets.* (See also animation files, Appendix A4.)

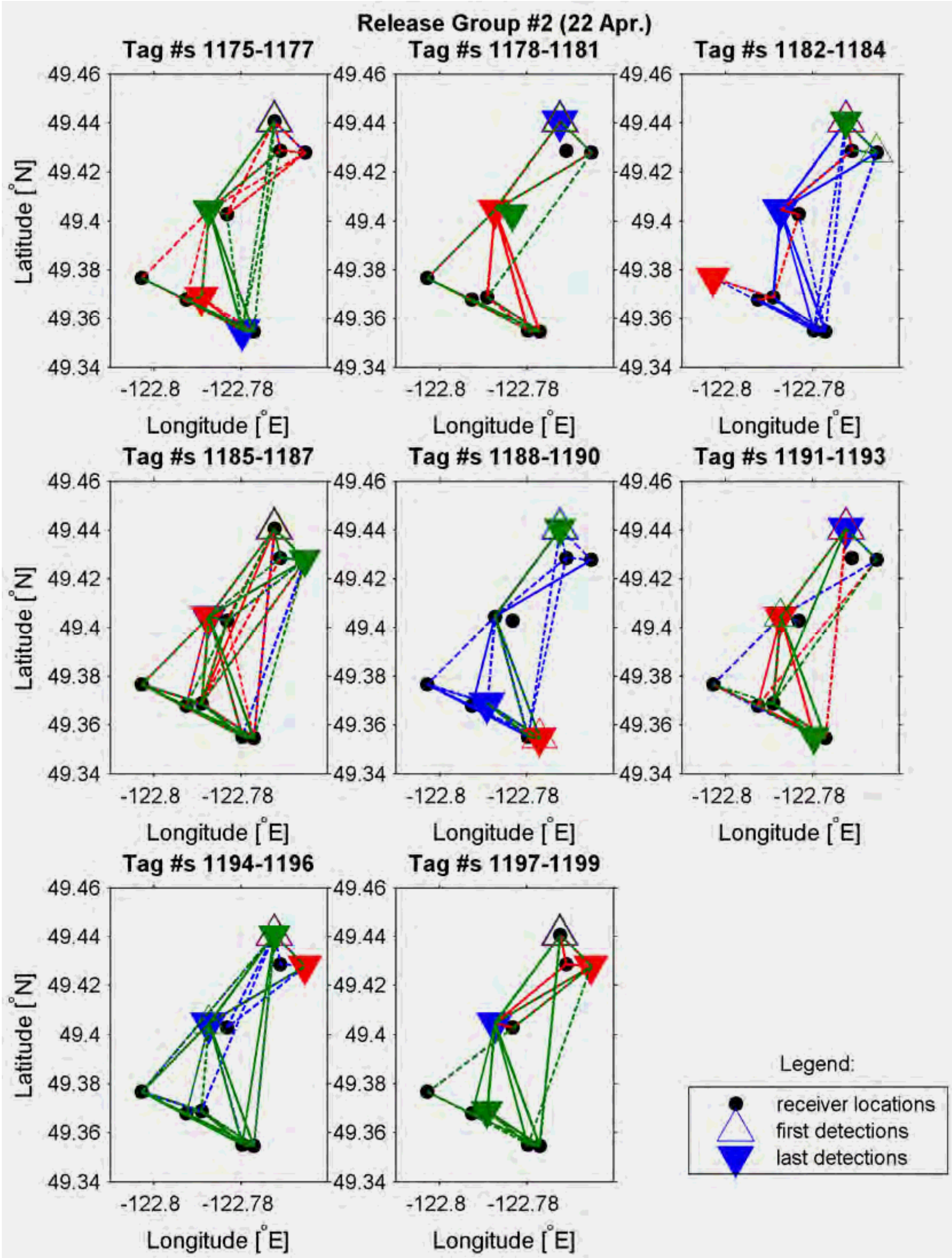

Figure 11. Motions of all tagged coho smolts released on April 22, 2005, through the Coquitlam Reservoir. Black dots mark the locations of the Coquitlam Reservoir receivers (see Figure 1); dashed lines connect successive fish detections (solid lines occur where two or more lines overlap); empty and filled triangles indicate first and last detections, respectively. Each panel shows the movements of three fish, each plotted in a separate colour. *Repeated excursions over the entire length of the reservoir are evident for most fish from the second release group, demonstrating extensive use of the reservoir, and no evidence for preferred aggregation near the outlets.* (See also animation files, Appendix A4.)

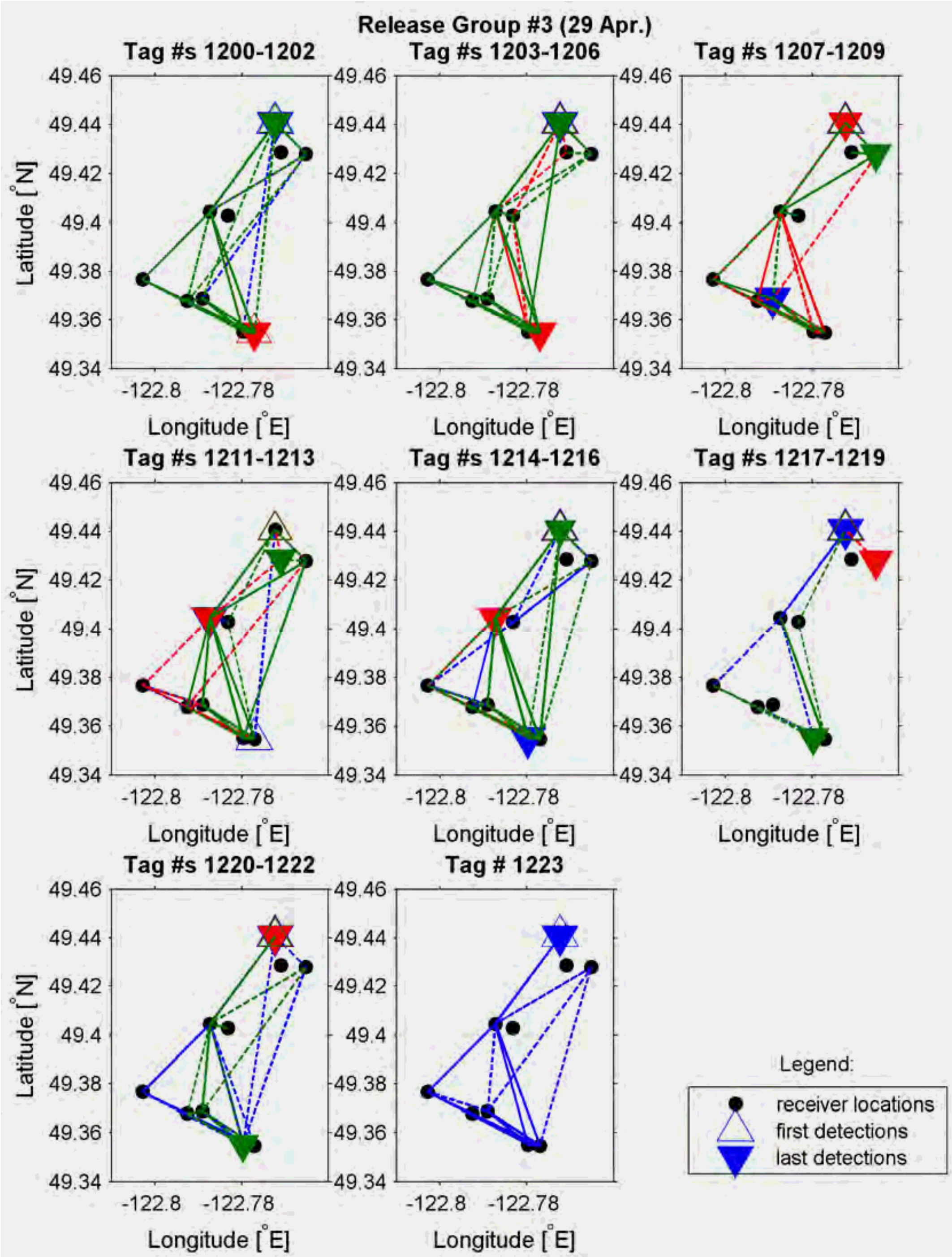

Figure 12. Motions of all tagged coho smolts released on April 29, 2005, through the Coquitlam Reservoir. Black dots mark the locations of the Coquitlam Reservoir receivers (see Figure 1); dashed lines connect successive fish detections (solid lines occur where two or more lines overlap); empty and filled triangles indicate first and last detections, respectively. Each panel shows the movements of three fish (one fish in the last panel), each plotted in a separate colour. *Repeated excursions over the entire length of the reservoir are evident for most fish from the third release group, demonstrating extensive use of the reservoir, and no evidence for preferred aggregation near the outlets.* (See also animation files, Appendix A4.)

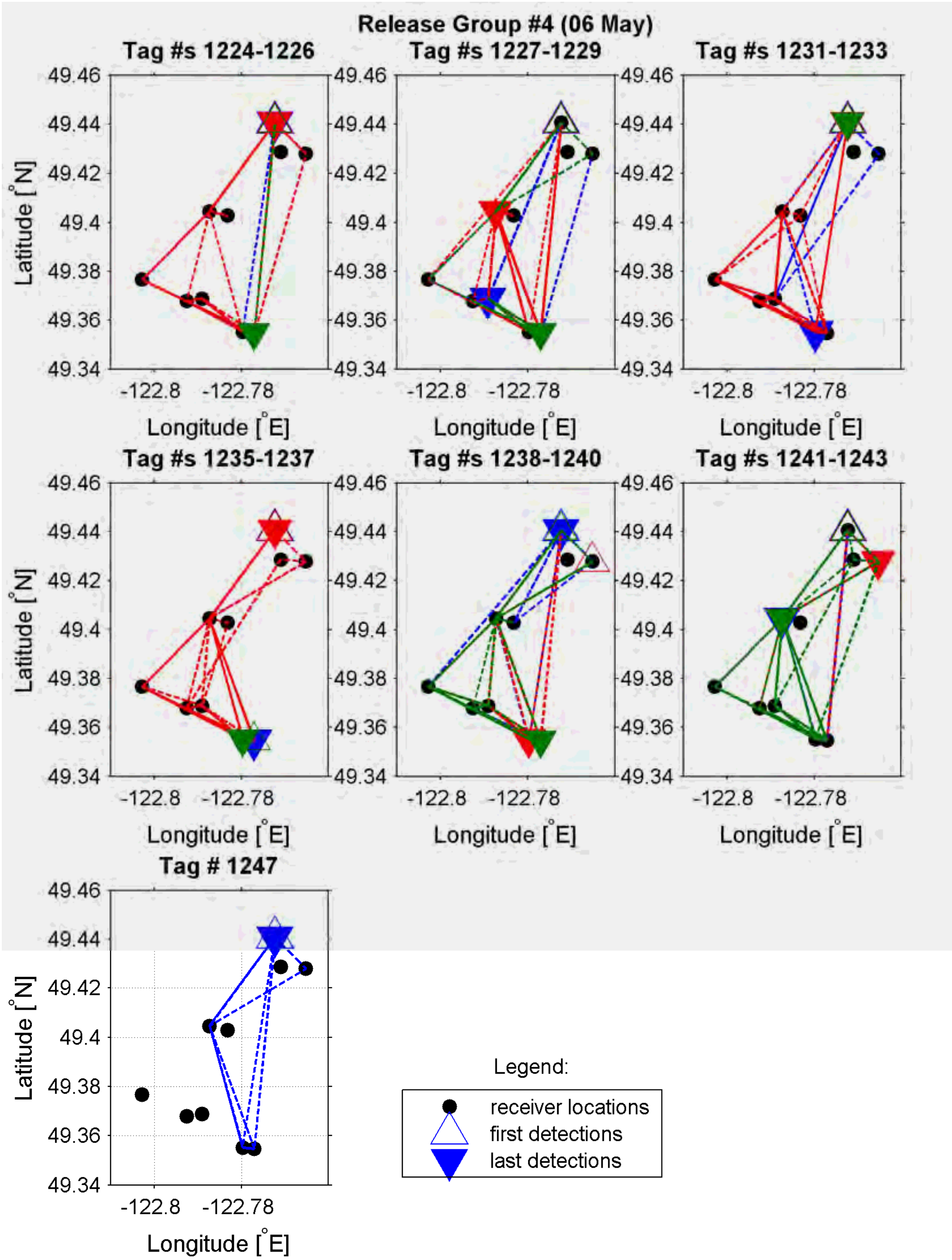

Figure 13. Motions of all tagged coho smolts released on May 06, 2005, through the Coquitlam Reservoir. Black dots mark the locations of the Coquitlam Reservoir receivers (see Figure 1); dashed lines connect successive fish detections (solid lines occur where two or more lines overlap); empty and filled triangles indicate first and last detections, respectively. Each panel shows the movements of three fish (one fish in the last panel), each plotted in a separate colour. *Repeated excursions over the entire length of the reservoir are evident for most fish from the fourth release group, demonstrating extensive use of the reservoir, and no evidence for preferred aggregation near the outlets.* (See also animation files, Appendix A4.)

