1999 Telemetric Studies of Coho Salmon at Black Creek, Vancouver Island

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1999 TELEMETRIC STUDIES OF COHO SALMON AT BLACK CREEK, VANCOUVER ISLAND

by

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During the 1999 adult coho escapement enumeration project at Black Creek, Vancouver Island, BC, radio-tags were deployed on 100 adult coho salmon (*Oncorhynchus kisutch*) and tracked for approximately 6 weeks by fixed station receivers, foot and vehicle surveys and by helicopter. The purpose was to determine the distribution and importance of the various spawning locations within the watershed and to examine the migration timing and range of the coho adults.

The coho return to Black Creek in 1999 was lower than expected so the radio tags were not applied in proportion to population size. The escapement came in two groups of which approximately 10% (39/369) were tagged in the first group and 60% were tagged from the second group (61/101).

The early group took longer to reach their chosen spawning areas than the latter group, and there was no difference in geographic distribution between the two groups, which was a similar result to previous studies. 92% of the tagged coho adults migrated directly to their chosen spawning location and remained there.

The largest groups were found in the upper Black Creek mainstem (33%), the lower Black Creek mainstem (26%) and Millar Creek (22%).

RESUME

Baillie, S.J., Taylor, J.A, and Watson, N.M. 2015. 1999 telemetric studies of Coho Salmon at Black Creek, Vancouver Island. Can. Manuscr. Rep. Fish. Aquat. Sci. 3055: viii + 38 p.

Durant le projet de dénombrement des échappées de saumons coho adultes dans le ruisseau Black sur l'île de Vancouver (Colombie-Britannique) en 1999, des radioémetteurs ont été déployés sur 100 saumons coho adultes (*Oncorhynchus kisutch*), que l'on a ensuite surveillés pendant environ six semaines au moyen de stations de réception fixes, de relevés effectués à pied et en véhicule et par hélicoptère. L'objectif était de déterminer la répartition et l'importance des diverses zones de frai dans le bassin versant et d'examiner la période et l'aire de migration des saumons coho adultes.

Comme la montaison de saumons coho dans le ruisseau Black en 1999 a été plus faible que prévu, le nombre de radioémetteurs utilisés n'était pas proportionnel à la taille de la population. L'échappée est arrivée en deux groupes dont approximativement 10 % (39/369) des individus ont été marqués dans le premier groupe et 60 % dans le deuxième groupe (61/101).

Il a fallu plus de temps au premier groupe pour atteindre les zones de frai choisies que le dernier groupe et on n'a remarqué aucune différence entre la répartition géographique des deux groupes. Ces résultats sont similaires à ceux des études précédentes. Parmi les saumons coho adultes marqués, 92 % ont migré directement vers leur zone de frai choisie et y sont restés.

Les plus gros groupes ont été observés dans le cours principal supérieur du ruisseau Black (33 %), le cours principal inférieur du ruisseau Black (26 %) et le ruisseau Millar (22 %).

INTRODUCTION

The Black Creek Coho Project is an annual monitoring of smolt abundance and spawner escapements which entails enumerations, sampling of biological characteristics and coded wire tagging and tag recovery. One of only three wild stock assessment projects on the south coast of British Columbia, its results are extrapolated to other wild coho stocks in the Strait of Georgia and are used in the management of coho catches and assessment of freshwater habitat impacts. Specifically, coho smolts are enumerated, sampled and coded wire tagged as they leave Black Creek in the spring and 'jacks' and 'adults' (age X.0 males and age X.1 adults) are monitored when they return back to spawn.

This report documents the adult telemetry program for coho salmon at the Black Creek fence in 1999. Tagging was conducted at the permanent fence site located 100 m upstream of tidal influence, about 40 m downstream from Seaview Road in Miracle Beach Provincial Park, Vancouver Island, British Columbia. Data from the project, along with other sources, is used to predict coho distribution throughout the river migration to spawning grounds in Black Creek and its tributaries.

Reports for the Black Creek Coho Project from the 1988 to 1997 and 2006 to 2011 years of operation are available through the Canadian Manuscript Report series from Fisheries and Oceans Canada. Manuscript reports on the 1998 – 2005 years of operation, and from 2012 to present, are in preparation.

Study area

Black Creek is a moderately sized coastal stream located 30km north of Courtenay, on the east coast of Vancouver Island. It is approximately 31 km long and flows into the Strait of Georgia at Elma Bay. The watershed area is approximately 81 km^2 (Brown *et al.* 1996) and predominately comprises agricultural lands with forested areas in the upper catchment. Lower in the watershed, small lakes, of which Northy Lake is the largest, beaver ponds and swampy areas are abundant. These areas contribute to the characteristic humic stained flows in the lower sections via a number of tributaries, the largest being Millar Creek. Discharge is largely dependent on rainfall and agriculture irrigation and drainage projects have reduced already low summer flows in Black Creek so that in summer sections of the creek are dry. In contrast, fall freshets can result in discharges of up to 60 m^3/s (Labelle 1990). Once the storage capacity of the watershed is reached, the creek responds rapidly to rainfall and prolonged flood events tend to be the norm. In addition to coho, Black Creek supports populations of coastal cutthroat trout (*Oncorhynchus clarki*), and rainbow trout (*O. mykiss*).

METHODS

Radio tagging

Radio-tagging was performed concurrently with Floy[2] anchor tagging on a proportion of the adult escapement. We used ATS[3] model MCFT – 3BM radio-tags with 100 individual digital codes in 20 frequencies within 149MHz (149.013 - 149.203). Prior to deployment, reception from each radio tag frequency was assessed at a distance of approximately 100m from a submerged tag, using an ATS R2100 receiver. The best receiving frequency was not always the nominal frequency: for example, 149.013 provided a stronger signal when the receiver was set to 149.014. In each case, the frequency that generated the strongest signal was recorded for tracking.

Tags were lubricated with a small amount of glycerine and the antenna was threaded into an acrylic tube (15mm diameter) which was then used to insert the tag into the fish's stomach posterior to the pneumatic duct. Tag frequency and code were recorded in addition to Floy tag and biological data.

Tracking

The distribution and movements of radio-tagged fish were monitored using stationary and aerial tracking methods. Two fixed-station ground sites were established, one on Millar Creek and the second on Black Creek: both sites were located approximately 150m upstream of Northy Lake (Figure 1). These sites were selected to provide information on the movement of fish into known spawning areas in Millar Creek versus locations in the middle and upper Black Creek system. The radio-tag receiver was a combination of the ATS R2100 receiver coupled with an ATS DCCII model D5041 datalogger. Each receiver was powered by a 12-V marine battery that provided power for 10 - 14 days; however, a charged replacement was substituted during weekly data download visits. The receiver and battery were enclosed in a weather proof container drilled to accept the lead from a 4-element Yagi antenna. The receiver was set to a 6 second scan cycle for each frequency, but as a power conservation option, multiple records of individual tag codes were made only at 15 minute intervals in the absence of a new detection event. This also eliminated lengthy data records of stationary tags within range of the receiver. Data logging by the receiver included date and time, tag frequency and code but, unfortunately, while signal strength could be viewed on the display it did not form part of the data record. Data was downloaded to a laptop computer using the ATS Getcode v4.7 Xtcd3b software.

Seven aerial surveys were performed, approximately weekly (Table 1) with a Canadian Coast Guard Messerschmitt MBD105 helicopter (3 occasions) and a Bell 206 Jet Ranger

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[2] Floy Tag & Manufacturing, 4616 Union Bay Pl. NE, Seattle, WA, 98105

[3] Advanced Telemetry Systems, Inc, 470 First Ave. N., Isanti, MN, 55040-7123

(4 occasions). Tracking was conducted using the same receiver/datalogger combination noted above, paired with a directional "H" antenna (model AN-ADH). The DCCII was used in aerial mode to record date and time, tag frequency, code, pulse rate and signal strength. As above, a 6 second scan cycle was used to check individual frequencies and only active (released) frequencies were loaded into the scan partition. As tags were located these were filtered from the partition to facilitate the identification and locating of multiple signals while maintaining internal data logging of all tags by the receiver.

We initially hoped to generate tag location data through GPS, however, positional data were never sufficiently accurate (> ±500m) in the Black Creek watershed, potentially as a result of Selective Availability (SA) signal scrambling due to the proximity of the Comox Canadian Forces Base. Therefore, we used GIS maps based on augmented Terrain Resource Information Management (TRIM) data (Brown *et al*. 1999) to directly mark the location of radio tagged fish. One observer relayed the DCCII display information to a second person who plotted the position. This provided a real-time data set for date, time, and tag frequency and code combined with specific location. In addition, the location of the aircraft was recorded on these maps every minute, to facilitate correlation of tag detection events from the datalogger record with specific locations. Field notes were made regarding signal strength and potential locations of weak signal returns as well as spatially disparate returns that may have resulted from reflections from the helicopter rotor. Positional information was subsequently derived as Eastings and Northings and Longitude and Latitude using a digital version of the watershed maps (CGQ Main v3.46 provided by T.G. Brown, DFO, Nanaimo).

A majority of aerial surveys were conducted from the Black Creek estuary to the upstream portion of Millar Creek, then returning to Northy Lake to continue the flight along the northern watershed and west to sub-basin 14 (Figure 2). The helicopter flights were conducted at an air speed of approximately 90km/hour and an elevation of approximately 70m throughout most of the watershed: greater elevation was required over livestock and farm buildings to minimize noise. This reduced the range at which tags could be detected and provided greater accuracy in determining locations. It also resulted in greater initial signal strength upon tag detection with correspondingly fewer records per tag code generated by weak signals. At the end of each flight increased altitude was used to locate signals from tags that had not been detected. While most aerial surveys were concentrated directly along the mainstem, a series of 4 flights were conducted in a zigzag pattern perpendicular to the mainstem to determine if radio tagged fish were located in tributary areas.

Other surveys were conducted on foot and by vehicle in accessible areas of the watershed: principally Millar Creek, portions of sub-basins 1 and 5 and the upper sub-basins 12 and 13 in the vicinity of the Duncan Bay Main logging road.

Data processing

A telemetry database was compiled in Microsoft Access™ from screened data recorded electronically on aerial, stationary datalogger and ground surveys. Signals that were inconsistent with other records for the same time period or where the tag code was incorrectly logged were eliminated. The latter problem affected the first few days of stationary datalogging and necessitated changing an EPROM in the ATS DCCII to upgrade the operating system.

The database was further refined using manual records from aerial surveys by comparing machine locations with mapped tag detection events and timing of datalogged events. Multiple detections were reduced to one location per tag code on each aerial survey date, based on maximum signal strength. However, where concomitant records were available from the fixed stations, an individual fish could have two or more locations for a single day.

RESULTS

Radio-tagging

Between 29th October and 8th November 100 adult coho (53 females and 47 males) were radio-tagged and released at the counting fence. Our expectation of adult coho escapement was substantially greater than the 472 fish enumerated at the fence and we had intended to tag approximately 1 in 10 adults. Therefore, while radio-tags were applied to only 39 of 369 coho in the first 4 days of the program (release group 1), 61 tags were subsequently deployed on 101 adults as the possible weakness of the run became apparent (release group 2). Radio-tag application is summarized in Table 2. The escapement estimate, using a Bayesian estimator, was 511 adult and 575 jack coho (Baillie *et al.*, in preparation).

The mean fork length of radio-tagged coho was significantly larger than that of untagged fish (66.1cm versus 62.3cm: $t=5.27$ $p<0.001$). Larger fish tended to be selected for radio-tagging, which may account for the greater number of females tagged, although the intent was to tag equal proportions of both sexes. Early in the program males were selected in greater numbers (23 males to 16 females) although they formed only 37% of the adults captured. However, in November the ratio of tagged females to males closely approximated that of the escapement (0:0.65 versus 0:0.63).

Three tags were located on only 2 survey dates following their release (149.073-125, 149.083-165 and 149.103-105) and it was assumed that these malfunctioned. One possible incidence of regurgitation was noted: tag 149.193 code 105 was released on 8-November and only recorded once, in the vicinity of the fence. While it is possible that the tag could have failed, if regurgitated, it would likely have been washed into the estuary during flooding, with an equivalent result. All other 96 tags were tracked successfully throughout the study.

Movements and rate of travel of radio-tagged coho

Tracking produced 1,964 individual records of tagged fish, including 532 events recorded by the fixed station receivers. The Millar Creek site generated the majority of these (469 records) since the receiver was located in the vicinity of a spawning area, while the lower number of records from the Black Creek site reflected transitory movement to upstream spawning areas. Most fish moved out of range of the receiver at the fence within one day after tagging, suggesting that tag deployment did not delay migration.

