SEASONAL BEHAVIOURS OF COASTAL CUTTHROAT TROUT (*ONCORHYNCHUS CLARKII CLARKII*) IN THE KITIMAT RIVER WATERSHED: OBSERVATIONS AND INFLUENCES

by

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ABSTRACT

Coastal cutthroat trout (*O. clarkii clarkii,* CCT) are arguably the most poorly understood species of salmonid and little is known of their seasonal patterns of movement, particularly in British Columbia. My study was conducted to assess the overwintering and spawning behaviours of migratory CCT in the Kitimat River watershed and to evaluate how behaviours were influenced by a suite of biotic and abiotic metrics. Radio transmitters were surgically implanted into mature CCT in the late summer and fall of 2012 (Year 1; n = 41) and 2013 (Year 2; n = 68). In the late fall, CCT aggregated within deep, slow moving pools. During the winter, CCT either remained stationary within a single overwintering habitat, or were mobile, moving among 2 to 5 habitats. Spawning occurred in first to third order tributaries throughout the watershed, from April 14 to May 15. Spawning mortality was high, and 57% of radio tagged CCT did not survive spawning. I used an information-theoretic model to assess the influence of mean daily mainstem water temperature and discharge, photoperiod, thermal experience (accumulated thermal units [ATU]), distance travelled to spawn, migration type (mobile or stationary), fork length and sex on the timing that CCT moved out of overwintering habitats and into spawning tributaries. The analysis demonstrated the inherent seasonality of when spawning migrations are initiated and suggested that photoperiod combined with fork length and distance to spawn was best able to predict when CCT moved out of overwintering habitats. The spawning analysis demonstrated that when CCT arrive in spawning tributaries was most strongly influenced by combinations of thermal experience, photoperiod and migration type. My study has provided a comprehensive review of the overwintering and spawning behaviours of migratory CCT at a spatial and temporal scale that has not been completed previously. Behaviours associated with life history events, however, exhibited tremendous variability which has reinforced the need for local, watershed specific research when considering management strategies for the species.

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PROLOGUE

The movement of animals across heterogeneous landscapes is poorly understood, but movement patterns are a fundamental component of understanding the biology of a species. Movements are responsible not only for the contemporary distribution and assemblage of species that exist today (Hanski 1999, Brunsfeld et al. 2001), but continue to influence species evolution by promoting gene flow and colonization of new habitats (Hanski 1999, Hanski and Gaggiotti 2004, Brenkman et al. 2008). It is ultimately the individual's ability to move through the environment, both into critical habitats and away from degraded habitats and predators that permits its continued persistence (Roff 1974, Kareiva et al. 1990, Pickett and Cadenasso 1995). Thus, a thorough understanding of the potential forces influencing species movement is necessary to make accurate ecological predictions on the effects of habitat fragmentation, climate change, or other anthropogenic impacts on species (Saunders et al. 1991, Walther et al. 2002, Morales et al. 2010).

The challenges of understanding species movements and range of migratory behaviours, however, can be substantial. One of the greatest challenges in understanding behaviour of a species is simply observing them, as individuals often reside within environments that are inhospitable to humans or undergo movements that occur over vast spatial and temporal scales (Belisle 1986). Even when movements are readily detected, variability among individuals and populations may limit the ability to extrapolate patterns that are representative of larger populations (Waples and Gaggiotti 2006, Cagnacci et al. 2010).

These difficulties are often encountered in members of the Family Salmonidae. Throughout their life cycle, salmonids are dependent on a diverse array of habitats, from small rearing streams to productive marine foraging areas. Often, these habitats are separated by considerable distances, requiring salmonids to make significant movements and migrations to forage and reproduce. While long distance migrations can be risky and physiologically demanding, the ontogenic partitioning of resources permits the development of far greater population densities than would otherwise be possible within a single homogenous habitat (Quinn 2011).

There are clear ecological and evolutionary advantages that favour dispersal and migration to high quality foraging and reproductive habitats. For example, gene flow among populations can contribute to genotypic variation and reproductive success is often positively correlated with body size (Beacham and Murray 1993, Bohonak 1999, Wenburg and Bentzen 2001). Thus, migration and movement between critical habitats are central to the viability of salmon populations, necessitating the maintenance of not only life history stage-specific habitats, but also migration corridors between them. While effective conservation and management requires a thorough understanding of salmonid migration patterns and habitat requirements, the large spatial and temporal scales at which these behaviours typically occur make this task inherently challenging.

A particularly interesting salmonid is the coastal cutthroat trout (*Oncorhynchus clarkii clarkii*). The most widely distributed of the 14 cutthroat trout subspecies, coastal cutthroat trout (CCT) range from the Eel River in California to Gore Point in Alaska, roughly coinciding with the Pacific temperate rainforest (Behnke 1992). Populations are predominantly found in small to medium sized watersheds draining directly into the Pacific Ocean, however, they have also been documented in the lower tributaries of larger systems such as the Fraser, Skeena and Stikine Rivers in British Columbia as well as the Columbia River in Oregon and Washington (Johnson et al. 1999, Connolly et al. 2005, Costello and Rubidge 2005). CCT are relatively small in comparison to anadromous salmonids, a characteristic that has permitted the subspecies to occupy and reside within freshwater habitats that are generally inaccessible to larger salmonids (Trotter 2008). Unfortunately, the small, low gradient headwater streams the subspecies is dependent upon are areas that are often coveted for human development and are often overlooked by landscape managers (Rosenfeld et al. 2002, Costello and Rubidge 2005, Slaney and Roberts 2005). Consequently, forest harvesting, agricultural practices and urban development have contributed to dramatic declines in the subspecies abundance throughout the last century. While declines have been the greatest throughout the highly developed southern portion of the subspecies range, it is expected that continued resource extraction and development in northern regions may produce similar detrimental effects (Johnson et al. 1999, Wildlife 2004, Connolly et al. 2005, Costello and Rubidge 2005, Slaney and Roberts 2005, Stein et al. 2012a).

Unlike other Pacific salmonids, CCT populations tend to be small; typically in the order of 100’s to 1000’s of individuals, of which mature breeding individuals may be limited to 10’s to 100’s (Sumner 1952, Slaney and Roberts 2005, Costello 2006). Within populations, life history behaviours are incredibly diverse and it is not uncommon for multiple life history strategies to exist in sympatry within the same watershed (Sumner 1972, Trotter 1989). It is also not uncommon for individuals to switch between strategies throughout their life. For example, an individual may move into marine environments one year and then return to freshwater habitats for two years before returning to marine environments again. While, CCT do migrate between critical spawning, foraging and overwintering habitats, the species is perhaps better known for its wandering, opportunistic movements that are frequently associated with seasonally abundant food sources (i.e. eggs during spawning of Pacific salmon; Bilby et al. 1996). Although the general timing and duration of movements within populations appear to be relatively consistent, there is a high degree of variability among populations and even among individuals within populations. The fact that multiple life history strategies, each showing unique movement behaviours, are often present within the same system adds further complexity to the subspecies movements. Not surprisingly then, the movement behaviours and migration patterns of CCT are arguably among the most complex, and least understood, of any salmonid (Trotter 2008).

There is however, a growing impetus to unravel the ecology of CCT, as this salmonid has suffered significant population declines throughout its range in recent years due to habitat alteration, over harvesting and species introductions (Johnson et al. 1999, Connolly et al. 2005, Costello 2008). While many, if not most, of British Columbia's medium sized coastal watersheds have been heavily impacted by forest harvesting throughout the last century, few have been further subjected to the extent of industrialization and urban development that has occurred throughout the Kitimat River watershed (Macdonald and Shepherd 1983, Karanka 1993, Simpson et al. 1998). Despite these impacts, the Kitimat River remains one of the most popular recreational angling destinations on the British

Columbia coast, primarily due to ease of access, proximity to population centers and the large numbers of returning hatchery raised Pacific salmon and steelhead trout (DFO 2009). Future pipeline and refinery developments in this region can be expected to not only further degrade habitat, but also indirectly increase angling pressure as these new industries attract workers. There is a need, therefore, to develop and institute conservation and management strategies aimed at salmonids in this watershed. This is of particular importance for species such as the CCT, which are particularly vulnerable to anthropogenic disturbances (Slaney and Roberts 2005). Doing so, however, requires a detailed knowledge of this subspecies life history related movements and migration behaviours between critical habitats.

To address these issues and contribute to the development of local conservation strategies for migratory CCT, this study employed radio telemetry to investigate the life history strategies and movement patterns of CCT within the Kitimat River. The first chapter of this study describes the overwintering and spawning behaviours of CCT in the Kitimat watershed. In Chapter 2, I examine the extent to which a suite of biotic and abiotic factors influence the timing of migrations from overwintering to spawning habitats. This research provides a comprehensive overview of the seasonal behaviours and habitat use of CCT in the northern portion of their geographic distribution and contributes to the development of science-based conservation and management initiatives in the region.

CHAPTER 1

Observations on the Seasonal Behaviours of Coastal Cutthroat Trout (*Oncorhynchus clarkii clarkii*) in the Kitimat River Watershed

INTRODUCTION

Pacific salmon are well known for their extensive, obligate migrations between rearing, foraging and spawning habitats (Quinn 2011). These generally take salmon from freshwater natal streams to the open ocean and back again over a period of 3 to 5 years. While these behaviours are predictable among the species of Pacific salmon, the same is not true for species of Pacific trout. Indeed, the migration strategies and life history behaviours of the trout species and subspecies are diverse and not well understood.

The coastal cutthroat trout (CCT) is a subspecies of cutthroat trout for which life history strategies are poorly understood – but appear highly variable (Trotter 2008). It has been suggested that CCT exhibit at least four distinct life history strategies: (1) a resident strategy in which individuals remain within small tributaries and headwater streams for the duration of their life; (2) a lacustrine strategy, characterized by individuals that forage and mature in lakes but rear and spawn in small inlet and outlet streams and tributaries; (3) a fluvial (river migratory) strategy in which small tributary and headwater streams are used for foraging and spawning and larger individuals migrate to larger streams and rivers to forage and mature, and; (4) a diadromous[1] (sea-run), form in which individuals spawn and

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[1] Diadromy, rather than anadromy, is preferred given that CCT in this study were primarily observed within fluvial habitats and migrations to sea were of short duration, lasting just weeks to months (McDowall 1997, 2001).

rear in small tributary and headwater streams but make short (3-8 month) migrations to marine environments to forage (Trotter 1989, Behnke 1992, McDowall 1997, 2001). Typically, multiple life history strategies will exist sympatrically within a watershed. Our current understanding suggests that the development of multiple life history strategies allows CCT to exploit the full spectrum of available habitats within coastal watersheds while also acting as buffer to environmental stochasticity (Northcote 1997a, Trotter 2008, Quinn 2011).

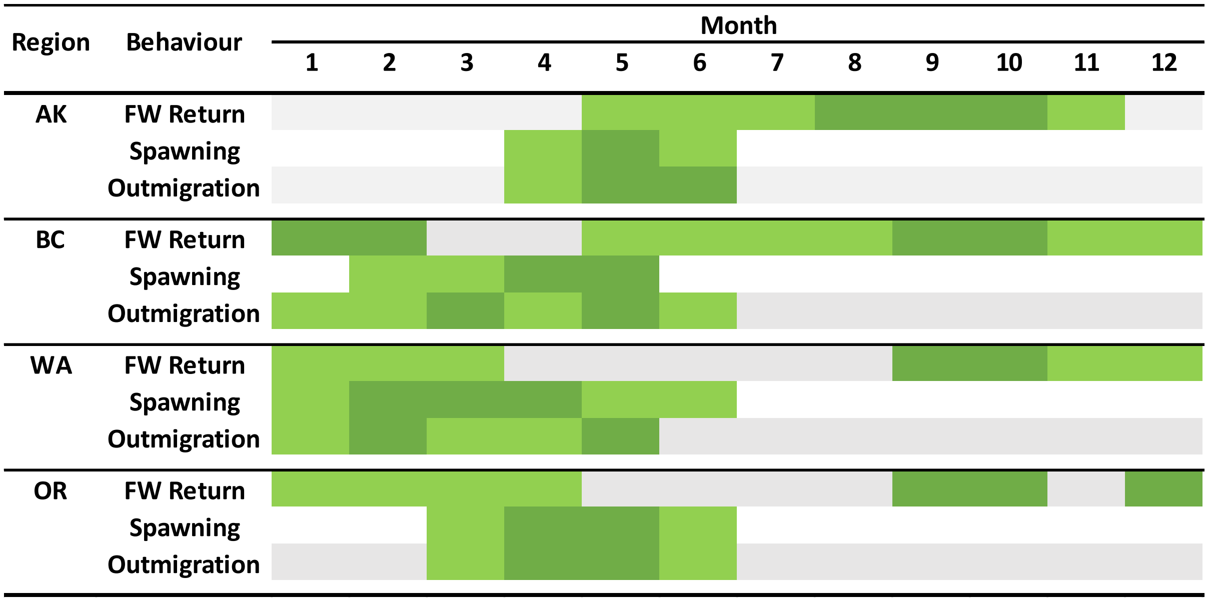
The development of multiple life history strategies and stream to stream wandering behaviour, however, may be opportunistic and allow CCT to exploit seasonally abundant food resources (Jones 1975, Johnson et al. 1999). Although aquatic invertebrates compose the majority of the subspecies diet in both marine and freshwater environments, individuals become increasingly piscivorous as they increase in size and will move extensively to capitalize upon seasonally abundant food sources (Sumner 1972, Pauley et al. 1989, Jones et al. 2008). For example, sea-run and fluvial CCT will move into lower river reaches to eat migrating salmon smolts in the spring and will follow spawning salmon upstream to forage on their eggs and carcasses in the fall (Giger 1972, Trotter 1989, Saiget et al. 2007). This opportunistic feeding strategy has likely influenced the subspecies contemporary distribution and resiliency (Trotter 2008).

Although CCT do make life history specific migrations between habitats, these movements may, in fact, be highly flexible, given the diversity of habitats the species occupies and the temporal variation of individual’s movements both within and among populations (e.g. Saiget et al. 2007). The factors influencing life history strategies of CCT are not fully understood, however, it appears that many of the same factors that structure the life histories of salmonids, namely natal stream conditions and stability, population density and species composition, migration distances between required habitats, and the relative sex selective advantages of migration also affect CCT (Jonsson and Jonsson 1993).

Coastal cutthroat trout do not typically remain in marine environments for more than 6-8 months (Mercer and Johnston 1979, Mercer 1980; but see Krentz 2007) and primarily return to fresh water for the winter where they overwinter in large deep pools that provide refuge from unfavourable stream conditions (i.e. extreme temperatures, high and low stream flows and ice flows) and are in proximity to food sources (i.e. emerging fry; Giger 1972, Johnston 1981, Behnke 1992, Trotter et al. 1993). Geographical differences in climate, condition and availability of suitable habitat appear to influence the use of overwintering habitats. In the southern portion of the subspecies range, where climates are relatively mild and winter precipitation is predominantly rain, there is less variability in winter stream flows and individuals primarily overwinter in large pools within the mainstem of their natal streams (Michael 1983, Hudson et al. 2008). Further north, sea-run CCT often overwinter in coastal lakes and beaver ponds, which may or may not be within natal watersheds (Jones and Harding 1998, Jones and Yanusz 1998, Saiget et al. 2007).

While some southerly populations may spawn as early as February, it appears that spawning occurs in the spring throughout much of the species range, typically from early April until June with peaks in early May (Table 1.1; Trotter 2008). Regardless of location or life history form, CCT primarily spawn in the most upstream sections of first and second order streams. Spawning in these upper stream reaches may act to increase spatial reproductive isolation when the subspecies occurs in sympatry with steelhead trout (*O. mykiss*; Ostberg et al. 2004, Buehrens et al. 2013). It has generally been perceived that mature CCT move from overwintering habitats directly to spawning grounds (e.g. Saiget et al. 2007), however this process may be more complex and some individuals may move out of overwintering habitats towards staging or foraging areas prior to moving to spawning grounds (pers. observation). Once on the spawning grounds, CCT typically remain within the immediate vicinity of their redds for a period of days or even weeks (Costello 2006, Saiget et al. 2007, Losee et al. 2016). Throughout the spawning period, pairs are unlikely to move more than 100 m from the spawning habitat (Saiget et al. 2007). Individuals may reside within spawning streams for as little as one to two days or as long as three to four weeks (Costello 2006, Saiget et al. 2007).

Table 1.1. Regional variation in timing of returns to freshwater (FW Return), spawning and downstream migrations of anadromous coastal cutthroat trout in Alaska, British Columbia (BC), Washington (WA) and Oregon (OR). Light and dark green squares indicate range and peak timing of behaviours, respectively.



Region	**Behaviour**	**Month**											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
AK	**FW Return**					🟩	🟩	🟩	■	■	■	🟩	
	Spawning				🟩	■	🟩						
	Outmigration				🟩	■	■						
BC	**FW Return**	■	■			🟩	🟩	🟩	🟩	■	■	🟩	🟩
	Spawning		🟩	🟩	■	■							
	Outmigration	🟩	🟩	■	🟩	■	🟩						
WA	**FW Return**	🟩	🟩	🟩						■	■	🟩	🟩
	Spawning	🟩	■	■	■	🟩	🟩						
	Outmigration	🟩	■	🟩	🟩	■							
OR	**FW Return**	🟩	🟩	🟩	🟩					■	■		■
	Spawning			🟩	■	■	🟩						
	Outmigration			🟩	■	■	🟩						

Regional References: Alaska: *Jones & Harding 1998, Jones & Yanusz 1998, Saiget et al. 2007, Marston et al. 2011*. British Columbia: *Slaney & Roberts 2005*. Washington: *June 1981, Michael 1989, Garrett 1998, Moore et al. 2010, Buehrens 2011*. Oregon: *Sumner 1972, Pearcy et al. 1990*; *Johnson et al. 1994; Stein et al. 2012*.