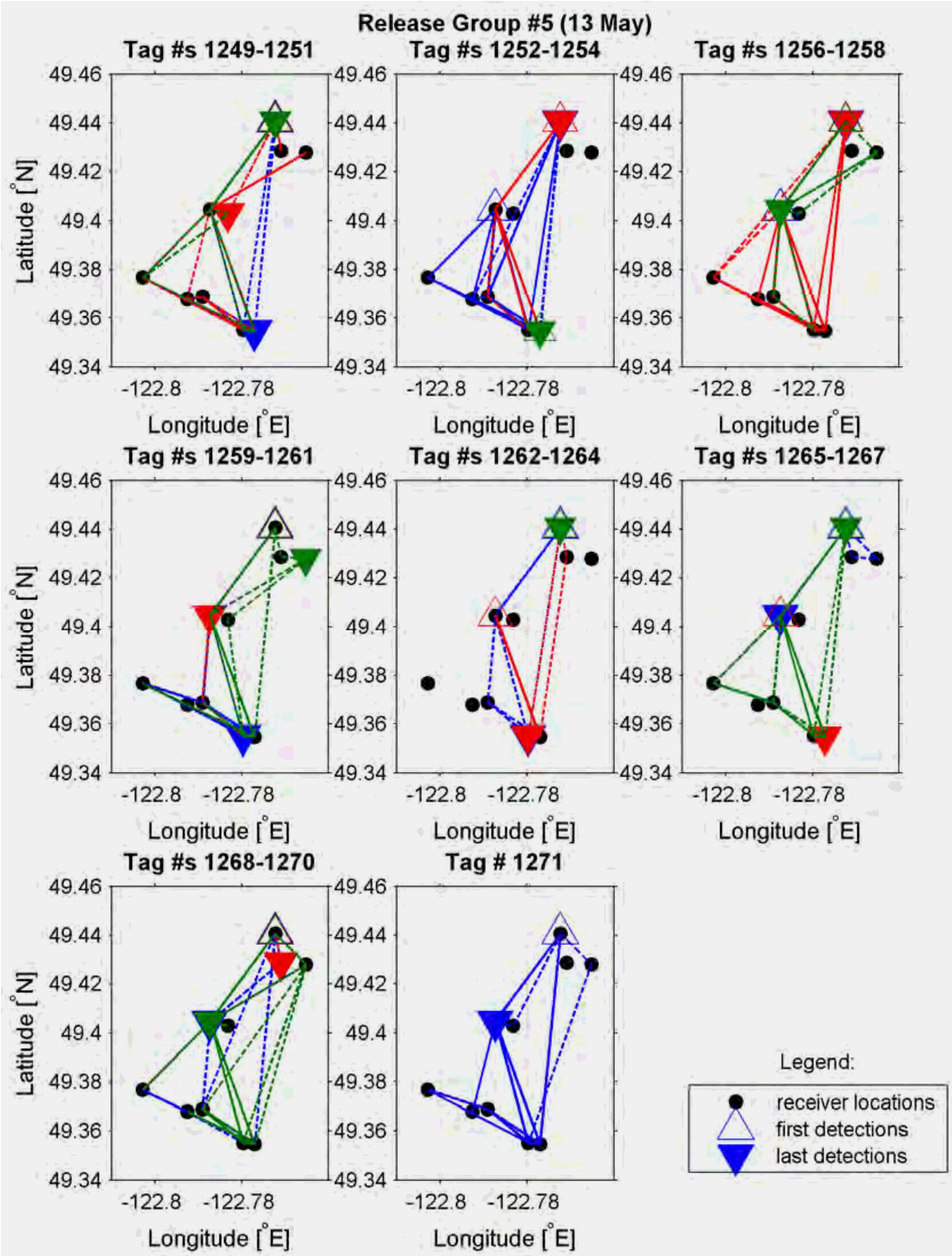

Figure 14. Motions of all tagged coho smolts released on May 13, 2005, through the Coquitlam Reservoir. Black dots mark the locations of the Coquitlam Reservoir receivers (see Figure 1); dashed lines connect successive fish detections (solid lines occur where two or more lines overlap); empty and filled triangles indicate first and last detections, respectively. Each panel shows the movements of three fish (one fish in the last panel), each plotted in a separate colour. *Repeated excursions over the entire length of the reservoir are evident for most fish from the fifth release group, demonstrating extensive use of the reservoir, and no evidence for preferred aggregation near the outlets.* (See also animation files, Appendix A4.)

The progress of fish along the pathways shown in Figure 10 - Figure 14 is illustrated in Figure 15 - Figure 19. For each release group, the distribution of fish at the end of each BC Hydro operation is shown; note that, unlike Figure 3 - Figure 6 in the previous section, each fish is counted at only one location in these figures, at the site where it was last detected. During the first 1-3 weeks after release, the smolts disperse from the north end of the reservoir, gradually occupying the entire length of the lake. In fact, as can be seen in the animations (Appendix A4), motion shortly after release tends to be directed toward the south end of the reservoir, becoming more random after this first traverse of the lake. While the first release group took longer to spread throughout the reservoir, final distributions are similar for all 5 release groups. As noted in the previous section, there is no evidence of clustering at the outlets. In addition, relative distributions do not appear to change in response to changes in BC Hydro operations.

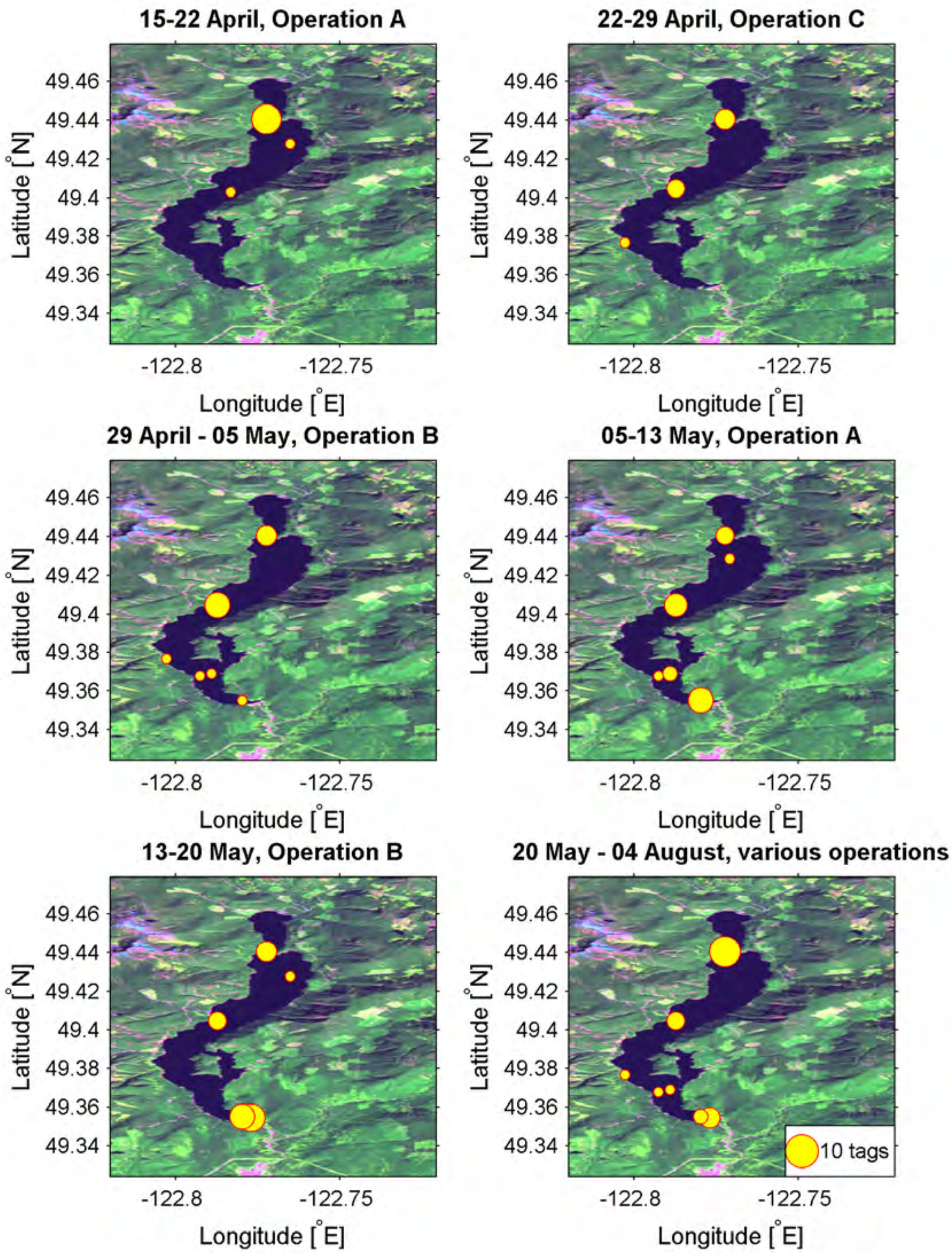

Figure 15. Last known locations of tagged fish released into the Coquitlam Reservoir on 15 April (release group #1, see Table 1), at the end of each of 6 periods during which BC Hydro operations were kept constant (see Table 2). The area of each circle represents the number of fish (tags) for which the last acoustic detection during the study was at the receiver located at the centre of the circle. Note that no Coquitlam Reservoir coho were detected at either the Fraser River receivers or the Buntzen Reservoir receiver (locations shown in Figure 1). *Smolts in the first release group disperse throughout the reservoir within 2-3 weeks of release, and make use of the entire reservoir, rather than clustering at the outlets. Distributions do not appear to change in response to changes in BC Hydro operations.*