Fixed station records show that movement by radio-tagged coho is not constrained to daylight hours, although some preference for the period between 9:00am and 4:00pm is indicated in Figure 3, where the frequency of detection events provides an approximation to movement patterns throughout a 24hr period. However, coho were active at all times, including the early morning. The mean number of detections recorded between 7:00am and 5:00pm (approximating daylight hours at Black Creek in November) was 24, while 16 per hour were recorded during the hours of darkness. The overall pattern of movement for radio-tagged fish, derived from fixed station daily detections, is compared with water levels in Figure 4. Movement appears to have been stimulated by increasing water levels from 5-November, and the magnitude of the peak reflects the release of an additional 61 radio-tagged fish between 6- and 8-November. There were two further increases in activity on 17- and 25-November that seem to be correlated with small increases in river height. It should be noted that activity levels depicted in Figure 4 do not represent, necessarily, migratory movements to spawning grounds, but merely increased movement of fish that brought them within range of the receivers. Since a majority of detections were recorded by the Millar station these peaks were probably associated with localized movements in the vicinity of the spawning grounds: possibly spawning activity on 17-November and subsequent movement of males from the redds.

The fixed station receivers on Millar and Black Creek provided the only continuous telemetric monitoring that enables estimation of travel timing and rate of movement. The latter was highly variable among individual coho and ranged from approximately 1.3km/hr for tag 149.023 code 105 to Millar Creek (based on approximately 19.2km river length after Brown *et al.* 1999) to a leisurely 10.8 days to attain the same distance by tag 149.023 code 185. The mean travel time for fish that were recorded at the Millar station was 136.3 hrs (st.dev. 109.6 $n = 33$ and for the Black Creek station 128.7 hrs, st.dev.. 108.3 $n = 22$). Rate of travel to the Millar station was significantly faster for fish that were counted through the fence during the second period of movement in November ($t=4.53$, $p<0.001$). The mean rate of travel for the early portion of the escapement was 0.10km/hr versus 0.29km/hr for later fish. It is likely that higher stream discharge stimulated this increase. Similarly, the rate of travel to the Black Creek station increased from 0.08km/hr to 0.28km/hr ($t=5.18$, $p<0.001$) for the second release group. The similarity between these estimates suggests that rate of movement did not differ as a function of total distance to the spawning grounds; specifically, fish that spawned in sub-basins 12 and 13 did not display a faster rate of travel in the lower system than fish spawning in Millar Creek. This contrasts with varying rates of travel determined by Koski *et al.* (1995) for Skeena River coho with different spawning destinations, where highest rates were associated with greatest distances to travel. The average travel speed for the Black Creek escapement (3.5 km/day) corresponds to the lower rates measured for lower Skeena coho (4-11 km/day) while the fastest movement (30.2 km/day) is in close agreement with speeds recorded for coho moving to the Morice and Sustut watersheds (33 km/day and 30 km/day).

A total of 4 coho were recorded at both the Millar and Black Creek stations. Tag 149.043 - 165 was released on 29-October and was first recorded at Millar station on 8-November and at Black Creek station later on the same day (11:38pm). Subsequently, this fish was recorded in sub-basin 12 on 14-November, during a vehicle survey. Similarly, tag 149.043 - 125 reached Millar on 31-October, 2 days after release, moved back into sub-basin 5 four days later and then passed the Black Creek station on the evening of 7-November (6:38pm). It was next recorded by helicopter survey on 10-November in sub-basin 13. Tag 149.053 - 165 was released on 30-October and was recorded at Millar station on 7-November and at Black Creek station on the following day. Two days later on 10-November it was found in sub-basin 12 and on 21-November it moved into sub-basin 13, probably having spawned. This tag was recovered from sub-basin 13 during mark-recapture surveys on 1-December (Table 3). Tag 149.143 - 145 was detected at Millar station within 2 days of its release on 7-November, after which it was recorded by helicopter survey in sub-basin 5 on the following day. Within 8 hours of this record it moved past the Black Creek station and was next recorded in sub-basin 12 on 15-November.

Only one tag, 149.173 - 105 was first recorded at Black Creek station and subsequently at Millar station. This fish was released on 8-November, moved through sub-basin 5 on 10-November and was detected on this date by the Black Creek station. On 11-November it was again detected by Black Creek station and then at Millar Creek 5 hours later, where it remained until 22-November, subsequently dropping downstream to sub-basin 5.

It is unfortunate that signal strength was not a component of the data record for these movements to clarify the relative proximity of tags to the fixed receivers. Trials at the Black Creek site suggested that a radio-signal could be identified at a distance of at least 100m. However, weather and hydrological conditions as well as battery strength undoubtedly influenced the ability of the receivers to identify tagged fish and it seems likely that, on occasion, both fixed receivers were capable of detecting tags on the boundaries of sub-basins 8 (Millar Creek), 10 (Black Creek) and 5 where Northy Lake is situated (Figure 2). Movements of coho in the lake for a period prior to moving to the spawning grounds may account for a portion of the described movements where coho appeared to change their final spawning destination (see also comments in the following section). This is likely to be particularly true for movements within the lower river (sub-basins 1 to 5) which occurred with detection of tags by the Millar and Black Creek stations followed by the return of these fish to sub-basins 5 or 1. Tags 149.113 - 105, 149.113 - 165, and 149.053 - 145 were recorded by the Millar station but returned to sub-basin 1 after 4-6 days. Tags 149.103 - 145 and 149.073 - 185 returned to sub-basin 5, also following detection by the Millar station. Only 2 tags recorded by the Black Creek station moved downstream again. Tag 149.013 - 105 returned to sub-basin 5 as did tag 149.023 - 185.

Distribution of radio-tagged coho

The dispersal pattern for male and female radio-tagged coho within the Black Creek system is illustrated in Figures 5 to 10 for the approximately weekly periods based on the timing of helicopter surveys (Table 1). Since the Black Creek watershed is oriented in a generally East - West direction, the relative movement into the creek has been approximated by longitudinal position (Eastings). This provides a picture of the spatial separation of fish within a sub-basin but does not accurately portray linear progress within the creek. The plotted locations represent the maximum distance from the release point achieved by each fish in each period. In some cases the graphical separation of data points has been exaggerated to clarify fish abundances.

The pattern of distribution of the 1999 escapement is also illustrated geographically in Figures 11 to 16, which display all locations determined for each tag on all dates, delineated by sampling period. The overall pattern of movement closely resembles that shown in the previous set of figures, however, in some cases multiple records are displayed from different survey types in the same week (e.g. fixed station and helicopter), giving the impression of a greater number of fish. Conversely, the scale of the plots does not permit individual tags to be represented in all cases: exaggeration of the spatial separation of fish has not been performed for these figures.

From initial entry into the system, the distribution of coho throughout the watershed was rapid and simultaneous. In the first 3 to 5 days following the release of the initial 39 tags, fish were recorded from sub-basin 5 and four fish had already reached Millar Creek (Figures 5 and 11). By period 2, known spawning areas in sub-basins 8, 12 and 13 were populated. The primary transition area, sub-basin 10, did not hold fish for long periods and a majority of records from this area occurred during the initial dispersal of the escapement (Figures 6-7 and 12-13). The increase in numbers of fish in sub-basins 3, 6 and 10 in period 3 corresponds to the increase in activity shown in Figure 4, and may reflect final movements of fish onto spawning grounds. The first occurrence of coho in sub-basin 6 can be seen in week 3 (Figures 7 and 13), however, the apparent increase in population in week 5 (Figures 14 and 15) reflects multiple records for tags 149.063-145 and 149.153-125 (Figure 9). By week 6 (Figure 16) this area had accumulated 10 radio-tagged fish, most of which originated in sub-basin 5 (6 tags): these were probably spawned out fish moving into areas of low flow. Only 4 fish were recorded as having moved directly to sub-basin 6: the two noted above plus 149.123-185 and 149.163-105. The last of these was consistently located near the boundary between sub-basins 5 and 6 and was assessed as having spawned in the former area. No fish were located in sub-basins 2, 4, 9 or 11 during any survey: one tag (149.133-185) was found on the boundary of sub-basins 10 and 11 on two occasions (Figures 13 and 14) and it is possible that a small portion of the escapement spawned in sub-basin 11.

The stability of the overall distribution was surprisingly high. With the exceptions noted in the previous section, the relative proportions of fish in each major location remained relatively constant after the initial dispersal phase. This is illustrated in Figure 17 where the high proportions of fish in sub-basin 1 in periods 1 and 2 (73% and 40%) correspond to accumulations during the two release periods and subsequently, lower, numbers more accurately depict the spawner population. In periods 3 to 6 sub-basin 1 held between 21% and 31% of the total releases. This area displayed greater than average variability in numbers, not only as the initial location for all releases, but due to movements of fish as far as sub-basins 8 and 10 before returning downstream (as described previously). Millar Creek accumulated 19% of the total active tags by period 2 with a reduction in numbers to 16% in period 5. Sub-basins 12 and 13 can be considered as one unit due to their isolation and the location of a spawning area on their boundary. These areas contained 31% of the releases by period 3 and maintained this level with little reduction (2%) due to post spawning emigration in period 6 (5 radio-tagged carcasses were recovered from this area during mark-recapture surveys). Sub-basin 5 was a corridor to other spawning areas such as Millar Creek and the upper system, but held between 9% and 15% of the tagged population between periods 2 and 6. Sub-basin 6 held fewer than 5% of tagged fish and was not an important spawning area, however, in period 6 this proportion increased to 10%, as described above.

A number of radio tags were not located by any survey method in each of the survey periods (illustrated as unknown in Figure 17). These tended to be different between specific periods, other than the 4 tags that likely malfunctioned. Excluding these, only two tags were not located in more than one period between periods 2 and 5 (149.064-185 was not located in periods 2 and 5, while 149.183-165 was not found in periods 3 and 4). It is not clear why certain tags were not found on all sampling dates. For example, 149.183-165 was recorded moving past the receiver on Black mainstem on 31-October and later recorded in sub-basin 12 during helicopter surveys in periods 2, 5 and 6. Signal deflection or degradation from fish hiding in areas such as undercut banks may play some role, as may water depth in areas such as Northy Lake. We did not directly assess the detectability of tags in Northy Lake, where Bocking *et al.* (1988) suggested coho may reside for some time before continuing to migrate upstream. During weeks 2 and 3, when staging would have been anticipated, the proportions of radio tags not located by helicopter were low (9% and 8% Figure 17) and only 6 tags were likely to have been in Northy Lake. Primary candidates were 149.023-165, 149.033-165, 149.064-125 and 185, and 149.103-145 all of which transited Northy Lake to reach either Millar Creek or sub-basin 12. However, none were missing in consecutive periods and we have no evidence for prolonged residence in the lake.

The overall relative spawning distribution is provided in Table 4. Determination of the spawning location for individual tagged fish was simple in many cases, particularly for those that reached sub-basins 12 and 13, where only one tag (149.172 - 105) moved or was washed downstream again. Other determinations, where more than one location was recorded for a tag in the final 3 sampling periods were generally based on the number of consistent prior records for that tag.

The proportions of tagged fish, from each release group, that spawned in the primary spawning sites (sub-basins 1, 5, 8 and 12-13) were generally similar (Table 4). However, coho from the first release group were more numerous than expected in sub-basin 5 (X^2 = 9.47, df = 1, p = 0.002). The proportions of males and females from the two release groups were more variable, with unequal contributions from the respective releases occurring in sub-basin 1 for males and females, (respectively X^2 = 5.33, df = 1, p = 0.021 and X^2 = 7.03, df = 1, p = 0.008), sub-basin 5 for males and females, (X^2 = 16.74, df = 1, $p < 0.001$ and X^2 = 4.24, df = 1, p = 0.039), sub-basin 12 for females, (X^2 = 6.26, df = 1, p = 0.012) and sub-basin 13 for males (X^2 = 4.98, df = 1, p = 0.026).

DISCUSSION

Movement of coho into Black Creek followed a similar pattern in 1999 to previous years, with an initial movement coincidental with the first freshet and a second pulse with the next increase in water levels. However, the latter was much smaller than anticipated and almost the entire escapement, 369 adults, entered the creek in the initial period. The distribution patterns of the two groups of fish were not dissimilar, with the exception of a higher than expected number of early coho choosing to spawn in sub-basin 5. Consequently, at least in 1999, there is no evidence that the escapement comprised two groups of fish identifiable by run-timing and genetically predisposed to target different portions of the watershed for spawning. Similarly, it is clear that the Black Creek escapement does not display an initial migration to staging areas, such as Northy Lake, followed by subsequent dispersal to the spawning grounds, at least under the hydrologic conditions encountered in 1999. While some movement among sub-basins was noted, a total of 88 of the 96 radio-tags moved directly to their final destination. Of the 8 exceptions, most were found to move to adjacent sub-basins, rather than undergo radical changes in destination.

Overall, the relative distribution of spawners was similar to historical estimates (Figure 18). Most of the escapement spawned in sub-basins 12 and 13, which, together, accounted for 33% of the run (by extrapolation 170 adults). This figure is remarkably similar to the 37% determined by Brown *et al.* (1999), but the proportion of spawners in sub-basin 12 was substantially greater in 1999 (20%), compared with previous years. The former authors depict all of the currently (1989 - 1994) utilized spawning habitat in sub-basin 13 as proximal to the boundary with sub-basin 12. While this general area was heavily utilized in 1999 (Figures 13-16), a majority of spawners were located in sub-basin 12. Interestingly, most of the sub-basin 13 spawners were located further upstream, although not distributed as far as the most heavily utilized area determined by Hamilton (1978, as illustrated by Brown *et al.* (1999)Map 6, pg. 40). No radio-tagged fish were located in sub-basin 14.