Studying the movement and behaviours of any species in their natural environment is inherently challenging, but when the species of interest cannot be directly observed and movements occur over extended spatial and temporal scales these challenges are compounded. Fortunately, many creative and effective methods have been, and continue to be, developed to directly and indirectly track individuals in aquatic environments. Telemetry, both radio and acoustic, are technologies that have greatly contributed to our current understanding of the life history and movement behaviours of fish (Adams et al. 2012), including CCT. Recent studies employing telemetry in the lower Columbia River, for example, have provided the most comprehensive review of anadromous CCT movement patterns in the southern region of the species range (Hudson et al. 2008, Johnson 2008, 2009, Zydlewski et al. 2008, 2009). These studies have demonstrated that both mature and juvenile emigrants use the lower Columbia River tributaries, mainstem, plume and estuary extensively, that downstream migrations are strongly influenced by both diel and tidal cycles, and that individuals regularly make 3 to 5 km crossings of the shipping channel. Telemetry studies in Alaska have focused primarily on spawning behaviours and have identified size and sex gradients among spawners (Jones and Yanusz 1998), have described the variability in spawning behaviours of diadromous and fluvial CCT (Saiget et al. 2007), and have documented spawning habitats and migration behaviours (Marston et al. 2011). While similarities do exist in the behaviours of southern and northern CCT populations, tracking studies reinforce the inherent variability in behaviours among and within populations and suggest a high degree of adaptation to the local environment.

Despite the insight that these studies have provided into the behaviours of CCT, there is still a strong argument to be made that CCT are among the most poorly understood species of salmonid (Trotter 2008). Certainly, there has been far less systematic research into the ecology and behaviours of this subspecies relative to other salmonids. All too often, stream specific information is anecdotal or has been collected indirectly during studies of other species (McCubbing 2002, Trotter 2008). The diverse array of habitats occupied by CCT and the varied life history strategies displayed by the species have added to the challenges in extrapolating range-wide trends from the research that has been conducted. For these reasons, watershed-specific, or at least regional evaluations of CCT are required to assess and manage stocks appropriately. This is of particular importance in British Columbia, which contains the majority of the species native range. To date, however, the research on the migration patterns and movement behaviours of CCT has occurred overwhelmingly at the extremities of the species range (specifically, in Oregon and Alaska).

Coastal Cutthroat Trout of the Kitimat Watershed

The Kitimat River flows into Douglas Channel near the town of Kitimat, on the northern coast of British Columbia. The geography, flora and fauna of this medium sized coastal watershed have attracted industry and recreationists for decades. Heavy industrial developments have been occurring in the lower Kitimat River and estuary since the 1950's. The watershed has also experienced extensive forest harvesting, much of which occurred prior to the development of harvesting guidelines designed to mitigate impacts on salmonids (Karanka 1993). The unique geographic features that initially attracted industry to Kitimat continue to do so and multiple major energy projects are currently in the proposal and development phases. Despite the extensive industrial activity, artificial supplementation has contributed to an abundance of Pacific salmon which draw recreational anglers from around the world. Coastal cutthroat trout are captured as by-catch during salmon fisheries and are targeted by local recreational anglers throughout the winter and spring. Though not as popular as the salmon fishery, the life cycle, behaviours and population structure of CCT make them increasingly vulnerable to angling and industrial activity (Slaney and Roberts 2005). The development of major energy projects in the watershed is likely to impact local salmonid populations by directly affecting habitat connectivity and quality, and indirectly by increasing infrastructure and the local population base.

Identifying the best means of mitigating further impacts to CCT in the face of continued development within the watershed requires a thorough understanding of the subspecies' movements, behaviours and habitat use. This research will contribute to our knowledge of the basic life history and ecology of CCT in the northern portion of this subspecies geographic distribution, and should thus contribute to regional fisheries management and conservation efforts.

My objective was to describe the observed variation in overwintering, staging and spawning behaviours for CCT in the Kitimat watershed. I used radio telemetry to examine the distribution of overwintering and spawning areas throughout the watershed, but also to determine the timing of CCT movements throughout the winter, staging and spawning periods. This approach allowed me to determine timing of departure from and arrival to, overwintering and spawning habitats. This research, will contribute to our knowledge of the basic life history and ecology of CCT in the central/northern portion of the species geographic distribution.

METHODS

Fish Capture, Sampling and Radio Tagging

Coastal cutthroat were captured by angling throughout the Kitimat watershed over two sampling seasons, from August to mid-December of 2012 (year 1) and from June to mid-October of 2013 (year 2). Angling effort was widely distributed throughout the Kitimat watershed to ensure a diverse array of fluvial and diadromous life history strategies would be included in the radio tagged sample. Angling effort was primarily focused on mainstem, side-channel and major tributary habitats believed to support fluvial and diadromous CCT. Angling effort (rod hours), pH, water temperature, air temperature, location (UTM) and habitat type (i.e. pool, riffle, glide) were recorded at each sampling location.

Upon capture, all fish visually identified as coastal cutthroat trout were placed within a black PVC recovery bag and were kept at the site of capture until angling was complete. All sampling was conducted in the field and regardless of size all captured CCT were photographed, measured for fork length (mm) and weight (± 5 g) determined using a calibrated spring scale. Scale and tissue samples were also collected from CCT greater than 100 mm in length. Scales were collected from the left side of the fish, above the lateral line and slightly posterior to the distal insertion of the dorsal fin and were stored within adhesive scale envelopes for age determination by Birkenhead Scale Analyses (Lone Butte, BC). Tissue from the adipose fin was collected for genetic analysis and stored in 95% ethanol. To ensure that sampled fish were not mistaken for hatchery released fish the natural shape of the adipose fin was maintained as much as possible. Tissue samples were used for genetic determination of sex as well as species diagnostic testing to identify potential hybrids. Analysis was performed by AB Costello (University of Northern British Columbia). A uniquely numbered Floy™ tag was also inserted between the vestigial rays at the base of the dorsal fin in all CCT greater than 250 mm.

Ninety uniquely coded Lotek® MCFT2-3EM series radio transmitters (Lotek Wireless Inc., New Market, ON) were surgically implanted into the intraperitoneal cavity of CCT greater than 440 g. Tags were 12 mm x 53 mm, weighed 11 g in air and 4.6 g in water with a 43-cm antenna. To reduce collisions, each tag was programmed with either a 5 or 5.5 s burst rate and a frequency of either 150.350 MHz or 151.700 MHz. Expected battery life for all MCFT2 type transmitters was 423 d. Additionally, ten smaller radio transmitters were implanted intraperitoneally into CCT greater than 250 g during the 2013 sampling season (Lotek® MST-930 series). These tags were 9.5 mm x 28 mm and weighed 4 g with a 37.5 cm whip antenna. The smaller tags also had a 5.5 s burst rate with an expected battery life of 222 d, and transmitted at 150.350 MHz. The predefined weight limits ensured that the dry weight of radio tags was no greater than 2.5% of the total weight (in air) of CCT. Though this is outside of the generally followed "2%-rule" (Winter 1983), it is consistent with previous radio telemetry studies of cutthroat trout where tags less than 2.5% were implanted (Waters 1993; Hendricks 2002; Goetz et al. 2013; Smircich and Kelly 2014).

Coastal cutthroat trout selected for surgery were anaesthetized in a 30 L tote with oxygenated river water containing 50 mg $\cdot$ L^{-1} clove oil emulsified in ethanol. A general loss of reactivity to external stimuli and slightly decreased opercular rate were used to assess depth of anaesthesia (Stage 2, Summerfelt and Smith 1990; Brown et al. 2008). Upon reaching the fourth stage of anaesthesia fish were removed from the anaesthetic bath and placed within a custom LEXAN™ plastic surgical trough lined with wetted closed cell foam (Summerfelt and Smith 1990; Brown et al. 2008).

A 2-cm incision was made anterior to the pelvic girdle and lateral to the midline. A cannula was then inserted into the peritoneal cavity through the incision and positioned such that it exited posterior to the pelvic girdle. The antenna of the radio transmitter was fed through the cannula and the transmitter was inserted into the peritoneal cavity. Two sutures (3-0, 26 mm 1/2c Tapered Monocryl violet monofilament) were used to close the incision and the fish was immediately transferred to a recovery tote containing 35 L of river water oxygenated with a portable aquarium air pump. A turkey baster was used to apply fresh oxygenated water to the gills throughout the entire surgical procedure. The duration of each surgery was timed from the moment the fish was removed from the anaesthetic until the moment it was returned to the recovery tote. Surgeries ranged in duration from 145 to 702 s with a mean and standard deviation of 307 ± 106 s. Once equilibrium was regained and the fish appeared to respond to external stimuli it was transferred from the recovery tote to the black PVC recovery bag at the location of capture. When the fish appeared vigorous, the recovery bag was opened and fish released.

Relocation of Radio Tagged CCT

Movements of radio tagged CCT were monitored using a combination of active and passive relocation techniques. The positions of radio tagged CCT were identified via aerial and ground based searches. Fixed receiver sites were erected at key points throughout the watershed and passively monitored CCT moving past their location (Figure 1.1). In combination, these two monitoring techniques provided a means of identifying where and when CCT moved throughout the watershed. Indeed, stationary receivers provided insight into the timing of migrations while mobile tracking revealed the spatial distribution of CCT during these migrations.

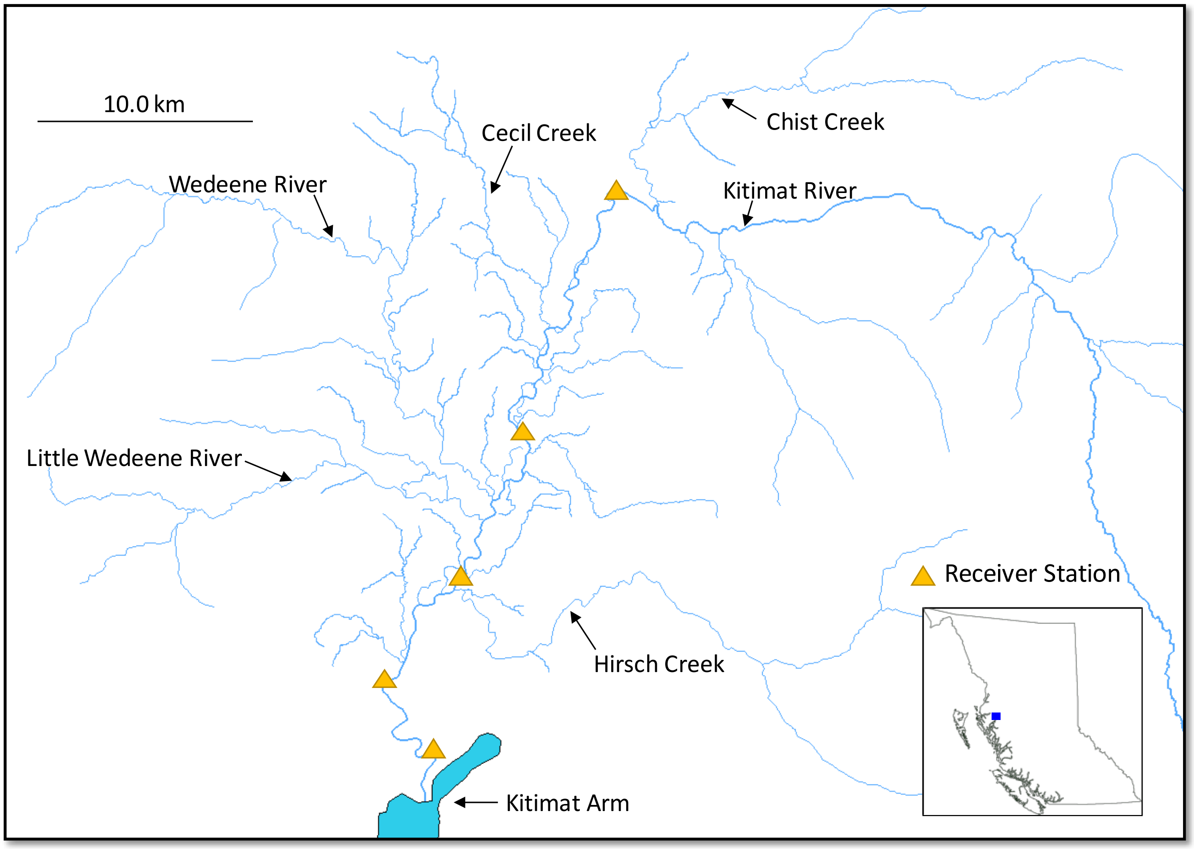


Figure 1.1. Position of stationary antenna arrays within the Kitimat watershed.

Search methods that identify the positions of all individuals at a single point in time are preferred as they reduce contact bias between individuals (Rogers and White 2001). Thus, a helicopter was used to conduct aerial tracking and to ensure that all available habitats were searched at a single point in time. The relocation snapshot provided by aerial tracking is also beneficial as it provides greater insight into how individuals have responded to changes in their environment than could be achieved through ground based or passive search techniques. For these reasons, active tracking by helicopter was the primary means of relocation throughout the key periods of interest in this study: the winter and spring.

A total of 32 aerial tracking flights were completed with a Bell 206 Jet Ranger mounted with a single 3-element Yagi antenna (Lotek Wireless Inc.). This antenna was connected to two SRX-400 Receivers (Lotek Wireless Inc.), each of which monitored one of the two transmitter frequencies. The time on the receivers was synchronized to the time on a Garmin 60CSx handheld Global Positioning Systems unit (GPS) (Olathe, KS) which recorded a track of the helicopters position at 1 s intervals. To determine relocation positions, the time at which the maximum signal power was recorded was matched to the time of the recorded flight track. For redundancy, the maximum power and helicopter position at the time of maximum power was also physically recorded as a waypoint on the GPS.

Relocation flights followed a standardized flight path that covered the mainstem of the Kitimat River and its major tributaries. However, throughout the spawning period short deviations from this path were required to identify spawning positions in small tributaries. Tracking flights ranged from 1.2 to 3.5 h (mean 2.5 ± 0.09 h) and were relatively shorter during the winter (mean 2.0 ± 0.09 h) than during the spawning period (mean 2.8 ± 0.8 h). Active aerial tracking occurred at altitudes of roughly 100-200 m and at speeds from 30-60 km/h. During all tracking flights signal power was communicated to a navigator who directed the pilot. To improve tracking efficiency, Avenza PDF Map's (Toronto, ON) was used to display the last known positions of all CCT on a georeferenced orthorectified satellite image of the Kitimat watershed. To determine the type and characteristics of relocation habitats a GoPro® (San Mateo, CA) camera was mounted to the helicopter and filmed and photographed throughout the flights.

The frequency, duration and scale of relocation flights reflected the predicted seasonal behaviours of CCT. When CCT were expected of being sedentary throughout the winter, tracking flights were conducted monthly and focused primarily on the mainstem of the Kitimat River and its major tributaries. In the spring as CCT moved to spawning habitats the frequency of tracking flights increased to every 4-8 d and scale expanded to include both minor tributaries and uppermost reaches of the Kitimat watershed.

Throughout the late winter and spring, tracking flights were supplemented with daily ground based mobile tracking. Mobile tracking was primarily used to monitor the timing of movements out of overwintering habitats, confirm aerial relocation positions, verify suspected spawning areas, and recover radio transmitters from mortalities. A 3-element directional antenna connected to an SRX-400 was used to triangulate positions which were then marked using a handheld GPS device. Relocation habitat types were recorded and photographed. During the spawning period, the vicinity was visually searched for signs of spawning (i.e. redds, spawning gravels, paired up CCT, precocious males). No formal habitat classification or measurements were conducted throughout this study.

Active aerial and ground based search methods were necessary to identify where CCT travelled throughout the watershed however they provided limited information on when individuals moved between habitats. Insight into the timing of movements between habitats was provided by an array of stationary receivers set up throughout the watershed. These receivers provided information on the timing of movements out of overwintering and spawning habitats as well as the timing of movements towards the estuary.

Four fixed receivers were erected along the Kitimat River in Mid-August of 2012 and a fifth station was added in early April of 2013 (Table 1.2). Each receiver location consisted of an upstream and a downstream facing 4-element directional Yagi antenna connected to a Lotek SRX-400 receiver and powered by a 12 V deep cycle marine battery. Receivers were housed within a secure steel box mounted to a tree along the margin of the Kitimat River. A GPS unit was used to synchronize the date and time of all stationary receivers. Receiver stations operated continuously and recorded the date, time, code and power of all relocation events. Movements to and from the Kitimat Estuary were monitored by a receiver station immediately upstream of the tidal boundary (2.8 rkm). Movements within the lower and middle river were monitored by receiver stations at 8.2 rkm and 16.1 and 25.1 rkm, respectively. The uppermost receiver station was located at 41.7 rkm and monitored the timing of movements to and from the upper watershed.

All receiver stations were erected in August of 2012, except the receiver at 2.8 rkm, which was erected in April of 2013. Receivers were inspected, downloaded and maintained weekly. Logistical challenges associated with access and maintenance of stationary receivers prevented continuous operation throughout the winter, except for the receiver station at 8.2 rkm which was graciously operated with the support of the DFO operated Kitimat River Fish Hatchery. Excluding the station at 8.2 rkm which operated until July 23, 2014, all receiver stations were dismantled on June 1, 2014. Table 1.2 provides a summary of the periods of operation for each receiver station. Lotek SRX-400 receivers and telemetry equipment were provided by the BC Ministry of Forests, Lands and Natural Resource Operations (FLNRO).

Table 1.2. Summary of location and operation period of stationary receiver stations in the Kitimat watershed.

Receiver #	rkm	Year	Operation Period
00	2.7	1	02-Apr-13 to 10-Oct-2013
		2	31-Mar-14 to 01-Jun-2014
01	8.7	1 & 2	16-Aug-12 to 23-Jul-2014
02	16.5	1	19-Aug-12 to 19-Dec-2012
		1	01-Mar-13 to 06-Oct-2013
		2	24-Mar-14 to 30-May-2014
03	25.1	1	19-Aug-12 to 06-Oct-2013
		2	21-Mar-14 to 20-May-2014
04	41.7	1	19-Aug-12 to 15-Dec-2012
		1	06-Feb-13 to 16-Oct-2013
		2	21-Mar-14 to 01-Jun-2014

Data Processing and Analysis

Relocation accuracy to within 500 m was deemed sufficient to meet the objectives of this study. Thus, no direct measure of the accuracy of aerial relocation positions were conducted. Ground based mobile tracking, however, confirmed that actual fish positions were typically within 100 m, and often within 10 m, of the aerial relocation positions. Positions identified by mobile tracking were similarly not tested for accuracy as only the strongest signals were used to identify relocation positions.

Greater than 1.3 million detections were recorded by the fixed receiver stations throughout this study. To filter out weak and potentially erroneous detections a set of rules were applied to the fixed station (Table 1.3). These rules were applied to all detections of a specific code by a specific receiver on a single date, if any rule was met the relocation event for that date was included in the analysis. Overall these rules reduced the number of detections included in the analysis by approximately 42%.

Table 1.3. Summary of tests applied to stationary receiver data to remove potential erroneous detections.