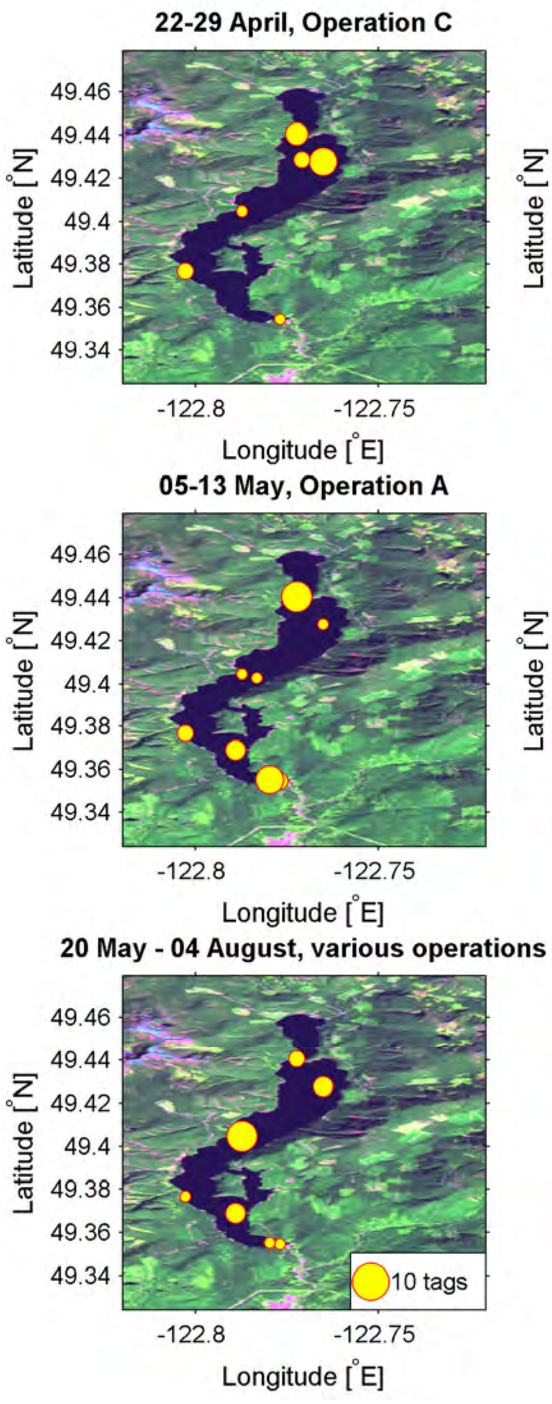

Figure 16. Last known locations of tagged fish released into the Coquitlam Reservoir on 22 April (release group #2, see Table 1), at the end of each of 5 periods during which BC Hydro operations were kept constant (see Table 2). The area of each circle represents the number of fish (tags) for which the last acoustic detection during the study was at the receiver located at the centre of the circle. Note that no Coquitlam Reservoir coho were detected at either the Fraser River receivers or the Buntzen Reservoir receiver (locations shown in Figure 1). *Smolts in the second release group disperse throughout the reservoir within one week of release, and make use of the entire reservoir, rather than clustering at the outlets. Distributions do not appear to change in response to changes in BC Hydro operations.*

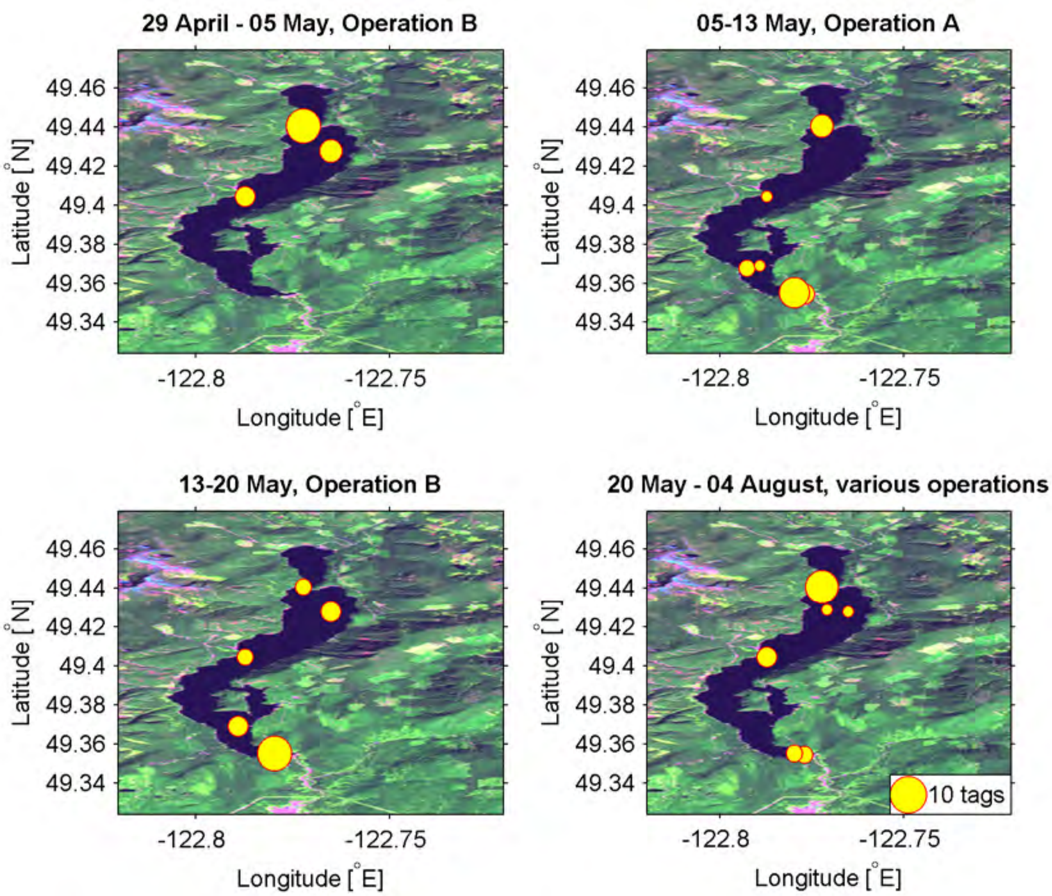

Figure 17. Last known locations of tagged fish released into the Coquitlam Reservoir on 29 April (release group #3, see Table 1), at the end of each of 4 periods during which BC Hydro operations were kept constant (see Table 2). The area of each circle represents the number of fish (tags) for which the last acoustic detection during the study was at the receiver located at the centre of the circle. Note that no Coquitlam Reservoir coho were detected at either the Fraser River receivers or the Buntzen Reservoir receiver (locations shown in Figure 1). *Smolts in the third release group disperse throughout the reservoir within 1-2 weeks of release, and make use of the entire reservoir, rather than clustering at the outlets. Distributions do not appear to change in response to changes in BC Hydro operations.*

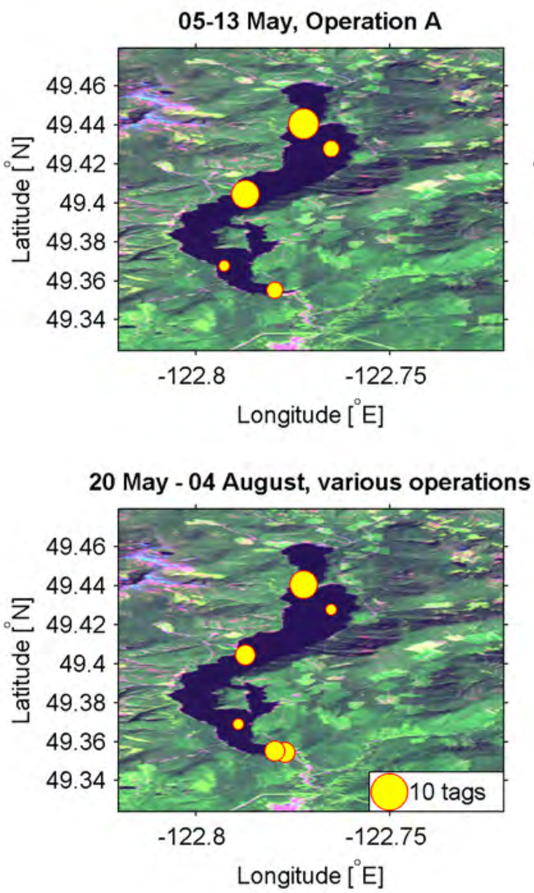

Figure 18. Last known locations of tagged fish released into the Coquitlam Reservoir on 06 May (release group #4, see Table 1), at the end of each of 3 periods during which BC Hydro operations were kept constant (see Table 2). The area of each circle represents the number of fish (tags) for which the last acoustic detection during the study was at the receiver located at the centre of the circle. Note that no Coquitlam Reservoir coho were detected at either the Fraser River receivers or the Buntzen Reservoir receiver (locations shown in Figure 1). *Smolts in the fourth release group disperse throughout the reservoir within one week of release, and make use of the entire reservoir, rather than clustering at the outlets. Distributions do not appear to change in response to changes in BC Hydro operations.*

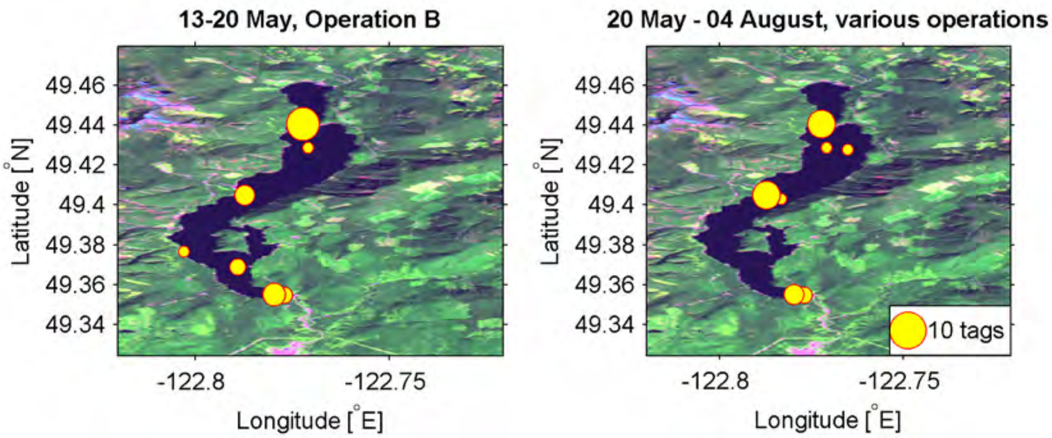

Figure 19. Last known locations of tagged fish released into the Coquitlam Reservoir on 13 May (release group #5, see Table 1), at the end of each of 2 periods during which BC Hydro operations were kept constant (see Table 2). The area of each circle represents the number of fish (tags) for which the last acoustic detection during the study was at the receiver located at the centre of the circle. Note that no Coquitlam Reservoir coho were detected at either the Fraser River receivers or the Buntzen Reservoir receiver (locations shown in Figure 1). *Smolts in the fifth release group disperse throughout the reservoir within one week of release, and make use of the entire reservoir, rather than clustering at the outlets. Distributions do not appear to change in response to changes in BC Hydro operations.*

4.5. Average Rates of Travel

4.5.1. Southward Rates of Travel Post-Release

As discussed in Section 4.4, newly released fish tend to swim toward the south end of the lake. The rate at which this first traverse of the lake is accomplished is described in Table 5. Average rates of travel are slow, and vary between 0.2 and 1.6 cm/s (i.e., at best only slightly over one-tenth of a body length per second), so that the newly released smolts arrive at the base of the dam between 8 and 27 days after their release almost 12 km away. Note that these average rates of travel are calculated based on straight-line paths between acoustic lines, and likely underestimate the actual speeds at which individual smolts are swimming. Average rates of travel tend to be higher for later release groups, although speeds in body lengths/second were not significantly greater for the older fish (Table 1). In addition, for each release group, rates of travel are considerably higher toward the south end of the reservoir (note that this is only the case for the first southward traverse, see Section 4.5.3 for details). While it is difficult to distinguish any potential effects of changing hydro operations from this trend, there does not appear to be any clear changes in rates of travel in response to changes in operations (Table 5). As rates of travel for migrating smolts in the ocean measured using the POST array are typically on the order of 1-2 body lengths per second, the tagged coho are not strongly orienting towards the outflow regions at the south of the lake.