The second largest portion of the escapement spawned in sub-basin 1, accounting for 26% of the population. This area appears to have increased in importance for spawning over that estimated from 1990-1996 and is approaching the 30% noted by Hamilton (1978). The general pattern of utilization of spawning areas within sub-basin 1 agrees well with mapping by Brown *et al.* (1999) with concentrations of coho below Lalum Road tributary and probable spawning in the lower end of the tributary (Figure 13). The only other area of the lower river that held substantial numbers of spawners was sub-basin 5. We did not find any portion of the 1999 escapement spawning in sub-basins 2 or 4: Brown *et al.* (1999) located a small proportion of spawners in sub-basin 4, but suggested that spawning habitat has been eliminated in sub-basin 2. Similarly, sub-basin 3 had a small number of coho present during week 3 (2 radio-tags), but these fish subsequently moved into sub-basin 1. In contrast, sub-basin 5 contributed 14% of spawners, rather less than the average between 1990 and 1996 (Figure 18). In common with observations by Hamilton (1978) and Brown *et al.* (1999) most spawners in sub-basin 5 were located in the lower portion, below the Sturgess Road Bridge.

Millar Creek is the most important spawning area in sub-basin 8 and contained 22% of the escapement in 1999, a 7% increase over the proportion noted by Brown *et al.* (1999) and more than twice the level of utilization noted by Hamilton (1978). Unfortunately, the trend of increasing proportional utilization with decreasing numbers of fish, continued for the 1999 escapement: 112 spawners (22%) versus 800 (10% of the 1974 run estimated by Hamilton 1978) and 150 (15% of the 1997 escapement estimated by Brown *et al.* 1999). Most spawners in 1999 were located in the upper Millar Creek area (Figures 13-15), with some fish penetrating to the uppermost location illustrated by Brown *et al.* (1999) in their Appendix II Map 5.

Prior to this study, the spawning distribution of coho in Black Creek was assessed, primarily, through visual surveys with their associated subjectivity. Brown *et al*. (1999) caution against comparisons among years where escapement totals are strongly different. However, the general distribution of spawners among the primary areas in Black Creek, sub-basins 1, 5, 8 and 12-13 are less variable then might be expected from the disparity of population sizes in the various years illustrated in Figure 18. It would have been desirable to have marked a substantially larger escapement to avoid bias in tag application and the non-representative rate of application on the second portion of the run. While an extremely large escapement was not anticipated, the size of the 1999 escapement was particularly disappointing, following the 7,616 adults recorded in the previous year when exploitation fell to 3.0% (Table 5). This study year (1999) was the second lowest escapement since 1987, approaching the lowest recorded escapement of 284 adults in 1996 (Baillie *et al.* 2004). The estimated 1.7% survivorship for the 1998 smolt output is the lowest survival in the current Black Creek time series (Table 5). The decline in ocean survival, seen through the 1990's, mirrors declines seen elsewhere in the Strait of Georgia basin (Figure 19). This is a serious conservation concern and has resulted in the virtual elimination of fishing, as seen in the exploitation rate estimate for 1999 of 3.0% (the average exploitation of Black Creek coho between 1986 and 1998 was 70.4%).

ACKNOWLEDGEMENTS

We wish to express our appreciation to Derek Kyostia, Hugh MacLellan and Dustin Alix who formed the core of our field crew. The recovery totals for adult coho would have been much lower if not for their dedication and persistence. We also are grateful to Jim Amos, Ian MacDonald, Gary Moult, Andrew Rody, Terry Steele, Mark Atkinson and Deidre Garvey who assisted with fence cleaning and sampling during high water. We would also like to thank Tom J. Brown who prepared the figures on geographical distribution and Tom G. Brown for permission to reproduce Figure 19 with our data and who both contributed suggestions and information. We are indebted to the pilots who performed the radio telemetry surveys: Gerry Emery and Glen Diachuk, Canadian Coast Guard and Craig Houston, Longbeach Helicopters.

LITERATURE CITED

Baillie, S. J., Simpson, K., and Taylor, J. A. 2004. Enumeration studies of coho salmon at Black Creek: 1995 adults and 1996 juveniles and adults. Can. Manuscr. Rep. Fish. Aquat. Sci. 2698: vi + 49 p.

Bocking, R. C., J. R. Irvine, K. K. English, and M. Labelle. 1988. Evaluation of random and indexing sampling designs for estimating coho salmon (*Oncorhynchus kisutch*) escapement to three Vancouver Island streams. Can. Tech. Rep. Fish. Aquat. Sci. 1639: 95 p.

Brown, T.G., L. Barton, and G. Langford. 1996. The use of a geographic information system to evaluate terrain resource information management (TRIM) maps and to measure land use patterns for Black Creek, Vancouver Island. Can. Manuscr. Rep. Fish. Aquat. Sci. 2395: 34p.

Brown, T.G., L. Barton, and G. Langford. 1999. Coho salmon habitat within Black Creek, Vancouver Island. Can. Tech. Rep. Fish. Aquat. Sci. 2294: 75p.

Hamilton, R.E. 1978. Black Creek, Vancouver Island, B.C. hydrology, fisheries resource, and watershed development. Fish Mar. Ser. MS Rep. 1484: 82p.

Koski, W.R., R.F. Alexander and K.K. English. 1995. Distribution, timing and numbers of coho salmon and steelhead returning to the Skeena watershed in 1994. Unpubl. Rep. for B.C. Ministry of Environment, Lands and Parks.

Labelle, M. 1990. A comparative study of the demographic traits and exploitation rates of coho salmon stocks from S.E. Vancouver Island. Thesis (Ph.D.) - University of British Columbia, 1990. ix, 264 p.

TABLES

Table 1. Definition of sampling periods and timing of helicopter surveys within the Black Creek watershed.

	Start date	End date	Aerial survey
Period 1	28/10/99	3/11/99	1/11/99
Period 2	4/11/99	10/11/99	10/11/99
Period 3	11/11/99	17/11/99	15/11/99
Period 4	18/11/99	24/11/99	21/11/99
Period 5	25/11/99	29/11/99	26/11/99
Period 6	30/11/99	7/12/99	30/11/99 and 2/12/99

Table 2. Summary of radio-tag deployment by date and sex.

Date	Males released	Females released
29/10/99	10	10
30/10/99	12	5
31/10/99	1	1
06/11/99	0	3
07/11/99	14	21
08/11/99	10	13

Table 3. Summary of recoveries of adult coho from sampling sites, enumerated by mark type and the presence of an adipose fin clip.

Date collected	Site number	Floy tag	Opercular punch	Radio tag frequency/code
20-Nov-99	I14	1539	Y	149.163-145
20-Nov-99	I14	502	Y	149.063-185
20-Nov-99	I14	721	Y	
20-Nov-99	I14	764	Y	
20-Nov-99	I12	1676	Y	
22-Nov-99	I4	409	Y	
22-Nov-99	I5	626	Y	149.013-145
22-Nov-99	I5	93	Y	
22-Nov-99	I4	not tagged	N	
22-Nov-99	I4	1543	Y	149.173-105
23-Nov-99	I7	1507	Y	
23-Nov-99	I7	n/a [1]	Y	
23-Nov-99	I7	1505	Y	149.103-125
25-Nov-99	I4	105	Y	
01-Dec-99	I4	1550	Y	149.183-105
01-Dec-99	I14	1500	Y	149.183-125
01-Dec-99	I14	n/a [1]	Y	
01-Dec-99	I12	not tagged	N	
01-Dec-99	I12	118	Y	149.053-165
01-Dec-99	I12	1547	Y	149.173-185

n/a [1] partial carcass collected with head affixed

Table 4. Geographical distribution of radio-tagged coho for sub-basins where spawning is presumed to have occurred, stratified by release period and sex. Numerical and proportional abundances, by category, are shown.

	Sub-basin 1		Sub-basin 5		Sub-basin 6		Sub-basin 8		Sub-basin 10		Sub-basin 12		Sub-basin 13	
	# tags	%	# tags	%	# tags	%	# tags	%	# tags	%	# tags	%	# tags	%
Release 1	10	25.6	9	23.1	0	0	10	25.6	0	0	7	18.0	3	7.7
Male	4	16.7	6	25.0	0	0	8	33.3	0	0	5	20.1	1	4.2
Female	6	40.0	3	20.0	0	0	2	13.3	0	0	2	13.3	2	13.3
Release 2	16	26.7	5	8.3	3	5.0	12	20.0	1	1.7	13	21.7	10	16.7
Male	7	30.4	1	4.4	0	0	9	39.1	0	0	3	13.0	3	13.0
Female	9	24.3	4	10.8	3	8.1	3	8.1	1	2.7	10	27.0	7	18.9
All releases	26	26.3	14	14.1	3	3.0	22	22.2	1	1.0	20	20.2	13	13.1
Male	11	23.0	7	14.9	0	0	17	36.2	0	0	8	17.0	4	8.5
Female	15	28.9	7	13.5	3	5.8	5	9.6	1	1.9	12	23.1	9	17.3

Table 5. Estimated marine survival and associated exploitation rate in marine fisheries.

Return Year	% Smolt to Adult Survival	% Exploitation
1979	19.0[1]	91.5[2]
1980	19.8[1]	83.6[2]
1981	-	-
1982	-	-
1983	-	-
1984	-	-
1985	-	-
1986	12.5	72.7
1987	11.5	84.7
1988	13.4	67.6
1989	11.5	69.7
1990	12.9	71.3
1991	8.0	77.7
1992	12.5	76.7
1993	5.4	73.9
1994	5.9	79.0
1995	4.5	56.7
1996	3.4	70.3
1997	4.9	54.1
1998	4.5	3.0
1999	1.7	3.0

[1] Probable under-estimate due to probable under-estimate of escapement.

[2] Probable over-estimate due to probable under-estimate of escapement.

FIGURES

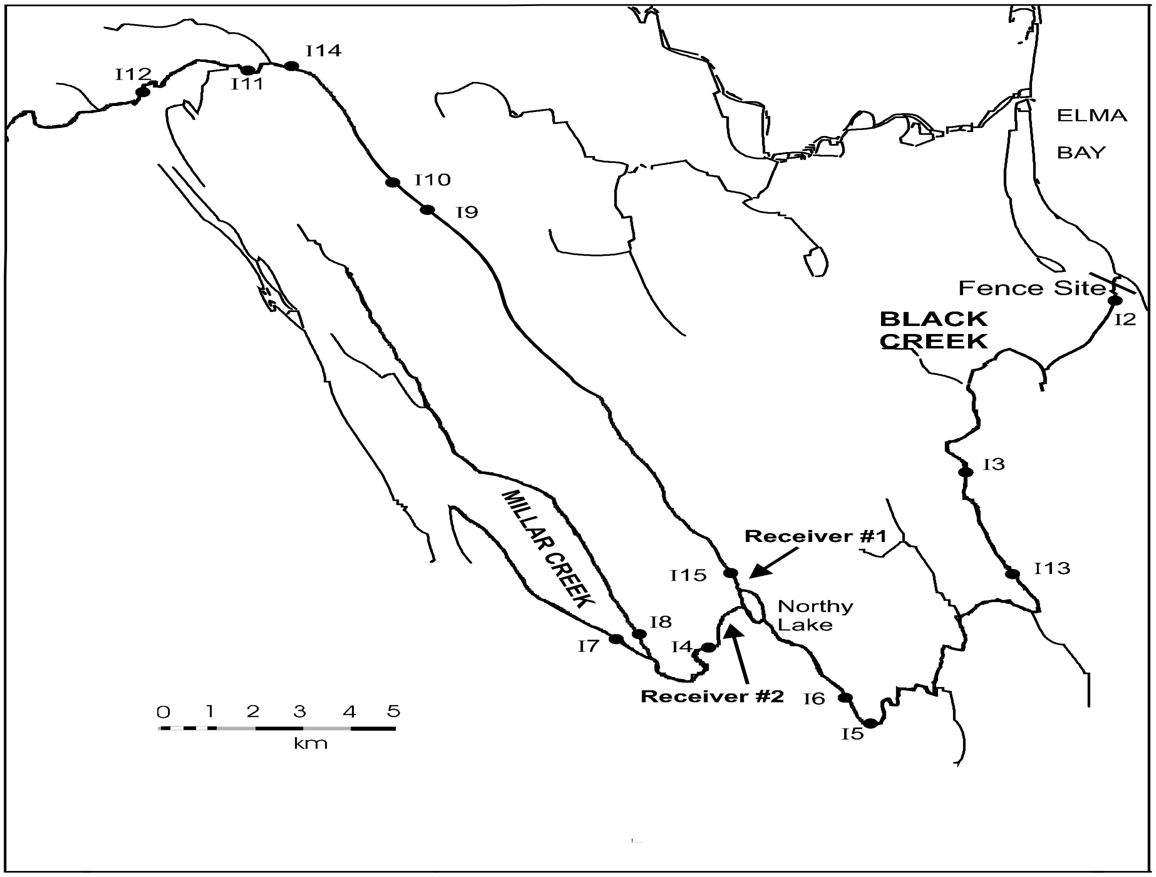

Figure 1. The study area, showing the location of the counting fence, fixed station receivers at Millar Creek and Black Creek and mark-recapture recovery sites.