Test of:	Test #	Description
Signal Power	**1**	Average power greater than 175 and more than 10 detections in a day.
	2	Maximum power is greater than 195 and there are greater than 25 detections in a day.
	3	Average power is greater than 120, maximum power is greater than 200 and at least 10 detections in a day.
# Relocations	**4**	Greater than 500 events in a day and average power is greater than 110.
	5	Greater than 250 events in a day and average power is greater than 130.
% of Possible Relocations	**6**	At least 25% of the possible detections were recorded over a 1 hour time period and the average power is 140.
	7	Fish relocated at least 20% of the time over a period of at least 20 minutes and the average power is greater than 120.

The Linear Referencing toolset in ArcMap 10.1 (ESRI, Redlands, CA) was used to assign each relocation event to the nearest stream (Euclidean distance) in the British Columbia Watershed Atlas. The same toolset in ArcMap was then used to measure the linear distance (measured in river kilometers, rkm) of the relocation position from the estuary along the stream network. This method permitted an accurate and consistent means of determining the position of each CCT within the stream network. Measurements of mainstem position (rkm) were measured upstream from the estuary (0 rkm) while measures of tributary position (tkm) were measured upstream from the confluence with the last major watercourse. A database was developed in a spreadsheet that used these measures of rkm and tkm to calculate the distance that individuals moved between relocations. This resulted in a final spatial dataset that included the date and position (in terms of waterbody, rkm and tkm) for each relocation event of each fish within the watershed as well as the distance each individual had travelled since it was last relocated.

Two datasets were generated for this study: a biological dataset containing all fish sampling information and a spatial dataset containing the measured relocation positions of all radio tagged CCT. Together, these datasets were used to interpret the variation in observed seasonal behaviours of radio tagged CCT. Prior to performing any analyses on the behaviours of CCT, the metrics within the biological dataset were compared between sampling seasons to ensure that CCT radio tagged in 2012 and 2013 were similar in terms of the distribution of sex, age, fork length, weight and contribution. The relocation data was used to generate movement profiles depicting the river and tributary position of each radio tagged CCT over time. These profiles were visually inspected to identify the location of, as well as the timing that CCT occupied overwintering, staging and spawning habitats. The spatial dataset was then used to summarize the movements and behaviour of CCT within each of these habitats. Coastal cutthroat trout exhibiting similar behavioural patterns were grouped and analysed in greater detail.

Overwintering Behaviours

The locations of overwintering areas were identified by examining movement profiles and identifying areas where CCT aggregated throughout the winter. The position (rkm and tkm) of each overwintering area was defined as the mean relocation position of all aggregated CCT. Movements of CCT within and between overwintering habitats were also summarized to assess variability in winter behaviours. For each CCT relocated within a given overwintering area, the date of arrival and departure, and distance travelled to mean overwintering position was calculated. An individual’s date of arrival and departure from a given overwintering area was defined as the first and final date of relocation, respectively (measured in Julian date). The distance travelled towards initial overwintering areas was calculated as the difference in position from the location of capture to the mean position of the first overwintering habitat each CCT was observed within. This approach reduced contact bias resulting from an unequal number of relocations among CCT by ensuring that all measures of distance moved towards an overwintering area were not based upon a single relocation event. Distance travelled between overwintering habitats was measured as the difference between the mean river position of each habitat. Based on these overwintering behaviours, CCT were classified as stationary if they occupied a single overwintering area throughout an entire winter or as mobile if they moved between multiple overwintering areas throughout the winter. The resulting overwintering behaviours dataset was then merged with the morphological dataset to examine whether the physical characteristics of CCT differed among overwintering groups. This merged dataset was used to complete a set of independent tests examining variability in overwintering behaviours. These tests aimed to identify whether the date of arrival and departure from overwintering habitats and the distance travelled to initial overwintering habitats differed between years, sex or behavioural groups.

Staging Behaviours

Radio tagged CCT observed moving from overwintering areas to a location downstream of eventual spawning habitats were assumed to be staging prior to spawning. Individuals observed moving back and forth between staging habitats and the lower reaches of spawning tributaries were considered to be searching. These individuals were not considered to have departed staging habitats until they were observed making continuous upstream movements towards eventual spawning grounds. The date of arrival and departure as well as distance of staging habitats from overwintering areas and to maximum upstream spawning positions was calculated for each staging CCT.

Spawning Behaviours

Movement profiles of each CCT were visually inspected to identify period and location of spawning. Spatial data were then used to define position of spawning habitats and summarize behavioral characteristics of all CCT observed moving into tributaries throughout the spawning period. This summary provided a means of capturing spatial and temporal variability in spawning behaviours among individual CCT as well as among CCT using common spawning grounds. No radio-tagged CCT were visually observed on redds throughout the spawning period. Thus, each individual is assumed to have spawned at the location of, and on the date corresponding to, the maximum upstream relocation position within a putative spawning tributary. This approach is warranted given that the spawning behaviours observed during this study (i.e. direct movements into small tributaries throughout the spring) coincide with findings from previous research on coastal cutthroat trout. A similar technique was recently applied by Homel et al. (2015) to identify the timing and location of spawning west slope cutthroat.

Temporal variability in spawning behaviours was quantified by defining the period during which each CCT spawned. The spawning period for each CCT was defined by date of arrival, date corresponding to maximum upstream relocation position, and date of departure from a putative spawning tributary. Date of arrival in a putative spawning tributary was defined as the first relocation date immediately prior to continuous upstream movement towards the maximum upstream tributary position. Spawning was assumed to have occurred on the date a CCT was observed in its most upstream position within a supposed spawning tributary. Date of departure from spawning habitats was defined as the last date on which CCT were relocated within their assumed spawning tributary. Individuals that were only relocated once in a single tributary throughout the spawning period are assumed to have arrived, spawned and departed on the date of that relocation. These three temporal measures were then used to define the duration CCT travelled to reach spawning habitats as well as the median date of arrival and spawning (max tkm).

In addition to the temporal measures, spatial metrics were calculated for each CCT observed in a spawning tributary. Spatial measures aimed to quantify the distances CCT travelled to reach spawning habitats as well as to examine the relationship between location of capture, overwintering, staging and spawning habitats. Distance travelled to spawning habitats was calculated as the difference in river position from the maximum upstream spawning position to the mean position of a given overwintering area. For mobile CCT, this distance was measured from initial and final overwintering habitats to examine whether mobile CCT selected initial overwintering habitats that were proximal to spawning tributaries and whether movements throughout the winter reduced the distance to eventual spawning grounds. Similarly, distances from capture and staging habitats were measured as the difference in river position from the maximum upstream spawning position to the location of capture and the mean staging position.

Variability in these spatial and temporal measures of spawning behaviours were analyzed using numerous independent tests. The distance travelled to spawning habitats as well as the date that CCT arrived in spawning tributaries and at their maximum upstream tributary position were compared between years, sexes and migration types. Similarly, these same tests were performed on all CCT within a spawning season period.

Statistical Analyses

Welch's two-sample t-test was used to test for differences in physiological measures between sampling periods, behavioural groups and sexes. The same test was used to examine how the magnitude of movements from capture to overwintering habitats as well as from overwintering habitats to staging and spawning habitats differed between sexes, behavioural groups and years. No tests of homogeneity of variance were conducted on comparisons of two groups as Welch's two-sample t-test is robust to heterogeneity in variance between groups.

Variation in the timing of behaviours was examined using a two-sample Kolmogorov-Smirnov test. This test compared the distribution of dates that CCT arrived in and departed from overwintering, staging and spawning habitats. Radio tagged CCT were assumed to have remained within a habitat until they were relocated elsewhere. Spawning was not observed during this study and is assumed to have occurred on the date corresponding to the maximum upstream tributary position. Spawning departure dates are defined as the last date each CCT was observed within a tributary. Radio tagged CCT observed making downstream movements towards the estuary immediately following spawning are assumed to be sea-run and are to have arrived in and departed from the estuary on the date corresponding with the last, and first relocation on the most downstream fixed receiver station, respectively. A Spearman correlation test was used to examine the relationship between capture date and the physical characteristics of radio tagged CCT.

Measures reporting the overall timing of seasonal movements are presented as the date at which 50% of CCT were observed to have moved (median ± standard deviation). Additional descriptive measures are presented as the sample mean ± standard error along with the range of raw values. This approach is preferred as it demonstrates the degree to which the sample mean can be expected to vary from the true population mean. Measures of range are included to provide perspective on the spread of values in the dataset. Tests with alpha values less than 0.05 were considered significant. However, to reduce type 1 error, a Bonferroni correction was applied to significance values when multiple comparisons were made with the same dataset. Tests found to be statistically insignificant but for which there appears to be a biological significance or trend are presented. All significant test results are presented in bold.

RESULTS

Fish Collection Effort

Angling was conducted over a 54-day period from August 8 to December 15, 2012 (year 1) and over a 72-day period from June 20 to October 18, 2013 (year 2). A total of 258 trout were sampled during angling in year 1 (n = 103) and 2 (n = 155). Of these, 41 trout angled in year 1 and 68 trout angled in year 2 were of suitable size to be radio tagged. Throughout the first and second sampling season a mean of 0.76 and 0.94 CCT were radio tagged per day of angling, respectively. The date on which 50% of tags had been deployed was significantly later for the first year of sampling (October 8) than for the second (September 7) (Two Sample KS Test, H_o: Year 1 > Year 2; D = 0.43, P = 0.002).

Angling effort was widely distributed throughout the lower 50 rkm of the watershed (Figure 1.2). Coastal cutthroat trout selected for radio tagging were angled in the estuary (n = 1), the lower river (from 0-21 rkm; n = 39), the middle river (21-41 rkm; n = 47) and the upper middle river (>41 rkm; n = 15) (Table 1.4). Cutthroat trout selected for radio tagging were also captured in tributaries in year 1 (n = 13, 13% of sampled CCT) and year 2 (n = 33, 21% of sampled CCT).

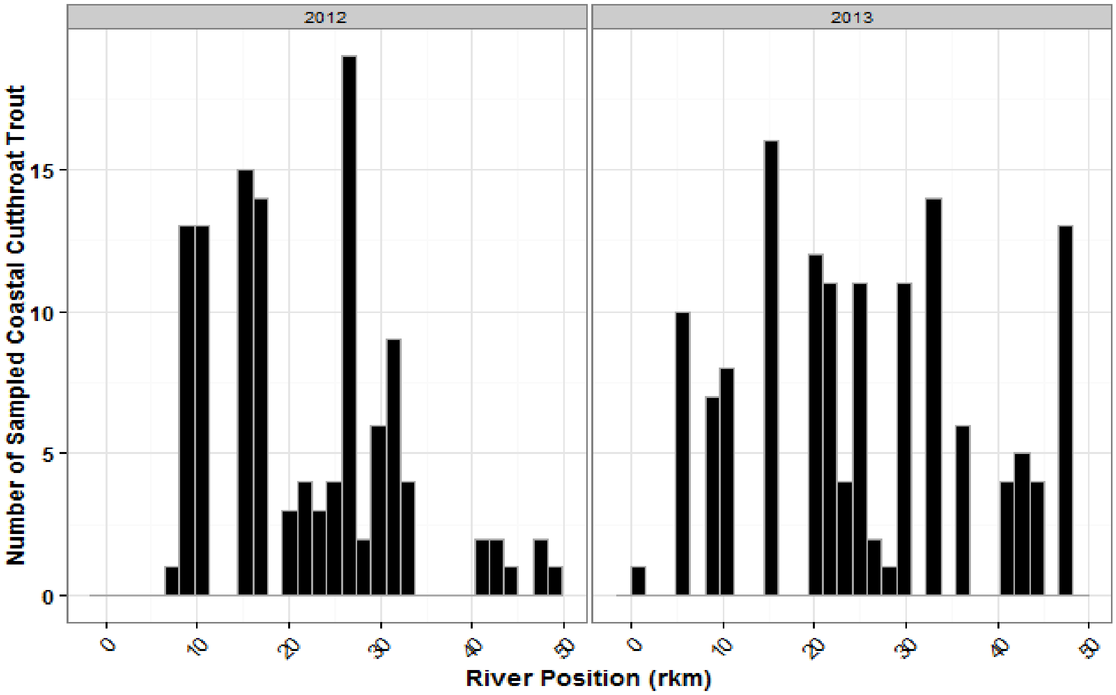


Figure 1.2. Histogram comparing the location that radio tagged CCT were sampled throughout the Kitimat watershed.

Table 1.4. Mainstem river position (rkm) of radio tagged CCT at capture in year 1 and year 2.

		Number of Radio Tagged CCT	
Water Body	**rkm**	**Year 1**	**Year 2**
Kitimat River Mainstem		25	36
Lower Mainstem	0 – 20.9	5	4
Middle Mainstem	21 – 40.9	13	22
Upper Mainstem	> 41	7	10
Estuary	0	0	1
Duck Creek	10.6	1	1
Goose Creek	10.8	1	3
Hirsch Creek	15.7	4	9
Powerline Creek	16.5	2	0
Little Wedeene Creek	20.1	1	8
Big Wedeene Creek	21.4	2	4
Nalbeelah Creek	24.8	1	3
Humphrey Creek	29.7	4	1
Total:		**41**	**66**

Sampled CCT

Sampled coastal cutthroat trout ranged in length and weight from 110 to 480 mm FL (325 ± 4 mm FL) and 35 to 1180 g (464 ± 17 g), respectively (Table A1.1[2]; Figure A1.1A and B). Age was estimated from the scales of 205 CCT ranging in size from 135 to 480 mm and 35 to 1120 g. The mean age of all sampled individuals was 3.8 ± 0.8 years, though estimates ranged from 2 to 7 years (Figure A1.1C). Genetic analysis was performed on 241 samples and identified that female CCT were sampled disproportionately relative to males. Indeed, females represented 64% of all sampled CCT. Female CCT were found to be significantly longer, heavier and older than male CCT (Table A1.1). Even though females were

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[2] Table and figure references in appendices are denoted by "A".

significantly larger than males, no difference in condition factor was apparent between the sexes (Table A1.1; Figure A1.1D). A fork length frequency distribution for all sampled cutthroat is presented in Figure 1.3.

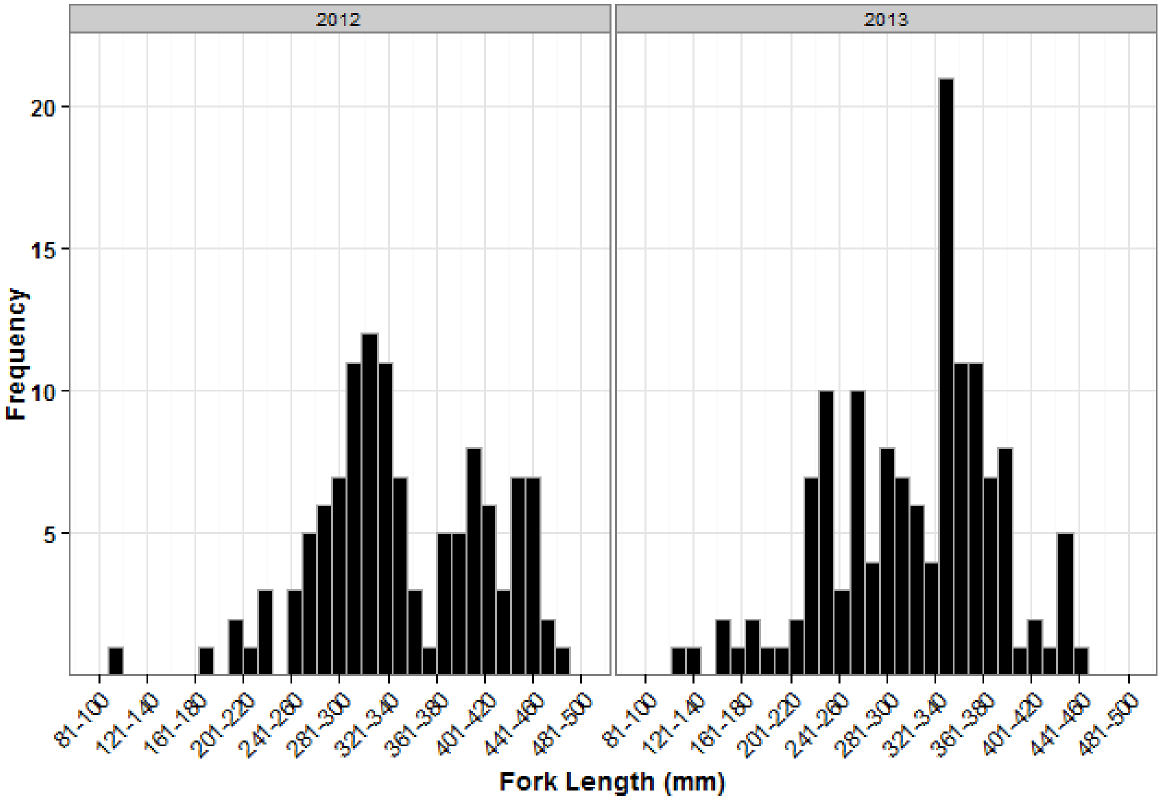

Figure 1.3. Fork length frequency histogram of all CCT captured in 2012 and 2013.

Radio Tagged CCT

A total of 99 CCT were implanted with the larger radio transmitters during sampling in year 1 (n = 41) and year 2 (n = 58). Six radio transmitters recovered from spawning mortalities during the spring of year 1 were reapplied to trout captured during the second sampling season. An additional three transmitters collected from CCT that died during tag implantation in year 2 were sterilized and reapplied.

Fork length and weight of CCT implanted with the larger tags ranged from 330 to 480 mm (385.6 ± 4.4 mm) and 430 to 1180 g (671.6 ± 20.5 g), respectively (Table A1.2; Figure 1.4A and B). Overall, radio transmitters represented a mean of 1.78 ± 0.05 % of the dry weight of these CCT, though this ranged from 0.93 to 2.62%. Scales from 96 radio tagged CCT were aged and fish ranged from 3 to 7 yr; mean age of 4.2 ± 0.1 yr (Figure 1.4C). Genetic analysis of the radio tagged CCT indicated that 66% were female; a ratio that was consistent in both sampling years. Coastal cutthroat trout tagged in year 1 were longer (FL) and heavier than CCT tagged in year 2. Despite being larger, CCT tagged in the first sampling season had significantly lower condition factor than those tagged in year 2 (Figure 1.4D).

Differences in size of fish caught in the two years of the study were principally driven by the size of males; which were significantly longer and heavier in year 1 than year 2. Female CCT radio tagged during both sampling periods were older and heavier than radio tagged male CCT, but differences were not significant (Table A1.2; Figure 1.4A and B). Females in year 1 were significantly younger than in year 2 (Table A1.2; Figure 1.4C), and; males in year 1 had significantly lower condition factor than in year 2 (Figure 1.4D).