Release group	*(a) Number of days from release to first detection on each listening line Mean transit time (range)*					
	Northern "neck"	*Line 1*	*Line 2*	*Line 3*	*GVRD inlet*	*Dam*
Group 1, Operation A	11 (1-31)	22 (2-45)	19 (5-31)	26 (14-47)	25 (14-44)	27 (15-44)
Group 2, Operation C	5 (<1-19)	10 (<1-40)	9 (1-20)	12 (3-22)	16 (5-65)	15 (5-29)
Group 3, Operation B	4 (<1-13)	16 (1-39)	11 (1-22)	15 (8-23)	14 (7-20)	15 (3-38)
Group 4, Operation A	2 (<1-20)	11 (2-17)	4 (<1-10)	10 (3-17)	13 (2-65)	12 (5-23)
Group 5, Operation B	3 (<1-24)	7 (2-27)	4 (<1-20)	8 (3-21)	7 (3-16)	8 (<1-23)
Release group	*(b) Average swimming speed (cm/s) Average speed (range)*					
	Northern "neck"	*Line 1*	*Line 2*	*Line 3*	*GVRD inlet*	*Dam*
Group 1, Operation A	0.2 (0.1-1.9)	0.2 (0.1-1.9)	0.4 (0.2-1.4)	0.4 (0.2-0.9)	0.5 (0.3-1.0)	0.5 (0.3-0.9)
Group 2, Operation C	0.3 (0.1-4.0)	0.3 (0.1-7.1)	0.8 (0.3-6.1)	0.9 (0.5-3.6)	0.8 (0.2-2.6)	0.9 (0.5-2.8)
Group 3, Operation B	0.4 (0.1-3.5)	0.2 (0.1-2.6)	0.6 (0.3-5.4)	0.7 (0.5-1.5)	1.0 (0.7-1.8)	0.9 (0.4-5.3)
Group 4, Operation A	0.7 (0.1-4.7)	0.3 (0.2-1.6)	1.7 (0.7-12.4)	1.2 (0.7-3.5)	1.0 (0.2-7.0)	1.2 (0.6-2.7)
Group 5, Operation B	0.6 (0.1-4.7)	0.4 (0.1-1.7)	1.5 (0.3-10.0)	1.4 (0.5-4.5)	1.9 (0.8-4.8)	1.6 (0.6-15.9)

Table 5. Number of days between release and first detection on each listening line in the Coquitlam Reservoir (a), and corresponding average swimming speed (b) (see Figure 1 and Table 3 for a description of the listening lines, Table 1 for a description of fish release groups, and Table 2 for a description of BC Hydro operations). Mean times and speeds (for all fish in each release group) are shown, along with values for the first and last fish to arrive at each line. Note that line avoidance occasionally causes the time to first arrival at a given line to be less than that for more northern lines; see Section 4.1. Also note that apparent transit times may appear shorter than they are in reality when the first and last detections on the two lines both occur at the outer portion of the receivers' range. *Fish arrived at the south end of the reservoir an average of 1-4 weeks after release, indicating average directed swimming speeds of 0.5-1.6 cm/s .*

4.5.2. Variations between Release Groups

Travel rates may also be calculated for all occurrences of travel between a given pair of acoustic listening lines. While this estimate of swimming speeds may be biased by fish that are detected on the edge of the range of one or both acoustic receivers, as well as by the exclusion of fish which “avoid” lines (Section 4.1), it can provide some indication of the average rates at which fish are moving north or south along the reservoir. It should be noted that the rates of travel calculated in this way cannot be compared directly with those listed in Section 4.5.1. The rates of travel in Section 4.5.1 are calculated for the entire first southward traverse of the reservoir, and may include extended residence at intermediate sites or reversals in direction; in contrast, velocities in this section are calculated using only direct travel from one listening line to another, and as such are generally much higher.

Average rates of travel over the entire study period are shown for each of the five release groups in Figure 20. While rates of travel during the first southward traverse of the lake are considerably higher for later release groups, average speeds over the entire study period are similar over all five groups. This makes it possible to combine all five groups in calculations of “typical” swimming speeds, yielding a sample size adequate for the consideration of variations in response to changes in BC Hydro operations (next section).

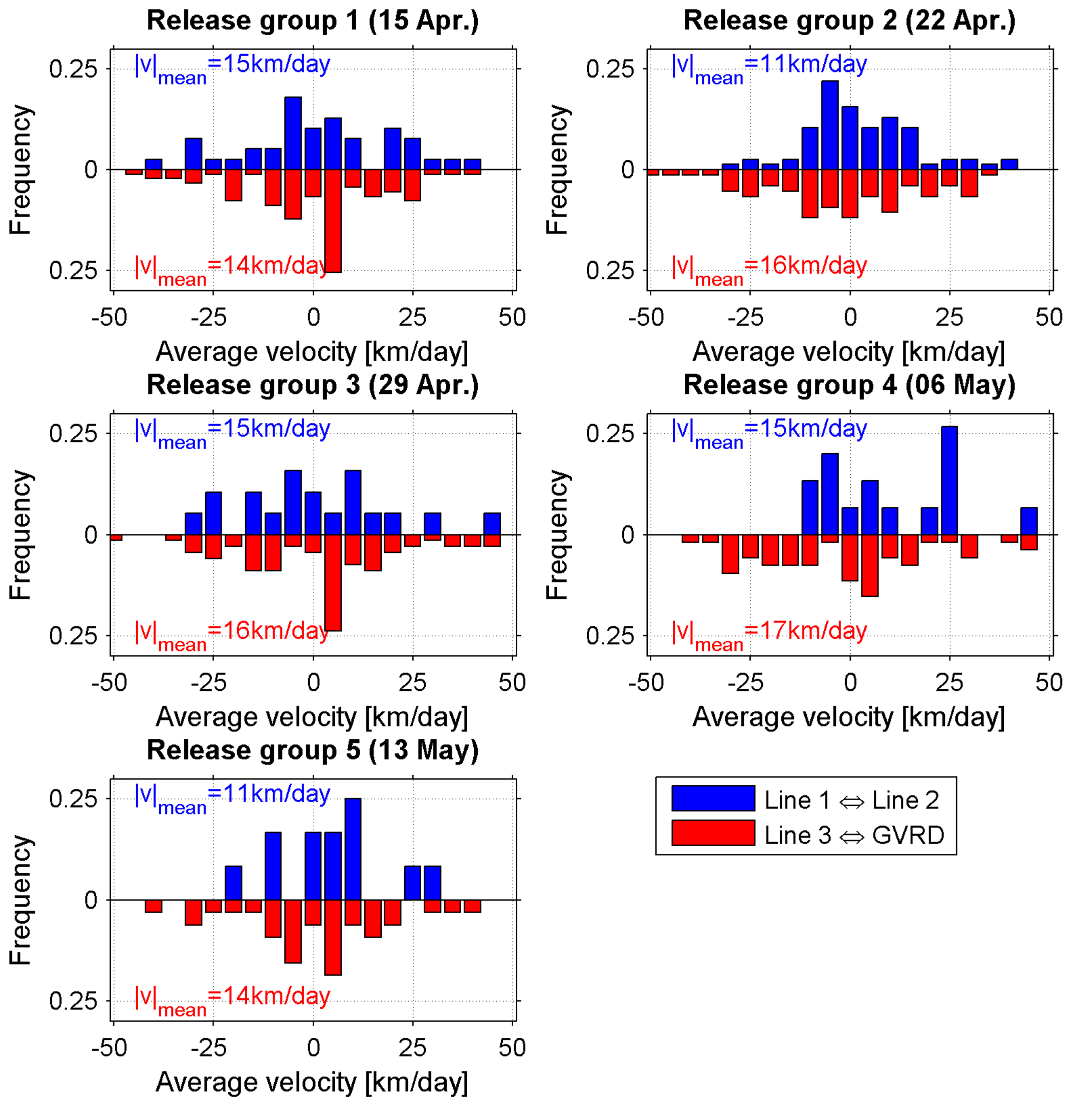

Figure 20. Histograms of average swimming speed between acoustic line numbers 1 and 2 (north of the Buntzen tunnel), and between line 3 (south of the tunnel) and the GVRD water inlet (see Figure 1, Table 3), for each of the five groups of tagged smolts released into the Coquitlam Reservoir (Table 1). Average swimming speeds are calculated from the time between the last detection on one line and the first detection on the next, and are positive for northward travel. The average speed (absolute value of the velocity) is labelled on each graph. These speeds are sufficient for the smolts to swim the length of the reservoir in one day. Note that speeds greater than ±50 km/day are not shown (likely the result of sequential detections for fish located between two nearby receivers). *Swimming speeds at the north end of the reservoir were similar to those measured at the south end, and speeds of movement were similar for fish going north or south in the reservoir, for all groups.*

4.5.3. Effect of BC Hydro Operations

Average rates of travel between lines in the middle and southern sections of the Coquitlam Reservoir are shown in Figure 21 - Figure 24. Note that, in contrast with the first southward traverse of the lake, average rates of travel between acoustic listening lines now appear to be slightly greater toward the north end of the reservoir, with fish "lingering" at the south end (this can also be seen in the animations, Appendix A4).

For most operations, a significant number of trips between pairs of lines (i.e., tens or hundreds of crossings) were observed during each operation, making it possible to compare average rates of travel with a reasonable level of confidence. The only exception is Operation C (high flow through the LLO); as noted in Section 4.3, few to no fish were present at the south end of the reservoir during these first two weeks of the study. Considering each of Figure 21 - Figure 24, while there is considerable variation in the average swimming speeds observed during each one-week period, there are no consistent differences when comparing rates of travel under operation A with those under operation B. Not only were average speeds (absolute value of the velocity) similar, but there was no consistent shift toward predominantly northward or southward travel. As with observations of fish distributions and movements, these results do not suggest changes in behaviour in response to changing operations.