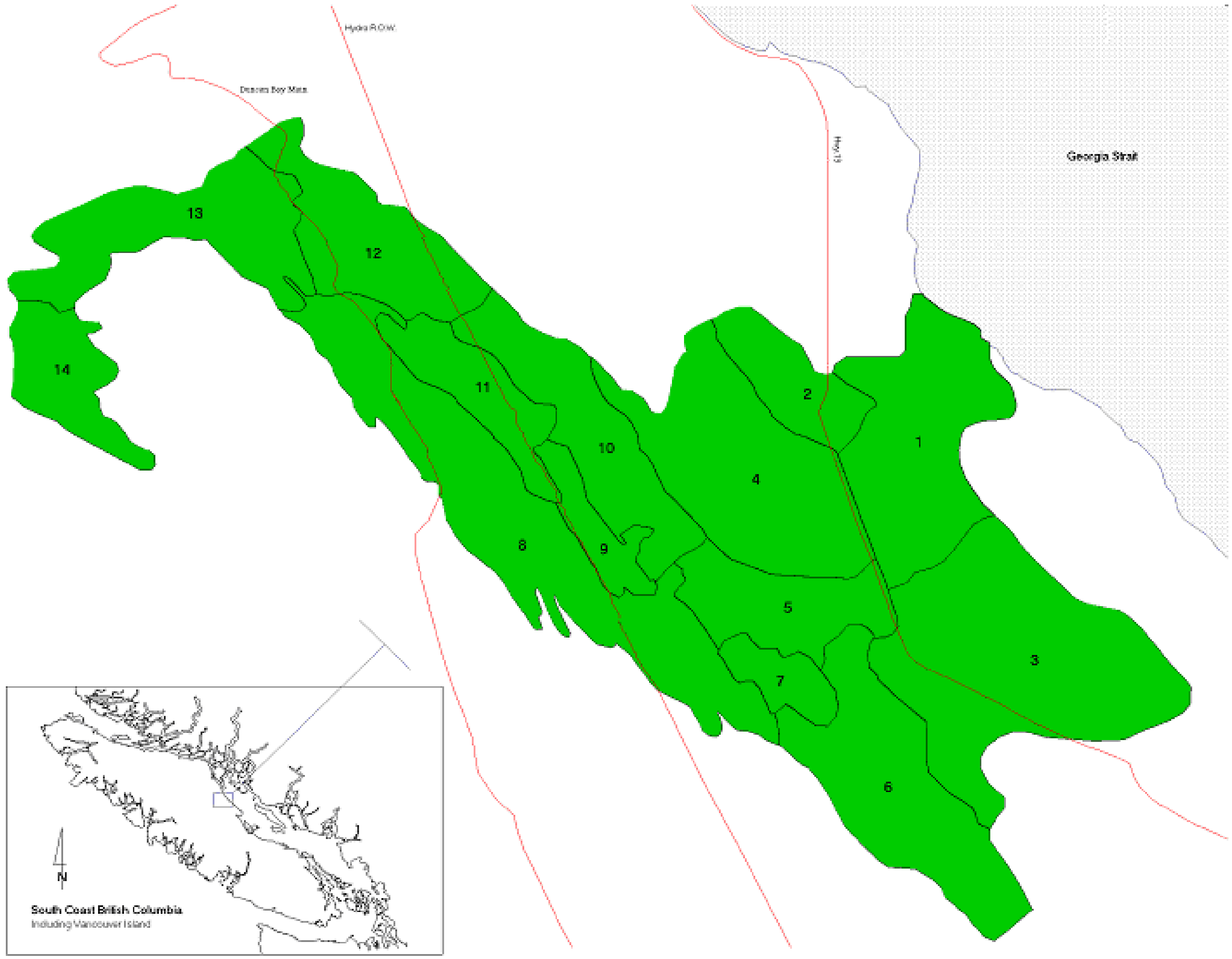

Figure 2. The Black Creek watershed and sub-basin boundaries (after Brown et al. 1999).

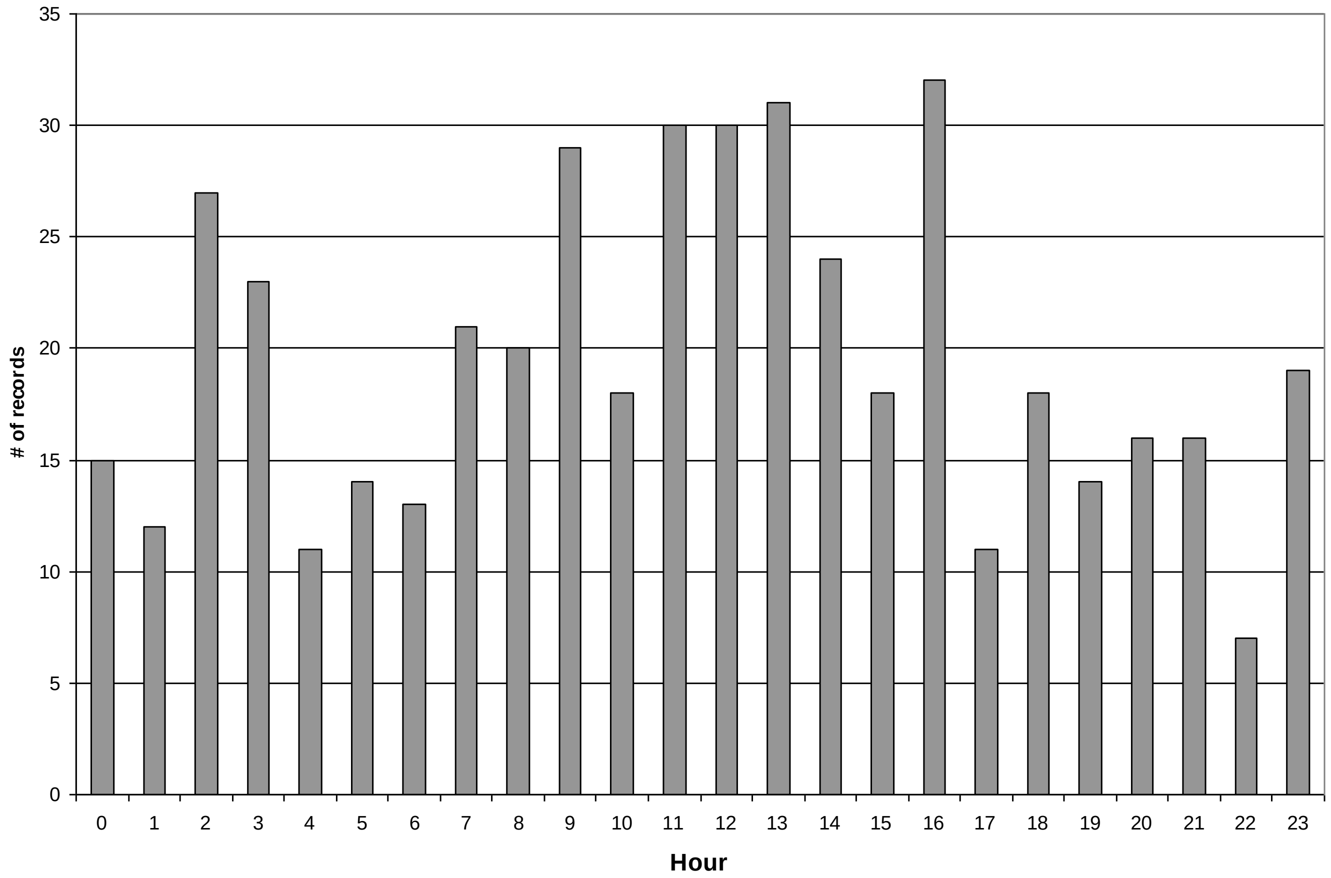

Figure 3. Frequency of detection events recorded to the nearest hour by the Millar and Black Creek fixed station receivers as an illustration of the pattern of diel movement by radio-tagged coho.

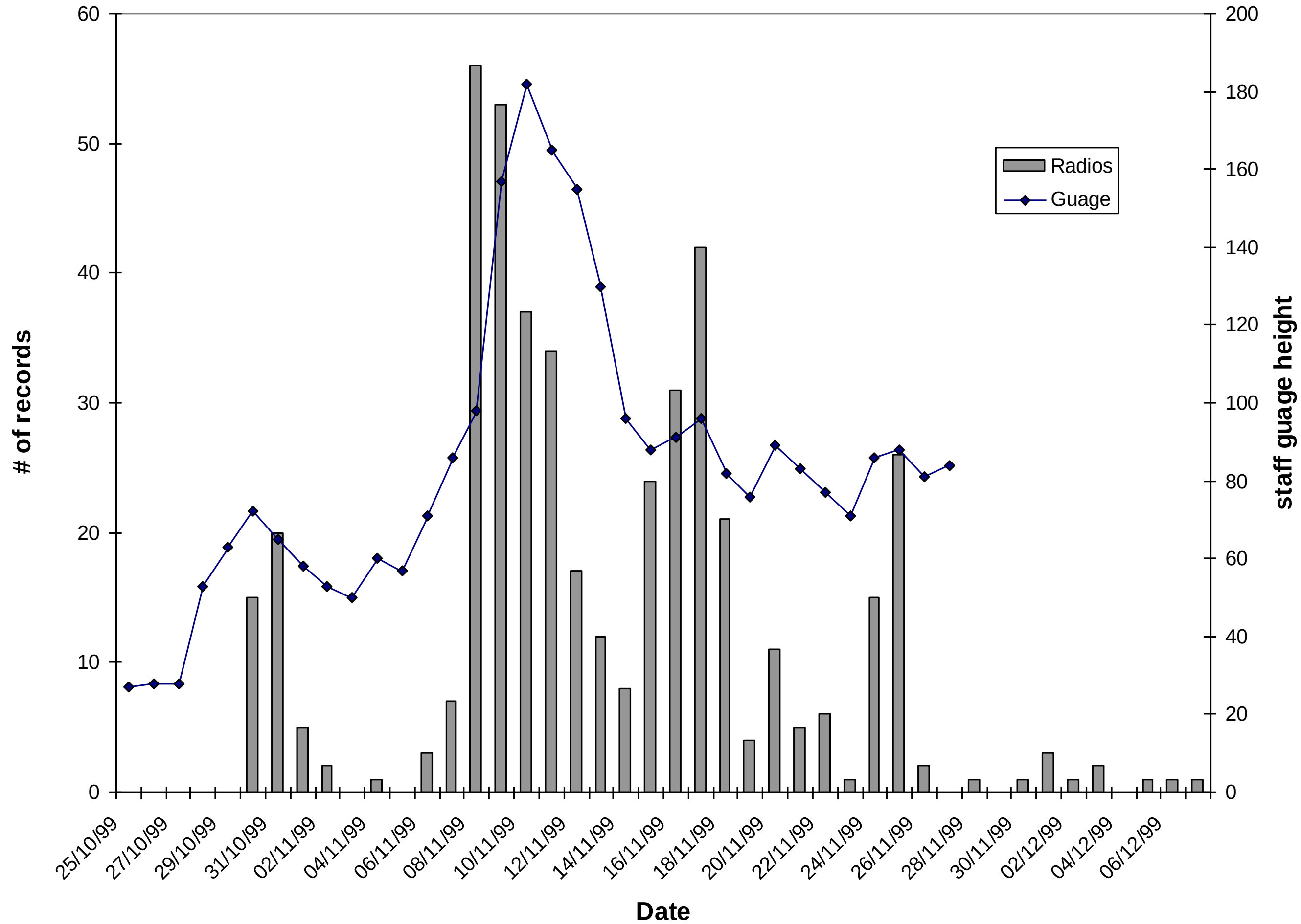

Figure 4. Daily movement of radio-tagged coho as denoted by fixed station detections, in relation to stream height.