In year 2, an additional 10 CCT implanted with the smaller radio transmitters were between 3 and 5 years of age (3.7 ± 0.2 yr) and ranged in length from 276 to 355 mm (314.8 ± 8.9 mm). The weight of these CCT ranged from 250 to 470 g (mean = 329 ± 53.1 g), and transmitters represented between 0.86 to 1.60% (1.27 ± 0.08%) of the dry weight of these CCT. Condition factor ranged from 0.87 to 1.33 $g \cdot cm^{-3}$ (1.05 ± 0.04 $g \cdot cm^{-3}$). There was also a female biased sex ratio in the smaller tagged fish (67% female).

Of the 109 radio tagged CCT a total of 19 (18% of total tagged) likely expelled their transmitters or died shortly after the tagging procedure, including three CCT that died during the operating procedure in year 2. In the second sampling period, six CCT (6% of total tagged) moved directly to the estuary after being radio tagged and were not subsequently relocated. Though the fate of these individuals is unclear they are presumed to have died. Additionally, three CCT (3%) appear to have died after moving into overwintering habitats in year 1 (n = 1) and year 2 (n = 2). An additional eight CCT (7% of total tagged) were not relocated – or were relocated sporadically following tagging in year 1 (n = 2) and year 2 (n = 6). In total, this represents a potential tagging mortality rate of up to 34% for all radio tagged CCT.

The physical characteristics and fate of all radio tagged CCT, and the timing and physical state of recaptured radio tagged CCT are summarized in Table A1.3 and Table A1.4, respectively. The physical condition of radio tagged CCT that were recaptured during subsequent sampling are described in Appendix A1. Supplemental Recapture Data.

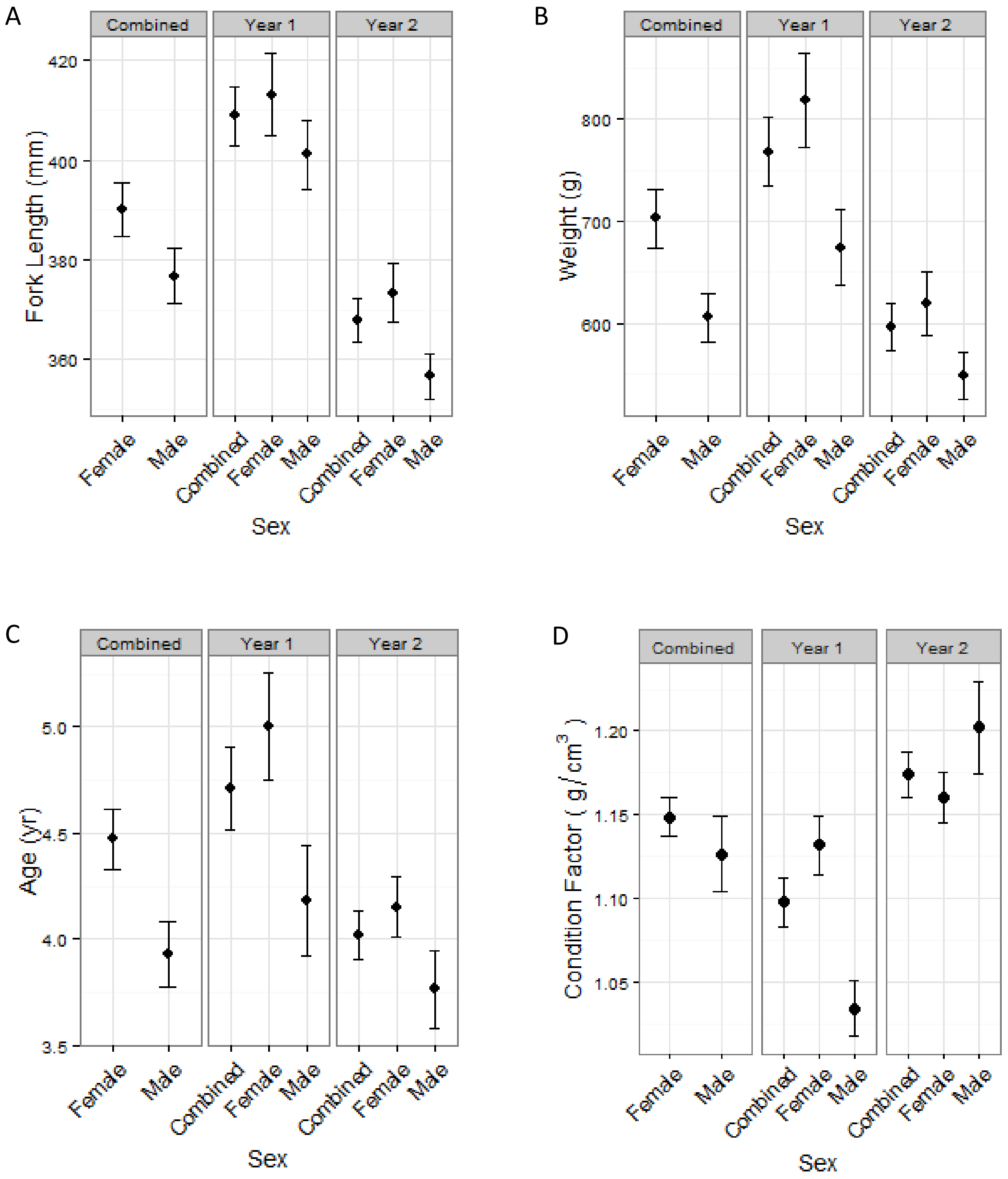

Figure 1.4. Fork length (A), weight (B), age (C) and condition factor (D) of male and female CCT radio tagged with large transmitters in year 1 and year 2.

Overwintering Behaviours

A total of 68 radio tagged CCT were relocated in overwintering habitats and were successfully tracked throughout the winters of year 1 (n = 31) and year 2 (n = 37). Forty-two of the CCT tracked throughout the winter were observed moving from their position of capture into overwintering areas. The remaining 26 CCT were captured and radio tagged within overwintering areas, 17 of which eventually moved to new overwintering habitats at a later date. The number of CCT captured in overwintering habitats did not differ between years, even though sampling occurred significantly later in year 1. Six CCT radio tagged in year 1 were observed in overwintering areas during both winters (Table A1.5). An additional 11 CCT were tracked into overwintering areas, but were not relocated sufficiently to be included in further analyses.

Two distinct behavioral patterns were apparent in the winter movement profiles of CCT that were tracked throughout the winter. The first behavioral pattern was one of relative inactivity. These “stationary” CCT remained within the immediate vicinity of a single overwintering area throughout the winter. Stationary CCT were observed during both winters, however this behaviour was far more prevalent in year 1 (n = 19) than year 2 (n = 6). The second behavioral pattern was characterized by movement between multiple overwintering aggregation areas throughout the winter. “Mobile” CCT were observed moving between proximal habitat features within overwintering areas (i.e. adjacent riffles and pools), back and forth between overwintering areas as well as continuously moving towards new overwintering areas.

When data from both years was combined, stationary CCT were found to be significantly longer and heavier than mobile CCT (Table A1.6; Figure 1.5A and B). Although, the mean age of stationary fish was also older, the difference was not significant (Figure 1.5C). Additionally, condition factor did not differ between behavioural groups, although condition factor of mobile CCT was significantly greater in year 2, than year 1 (Figure 1.5D).

Six female CCT radio tagged in year 1 were relocated in overwintering areas during both winters; four of which were tracked sufficiently to determine overwintering behaviours for both years. Throughout the winter of year 1, four of the six CCT exhibited stationary behaviours and two exhibited mobile behaviours. During the following winter, however, one of the four year 1 stationary CCT was observed moving between overwinter areas in year 2. Two of the three CCT that displayed stationary behaviours during both winters occupied the same overwintering areas in year 1 and 2 (ID#009 and ID#013), while the third remained stationary in each year, but in different overwintering habitats (ID#050). The movement behaviours of these CCT are summarized in Table A1.5

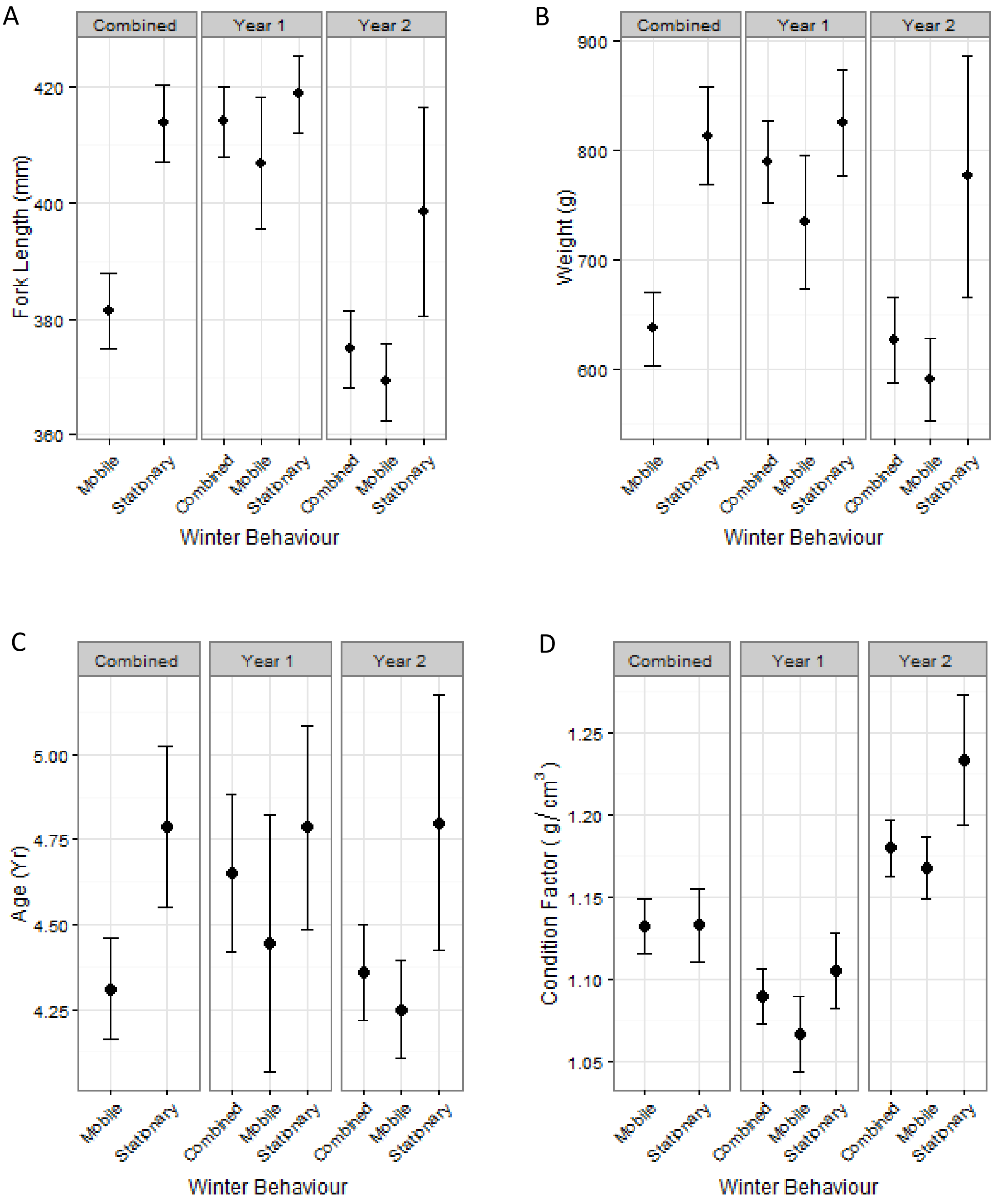

Figure 1.5. Fork length (A), weight (B), age (C) and condition factor of mobile and stationary CCT tagged with large transmitters in year 1 and 2.

Overwintering Areas

Tracking of radio tagged CCT identified nine areas where CCT aggregated in the Kitimat watershed (Figure 1.6). Overwintering areas were located in the lower and middle sections of the Kitimat watershed, from 10 to 35 rkm (Figure 1.7). No radio tagged CCT were observed upstream of 35 rkm from mid-December until late March of either winter. Overwintering aggregations were identified in the mainstem of the Kitimat River, the lower reaches of major tributaries and within sloughs and back channels associated with minor tributaries. Deep, slow moving pools and backchannel sloughs were used most commonly, however radio tagged CCT were frequently relocated within adjacent riffles and glides. The position of initial (Figure 1.7) and final overwintering habitats (Figure 1.8) did not differ significantly between years, sex (Table A1.7), or behavioural groups (Table A1.8).

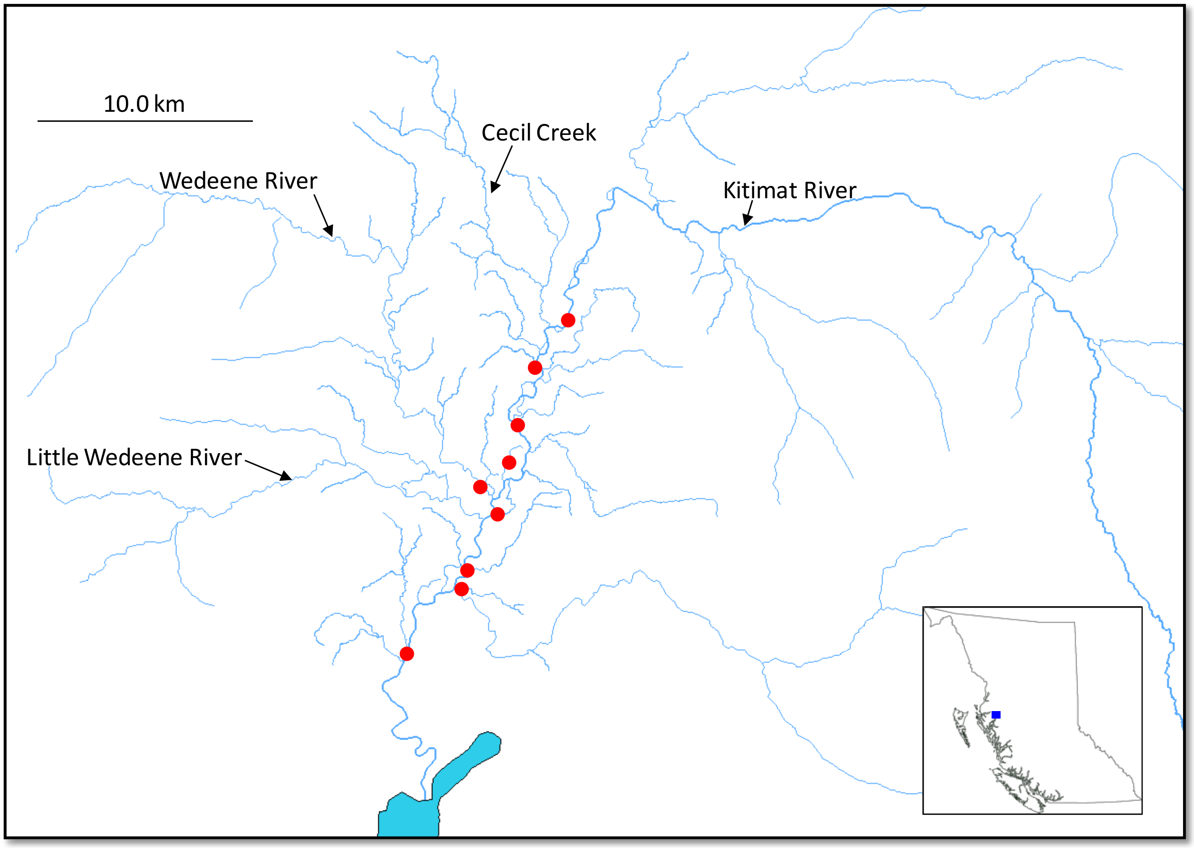

Figure 1.6. Position of winter aggregation areas (red dots) used by radio tagged CCT in the Kitimat watershed.

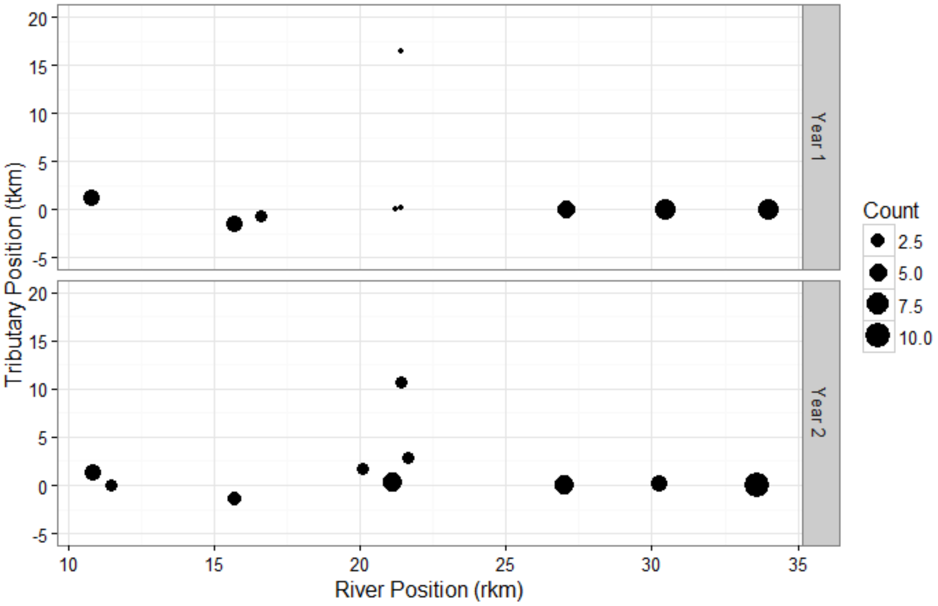

Figure 1.7. Mean river and tributary position of initial overwintering habitats used by radio tagged CCT in year 1 and 2. Note that northern and southern tributaries are identified by positive and negative values of tributary position, respectively.