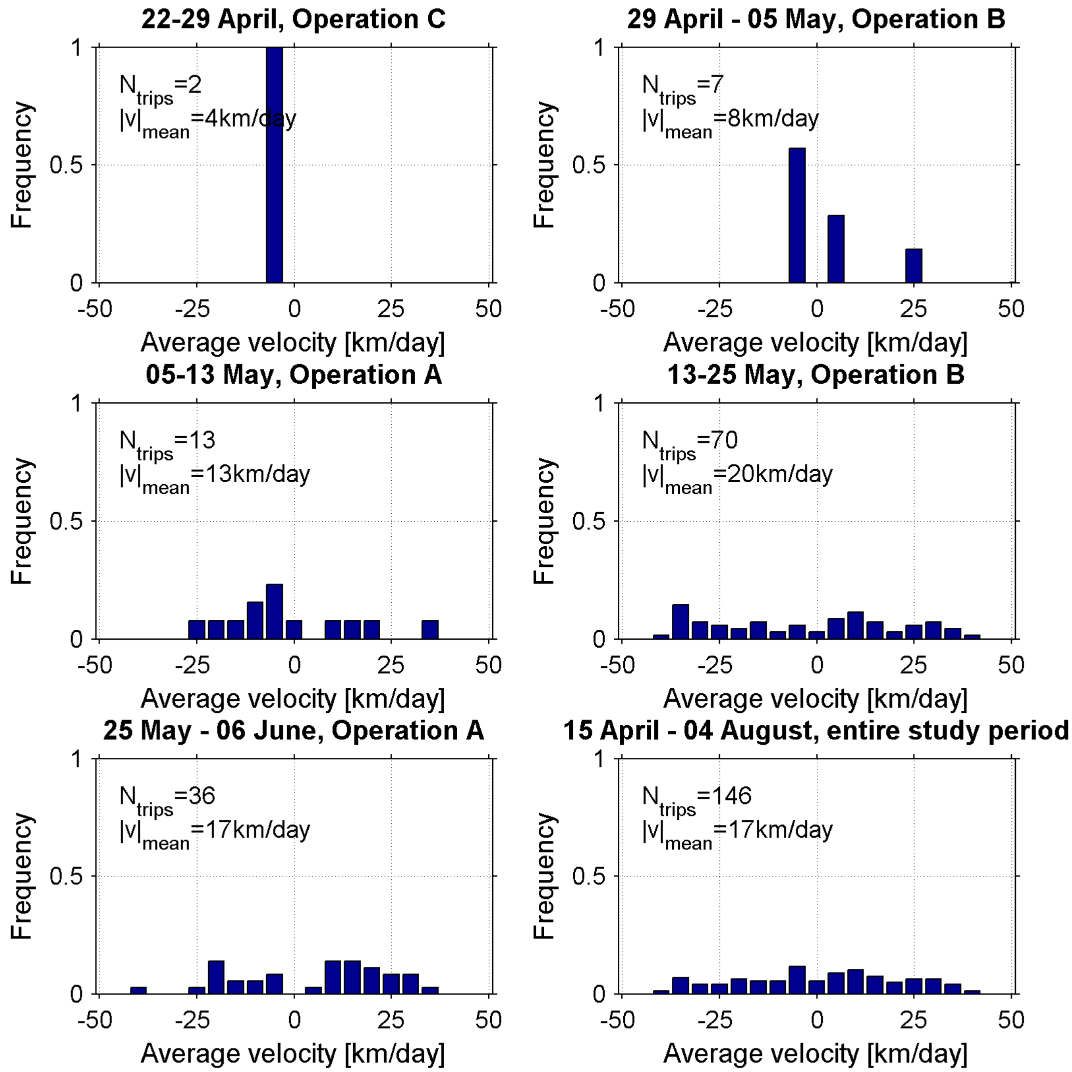

Figure 21. Histograms of average swimming speeds between acoustic line #2 (receiver #s 1823, 1824) and the Buntzen tunnel inlet (see Figure 1), for all fish detected on those lines between the dates indicated. Average swimming velocity is calculated from the time between the last detection on one line and the first detection on the next, and is positive for northward travel. The number of trips between the two lines and the average speed (absolute value of the velocity) are labelled on each graph. Note that speeds greater than ±50 km/day are not shown (likely the result of sequential detections for fish located between two nearby receivers). *The average swimming speed between line 2 and the Buntzen tunnel inlet does not vary significantly with BC Hydro operations; in particular, there is no evidence of motion toward the tunnel during periods of increased flow at that location (operation B).*

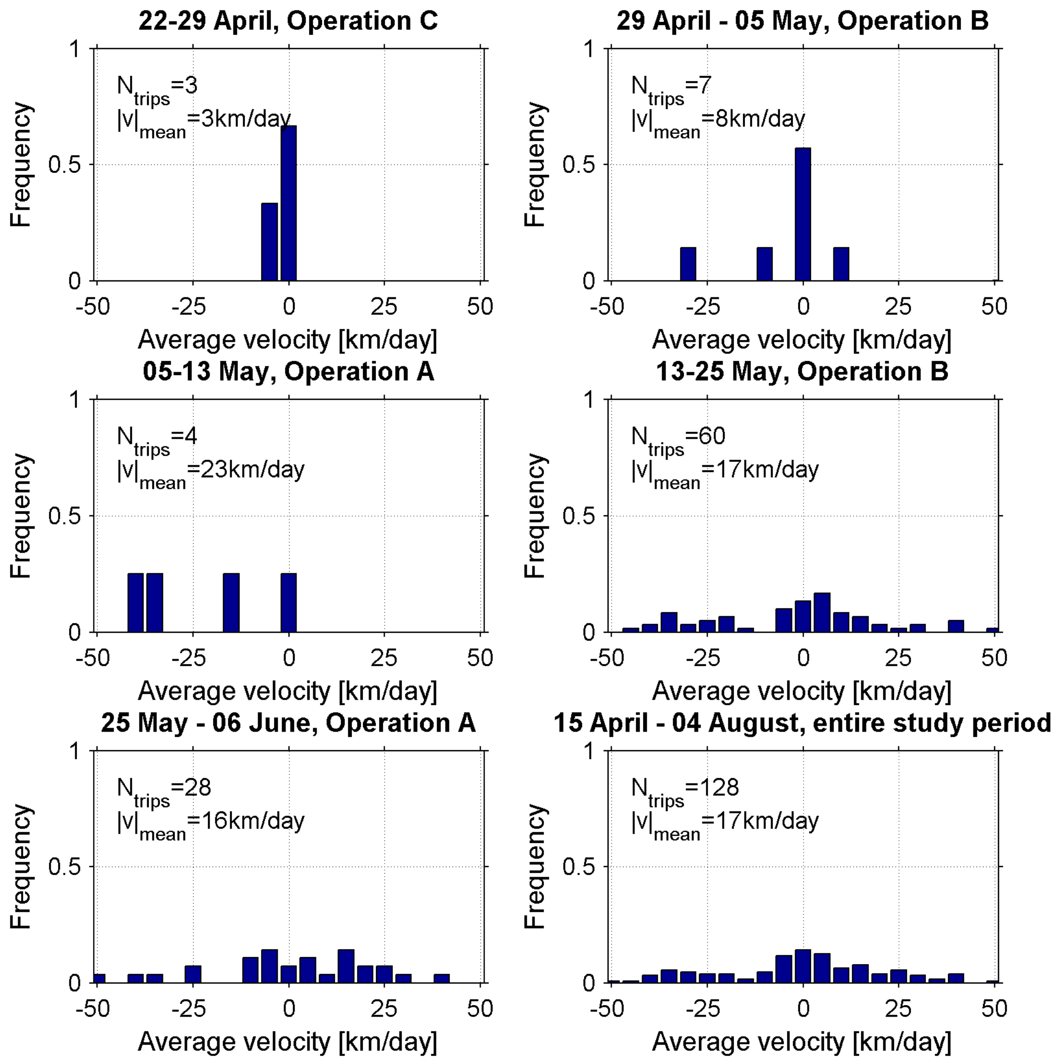

Figure 22. Histograms of average swimming speeds between the Buntzen tunnel inlet and acoustic line #3 (receiver #s 1801 and 1797) (see Figure 1), for all fish detected on those lines between the dates indicated. Average swimming velocity is calculated from the time between the last detection on one line and the first detection on the next, and is positive for northward travel. The number of trips between the two lines and the average speed (absolute value of the velocity) are labelled on each graph. Note that speeds greater than ±50 km/day are not shown (likely the result of sequential detections for fish located between two nearby receivers). *The average swimming speed between the Buntzen tunnel inlet and line 3 does not vary significantly with BC Hydro operations; in particular, there is no evidence of motion toward the tunnel during periods of increased flow at that location (operation B).*

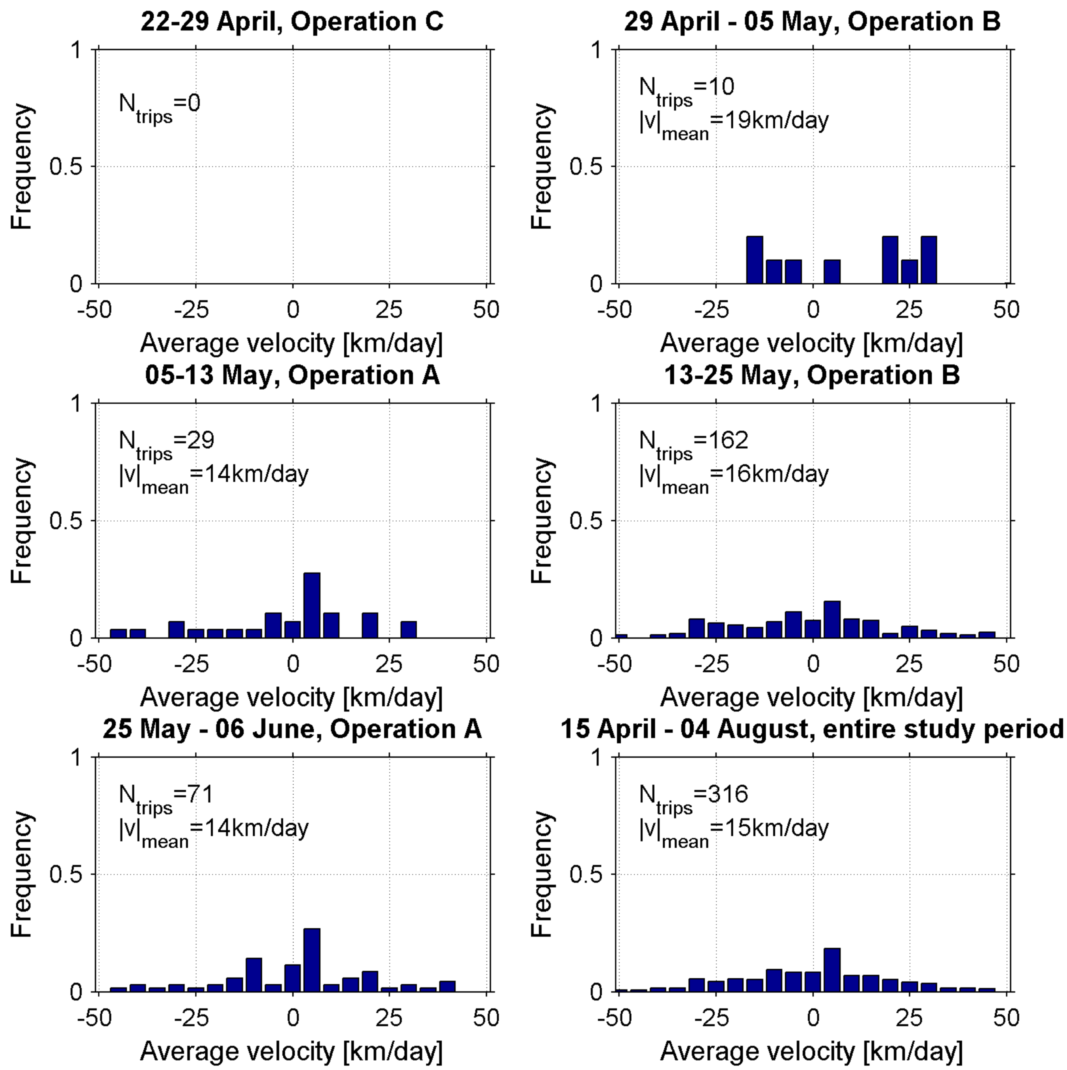

Figure 23. Histograms of average swimming speeds between acoustic line #3 (receiver #s 1801 and 1797) and the GVRD water inlet (receiver #1799) (see Figure 1), for all fish detected on those lines between the dates indicated. Average swimming velocity is calculated from the time between the last detection on one line and the first detection on the next, and is positive for northward travel. The number of trips between the two lines and the average speed (absolute value of the velocity) are labelled on each graph. Note that speeds greater than ±50 km/day are not shown (likely the result of sequential detections for fish located between two nearby receivers). *The average swimming speed between line 3 and the GVRD inlet does not vary significantly with BC Hydro operations.*