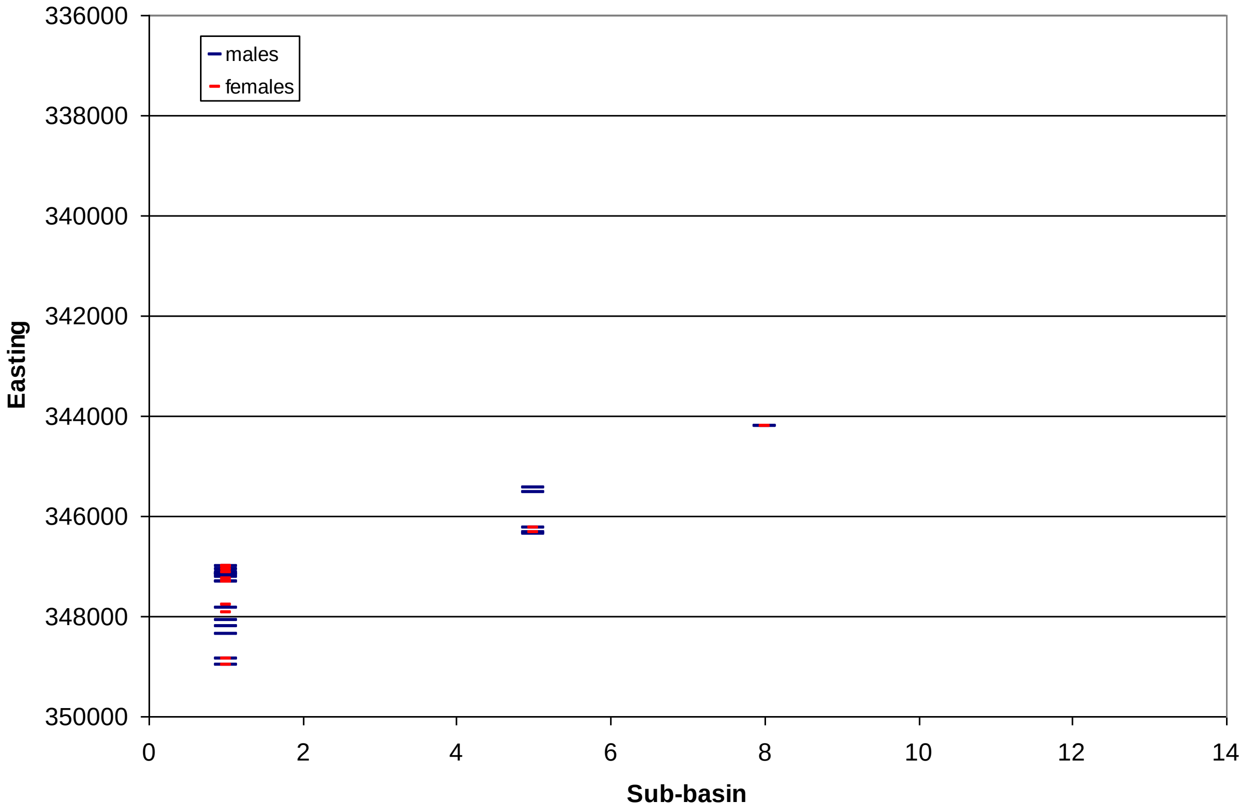

Figure 5. Dispersal of radio-tagged coho, by sex, within Black Creek during week 1. Spatial separation within the sub-basins is approximated by Eastings, with some exaggeration for the sake of clarity in portraying numbers of fish.

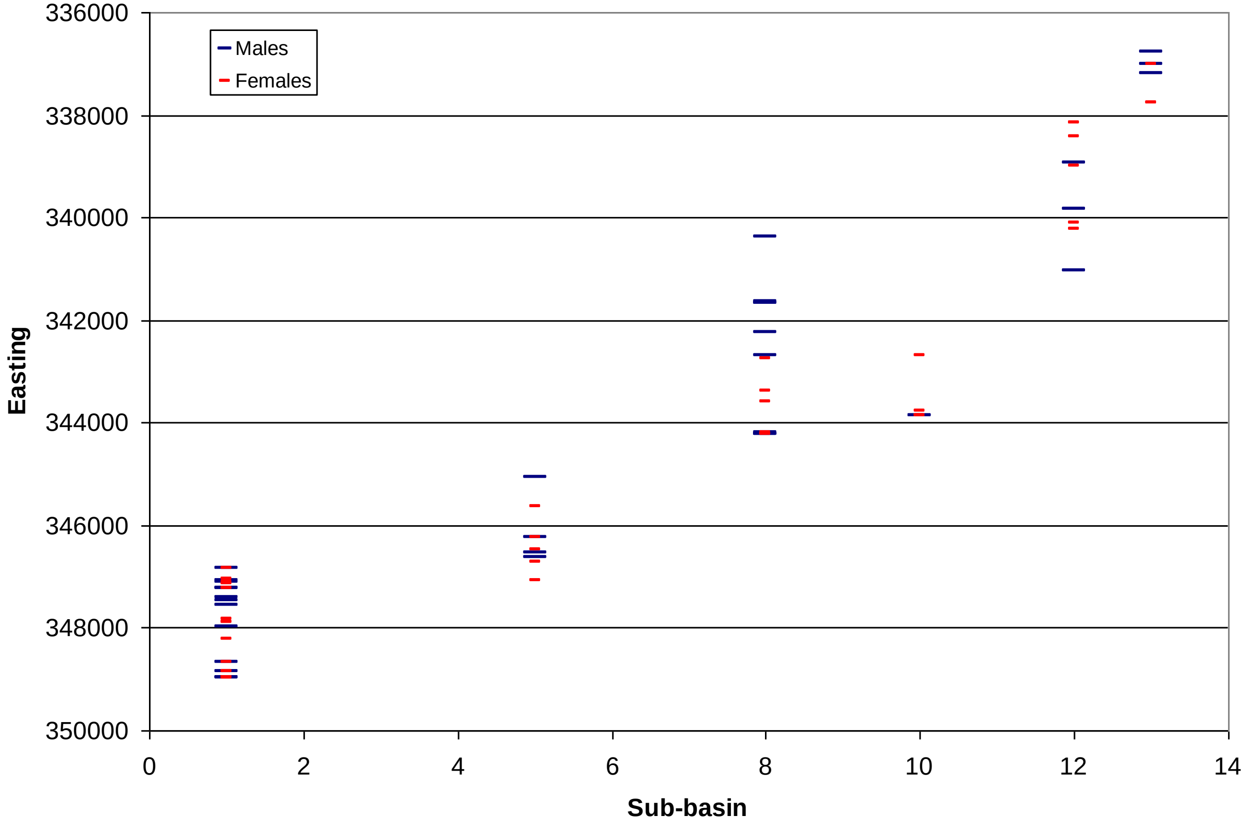

Figure 6. Dispersal of radio-tagged coho, by sex, within Black Creek during week 2. Spatial separation within the sub-basins is approximated by Eastings, with some exaggeration for the sake of clarity in portraying numbers of fish.

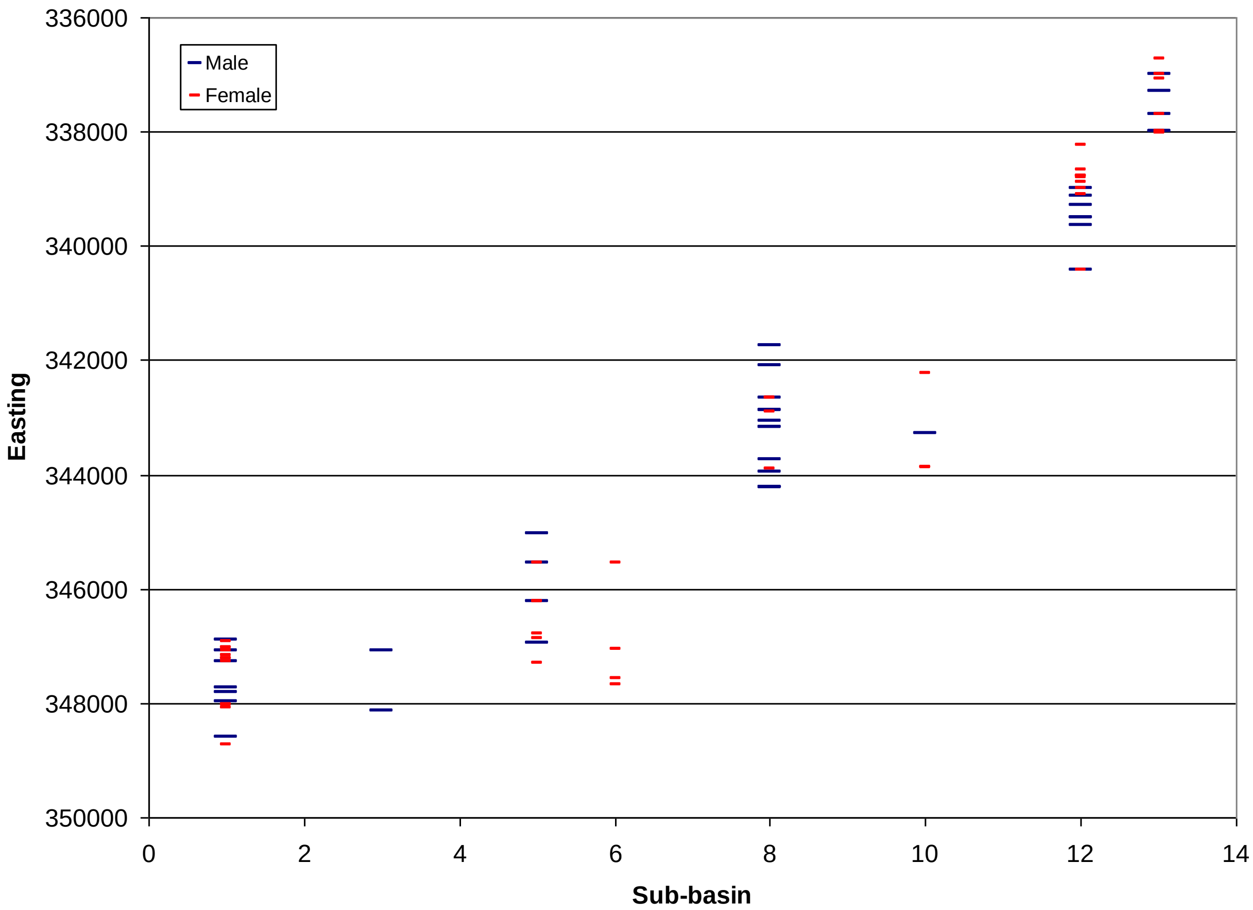

Figure 7. Dispersal of radio-tagged coho, by sex, within Black Creek during week 3. Spatial separation within the sub-basins is approximated by Eastings, with some exaggeration for the sake of clarity in portraying numbers of fish.

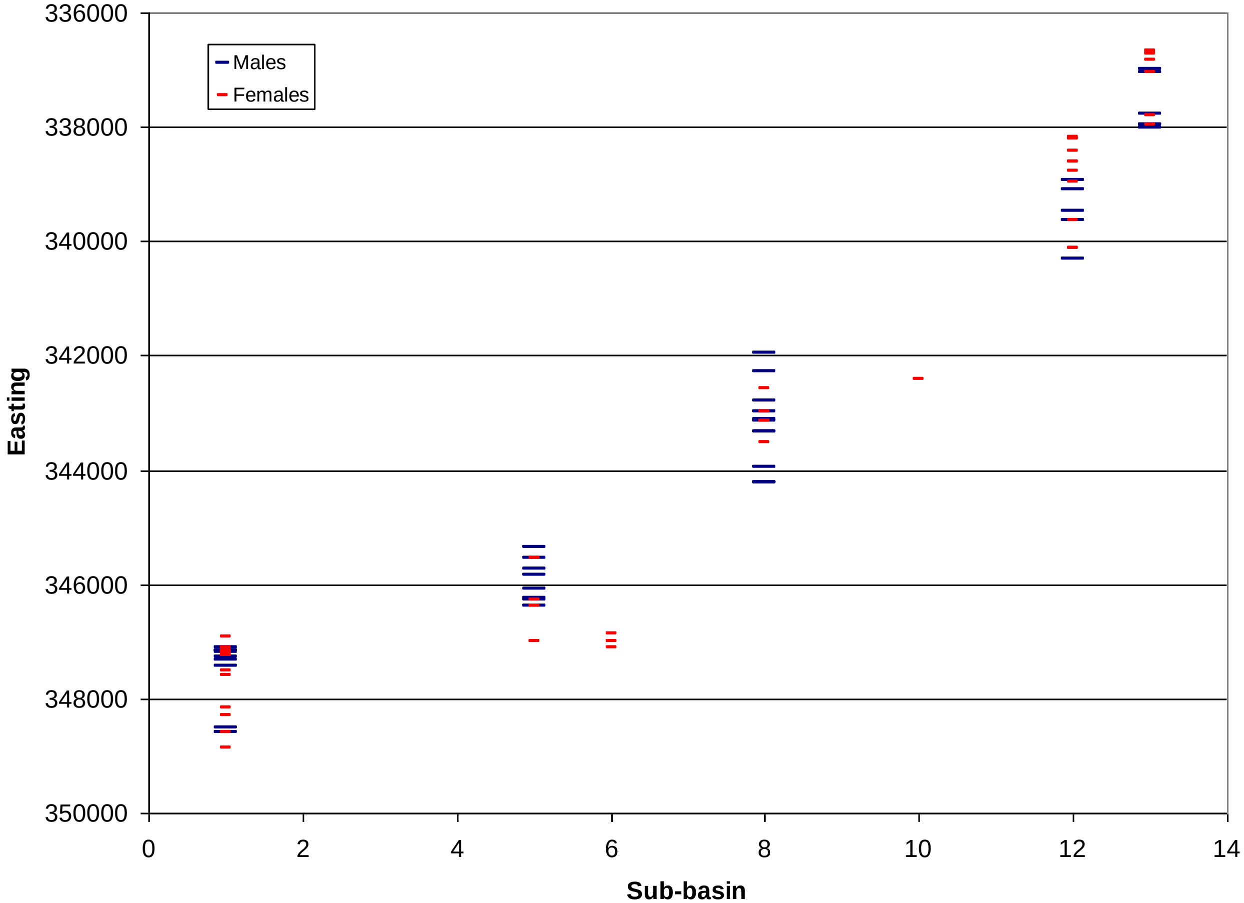

Figure 8. Dispersal of radio-tagged coho, by sex, within Black Creek during week 4. Spatial separation within the sub-basins is approximated by Eastings, with some exaggeration for the sake of clarity in portraying numbers of fish.