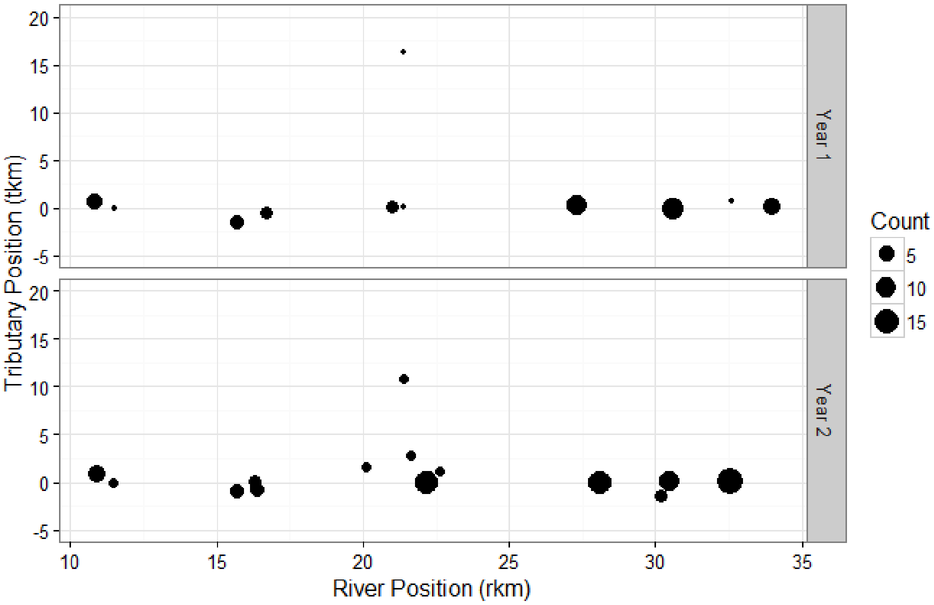

Figure 1.8. Mean river and tributary position of final overwintering habitats used by radio tagged CCT in year 1 and 2. Note that northern and southern tributaries are identified by positive and negative values of tributary position, respectively.

Timing of Arrival in Initial Overwintering Areas

The timing that CCT first moved into overwintering habitats was estimated using relocation and capture data. Relocation data suggested that half of all CCT radio tagged in year 1 had been relocated within overwintering areas by November 20, significantly later than the median date of arrival in year 2 (October 21). When data from both years was combined, no differences were observed in the date that CCT were captured in overwintering habitats between sexes (Table A1.9; Figure 1.9A) or winter behavioural groups (Table A1.10; Figure 1.10A). Median dates of arrival in overwintering areas, however, directly corresponded with the date of the first aerial tracking flights during each winter (Figure 1.9B and Figure 1.10B). Thus, it is likely that the median arrival dates observed in this study are not only conservative, but that they were biased by the sampling design and aerial tracking frequency. This is particularly true for the first winter, as minimal sampling was conducted throughout October and the first flight was not conducted until November 20, 2012.

Given this bias, the relocation data was combined with the angling data to gain additional insight into when CCT arrived in overwintering areas. This provided a means of indirectly assessing arrival timing by examining the relationship between the relative proportion of CCT that had been radio tagged to the total number of radio tagged CCT observed and captured within overwintering habitats. Figure 1.11 demonstrates that the relative proportion of CCT captured within overwintering habitats increased steadily from late October of year 1, and from mid-October of year 2, suggesting that CCT may have moved into overwintering habitats earlier than the dates identified by aerial tracking flights.

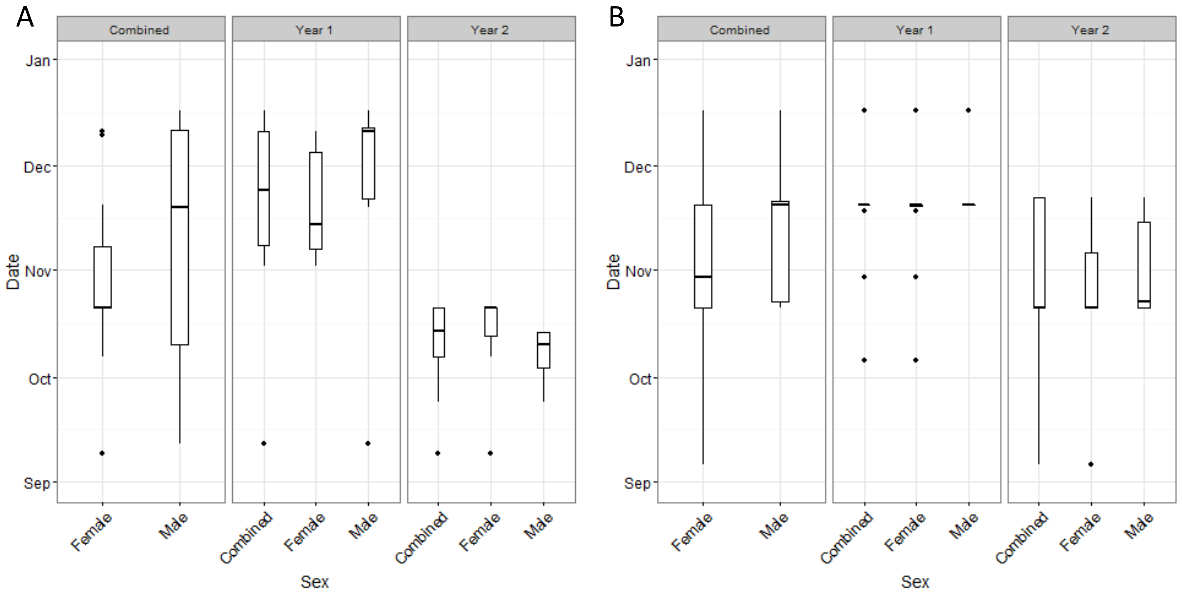

Figure 1.9. Date that male and female CCT were captured within (A), and first relocated within (B), initial overwintering habitats in in year 1 and 2. Note CCT that were captured in overwintering habitats are not included in Figure 1.9A.

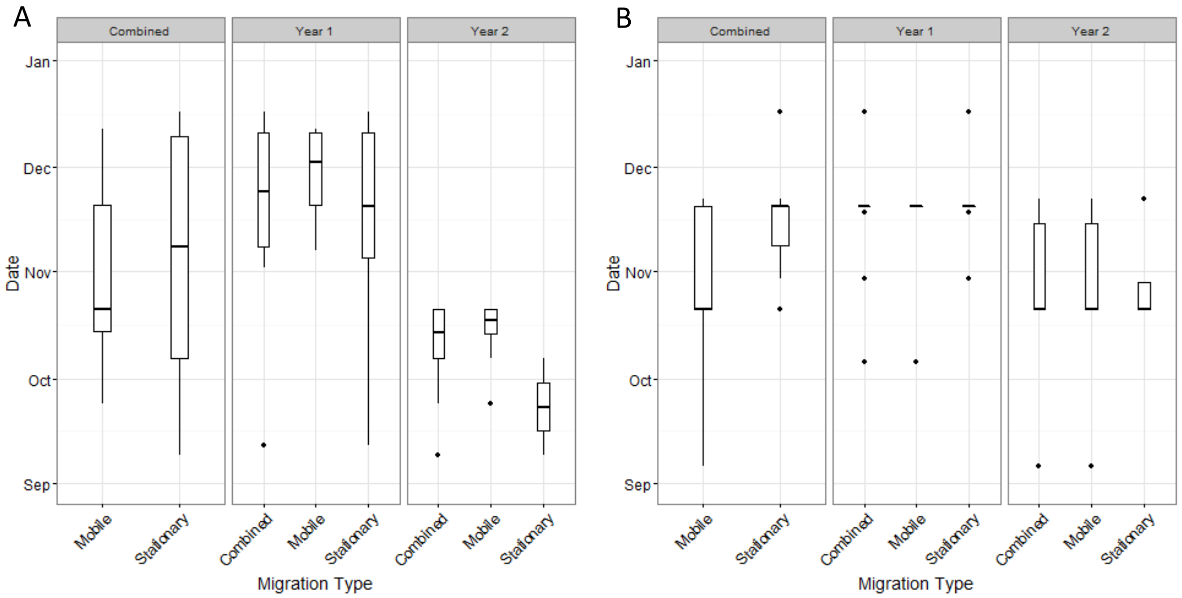

Figure 1.10. Date that mobile and stationary CCT were captured within (A), and first relocated within (B), initial overwintering habitats in in year 1 and 2. Note CCT that were captured in overwintering habitats are not included in Figure 1.10A.

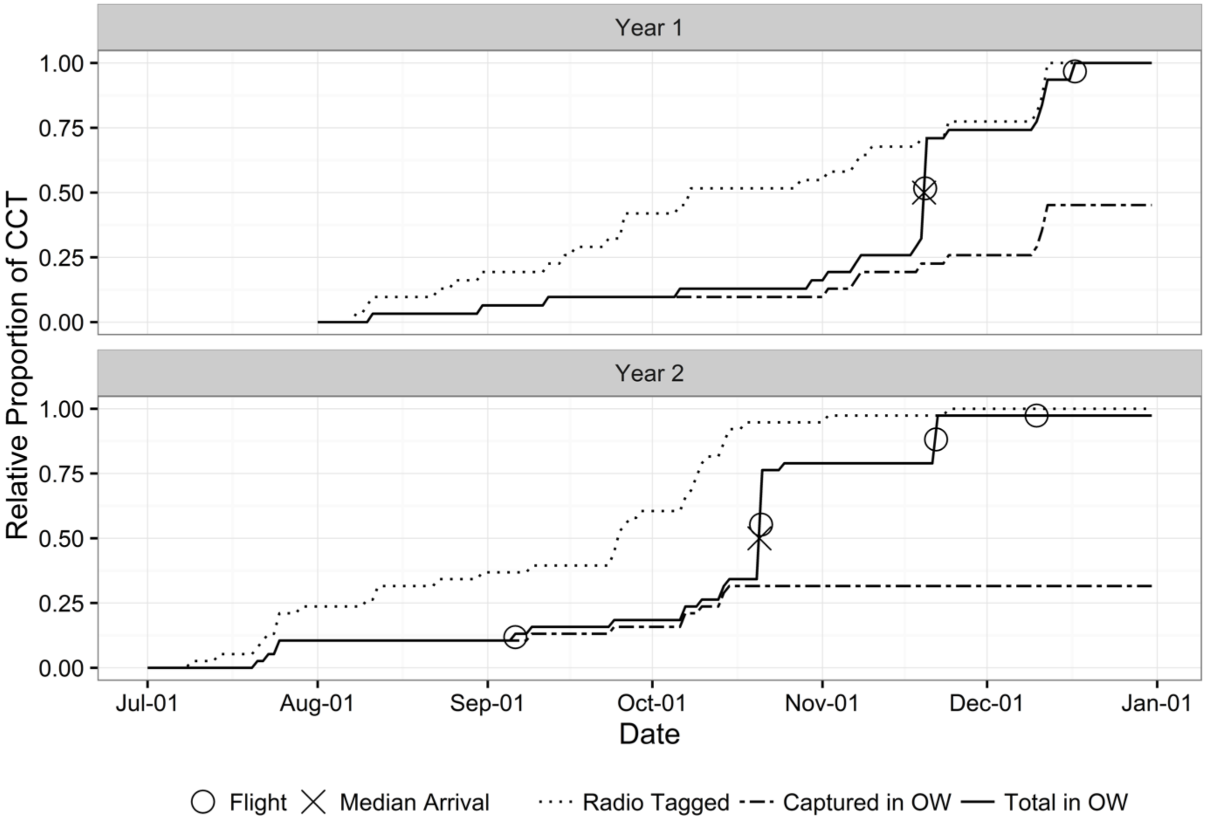

Figure 1.11. Comparison of the relative proportion of radio tagged CCT (dotted line) that were observed (solid line) and captured (dashed line) in overwintering habitats in year 1 and 2. The dates when aerial relocation flights were conducted are indentified by circles. The median date when radio tagged CCT were observed within overwintering habitats in each year is identified by an "X". Note that the relative proportion of CCT observed within overwintering habitats (dashed line) includes CCT that travelled to overwintering habitats, as well as CCT that were captured within overwintering habitats.

Travel to Initial Overwintering Areas

Excluding the 27 CCT that were captured within initial overwintering areas, radio tagged trout were observed traveling up to 22.0 rkm and up to 12.0 tkm from their location of capture to initial overwintering areas (Table A1.11 and Table A1.12). When the data from both years were combined female CCT travelled significantly further than males through the mainstem (rkm) as well as in total when mainstem and tributary distances were combined (Table A1.11; Figure 1.12A and Figure 1.13A). When sex data in each year was combined, CCT travelled further in year 2, through the mainstem as well as in total, although the differences were not statistically significant. The apparent difference was likely driven by males in year 1 which were captured closer to OW habitats than females in year 1, and males in year 2. Distances travelled to overwintering habitats did not differ between mobile and stationary CCT during either year, or when years were combined (Table A1.12; Figure 1.12B and Figure 1.13B). Nor were differences apparent between years when behavioural groups were combined.

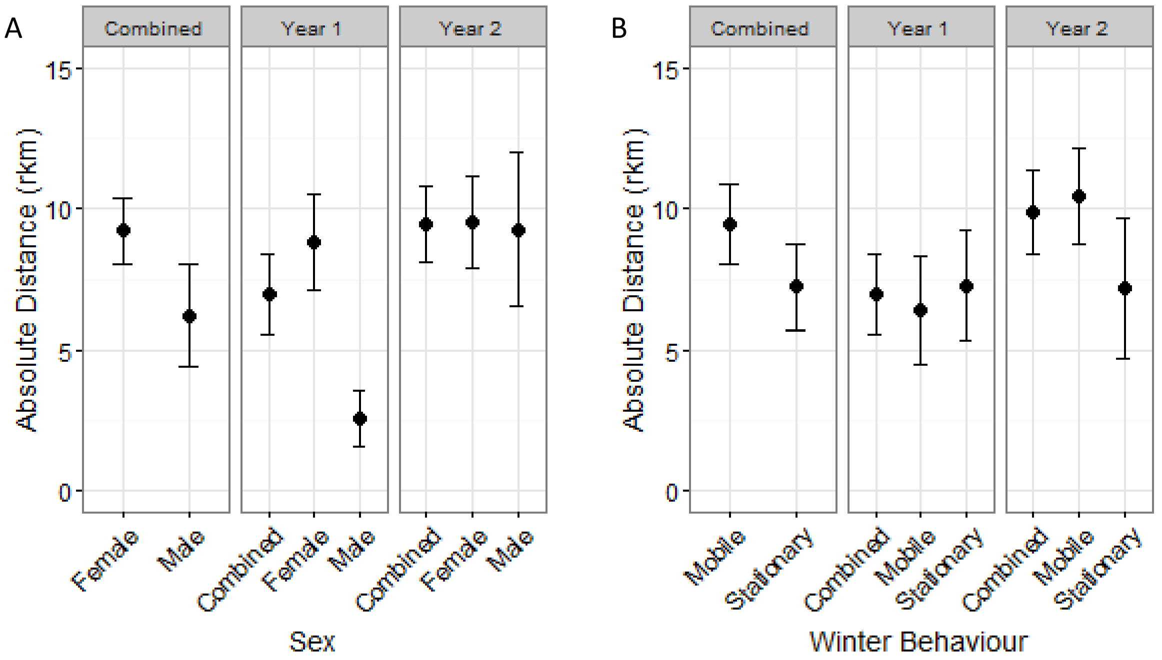

Figure 1.12. Mean and SE absolute distance male and female (A), and mobile and stationary (B) CCT travelled through the mainstem from their location of capture to initial overwintering habitats in year 1 and 2.

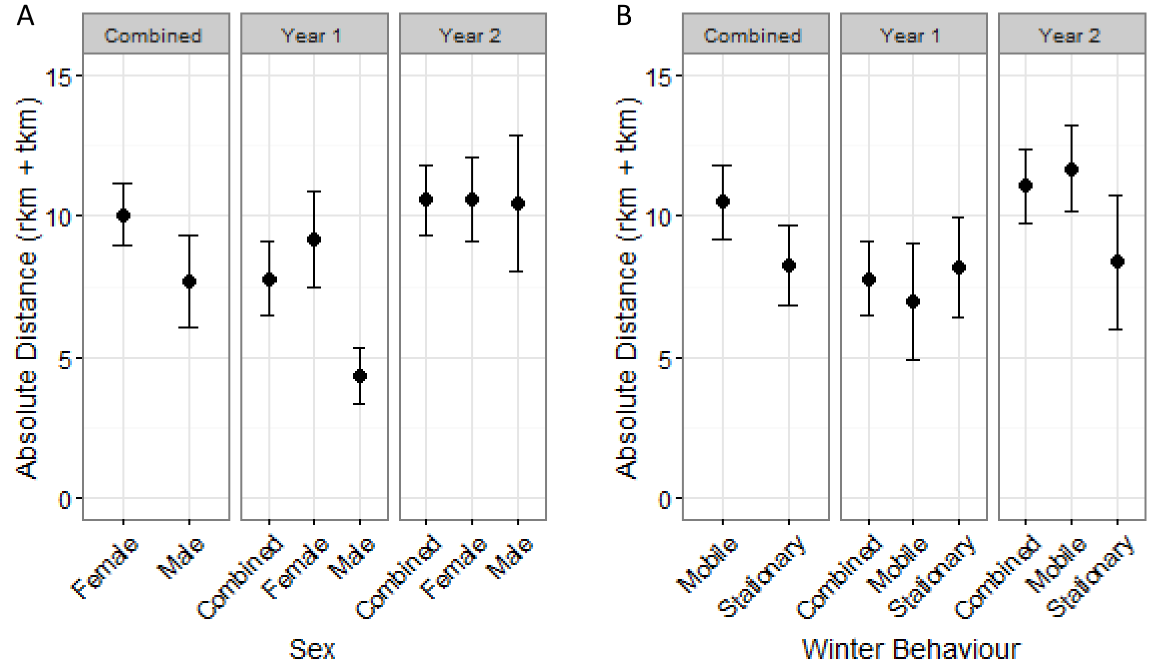

Figure 1.13. Mean and SE absolute distance male and female (A), and mobile and stationary (B) CCT travelled through the mainstem and tributaries from their location of capture to initial overwintering habitats in year 1 and 2.

Movement Between Overwintering Habitats by Mobile CCT

Stationary CCT were only observed within a single overwintering location. In contrast, mobile CCT moved between 2 to 5 overwintering habitats from November 20 to March 21. The number of CCT in mainstem overwintering aggregations generally increased throughout the winter (Figure 1.14). Mobile CCT travelled total distances of up to 15.0 km between overwintering habitats and both up- and downstream movements were observed. Final overwintering positions were a mean distance of 1.7 ± 0.7 km downstream of initial overwintering habitats, though final overwintering positions were observed as far as 12.0 km up and downstream of initial overwintering locations. Males tended to move between more overwintering habitats than females in year 1 and females tended to move between more habitats than males in year 2. However, the mean distance CCT travelled between habitats did not differ statistically between sexes or years, nor were differences apparent in the total distance CCT travelled throughout the winter (Table A1.13). Cutthroat moving between more overwintering habitats did not necessarily move greater total distances throughout the winter. Indeed, male CCT occupied relatively, but not significantly, more habitats in year 1 than year 2, yet no difference was observed in the total distance travelled between years.