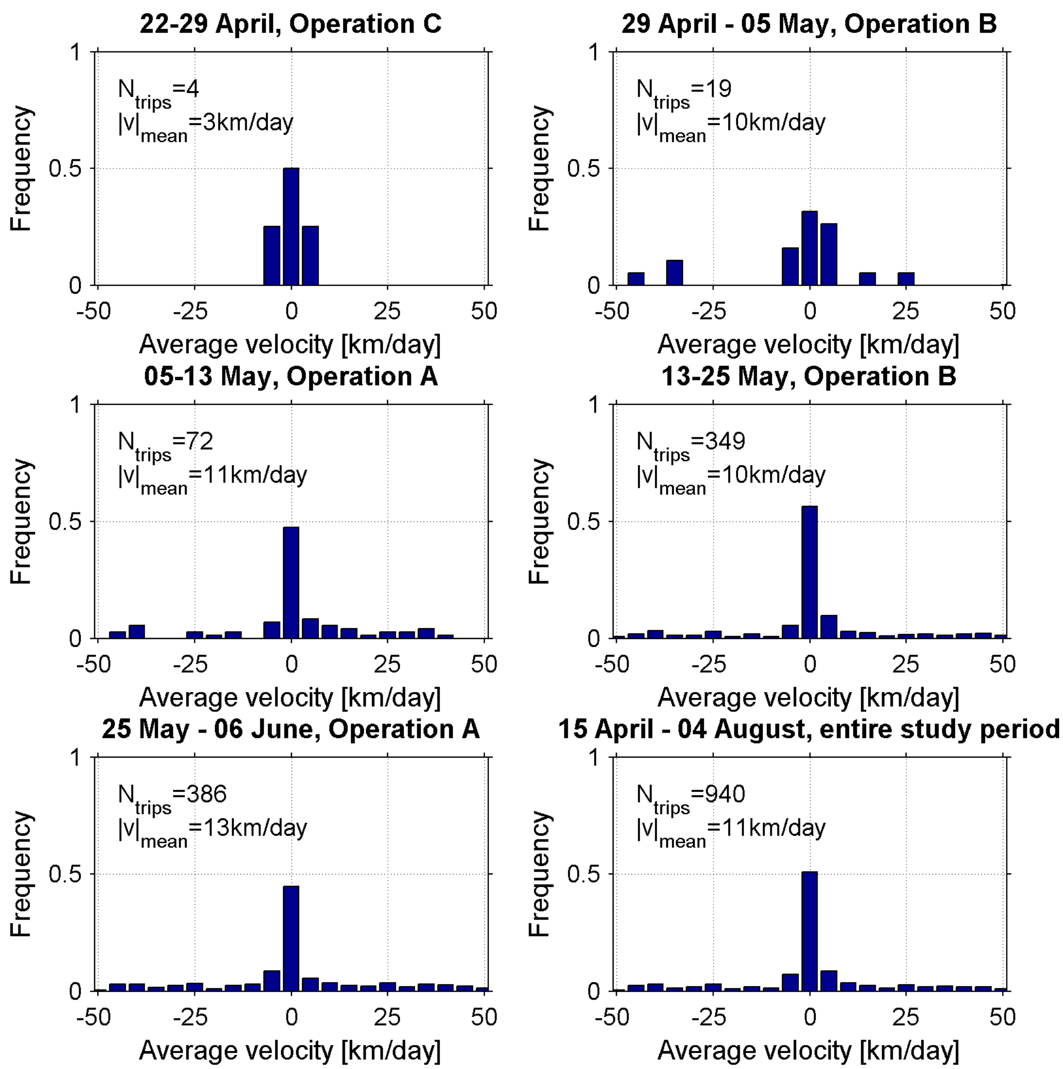

Figure 24. Histograms of average swimming speeds between the GVRD water inlet (receiver #1799) and the Coquitlam dam (receiver #s 1798 or 1627, see Figure 1), for all fish detected on those lines between the dates indicated. Average swimming velocity is calculated from the time between the last detection on one line and the first detection on the next, and is positive for northward travel. The number of trips between the two lines and the average speed (absolute value of the velocity) are labelled on each graph. Note that speeds greater than ±50 km/day are not shown (likely the result of sequential detections for fish located between two nearby receivers). *The average swimming speed between the GVRD inlet and the dam does not vary significantly with BC Hydro operations*

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5. Conclusions

Between April 15 and August 4, 2005, the motions of tagged smolts through the Coquitlam Reservoir were tracked using an acoustic listening array. The main findings from this work are as follows:

- Of the 117 tagged smolts that were released, 94% were detected on the array, and 77% reached the south end of the reservoir. While some minor issues were identified with respect to the detection efficiency of the listening lines, the use of redundant lines made it possible to track fish with good confidence in the results.
- Smolt numbers decline after release at a rate of 4% per day, i.e. a survival rate of 30% per month. This decline reflects combined losses from mortality (e.g., predation), tag shedding, and possible emigration. While this represents a moderately high rate of loss, the population size during the main portion of the study was large enough to make useful observations on smolt behaviour, including how they exit the reservoir—the main focus of the study.
- There is excellent evidence that the tagged smolts made use of the entire reservoir. Fish were not specifically clustering at the three outlets from the reservoir.
- During the first 1-3 weeks after release, the smolts disperse from the north end of the reservoir, gradually occupying the entire length of the lake. While most smolts reach the south end of the lake fairly promptly after release, they do not remain there, but rather make repeated excursions over the entire length of the reservoir.
- Average travel rates between acoustic listening lines were typically on the order of 10-20 km/day (11.6-23.1 cm/s, or 1-2 body lengths per second), and are similar for fish going north or south along the length of the lake. These swimming speeds are sufficient for the smolts to traverse the full length of the reservoir in a single day.
- There are clear differences in the areas of the reservoir where the coho smolts prefer to spend their time, with apparent extended residence by some fish. In particular, large numbers of transmissions were recorded in the southernmost portion of the reservoir, near the GVRD inlet and dam.
- We found no evidence that any of the smolts ever left the reservoir. While it is possible that a small number of fish may have left the reservoir undetected, it is extremely unlikely that a significant number did so.
- Neither fish distributions nor swimming speeds changed significantly as BC Hydro operations were changed between operations A (Buntzen tunnel closed) and B (tunnel opened). The number of fish present at the dam during operation C (Buntzen tunnel closed, LLO outlets open at a high flow rate) was inadequate to fully assess responses to this change.

6. Summary & Recommendations

The purpose of the study reported here was to establish how salmon smolts left the Coquitlam reservoir, and what modifications to current BC Hydro operations would maximize smolt output via the low level outlet (LLO) from the dam into the Coquitlam River. Of the three existing exits from the reservoir, only smolts choosing the LLO into the river have any chance of returning and developing a sustained anadromous sockeye run.

Our study shows that in 2005 the acoustically tagged smolts failed to leave the reservoir. These animals made extensive use of the entire reservoir, but show no evidence of having changed their movement patterns in response to any of the hydro operations in effect during the study period (April-August). Failure of the smolt run to emigrate from the reservoir by the LLO effectively means that a self-sustaining run cannot be achieved. A mechanism must therefore be identified in future years that will lead to a substantial proportion of the smolts leaving via the Coquitlam River.

The findings outlined in the Conclusions section of this report point to the need to address the following list of questions, in order to move toward the project's overall goals:

- Do smolts actually closely approach the outlets, especially that of the lower level outlet from the dam?
- Are any fish leaving the reservoir undetected, and/or "disappearing" in the outlets?
- Would smolt behaviour and/or emigration be any different with different elevations or different flow rates at the lower level outlets, or possibly with a surface collector?
- Can observations on smolt behaviour under different flow conditions be used to find an effective but low-cost way of maximizing smolt emigrations?

If smolts do not leave the reservoir even under maximum flows to the river, it is unlikely that an anadromous run can be re-started without costly physical changes to the reservoir. In order to address these questions, the following changes are recommended for future work:

Species issues:

- Sockeye smolts should also be used, if available, in order to reduce uncertainty arising from possible differences in the behaviour of coho and sockeye smolts.

Operation issues:

- We found that smolts released at the north end of the lake take at least a week to distribute themselves throughout the lake. In order to ensure that high numbers of smolts are present at the outlets, larger numbers of tagged smolts should be used in each release group, with fewer releases. This will increase the number of animals present when testing the effect of operations on behaviour.
- In future years, hydro operations should be timed to ensure that large numbers of smolts are in the vicinity of the LLO when flows to the Coquitlam river are maximised.
- Changing the operational cycle to a series of shorter operations (with each lasting perhaps 2-3 days) would be more informative. The number of smolts present during each operation would be higher, and a better sense would be obtained of whether the smolts were investigating the LLO more frequently when flows to the river were increased. (A specialized acoustic tracking array capable of resolving smolt positions to ~1m is probably also needed to fully address the latter issue).

Detection issues:

- The following changes could be made to the acoustic listening array in order to improve its performance:
  - An additional 1-2 receivers could be added to those Coquitlam Reservoir lines with lower detection rates (these cover the wider sections of the reservoir).

  - An additional receiver could be placed near the mouth of the Coquitlam River to detect any smolts leaving the system and entering the Fraser River.
  - An additional receiver could be added in Buntzen Lake to ensure that fish do not exit the system via the tunnel undetected. This receiver should be placed far enough from the tunnel outlet to minimize noise from the waterfall at the tunnel mouth during high outflow.
  - The number of receivers at the Port Mann site in the Fraser River should be increased; specifically, by adding a mid-river receiver.
- It may be useful to address potential range issues with the V7 tags. One direct approach is to measure the range of the V7 and V8 tags directly within the Coquitlam Reservoir. If larger smolts (>14.5 cm) are available, switching to the more powerful V8 tags would increase smolt detection

Precision knowledge of smolt behaviour at the LLO:

- In order to obtain more precise information on the movements of smolts near the outlets, it may be useful to supplement the large-scale array with a specialized 3-D positioning system capable of positioning smolt movements to a resolution of about 1 metre. This would allow precise data to be collected at the face of the dam, which would help establish whether the smolts are attracted to the LLO exit during any of the current hydro operations.

7. Acknowledgements

Financial support for this study was provided by the BC Hydro Bridge Coastal Fish and Wildlife Restoration Program. Financial support for the POST array, including the experimental satellite-linked tracking units in the lower Fraser River, was provided from combined funding from the Bonneville Power Administration, the Gordon and Betty Moore Foundation, and the Alfred P. Sloan Foundation's Census of Marine Life program.

8. References

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Koop, W. 2001. Red Fish Up The River. A report on the former Coquitlam salmon migrations and the hydro-electric developments at Coquitlam Lake, British Columbia, pre-1914. Presented by the Kwikwetlem Nation through BCRP and Coquitlam/Buntzen Water Use Plan.