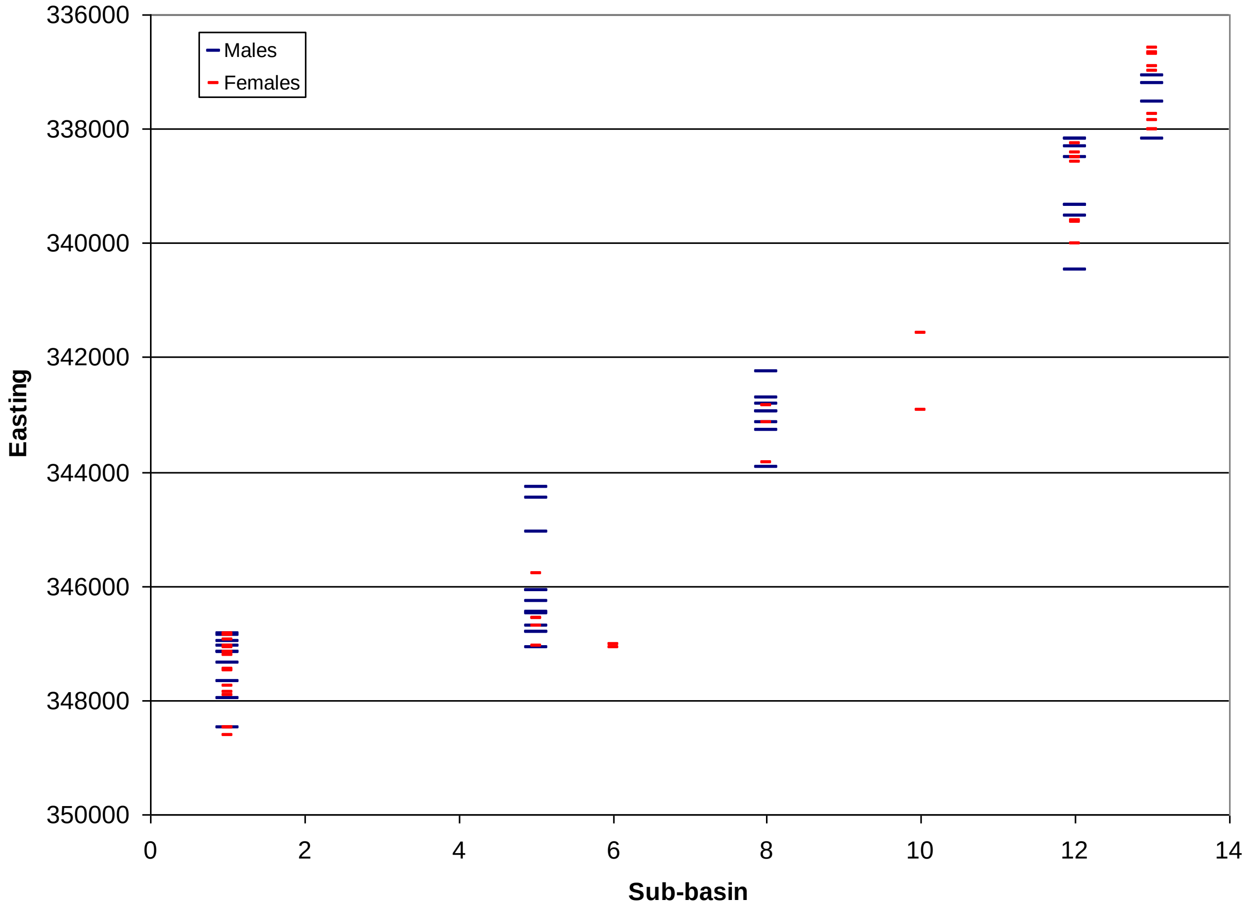

Figure 9. Dispersal of radio-tagged coho, by sex, within Black Creek during week 5. Spatial separation within the sub-basins is approximated by Eastings, with some exaggeration for the sake of clarity in portraying numbers of fish.

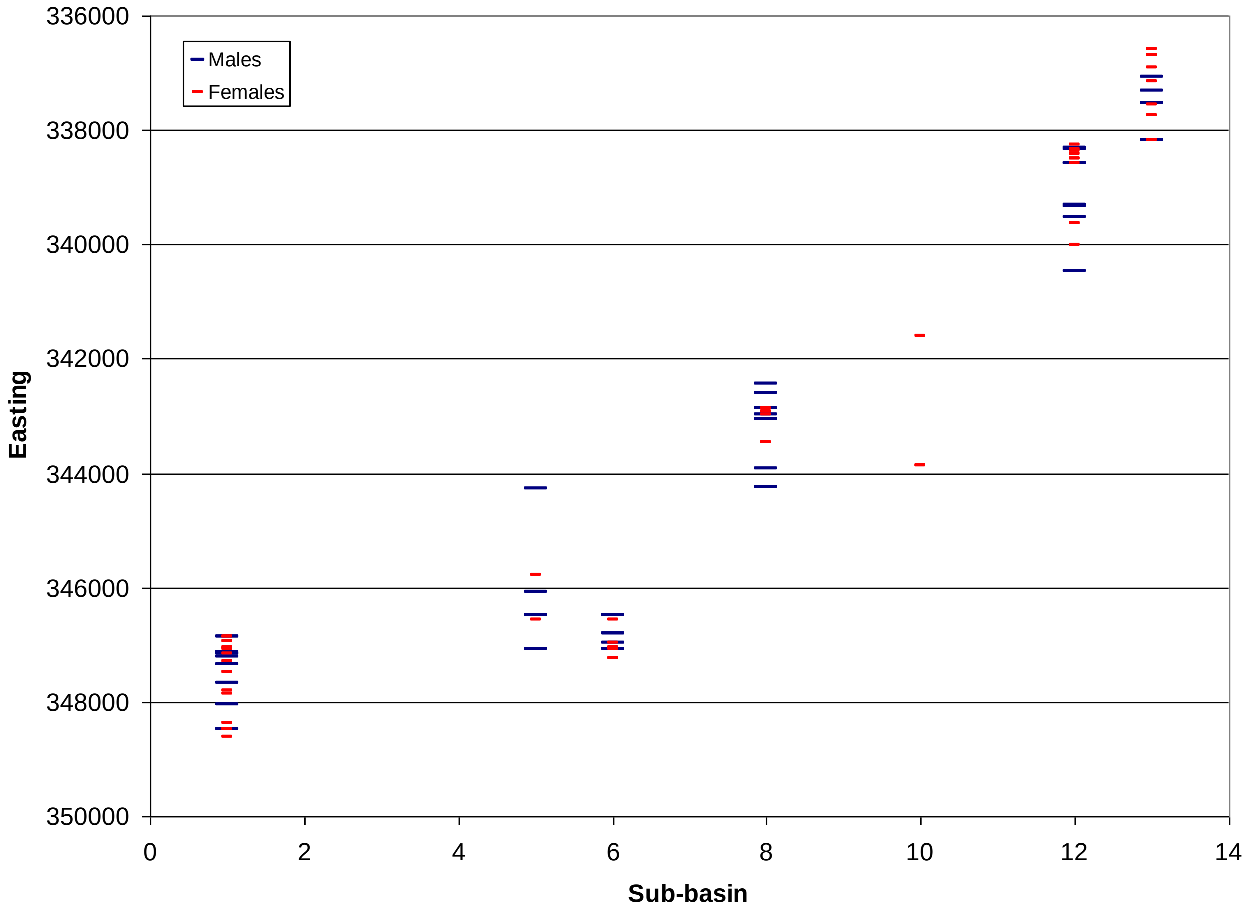

Figure 10. Dispersal of radio-tagged coho, by sex, within Black Creek during week 6. Spatial separation within the sub-basins is approximated by Eastings, with some exaggeration for the sake of clarity in portraying numbers of fish.

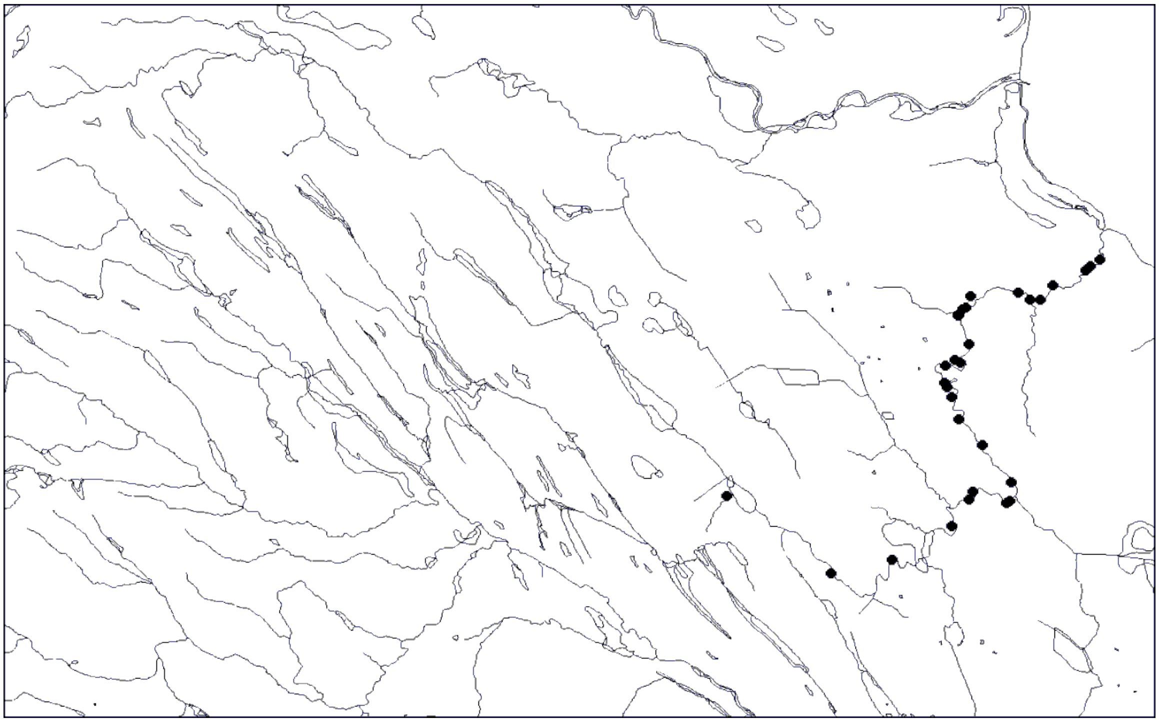

Figure 11. Locations of radio-tagged coho determined during week 1: data from all survey types.

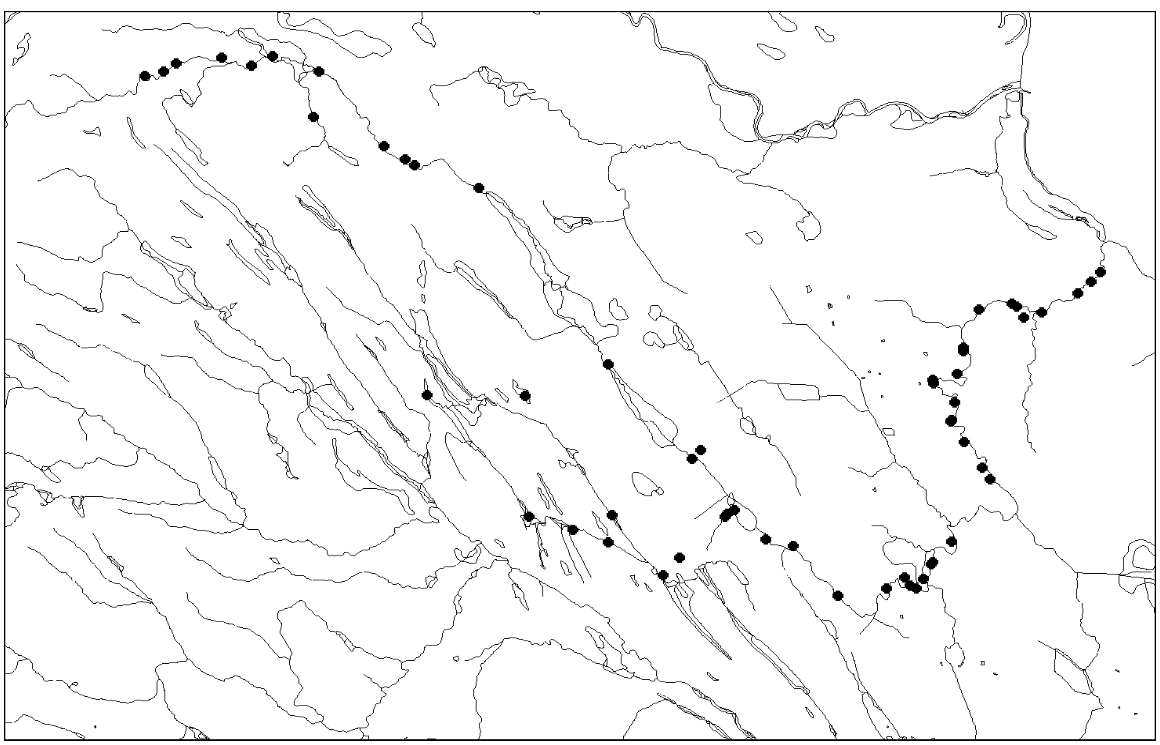

Figure 12. Locations of radio-tagged coho determined during week 2: data from all survey types.