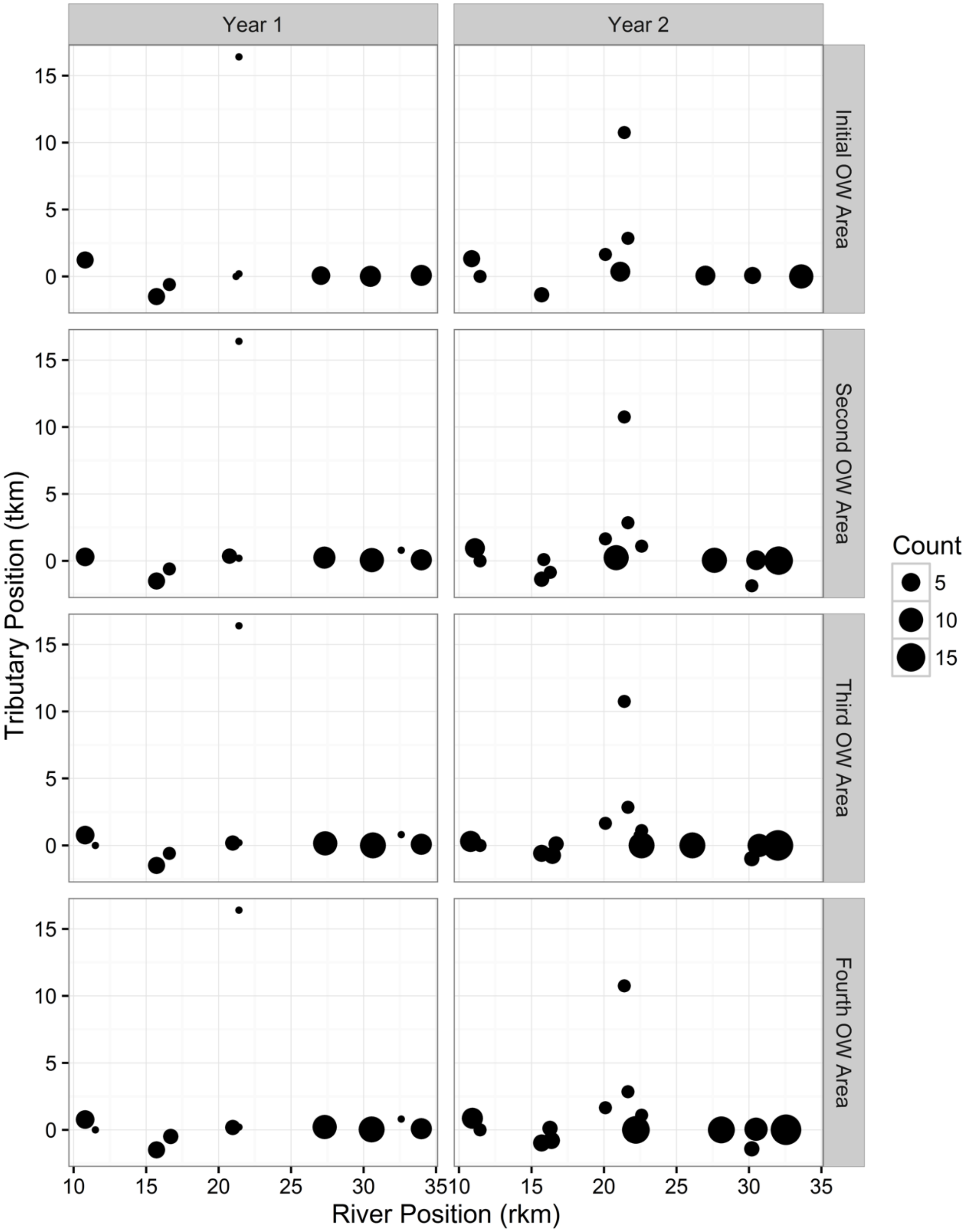

Figure 1.14. Mean river position of overwintering aggregation areas in the Kitimat watershed in year 1 and 2. The size of each point corresponds to the number of fish observed within each overwintering area. Initial overwinter (OW) areas represent the first overwintering habitat that mobile and stationary radio tagged CCT were observed within. The three lower panels represent the position of the second, third and fourth overwintering habitats used by mobile CCT, and thus demonstrate how the distribution of mobile CCT changed over time. Note that northern and southern tributaries are identified by positive and negative values of tributary position, respectively.

Departure from Overwintering Habitats

Radio tagged CCT departed overwintering habitats from early March to early May. Greater variability in departure times was observed between years than between sexes or behavioural groups. Indeed, departures occurred significantly earlier in year 1 than year 2 when movements of all CCT were considered as a whole, regardless of sex (Table A1.14) or behaviour group (Table A1.15). A strong negative correlation was observed between the date that CCT departed overwintering habitats and the total distance travelled to reach spawning habitat (Figure 1.15).

From overwintering areas, radio tagged CCT either moved directly into spawning tributaries or into pre-spawn staging areas. Staging and non-staging CCT departed overwintering habitats at similar times. Combining sex and behavioural data identified that non-staging CCT departed overwintering habitats significantly earlier in year 1 (Figure 1.16A and B). However, between year differences were not apparent among staging CCT (Figure 1.17A and B). Females departed overwintering habitats later than males in each year, however differences were not statistically significant. Nor were other differences apparent between males and females during, or between years.

Among mobile and stationary CCT, differences were apparent between years, but not between groups. Mobile CCT departed significantly earlier in year 1 than year 2 when staging and non-staging CCT were assessed together, but differences between years were not statistically significant when staging and non-staging fish were considered independently (Table A1.15). Departure times of stationary CCT did not differ between years.

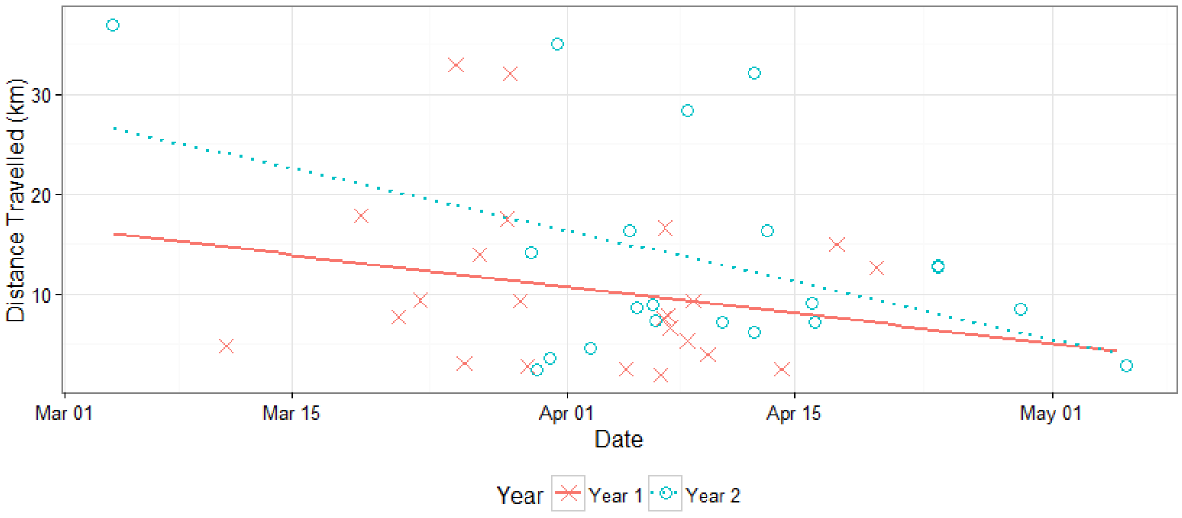

Figure 1.15. Correlation between the date that radio tagged CCT departed final overwintering habitats and the total distance travelled (rkm + tkm) to spawn.

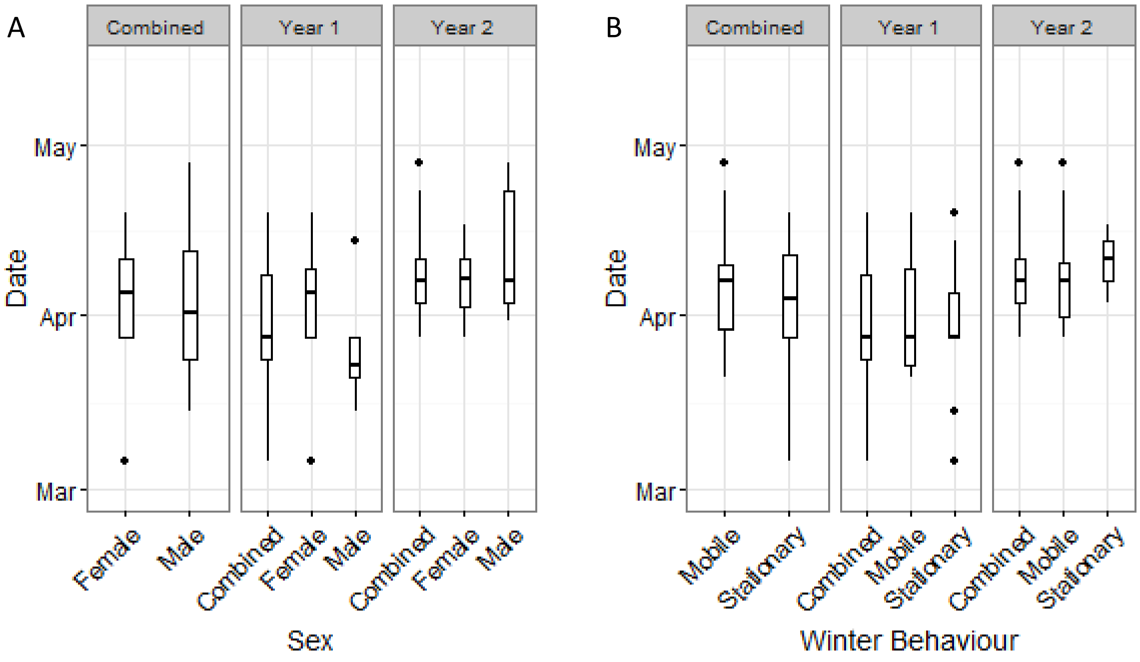

Figure 1.16. Median date non-staging male and female (A) and mobile and stationary (B) CCT departed overwintering habitats in year 1 and year 2.

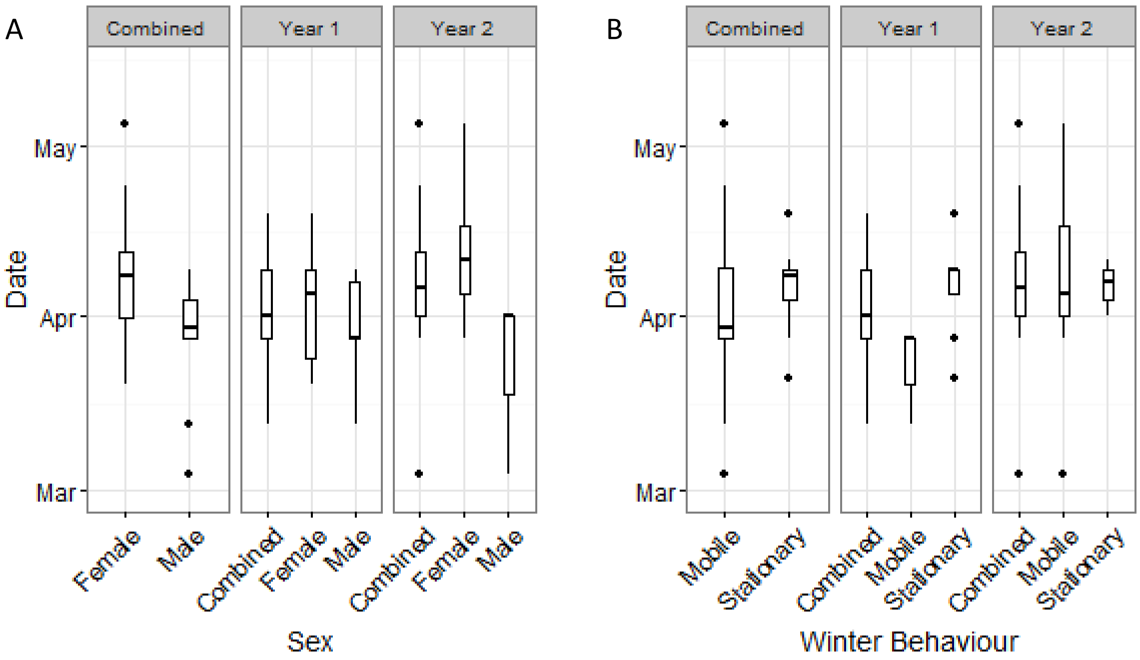

Figure 1.17. Median date staging male and female (A) and mobile and stationary (B) CCT departed overwintering habitats in year 1 and year 2.

Movement from Overwintering to Staging Habitats

Radio tagged CCT travelled up to 36 km from overwintering habitats to staging areas. Distances travelled to staging areas were more variable among behavioural groups than between years or sexes (Table A1.16). Mobile CCT tended to travel further to staging areas than stationary CCT, however differences between groups were not statistically significant within, or between years (Table A1.17).

From staging areas, CCT travelled up to 14.0 km to spawn. When data from both years were combined, stationary CCT appeared to select staging areas that were closer to spawning habitats than mobile CCT (Table A1.16), but the large range in movement of CCT in each movement group resulted in a lack of statistical significance. Indeed, mobile CCT appeared to travel greater mean distances in each year. No significant differences were observed between male and female CCT in the distance travelled to spawn from staging areas, nor were differences observed between years when sex data was combined (Table A1.17). The timing that CCT arrived in staging areas did not differ between years, nor did it differ between sexes (Table A1.18) or behavioural groups (Table A1.19). In fact, the median date CCT arrived in staging areas differed by only 1 day when sex and behaviour data was combined. Female and stationary CCT arrived later than males and mobile CCT in each year, but again differences were statistically insignificant.

However, when sex and behavioural data were combined, significant differences were identified in the date that CCT departed staging habitats between years. Indeed, departures occurred significantly earlier in year 1 than year 2. Departure dates did not differ between sexes, however females consistently departed staging areas later than males (Table A1.18). Similarly, no statistical differences were found between behavioural groups during or between years, though relatively greater variability was observed in the departure dates of mobile CCT than stationary CCT (Table A1.19).

Movement from Overwintering to Spawning Habitats

From overwintering habitats, staging and non-staging CCT travelled total distances of up to 37.0 and 35.0 km, respectively, to spawn. Distances travelled to spawn did not differ statistically between years, or between staging and non-staging CCT. Nor were differences apparent between sexes (Table A1.20) or behavioural groups (Table A1.21) within or between years.

Despite the lack of statistical significance, trends were apparent in the data comparing distances travelled by each sex that may be biologically important (Table A1.20). For instance, non-staging female CCT travelled further than staging females in both years, but especially further in year 2. Distances that staging and non-staging male CCT travelled to spawn were comparatively more variable between years; staging males travelled further than non-staging males in year 1, but the opposite was observed in year 2.

Non-significant, but potentially biologically important trends were also apparent when considering the distances travelled by CCT in each behavioural group (Table A1.21). Compared to staging CCT, non-staging stationary and mobile CCT travelled relatively further in each year. Additionally, overwintering locations used by staging and non-staging mobile CCT were consistently further from spawning habitats used by stationary CCT in each group.

Spawning Migrations

Radio tagged CCT moved into spawning tributaries from March 28 to May 6 in year 1 (median = April 19; n = 25) and from April 11 to May 9 in year 2 (median = May 1; n = 22). When sex and behaviour data were combined, CCT arrived in spawning tributaries significantly earlier in year 1 than year 2 (Table A1.22). Between year differences were also apparent among staging CCT when sex and behaviour data were combined (Figure 1.18A and Figure 1.19A), but not among non-staging CCT (Figure 1.18B and Figure 1.19B).

The timing that CCT moved into spawning tributaries differed between years, but not between sexes, behavioural groups or staging and non-staging fish. Male and female CCT entered spawning tributaries at similar times and comparisons of sex data did not identify any significant differences (Table A1.22; Figure 1.18A and B). However, male CCT in year 2 arrived later, but not significantly later than males in year 1 when staging and non-staging CCT were combined and when staging CCT were assessed independently. Stationary CCT consistently moved into spawning tributaries earlier than mobile CCT, but no other trends were apparent in the comparisons of behavioural groups (Table A1.23; Figure 1.19).

Spawning is assumed to have occurred at the maximum upstream relocation position within putative spawning tributaries. Radio tagged CCT spawned 0 to 24 days after first arriving in spawning tributaries (mean = 5.2 ± 0.5 days). Spawning occurred significantly earlier in year 1 (from April 6 to May 17; n = 23) than in year 2 (April 17 to May 15; n = 21). In year 2, staging CCT spawned significantly later than non-staging CCT and later than staging CCT in year 1 (Table A1.24).

During each year, male and female CCT spawned at similar times. In year 1, males spawned significantly earlier than in year 2, but this difference was not identified among females (Table A1.24). Nor were statistically significant differences apparent between male and female CCT during either year. Mobile CCT spawned later than stationary CCT in each year, but the difference in timing was not statistically significantly (Table A1.25). Comparisons between years also failed to identify significant differences in the date that mobile and stationary CCT spawned. Similarly, spawn date did not differ statistically between staging and non-staging CCT.