Appendices

A1. Financial Statement

Project #05.Co.02

Financial Statement Form

	Budget		**Actual**	
	BCRP	**Other (a)**	**BCRP**	**Other(a)**
INCOME Total Income by Source	140000	2437000	140000	2437000
Expenses				
Project Personnel-Wages	$ 35,900.00		$ 37,630.52	
Project Personnel-WCB			$ 1,084.19	
Project Personnel-GST			$ 1,190.61	
Material And Equipment				
Equipment Rental	$ 7,800.00		$ 1,818.15	
Materials Purchased	$ 82,400.00		$ 84,589.03	
Travel Expenses	$ 4,900.00		$ 3,878.93	
Drugs & Sutures	$ 3,000.00		$ 3,000.00	
Administration				
Photocopies & Printing			$ 114.69	
Postage, Courier			$ 693.88	
Office Overhead	$ 6,000.00		$ 6,000.00	
Total Expenses	$ 140,000.00	$ -	$ 140,000.00	
Grand Total Expenses (BCRP + Other)		$ 140,000.00		$ 140,000.00

Note (a): Other financial contributions include research support in both the Fraser River and the marine POST array along the coast. We have not broken down these contributions by category, since they did not enter the Coquitlam Reservoir.

A2. Confirmation of BCRP Recognition

The BC Hydro logo was included in presentations describing the use of the POST array in 2005.

A3. BC Hydro Operations

Flow rates through the Buntzen tunnel and Coquitlam dam lower level outlets are shown in Table 6 (see also the summary in Table 2). Flow through the GVRD inlet was not modified as part of the smolt migration study, and entry of smolts into the inlet was at least mostly prevented by a fine-meshed screen covering the opening. Except for two days in June, the GVRD inlet was open throughout the project; the average flow rate was 4.4 m^3/s, with hourly values ranging between 3.5 m^3/s and 7.6 m^3/s.

Dates	*Operation label*	*Buntzen Reservoir tunnel status*	*Coquitlam dam status*
15-22 Apr.	A	Closed	Fish valves open Flow ≈$1m^3s^{-1}$
22-29 Apr.	C	Closed	Fish valves + lower level outlet open Flow ≈$6m^3s^{-1}$
29 Apr. – 05 May	B	Open Flow ≈$34m^3s^{-1}$	Fish valves open Flow ≈$1m^3s^{-1}$
05-13 May	A	Closed	Fish valves open Flow ≈$1m^3s^{-1}$
13-20 May	B	Open Flow ≈$6.5m^3s^{-1}$	Fish valves open Flow ≈$1m^3s^{-1}$
20-25 May	B	Open Flow ≈$34m^3s^{-1}$	Fish valves open Flow ≈$1m^3s^{-1}$
25 May – 06 Jun.	A	Closed	Fish valves open Flow ≈$1m^3s^{-1}$
17-22 Jun.	B	Open Flow ≈$16m^3s^{-1}$	Fish valves open Flow ≈$1m^3s^{-1}$
22-29 Jun.	A	Closed	Fish valves open Flow ≈$1m^3s^{-1}$
29 Jun. – 09 Jul.	Dam maintenance	Closed	Pumping only (fish valves closed) Flow ≈$1m^3s^{-1}$
09-14 Jul.	Dam maintenance	Open Flow ≈$35m^3s^{-1}$	Pumping only (fish valves closed) Flow ≈$1m^3s^{-1}$
14-18 Jul.	B	Open Flow ≈$35m^3s^{-1}$	Fish valves open Flow ≈$1m^3s^{-1}$
18 Jul. – 04 Aug.	A	Closed	Fish valves open Flow ≈$1m^3s^{-1}$

Table 6. Details of BC Hydro operations during the Coquitlam smolt migration study. The locations of the Buntzen and Coquitlam Reservoirs are shown in Figure 1.

A4. Animations

A series of six animations, illustrating the movement of tagged fish throughout the Coquitlam Reservoir, is included on the CD attached to this report: one animation corresponding to each of the five release groups listed in Table 1, and a fifth animation summarizing the motions for all five groups of tagged fish. The .avi files may be viewed using most widely available media players. The XviD codec must be installed in order to run the animations; the XviD installation file (XviD-1.0.3-20122004.exe) is also included on the CD.

The following simplifying assumptions were made in creating the animations:

- When a fish is detected at a receiver, its location is shown at the receiver's location, although in reality it may have been present anywhere within the receiver's listening range.
- Motion between known locations is assumed to be in a straight line and at a constant speed.
- In the case of line avoidance (see Section 4.1), travel paths are interpolated between known locations, without attempting to guess the fish's actual route. Hence, fish may appear to travel over land in the animations; this indicates that one or more lines were missed between detections.
- Markers and paths are colour-coded only for ease in distinguishing movements of individual fish.

The information contained in these animations is also displayed statically and discussed in Section 4.4.

A5. Detailed Surgical Procedures

Overview of Surgical Tagging of Fish

Recent technological advances make it feasible to implant fish as small as salmon smolts with ultrasonic tags capable of individually identifying each tagged fish. Identification and tracking of such tagged fish has been demonstrated in river, lake, and ocean environments via the use of listening arrays formed of many acoustic receivers laid out to detect the ultrasonic transmissions of these tags throughout the water column. Such tracking arrays have the potential to be deployed in fresh and salt water bodies on a continental scale, and the recent (2004-2005) demonstration phase of the POST project has demonstrated that by a judicious optimization of tag programming and array geometry it is possible to directly measure movements and survival of salmon smolts in the ocean with a very high degree of accuracy. (The 2004 results demonstrated a 91% detection rate for individual salmon smolts migrating across 20 km long listening lines).

Before any tracking can occur, tags must be successfully implanted into fish, and both tag and fish have to function normally and long enough to be detected by the acoustic array. Implantation of the tag into the body cavity of a fish is considered major surgery and involves significant training and preparation, and also due consideration for the animal's well being. Kintama Research Corporation (KRC) surgeons follow the Canadian Council for Animal Care (CCAC) guidelines and KRC's Standing Operating Procedures, which were developed from veterinary consultation and years of hands-on experience. Implantation of tags is done by surgical teams which consist of two or more members, including at least one senior surgeon. Surgical teams are fully equipped, both in skill and in required materials to handle nearly every scenario encountered in the field.

The surgical process for implantation of the acoustic tag into fish can be broken down into four main steps. These are sedation, induction (anaesthesia), surgery, and recovery. Sedation is a state of numbness or light anaesthesia, and is very important as it aids in preoperative handling of the fish and helps to reduce stress from handling, transport, and immersion into the anaesthetic bath. Minimizing stress is crucial because it can negatively impact immune function as well as behaviour, which in turn can result in the fish being more susceptible to infectious agents, thus potentially reducing survivorship. Handling of fish can also predispose them to infection by disrupting the natural protective exterior mucous layer. So as an extra measure of protection, a synthetic mucous solution is added to all water baths and contact surfaces to help preserve this mucous layer. While under sedation fish are assessed to determine if they are candidates for the surgery. Fish that are deemed acceptable for surgery are transferred to a tank containing a higher concentration of anaesthetic for the purpose of inducing general anaesthesia. Once the fish is fully under it is transferred to a surgical cradle for implantation of the tag. When the surgery is completed the fish is transferred to a recovery tank for observation. Post surgery mortalities are uncommon in smolts in good condition, and in KRC'S experience can be less than 1%.

As with any invasive surgery it is very important to employ aseptic techniques in order to reduce the chance of infection. It is also important to maintain, as close as possible, the fish's normal physiological processes, and to keep ambient environmental conditions stable. To these ends, surgical instruments, tags, and gloves are disinfected prior to surgery and between each fish. The potential for oxygen deficiency (hypoxia) during surgery is eliminated by providing a constant flow of aerated water over the gills. This aerated water also contains a maintenance dose of anesthetic which ensures that the fish remains under general anaesthesia for the entire surgery. The aerated/anesthetic water is constantly recirculated using a pump and other specialized surgical equipment, and its temperature, dissolved oxygen (DO_2) levels, and general quality are continuously monitored using electronic sensors so that they do not fall outside CCAC guidelines. The entire fish is kept wet at all times and a moistened towel is draped over its head to protect it from UV light.

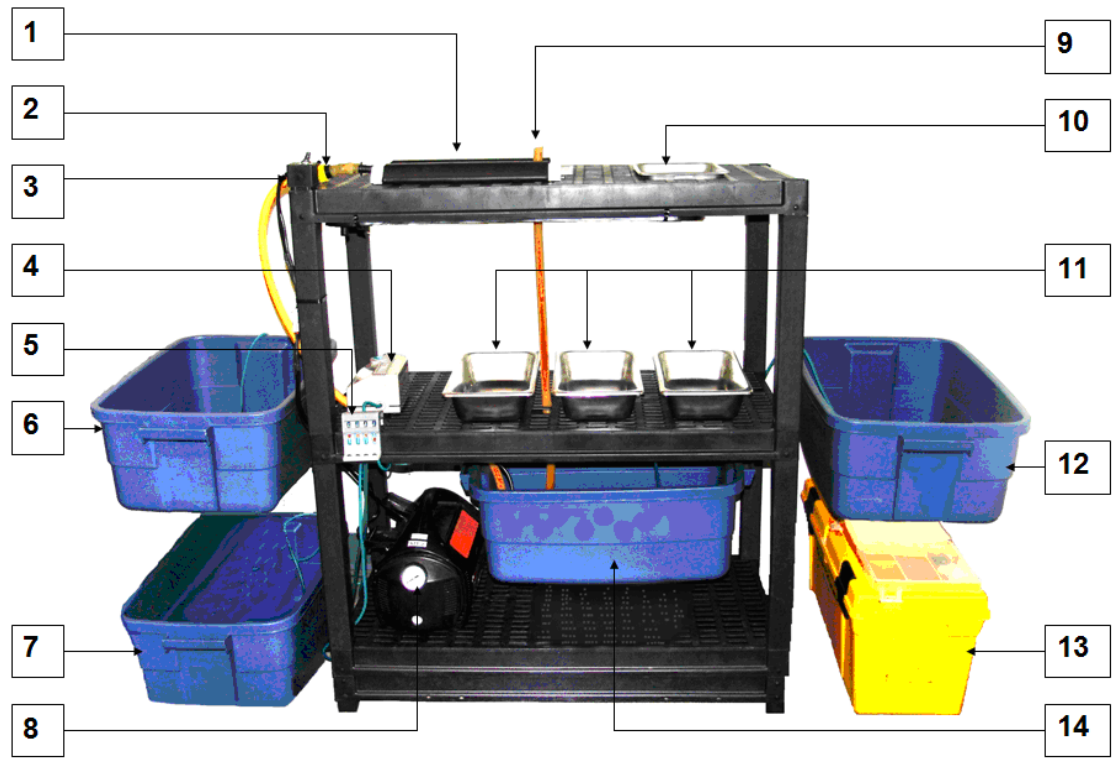
Implantation of the tag is achieved by making an incision through the body wall in the belly of the fish at the mid ventral line, allowing entry into the peritoneal cavity. The acoustic tag is gently inserted through this incision, seated properly, and the incision closed with absorbable monofilament suture material. The fish is then transferred to recovery and typically monitored for approximately twenty-four hours before release.

Portable Surgical Kits

KRC's portable surgical kits are comprehensive and provide the surgical teams with all the required materials necessary to complete the surgeries. Everything, from drugs (seadatives & anaesthetics), surgical tools and tables, to portable shelters and battery supplies is provided in each kit, allowing the surgical teams to work in remote locations and poor weather, while still maintaining high surgical standards.

The design of the surgical kits is kept simple and modular. Complete setup of a kit usually takes about thirty minutes but can be reduced to several minutes depending on the situation. For example, when only a few fish will be operated on and/or the surgeries are to be performed in a remote location, the surgeries can be performed without the need for battery operated pumps and aeration.