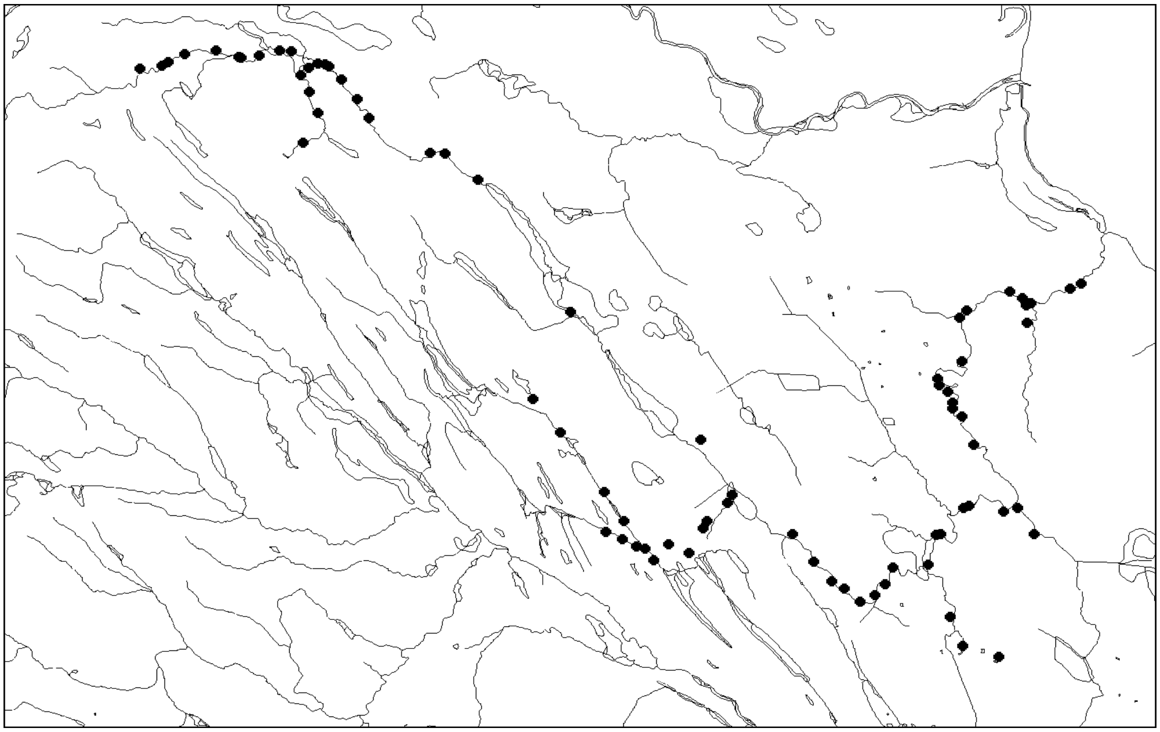

Figure 13. Locations of radio-tagged coho determined during week 3: data from all survey types.

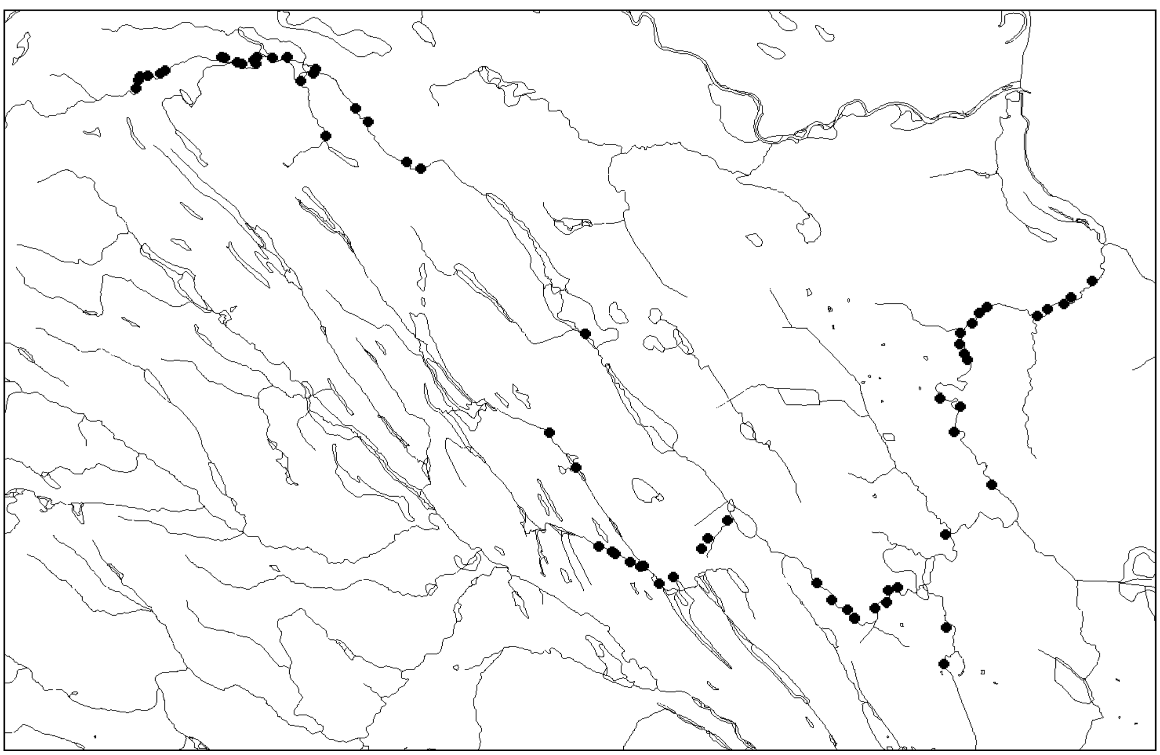

Figure 14. Locations of radio-tagged coho determined during week 4: data from all survey types.

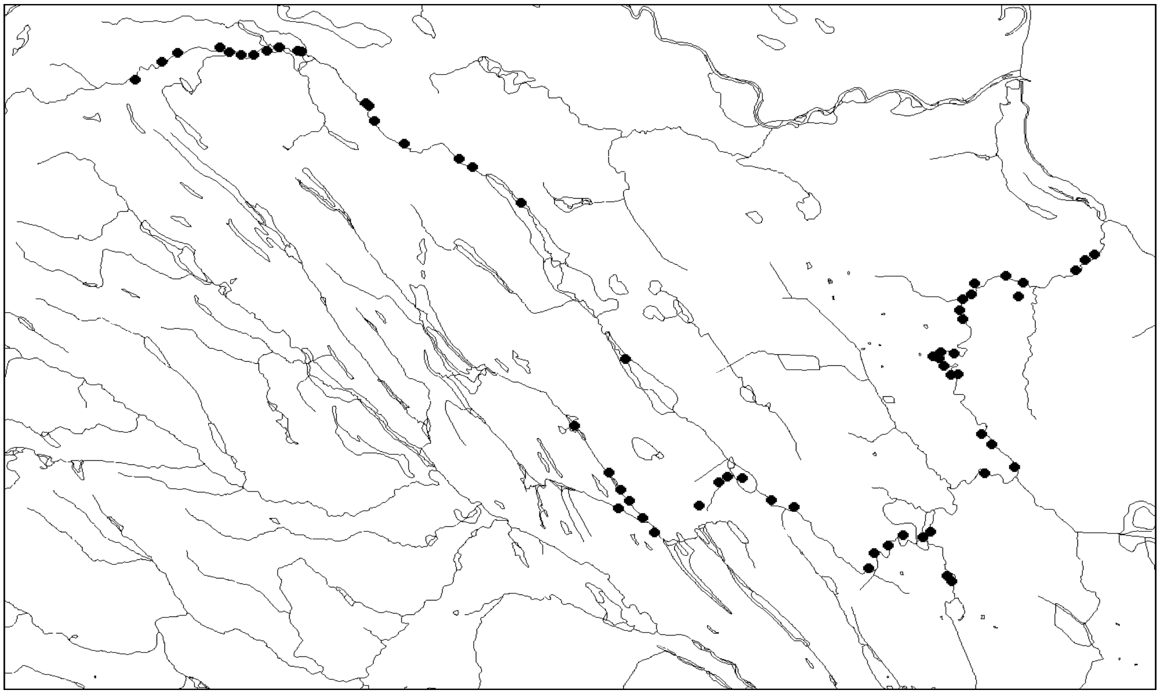

Figure 15. Locations of radio-tagged coho determined during week 5: data from all survey types.

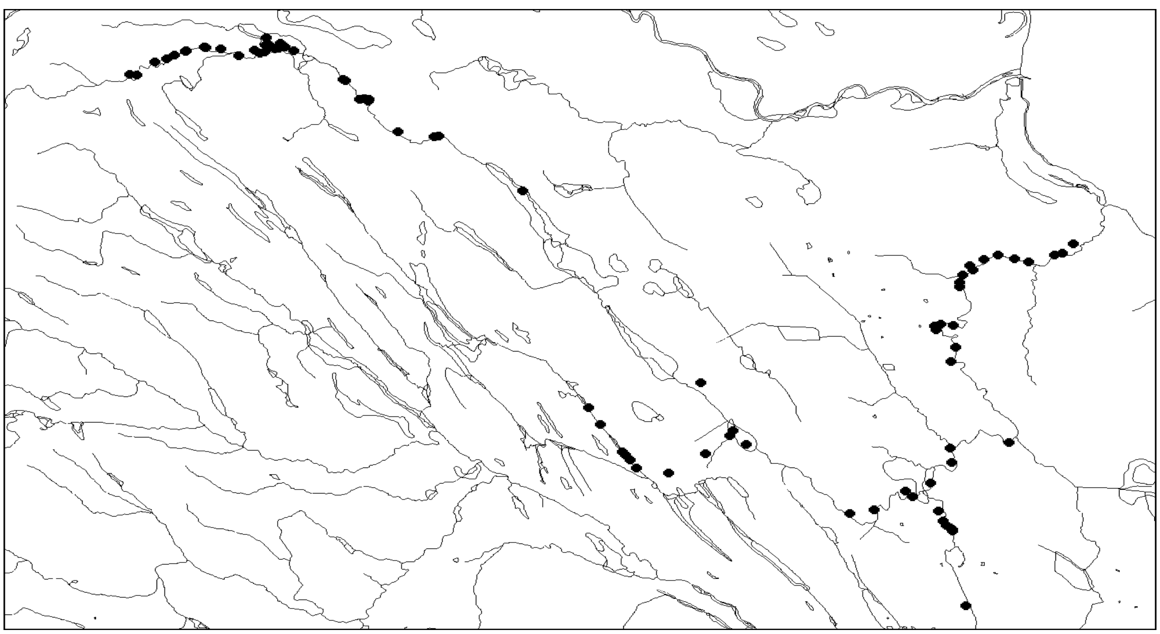

Figure 16. Locations of radio-tagged coho determined during week 6: data from all survey types.