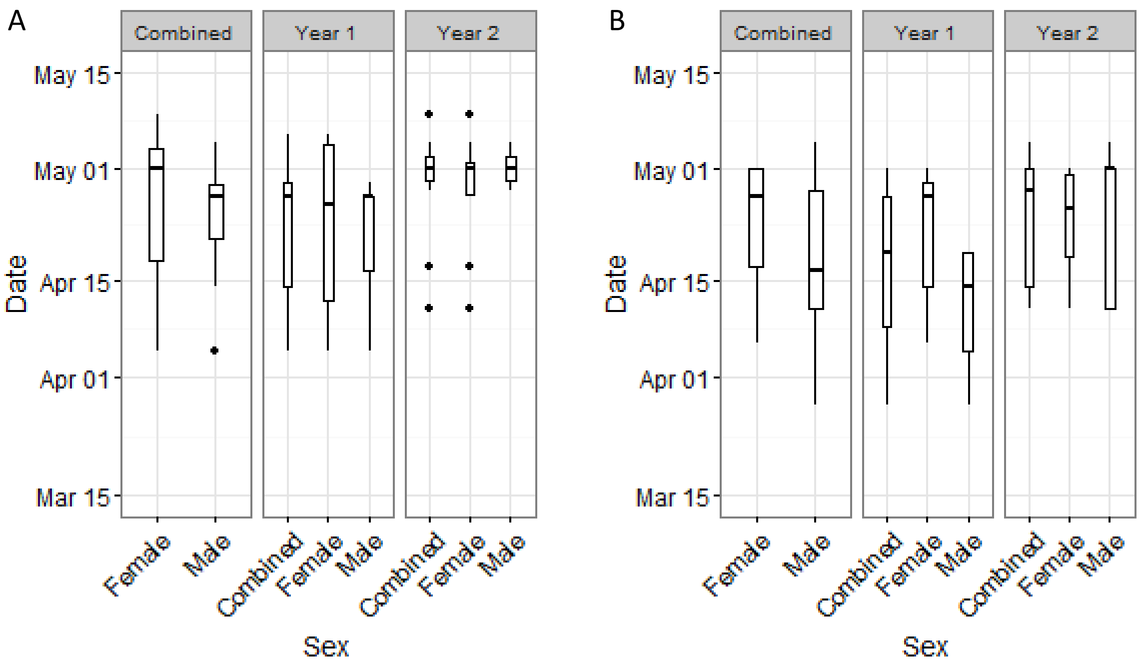

Figure 1.18. Median date that staging (A) and non-staging (B) male and female CCT arrived in spawning tributaries in year 1 and year 2

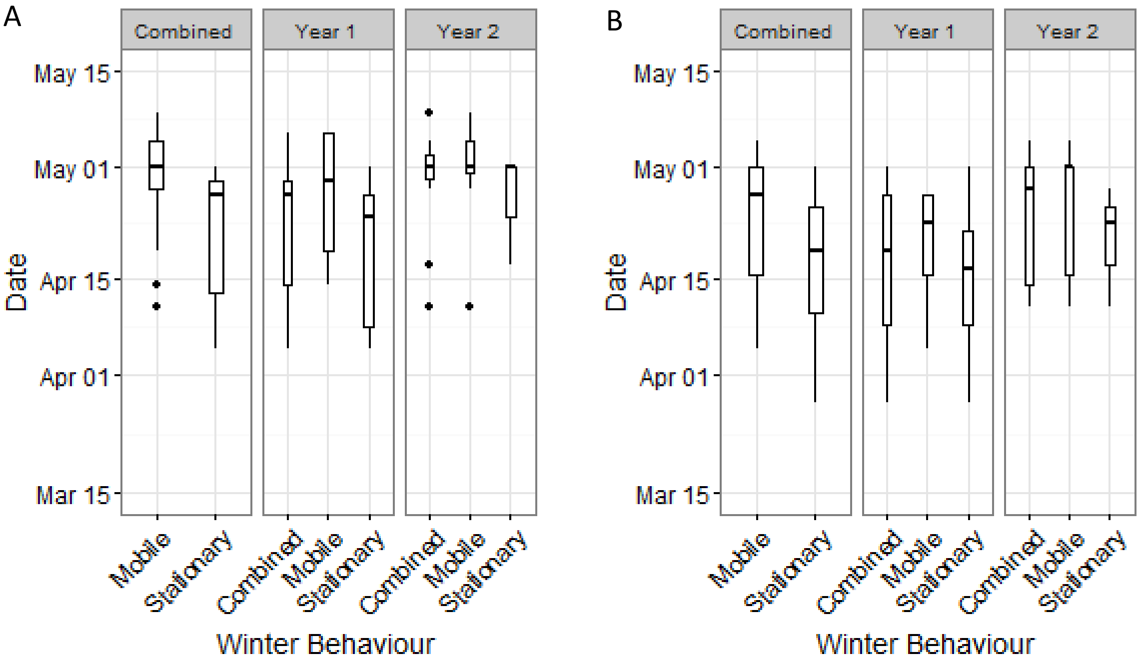

Figure 1.19. Median date that staging (A) and non-staging (B) mobile and stationary CCT arrived in spawning tributaries in year 1 and year 2.

Distribution of Spawning Habitats

Spawning activity was observed within the lower (0 to 21 rkm; 57% of all spawning activity), middle (21 to 41 rkm; 32%) and upper (>41 rkm, 11%) reaches of the Kitimat watershed (Figure 1.20, Table A1.26). The majority of spawning activity (n = 34, 72%) was observed within 9 of the 13 major drainages identified by Macdonald & Shepherd (1983). The remaining 28% (n = 13) of spawning activity occurred within 7 minor 1st to 4th order streams draining directly into the Kitimat River.

Within major drainages, putative spawning positions were observed in the main channel (n = 16), as well as within secondary and tertiary streams to the main channel (n = 18) (Figure 1.20, Table 1.5). First (22%), second (61%) and third (17%) order streams were used by CCT that spawned in secondary and tertiary tributaries. Spawning CCT were relocated as far as 30.9 km from the mainstem of the Kitimat River in major tributaries (mean = 7.0 ± 1.1 km) and 6.9 km in minor tributaries (mean = 3.8 ± 0.5 km). Cutthroat travelled up to 23.3 km to access secondary tributaries within major drainages (mean = 5.1 ± 1.3 km) and then travelled up to an additional 3.5 km within secondary and tertiary tributaries to reach putative spawning areas (mean = 1.3 ± 0.3 km). Three cutthroat spawned within the lower 1.2 ± 0.2 km of first and second order streams draining directly into the mainstem of the Kitimat River. These spawning streams were primarily within the upper watershed and joined the Kitimat River between 31 rkm and 68 rkm.

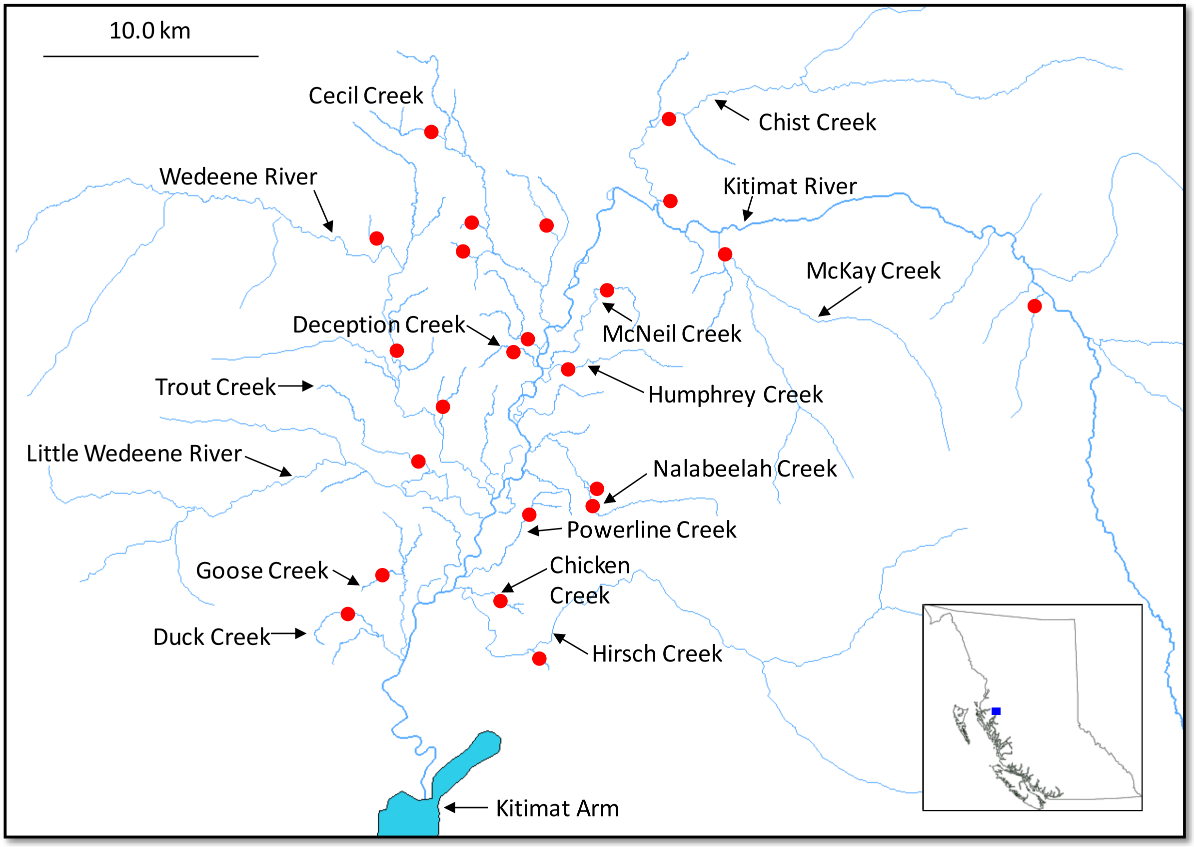

Figure 1.20. Location of putative spawning habitats (red dots) used by radio tagged CCT in the Kitimat watershed.

Table 1.5. Percent of CCT spawning in major and minor tributaries within the lower, middle and upper reaches of the Kitimat watershed.

	Major Tributaries		Minor Tributaries		Combined	
	n	% of All Spawners	n	% of All Spawners	n	% of All Spawners
Lower Watershed	7	15%	8	17%	15	32%
Middle Watershed	23	49%	4	9%	27	57%
Upper Watershed	4	9%	1	2%	5	11%
Total	34	72%	13	28%	47	100%

Spawning Mortality

Greater than half of all radio tagged CCT did not survive spawning in year 1 (56%) and year 2 (59%). No differences in mortality rate were observed between main channel and secondary/tertiary spawning CCT (Table 1.6). Nor were statistical differences detected between years, winter behavioural groups, sexes and staging and non-staging CCT. Mortality was greatest among male, mobile and staging CCT than among female, stationary CCT and non-staging CCT, respectively, however statistical differences between groups were non-significant.

Post Spawning Behaviours

Following spawning, surviving CCT travelled directly towards the estuary or travelled to positions in the mainstem or major tributaries. Less than half (9) of the 20 surviving CCT travelled directly towards the Kitimat River estuary following spawning. These CCT moved out of the Kitimat River (past the lowermost receiver stations) from May 20 to June 3 of year 1 and from June 1 to June 3 of year 2. Diadromous CCT spent a mean of 51.3 ± 8.9 days in the estuary and returned to Kitimat River from July 1 to September 6 in Year 1 (median = July 23) and from June 28 to July 18 of year 2 (median = July 5). Following spawning, 11 CCT moved to habitats in the mainstem (n = 8) and lower reaches of major tributaries (n =3).

Table 1.6. Summary of the relative mortality of CCT spawning within the main channel, and secondary and tertiary streams of major and minor tributaries to the Kitimat River.

Spawning Water Body	All CCT			Main Channel Spawning CCT			2° and 3° Spawning CCT		
	# Spawned	# Survived	% Mortality	# Spawned	# Survived	% Mortality	# Spawned	# Survived	% Mortality
Hirsch Creek	5	2	60%	0	-	-	5	2	60%
Big Wedeene	8	4	50%	2	1	50%	6	3	50%
Little Wedeene	2	1	50%	0	-	-	2	1	50%
Nalbeelah Creek	4	1	75%	4	1	75%	0	-	-
Humphrey Creek	1	1	0%	1	1	0%	0	-	-
Deception Creek	2	0	100%	2	0	100%	0	-	-
Cecil Creek	8	4	50%	5	4	20%	3	0	100%
Chist Creek	2	1	50%	1	1	0%	1	0	100%
McKay Creek	2	2	0%	1	1	0%	1	1	0%
All Major Tributaries	34	16	53%	16	9	44%	18	7	61%
Duck Creek	3	1	67%	3	1	67%	0	-	-
Goose Creek	3	1	67%	2	1	50%	1	0	100%
McNeil Creek	2	1	50%	2	1	50%	0	-	-
Powerline Creek	2	0	100%	2	0	100%	0	-	-
Unnamed Creeks*	3	1	67%	3	1	67%	0	-	-
All Minor Tributaries	13	4	69%	12	4.0	66.7%	1	0	100%

DISCUSSION

Radio tagged CCT in the Kitimat River displayed fluvial and diadromous life history strategies. Fluvial CCT moved between the mainstem and tributaries of the Kitimat River. Diadromous CCT moved throughout the mainstem and tributaries but also travelled into the estuary following spawning. High mortality throughout the spawning period limited the extent to which CCT could be defined as diadromous or fluvial. Furthermore, radio tagged CCT were not tracked for the duration of their life and it is possible that CCT displaying fluvial behaviours throughout the study period had previously, or would later, move into marine environments. Thus, described behaviours are considered for migratory CCT, which includes both diadromous and fluvial life history strategies. The results of this study should not be extended to stream resident CCT as they were not sampled during this research.

The behaviours displayed by radio tagged CCT fit within Northcote's (1997a) functional model of migration and residency. In the fall, CCT moved into habitats that provided refuge through the winter and in the spring, they moved from refuge to reproductive and then foraging habitats. However, when considered at a finer resolution the overwintering and spawning movements of radio tagged CCT appear to be more complex than have been previously documented for the subspecies. Indeed, multiple overwintering behaviours as well as pre-spawn staging behaviours were observed.

For many salmonids, winter is believed to be a period of reduced survival (Huusko et al. 2007). To improve winter survival, CCT select habitats that promote energy conservation and provide refuge from deleterious environmental conditions (Northcote 1997b, Harvey et al. 1999, Huusko et al. 2007, Trotter 2008). In this study, radio tagged CCT aggregated in deep, slow moving pools within side-channels and sloughs of the mainstem of the Kitimat River. The character and structure of these habitats are similar to the deep pool habitats used by more southern CCT populations (Bustard and Narver 1975a, Harvey et al. 1999, Slaney and Roberts 2008) and to the beaver ponds that are used in Alaska's Copper River Delta (Saiget et al. 2007). The use of off-channel habitats in this study suggests that the subspecies will select habitats that are best able to provide refuge throughout the winter – demonstrating the subspecies' ability to adapt to conditions of the local environment.

My study also showed that deep, slow moving off-channel habitats provide critical winter refuge for CCT in the Kitimat watershed. The importance of these habitats was reinforced by the fact that all major overwintering aggregations shared similar physical characteristics and that they were used during both years of the study. Furthermore, CCT appeared to actively select deep, slow moving off-channel habitats. Indeed, relative to other habitat types in the watershed, habitats matching the characteristics of the major overwintering aggregations were relatively limited in number, yet all habitats with these characteristics were used extensively. Additionally, mobile CCT consistently moved between aggregations and were infrequently relocated outside of them, suggesting that they were moving to specific habitats.

Recreational anglers frequently targeted aggregated CCT throughout the winter. For a number of reasons, this should be of concern to regional fisheries managers. First, if the behaviours of radio tagged CCT are representative of the greater population of CCT in the Kitimat watershed it is reasonable to assume that the majority of CCT are concentrated within a limited number of habitats during the winter. Thus, targeting aggregated CCT may promote a false sense of abundance among anglers, which may contribute to illegal retention (personal observation). In addition, capture by angling is physiologically stressful and energetically taxing (Ferguson and Tufts 1993, Meka and Margraf 2007). Thus, angling aggregated CCT may diminish the ability of overwintering habitats to provide winter refuge. Given that winter can be a period of increased mortality and that habitat selection appears to be a survival strategy, angling overwintering CCT could have long term detrimental population affects. Measures that provide additional protection of overwintering habitats should, therefore, be considered if there is concern about the status of CCT populations in the region.

Previous studies of CCT have generally stated that CCT remain within a single overwintering habitat throughout the winter (Trotter et al. 1993, Saiget et al. 2007, Trotter 2008). My findings, however, demonstrate that CCT may remain stationary within a single habitat, or move between multiple habitats throughout the winter. To the best of my knowledge, winter movement of lotic CCT at the scale and frequency reported in this study has not been described previously. Among other subspecies of cutthroat trout, winter movement appears to be common. Indeed, WCT appear to move frequently throughout the winter and similar mobile and stationary behaviours have been reported for the subspecies (Brown 1994, 1999, Jakober et al. 1998, Morris and Prince 2004). Given these observations and the frequency that radio tagged CCT moved between habitats, it is possible that cutthroat, as a species, may be more mobile throughout the winter than has been previously considered. Furthermore, similar behavioural structuring has been observed in studies examining the marine habitat use of CCT (Krentz 2007, Goetz et al. 2013), suggesting that CCT may adopt specific behavioural strategies throughout key life stages.

The factors contributing to the distinct winter behaviours observed in this study are not clear. However, studies of other salmonids provide insight and suggest that winter movements may be due to changes in environmental conditions, interspecific competition and/or external stressors (Mäki-Petäys et al. 2004, Huusko et al. 2007, 2013, Meka and Margraf 2007). Additional clarity is likely to be provided by studies that employ biotelemetry and monitor winter movements of migratory CCT in multiple watershed and at a finer temporal resolution.

Changes in water temperature and habitat occlusion caused by instream ice formation are frequently cited as a source of winter movement (Brown et al. 1993, Brown and Mackay 1995b, Jakober et al. 1998, Morris and Prince 2004, Huusko et al. 2013). Periods of hypercooling and instream ice formation were observed during both years of this study. The influence of water temperature and ice formation on winter movements, however, could not be assessed due to the low temporal resolution of the winter tracking data. It is likely that temperature, flow and ice conditions did contribute to the observed winter movements, but it is unlikely that they were the sole factor promoting winter movement. Indeed, movement was observed throughout the winter and not strictly during hypercooling or high flow events. Furthermore, radio tagged CCT remained within overwintering habitats throughout the winter and no single ice or flow event resulted in the movement of all individuals from a habitat.

In this study, stationary CCT were significantly older, longer and heavier than stationary CCT, suggesting that movement between overwintering habitats may be in response to interspecific competition. Dominance hierarchies and interspecific cohort segregation are often observed during studies of salmonids, and may be more pronounced in winter if multiple cohorts aggregate in the same habitats (Mäki-Petäys et al. 2004, Huusko et al. 2007). Furthermore, interspecific competition for habitats may increase when refuge habitats are of limited availability, which may benefit larger individuals (Harwood et al. 2001, Huusko et al. 2007). Intraspecific competition is less likely to have influenced winter behaviours as the two other salmonid species present in the watershed during the winter, Dolly Varden and resident rainbow trout, were consistently smaller than CCT selected for radio tagging.