The core components of the surgical kit are the surgical cradle, collapsible/height adjustable table, stainless steel surgical trays, aeration system, battery pack, recirculation reservoir, sedation bath, anaesthesia bath, recovery bath, and surgical supply box containing all required surgical supplies (see below). Wherever possible, all components are made from synthetic materials or surgical-grade stainless steel to avoid problems with corrosion and to facilitate disinfection of the surgical set-up.



1) Surgical cradle
2) Recirculation pressure valve
3) On/Off switch for recirculation pump
4) Air compressor
5) Air line multi-valve
6) Induction bath
7) Sedation bath
8) Battery pack
9) Drain tube
10) Surgical instrument tray
11) Disinfection/rinse trays
12) Recovery bath
13) Surgical supply box
14) Recirculation reservoir

The surgical table includes cut-outs for routing the plumbing required for the recirculation system, a drip tray, and attachment points for the electrical wiring which delivers power to the recirculation pump and air compressor. The surgical cradle holds the fish during surgery and is designed to keep the gills submerged throughout the procedure. Water from the recirculation reservoir, containing a maintenance dose of anaesthetic, is pumped into the head of the cradle where it then flows down past the head and gills and along the length of the fish. The water then exits via a drain tube at the opposite end of the cradle. Water flow is adjusted using a valve at the head of the cradle and the water level in the cradle is controlled via a stand-pipe at the exit drain tube. Water level is adjusted to allow the gills to remain bathed by flowing water while allowing the abdomen to protrude from the water, thus preventing water from entering into the abdominal cavity through the surgical incision.

The tools required for the surgeries are a pair of cutting needle drivers, scalpel, suture guide/shield, and surgical probe (Fig. 1). Two complete sets of these instruments are rotated during surgeries so that one set sits in one of three stainless steel trays containing Ovadine™ for disinfection, while the other set is being used for surgery. The other two stainless steel trays contain distilled water and are for rinsing the instruments free of Ovadine™ prior to use on the next fish.

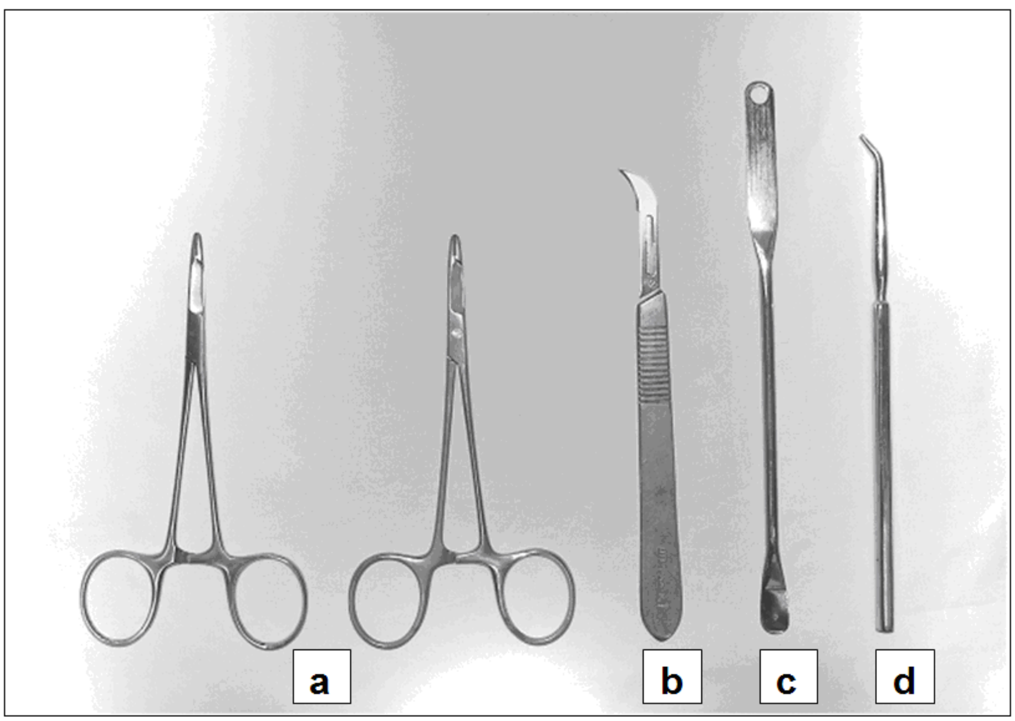


Fig. 1 - a) Needle drivers b) Scalpel c) Suture guide / shield and d) Probe

Anaesthesia

As per CCAC guidelines, only fish of appropriate size are considered for surgery. Fish deemed acceptable are typically first sedated with Metomidate (Aquacalm™); a sedative which helps to reduces stress, prior to handling or transport. In addition, a synthetic mucous (Vidalife™) is used to help preserve the natural protective mucous layer of the fish. General anaesthesia is achieved by using Tricaine Methane Sulphonate (MS-222™). Proper anaesthesia depends on water temperature, water hardness, salinity, oxygen concentration, the biomass and species of fish, and the length of time of immersion. Surgeons generally rely on their experience with the anesthetic and visual cues from the fish, rather than relying on strictly set dosages. However, in general the dosages required fall around 70ppm for induction into general anaesthesia and 50ppm for maintenance during surgery. As surgeries progress for a group of fish 5ml quantities of MS-222 are periodically added to compensate for loss due to metabolization of the drug. The acidity of MS-222 is buffered using stock solutions of sodium bicarbonate dissolved in water.

Implantation of Tags

Pre-operative preparation is generally accomplished through isolating the animals in a tank of their own and allowing them to acclimate to the new environment. Though it is not always possible to isolate the fish, it is helpful to do so because it gives the surgical teams an opportunity to assess the general health of the selected fish, based on how well they tolerate the transfer and subsequent acclimate to the new tank. If further handling is involved, such as in the case of size grading fish, the surgical teams can more closely examine the fish for signs of stress and/or disease. As handling subjects the fish to some level of stress, sedatives should be used to help minimise stress. This is very important because stressed fish are potentially unhealthy fish, with decreased vitality and increased susceptibility to disease, especially when combined with the stress of surgery. Whenever possible, fish deemed acceptable for surgery should not be fed for approximately twenty-four hours prior to surgery. This ensures that the fish have eliminated most of their gastric content, which helps because surgery on fish with full guts can be more difficult. (With wild-caught fish this is frequently more difficult, since the traps used to capture the smolts also capture and accumulate their prey).

Surgical tools and all surfaces should be disinfected with Ovadine™ prior to use, and surgical instruments are disinfected between each fish during surgeries. The surgical process is as follows:

1) Source water temperature and oxygen level are recorded on data sheets, along with general observations for that day;

2) Fish are transferred from source tank to the sedation bath and left covered and undisturbed for approximately ten minutes;

3) Individual fish are taken from the sedation bath and put into the anaesthesia (Induction) bath at about three minute intervals. This is about the time it takes for an experienced surgeon to complete the surgical implantation of the tag.

4) The fish remains in the induction bath until stage four or five anaesthesia is reached (Appendix A).

5) Once properly anesthetised, the fish can be measured (fork length and/or weight) and then transferred to the surgical cradle.

6) In preparation for surgery, the fish is placed ventral side up in the cradle with its mouth around the recirculation water output nozzle. The output nozzle and tubing is made from supple latex tubing so that the fish's mouth and teeth can grab on to it, thus helping to maintain position of the fish and proper water flow during surgery. Further support of especially small fish is accomplished, if necessary, using folded pieces of paper towels that are soaked in water and Vidalife™ and placed along the flanks of the fish to ensure proper positioning of the abdomen.

7) Water flow is adjusted and monitored throughout the surgery to provide a gentle flow through the mouth and over the gills. A properly positioned fish has its head nearly completely submerged with none of the gill lamellae exposed to air. The ventral body wall is above the water line in the cradle only enough to avoid spilling water into the body cavity and a squirt bottle is kept handy to ensure that all exposed parts of the fish remain wet during the procedure.

Extreme care is taken when making the incision in order not to damage any internal organs. The surgeon applies gentle pressure at the incision site by squeezing the belly of the fish with his gloved fingers. This helps to push internal organs down and out of the way of the scalpel blade and facilitates a safer and cleaner cut by helping to better maintain control of the scalpel when the blade cuts or pierces through scales. For smolt-sized Pacific salmon, the incision is made on the mid ventral line and is started several millimeters proximal to the pelvic girdle. The incision is extended cranially just long enough to allow insertion of the tag. Once the incision is completed, a quick visual inspection of the abdominal cavity is made to further assess the fish's condition. For example, the surgeon can see if the internal organs look normal (particularly the spleen), and he/she can see the amount of fatty tissue, and also if the fish is infected with some types of parasites. After inspection, the tag is gently inserted through the opening into the abdominal cavity and is seated lengthwise so that it sits parallel to the mid ventral and lateral lines. Proper positioning of the tag is very important because it helps to reduce pressure points inside the abdominal cavity. Pressure points are sources of chronic trauma and can result in internal damage, frequently in the form of contact necrosis of compressed tissues. If this occurs on the inside body wall or surface of the intestine, either an abscess may form or the tag may be encapsulated, either event possibly resulting in eventual expulsion of the tag. Once the tag is seated properly, the incision is closed with sterile monofilament absorbable suture material using simple interrupted sutures. In smolt-sized fish there is frequently little to no visible bleeding throughout the entire surgical procedure.

Recovery and Holding

After surgery, fish are gently transferred to a recovery tank where they are generally held for approximately twenty-four hours before release. This holding period allows the surgical team, or other persons attending the fish, to visually assess whether or not the fish have returned to normal behaviour patterns before release. Additionally, most mortalities that are the direct result of the surgical procedure occur within this timeframe (probably more as a result of stress, or the effect of the anaesthetic, rather than the actual surgery). Thus, holding the fish ensures that costly tags are not wasted on fish that would have died soon after release, and improves estimates of survival gained by monitoring the animal's movements over the acoustic array. Finally, the holding period is especially valuable to the surgical teams as it provides feedback that can be used to compare against records taken during surgery, thus allowing them to critically assess their work. The fish are released at an appropriate time after consultation with biologists, technicians or hatchery personnel who are most familiar with the release site and the purpose of the biological study, so as to give the fish the greatest chance of initial survival after release. (For example, releasing tagged smolts at dusk reduces mortality from visual predators such as birds). In addition, the surgically implanted fish are preferably released with a large number of similar non-implanted fish. This is done with the hope that initial predation will occur on the group as a whole rather than just on the tagged fish.

Stages of anaesthesia (modified from McFarland 1959 and Jolly et al. 1972) – Schreck C. B. and Moyle P. B., 1990. Methods for Fish Biology, p. 217 pp. American Fisheries Society, Bethesda Maryland. 665pp

0	Normal	Reactive to external stimuli; opercular rate and muscle tone normal
1	Light sedation	Slight loss of reactivity to external visual and tactile stimuli; opercular rate slightly decreased; equilibrium normal
2	Deep sedation	Total loss of reactivity to external stimuli except strong pressure; slight decrease in opercular rate; equilibrium normal
3	Partial loss of equilibrium	Partial loss of muscle tone; swimming erratic; increased opercular rate; reactive only to strong tactile and vibrational stimuli
4	Total loss of equilibrium	Total loss of muscle tone and equilibrium; slow but regular opercular rate; loss of spinal reflexes
5	Loss of reflex reactivity	Total loss of reactivity; opercular movements slow and irregular; heart rate very slow; loss of all reflexes
6	Medullary collapse (stage of asphyxia)	Opercular movements cease; cardiac arrest usually follows quickly