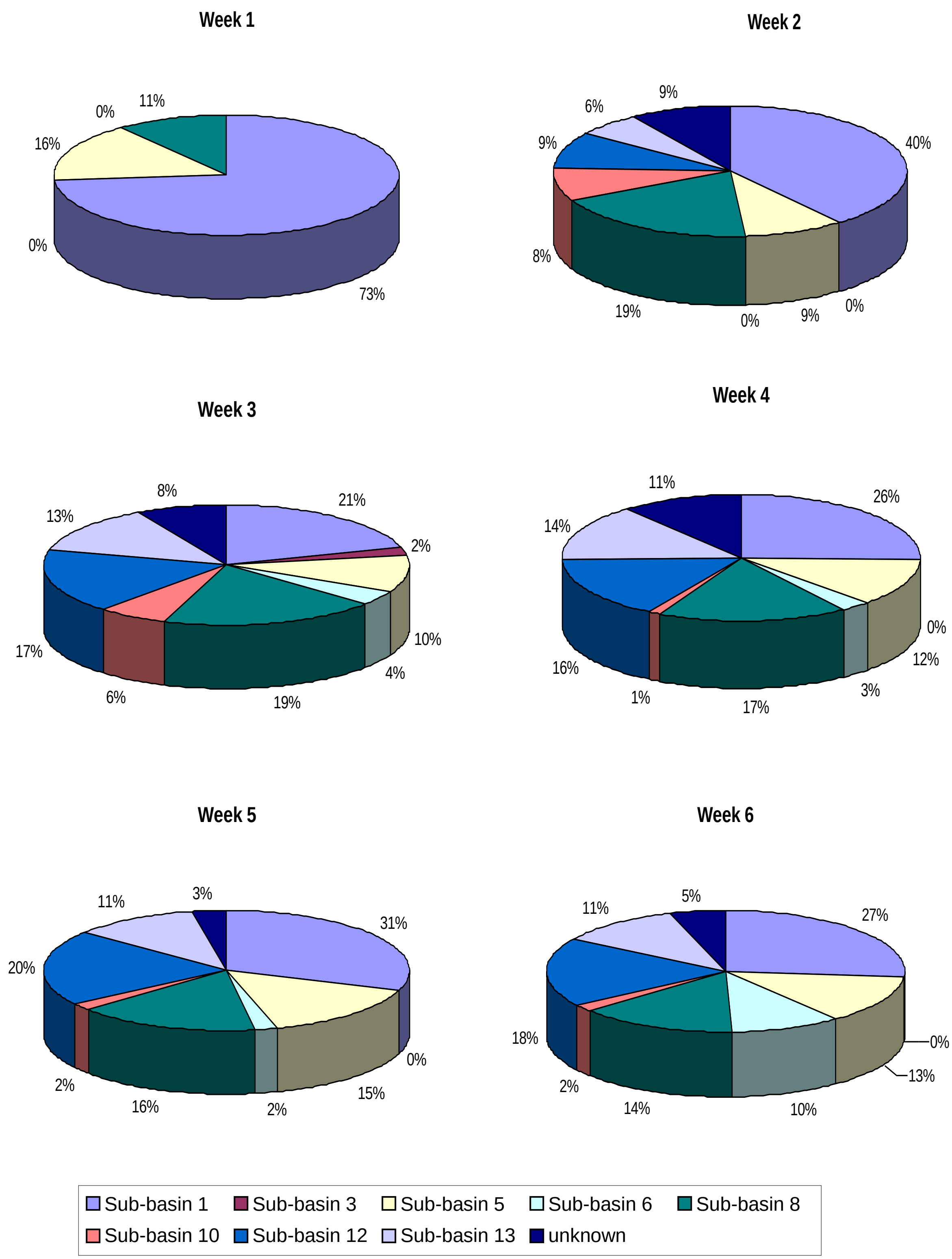

Figure 17. Proportional distribution of radio-tagged coho within Black Creek, by week.

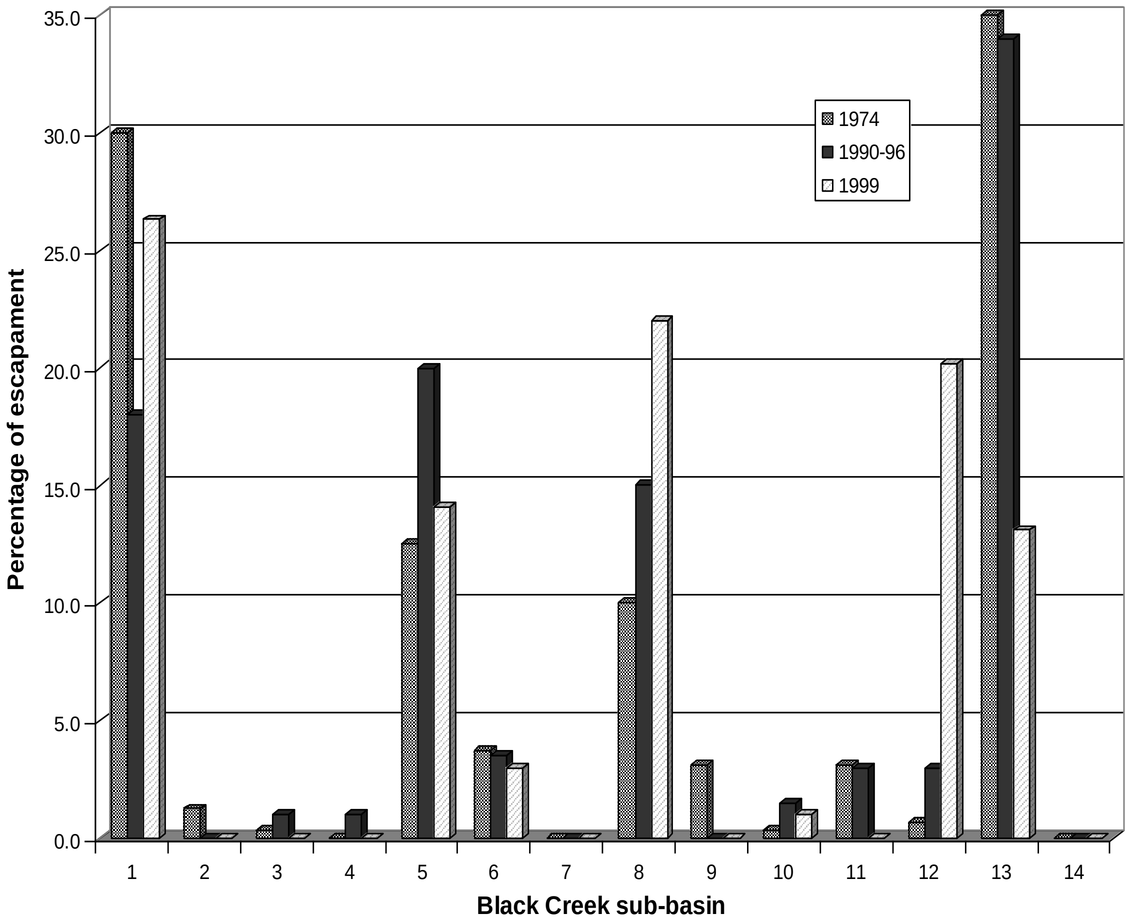

Figure 18. Comparison of the percent distribution of coho spawners in 1999 with historical data from Hamilton (1978) and Brown *et al.* (1999).

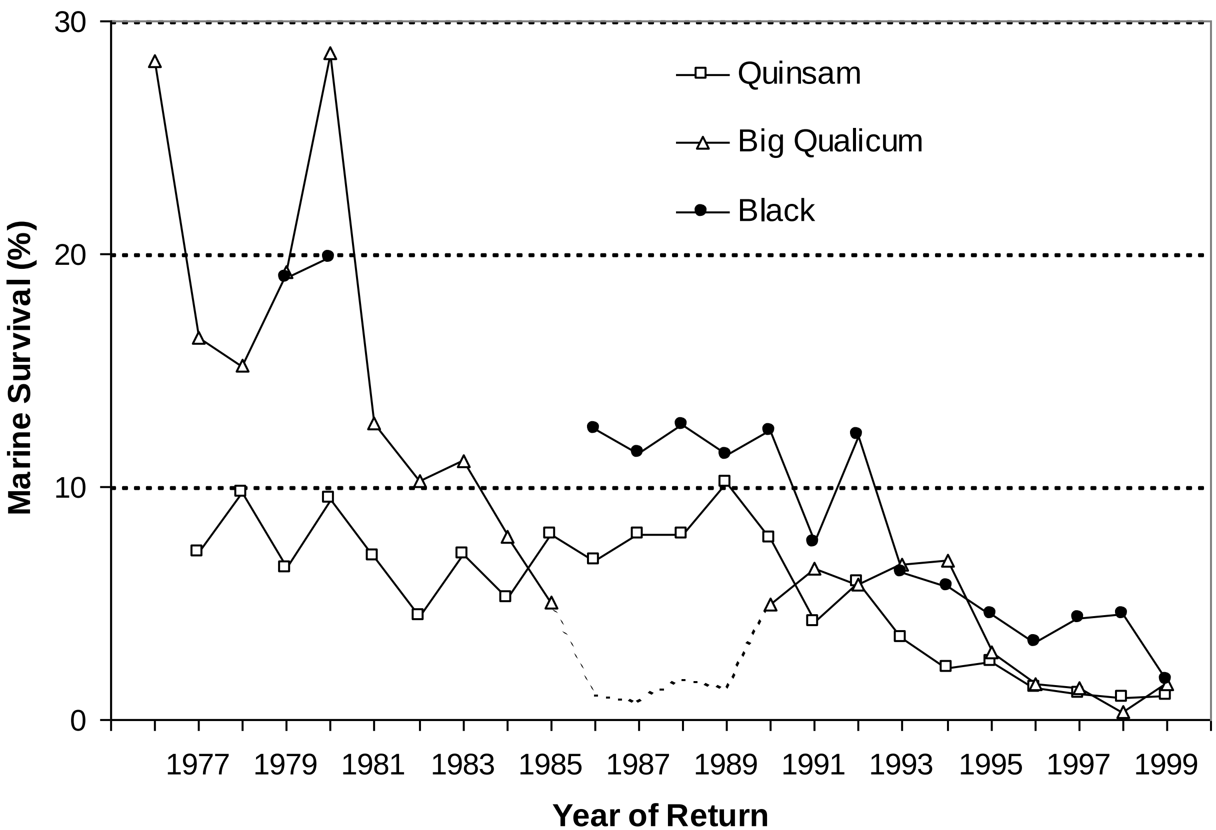

Figure 19. Comparison of marine survival rates for streams flowing into the Strait of Georgia.

APPENDICES

Appendix 1. Nominal and optimal tracking frequency and release times for radio-tags.

Nominal frequency	Optimal frequency	Code	Date released	Time released
149.014	149.013	105	29-Oct-99	11:09
		125	29-Oct-99	11:07
		145	29-Oct-99	12:22
		165	29-Oct-99	11:08
		185	29-Oct-99	11:00
149.023	149.022	105	29-Oct-99	11:22
		125	29-Oct-99	12:16
		145	29-Oct-99	11:24
		165	29-Oct-99	11:23
		185	29-Oct-99	11:20
149.033	149.032	105	29-Oct-99	11:44
		125	29-Oct-99	12:31
		145	29-Oct-99	11:26
		165	29-Oct-99	11:37
		185	29-Oct-99	11:35
149.044	149.043	105	29-Oct-99	12:14
		125	29-Oct-99	15:00
		145	29-Oct-99	11:39
		165	29-Oct-99	11:38
		185	29-Oct-99	11:50
149.053	149.052	105	30-Oct-99	9:04
		125	30-Oct-99	9:00
		145	30-Oct-99	9:12
		165	30-Oct-99	9:06
		185	30-Oct-99	9:21
149.064	149.062	105	06-Nov-99	11:15
		125	30-Oct-99	9:20
		145	30-Oct-99	9:02
		165	30-Oct-99	9:14
		185	30-Oct-99	9:15
149.073	149.071	105	30-Oct-99	11:17
		125	30-Oct-99	10:44
		145	30-Oct-99	11:04

Appendix 1. cont'd

		165	30-Oct-99	11:16
		185	30-Oct-99	11:23
149.085	149.084	105	31-Oct-99	9:00
		125	30-Oct-99	11:24
		145	31-Oct-99	9:01
		165	30-Oct-99	11:41
		185	30-Oct-99	11:49
149.094	149.093	105	06-Nov-99	12:46
		125	06-Nov-99	13:31
		145	07-Nov-99	11:45
		165	07-Nov-99	11:47
		185	07-Nov-99	11:49
149.104	149.103	105	07-Nov-99	11:53
		125	07-Nov-99	11:54
		145	07-Nov-99	11:57
		165	07-Nov-99	12:55
		185	07-Nov-99	12:57
149.113	149.112	105	07-Nov-99	13:00
		125	07-Nov-99	13:03
		145	07-Nov-99	13:04
		165	07-Nov-99	13:06
		185	07-Nov-99	13:09
149.123	149.122	105	07-Nov-99	13:12
		125	07-Nov-99	13:14
		145	07-Nov-99	13:15
		165	07-Nov-99	13:17
		185	07-Nov-99	13:19
149.133	149.132	105	07-Nov-99	13:22
		125	07-Nov-99	13:25
		145	07-Nov-99	13:27
		165	07-Nov-99	13:29
		185	07-Nov-99	14:37
149.143	149.142	105	07-Nov-99	15:03
		125	07-Nov-99	15:06
		145	07-Nov-99	15:08
		165	07-Nov-99	15:14

Appendix 1. cont'd

		185	07-Nov-99	15:16
149.153	149.152	105	07-Nov-99	15:18
		125	07-Nov-99	15:19
		145	07-Nov-99	15:22
		165	07-Nov-99	15:25
		185	07-Nov-99	16:17
149.164	149.163	105	07-Nov-99	16:19
		125	07-Nov-99	16:30
		145	08-Nov-99	11:36
		165	08-Nov-99	10:39
		185	08-Nov-99	11:44
149.173	149.172	105	08-Nov-99	11:46
		125	08-Nov-99	11:53
		145	08-Nov-99	1155
		165	08-Nov-99	12:00
		185	08-Nov-99	12:02
149.183	149.183	105	08-Nov-99	12:48
		125	08-Nov-99	12:51
		145	08-Nov-99	12:52
		165	08-Nov-99	12:58
		185	08-Nov-99	13:01
149.193	149.193	105	08-Nov-99	13:05
		125	08-Nov-99	13:09
		145	08-Nov-99	13:11
		165	08-Nov-99	15:00
		185	08-Nov-99	15:02
149.203	149.202	105	08-Nov-99	15:04
		125	08-Nov-99	15:06
		145	08-Nov-99	15:07
		165	08-Nov-99	15:09
		185	08-Nov-99	15:11