Recreational anglers were frequently observed targeting overwintering aggregations and stress associated with catch-and-release angling may have promoted movement between overwintering habitats. Certainly, capture by angling is a physiologically stressful and energetically taxing event and it is possible that movements out of overwintering habitats were an avoidance response (Ferguson and Tufts 1992, Meka and Margraf 2007). Arguably, activities that increase stress and energy expenditure while reducing foraging potential diminish the capacity of overwintering habitats to function as refuges. Future studies employing biotelemetry are recommended to better understand the extent to which catch and release angling affects the winter movements of CCT (Donaldson et al. 2008).

Pre-spawn staging behaviours have been well documented among salmonids (e.g. Colyer et al. 2005, High et al. 2011, Starcevich et al. 2012). Spawning movements of CCT, however, have generally been described as direct from overwintering to spawning habitats. To the best of my knowledge, pre-spawn staging behaviours of CCT have not been thoroughly assessed, though indirect references in recent studies suggest the behaviour may be more common than has been recognized. For instance, Saiget et al. (2007) described 4 CCT that held in small pools for 3-14 days while travelling towards spawning habitats. Temporary staging prior to spawning may be advantageous if it permits individuals to assess natal stream conditions, or select mates.

In my study, CCT were observed moving from overwintering to staging habitats prior to spawning. Staging habitats were 0.1 to 36.2 km from overwintering habitats and 0.8 to 14.0 km from spawning habitats. Cutthroat arrived in staging habitats from late March to early May and departed after a period of 1 to 25 d. Interestingly, stationary CCT were often observed in overwintering locations that were proximal to spawning tributaries (i.e. 0.1 km from confluence with spawning tributary). Radio tagged CCT staged in multiple locations including at the confluence of small first to 3rd order tributaries flowing into the mainstem and major tributaries; at the confluence of major tributaries with the Kitimat River and in the Kitimat River mainstem itself. Searching behaviours were common and involved movement into the lower reaches of a stream before returning to the staging location. From staging habitats CCT moved directly to putative spawning positions.

Radio tagged CCT were not observed actively spawning, nor were redds of radio tagged CCT identified during bank walks of spawning tributaries. However, observations of non-radio tagged CCT spawning as well as radio tagged CCT paired with migratory and stream resident CCT within first to third order streams suggests that movements into small tributaries in the spring were to spawn. Radio tagged CCT were first relocated in spawning tributaries from the last week of March to the first week of May, with peak arrival occurring in late April. Arrival at putative spawning positions occurred slightly later, from the first week of April to mid-May, with peak spawning occurring in late April and early May. Spawn times reported in this study are consistent with records of spawn timing throughout the range of CCT (Jones and Harding 1998, Jones and Yanusz 1998, Slaney and Roberts 2005, Saiget et al. 2007, Trotter 2008, Moore et al. 2010, Buehrens 2011, Marston et al. 2011, Stein et al. 2012b).

Coastal cutthroat may spawn in the upper reaches of small tributaries where other salmonids are less abundant to reduce competition of juvenile CCT with coho salmon and steelhead (Pearcy et al. 1990) and/or reduce hybridization with steelhead (Buehrens et al. 2013). In this study, radio tagged CCT were observed within ephemeral streams and in the upper most accessible reaches of small first to third order streams. Generally, tributaries used by radio tagged CCT throughout the spawning period were of similar character to those that have been previously described for the subspecies (e.g. Roberts and Slaney 2005, Costello 2006, Trotter 2008).

Mortality of spawning radio tagged CCT was high and demonstrates the risks that migratory CCT incur while spawning in relatively small streams. Similar rates of mortality have been observed in studies of CCT (Costello 2006) and WCT (Schmetterling 2011). When transmitters were recovered from dead radio tagged CCT, it was not clear what was the cause of death. A number of factors are likely to have contributed to the high rates of observed spawning mortality including, but not limited to: predation by eagles and otters; tagging related complications; intraspecific competition; fatigue from spawning, and; unfavorable environmental conditions. The extent to which each of these factors contributed to observed mortality rates is unclear; however, evidence of predation by eagles and otters was observed during bank walks of spawning tributaries.

Radio telemetry has the capability to provide great insight into the behaviours of cryptic species. However, the technology is not without its limitations, and biases in sampling design can influence how behaviours are interpreted (Adams et al. 2012). Variability in the frequency with which individuals are relocated can result in contact bias (Jones and Rogers 1998, Rogers and White 2001, Adams et al. 2012). In this study, the frequency of ground and aerial based relocation events as well as the behaviours of CCT (which influenced relocation success) contributed to contact biases. Indeed, the increased duration between relocation events throughout the winter is likely to have underestimated movement. Similarly, individuals that remained within known habitats were relocated more often than individuals that moved into new habitats. Thus, relocation success was greatest throughout the winter and lowest throughout the spring spawning period.

In addition to biases resulting from the application of radio telemetry, additional forms of bias may have been introduced by the location, timing and methods of sampling. Recent evidence suggests that resident and migratory life history forms are part of a single randomly mating population (Johnson et al. 2010). Given that sexual selection is likely to favour migration among females (Jonsson and Jonsson 1993) it is possible that targeting large, mobile CCT during sampling may have influenced sex ratios in this study. If CCT in the Kitimat watershed are panmictic (Johnson et al. 2010), it is therefore possible that a more balanced sex ratio would have been observed if resident CCT were included in sampling (Downs et al. 1997, Meyer et al. 2003). Similar sex ratios have been documented in studies of sea-run and lacustrine CCT populations where resident CCT were not sampled (Sumner 1972, de Leeuw 1987, Johnson et al. 1994, Foster 2003, Costello and Rubidge 2005). Consequently, the female biased sex ratios reported here are not likely to be representative of the Kitimat River CCT population as they fail to include stream resident CCT.

Sampling was conducted significantly later in year 1 than year 2, and radio tagged CCT were significantly larger in year 1 than year 2. However, a Spearman correlation test of capture date and fish length, weight, age and condition factor failed to detect a significant relationship between physical characteristics and capture date (results not presented). It is thus unlikely that the difference in the timing of sampling in year 1 and year 2 affected the observed behaviours.

The observations that I have reported on in this chapter demonstrate that there is considerable variability in the behaviours of individual CCT and that this variability often limits the statistical differentiation of relationships that may be of biological significance. Distinct behavioural patterns, however, were apparent when the data was considered at a coarser scale which focused on seasonal movement patterns. Indeed, this approach demonstrated that CCT displayed one of two behaviours throughout the winter. Additionally, movements from overwintering to spawning habitats and movements from spawning habitats to the estuary were highly synchronized and coordinated in each year.

Thus, my study suggests that CCT often behave in unison and that the subspecies' may be no more individual than any other species of salmonid.

In chapter 2, I apply a logistic regression modeling approach to explore the extent to which the timing that CCT moved from overwintering habitats to spawning habitats was influenced by a suite of biotic and abiotic conditions. The timing that these migrations were completed differed significantly between years and there is considerable evidence suggesting that salmonids are capable of adjusting migration behaviours in response to environmental conditions (see reviews by Jonsson 1991, Jonsson and Jonsson 2009, Taylor and Cooke 2012, Milner et al. 2012). Little is known, however, about the behavioural responses of CCT to changes in their environment. Fortunately, telemetry studies are particularly well suited to assess how behaviours are influenced by the environment (e.g. Erkinaro et al. 1999, Bendall et al. 2012, Thorstad et al. 2013), especially when considering migrations during ecologically sensitive periods, such as spawning (Tetzlaff et al. 2005). In combination, these two chapters provide insight into the seasonal behaviours of CCT and the factors that affect them.

CHAPTER 2

Environmental and Biological Factors Influencing the Spawning Migration of Coastal Cutthroat Trout *(Oncorhynchus clarkii clarkii)* in the Kitimat River Watershed

INTRODUCTION

Migratory patterns are associated with physiological and behavioural adaptations to the environment that function to maximize individual fitness and population viability (Fleming 1996, Svendsen et al. 2004, Jonsson and Jonsson 2009, Milner et al. 2012). Travelling long distances through a dynamic fluvial environment, however, is energetically taxing and migrations are often a period of increased mortality (Rand et al. 2006, Brönmark et al. 2014). Consequently, salmonids have adapted physiological processes and behavioural strategies to mitigate these costs and maximize individual fitness (Quinn 2011, Fraser et al. 2011, Milner et al. 2012). The timing of key life history events – such as spawning – are believed to be heritable and reflect adaptations to local environmental conditions (Stewart et al. 2002, Klemetsen et al. 2003, Tetzlaff et al. 2005, O'Malley et al. 2010, Fraser et al. 2011). Environmental conditions appear to be a key component in the realization of these complex strategies, functioning to control seasonal migration timing at both long and short temporal scales (O'Malley et al. 2010, Milner et al. 2012). The timing and extent of migrations will not only reflect the local environmental conditions but also the physical state and migration capacity of the individual (Jonsson 1991).

Photoperiod is an anticipatory cue for important life history events in a range of aquatic, avian and terrestrial species (Bradshaw and Holzapfel 2007). Among salmonids, photoperiod is believed to have both ultimate and proximate effects on migratory behaviour by synchronizing seasonal migrations and initiating physiological processes that may motivate migration, respectively (Thorstad et al. 2005, Binder et al. 2011). Photoperiod has been shown to initiate and influence the maturation cycle of rainbow trout (*Oncorhynchus mykiss*; Duston and Bromage 1986, Carrillo et al. 1989) and Atlantic salmon (*Salmo sala*r; Duston and Saunders 1990, Björnsson et al. 1994) and is considered to be the dominant environmental cue stimulating physiological changes associated with smolting in anadromous forms of both species (Zaugg and Wagner 1973, McCormick et al. 2002 and references within). Less understood is how physiological changes influence an individual's internal motivations to move (Thorstad et al. 2005, 2008) which may be affected by energy and stress levels, maturation state and hormones (Milner et al. 2012). Maturation, therefore, might motivate movements towards spawning habitats as gravid females have a relatively short window within which eggs are viable (Thorstad et al. 2008, Quinn 2011). Stimulating physiological changes that are likely to affect internal motivations, photoperiod may function to ensure that behaviours occur during temporal periods that have been determined through selection. Day length has also been shown to ultimately affect migration behaviours by directly stimulating rheotaxis (Dodson and Young 1977, Martin et al. 2012). The fact that the timing of life history events differs considerably between individuals within a population, however, reinforces that photoperiod is not the only factor influencing when behaviours are undertaken.

There is considerable evidence that migrations are influenced by prevailing stream conditions in larger bodied salmonids such as Atlantic salmon (see reviews by Jonsson 1991, Tetzlaff et al. 2005, Taylor and Cooke 2012, Milner et al. 2012). Similar results have been reported in studies of smaller salmonids such as brown trout (*S. trutta*), rainbow trout (*O. mykiss*), bull trout (*Salvelinus confluentus*) and multiple subspecies of cutthroat trout (*O. clarkii*) (Waters 1993a, Brown and Mackay 1995a, Swanberg 1997, Jakober et al. 1998, Simpkins et al. 2000, Meka et al. 2003, Stephan and Zurstadt 2004, Svendsen et al. 2004, Harper and Farag 2004, Bahr and Shrimpton 2004, Friesen 2005, Colyer et al. 2005, Bryant et al. 2009, Young et al. 2010, Gregory et al. 2011, Starcevich et al. 2012, Bennett et al. 2014, Ringel et al. 2014), suggesting that trends observed in Atlantic salmon are applicable to other salmonids. Discharge and water temperature are primarily identified as the environmental variables affecting migrations (Table A2.1 and A2.2). Although considerable variation has been reported among species and populations in their response to environmental variables, such differences likely indicate that populations have adapted responses to meet conditions of the local stream environment (Thorstad et al. 2008, Bronmark et al. 2013). The high incidence of homing as well as evidence of diminished reproductive success among straying salmonids is certainly indicative of local adaptation at the population scale (Dittman and Quinn 1996).

Temperature influences the rate at which physiological processes, such as maturation occur (Hoar et al. 1983, McCormick et al. 2002, Wilkinson et al. 2010), but also influences migration capacity (Brett 1971, Quinn 2005). Physiological processes function optimally within a relatively narrow thermal range (Farrell 2002, Lee et al. 2003).

Movements will likely occur at temperatures that maximize physiological efficiency and function to conserve energy for critical life history processes such as spawning. In contrast, sexual maturation which occurs over a period of months is also affected by temperature and is dependent on an individual's thermal experience, which is typically measured in accumulated thermal units (ATUs) (Petty et al. 2012, Chezik et al. 2014). Field and laboratory studies of the effects of antecedent water temperatures have shown that increased water temperatures can stimulate early sexual maturation (Quinn and Adams 1996, Sauter et al. 2001, Dahl et al. 2004, Clark et al. 2005, McMillan et al. 2011). The effect of temperature on spawning migrations, however is equivocal. Indeed, spawning migrations of coastal cutthroat trout (CCT) have often been positively associated with water temperature, but not always (Webb and McLay 1996, Gresswell et al. 1997, Jones and Harding 1998, Stephan and Zurstadt 2004, DeRito et al. 2010, Bennett et al. 2014). Similar inconsistencies have been observed in other species of salmonids and suggest local adaptation (Table A.1).

Responses to flow are variable among species and populations, however several patterns have been reported in the literature. First, flow response is relative to river size (Thorstad et al. 2008, Milner et al. 2012). Fish moving through large rivers are less likely to be affected by flow than those moving through small streams where reduced flows may physically limit habitat connectivity (Milner et al. 2012). Second, response to flow may vary based upon migration stage (Thorstad et al. 2008). Individuals may show minimal response to flow, therefore, while still moving through large rivers towards natal streams, but may delay entry into natal streams until flows are sufficient to enable movement past instream obstacles. Third, salmonids are most likely to respond to flow during specific life history stages or transitions, when internal motivations are elevated. For instance, migratory individuals can be expected to show a stronger response to flows than fish that are foraging or rearing. Finally, variability in the timing of life history events between years is common and may be related to interannual variability in temperature and flow regimes, as well as past climatic conditions (Smith et al. 1994, Gresswell et al. 1997, Dahl et al. 2004, Tetzlaff et al. 2005, Budy et al. 2012, Milner et al. 2012, Bennett et al. 2014).

The migrations of CCT from overwintering habitats to spawn were described in Chapter 1. As coordinated movements, departures from overwintering habitats represent the initiation of the spawning migration which are then culminated upon arrival within spawning tributaries (or more accurately at the arrival to spawning locations). However, it is likely that CCT will key in on different environmental stimuli during each stage of the migration. For instance, the distance that CCT travelled to reach spawning tributaries was frequently much greater than the distance travelled within spawning tributaries. Given metabolic costs of migration are increased when water temperatures are above or below a species thermal optima, it seems plausible that movements out of overwintering habitats would not occur until a threshold temperature had been achieved. Further, fish may show an elevated response to flow while moving into and within spawning tributaries relative to when they are moving towards them. Indeed, overwintering habitats were primarily within the mainstem of the Kitimat River and low flows are unlikely to have limited movements out of overwintering habitats. Whereas elevated flows will increase access to the upper reaches of small spawning tributaries, reduce predation and contribute to olfaction.

In addition to water temperature and discharge, several biotic factors are also likely to influence migratory behaviours. Previous research has observed variation in migratory behaviours between fish of different sex, size and life history type. For instance, Yanusz (1997) found that larger, predominantly female CCT in SE Alaska initiated movements from overwintering to spawning habitats earlier. Similar size gradients have also been observed in studies examining the spawning behaviours of steelhead, bull trout, brook trout (*S. fontinalis*) and Atlantic salmon (Swanberg 1997, Curry et al. 2002, Dahl et al. 2004, McLean et al. 2005). The factors contributing to size segregation, however, are not well understood.

Differences in migration behaviour between male and female salmonids are also well described (Dahl et al. 2004). For instance, female CCT may favor migration as increased size correlates positively with fecundity, in terms of eggs size and number (Downs et al. 1997). Differences in reproductive capacity may also influence the spawning behaviours of males and females. Females have a finite number of eggs and a relatively short temporal window to complete oviposition and are likely to move out of spawning habitats once oviposition is completed (Hoar et al. 1983). In contrast, males are capable of producing sperm throughout the spawning period and their reproductive capacity is only limited by the availability of females and the amount of energy that can be invested in spermatogenesis. Males may therefore maximize reproductive success by moving into spawning tributaries with the earliest mature females, and/or remaining within spawning tributaries for the duration that ripe females are present and available.

The distance separating habitats will also influence the timing that migrations are initiated and/or completed. Certainly, individuals travelling greater distances between habitats should be expected to initiate migrations earlier, or complete them later. For instance Bahr and Shrimpton (2004) observed that bull trout travelling the furthest distance to spawn were the earliest to initiate migrations. The distance that CCT travel to access spawning habitats may also differ among life history types and may influence how individuals respond to environmental cues. For instance, Quinn and Adams (1996) suggested that endogenous rhythms will have the greatest influence on the spawning migrations of species that complete long distance migrations and do not directly experience the environmental conditions of natal streams throughout much of their life, such as sockeye salmon (*O. nerka*). In contrast to sockeye salmon, the authors argue that spawn timing will be more variable among species that remain proximal to natal tributaries or within a single watershed (E.g., American shad, *Alosa sapidissima*) as these species are more likely to be influenced by, and respond to variable environmental cues stimuli. Their finding was corroborated by Dahl et al. (2004) who demonstrated that interannual variability in spawn timing was greater among brown trout than among further ranging Atlantic salmon. Relative to other species of Pacific salmon and trout, CCT are not far ranging and it is therefore possible that the subspecies will show an elevated response to environmental stimuli during migrations.

The life history behaviours and population structure of CCT make them particularly well suited for the study of migration behaviours at the watershed scale. Evidence of stream level population structure and diminished reproductive success among mature strays suggest that CCT are highly adapted to their local environment (Wenburg and Bentzen 2001, Quinn 2005). Furthermore, CCT generally remain in fresh water and are relatively sedentary throughout the winter prior to spawning in the spring. Due to the relatively sedentary nature of their overwintering behaviours, CCT can be tracked from overwintering to spawning habitats with relatively high temporal and spatial precision using radio telemetry. When combined with measures of the environment and the physical characteristics of radio tagged CCT, the telemetry data can provide invaluable insight into the factors that are structuring the migratory behaviours of CCT. Chapter 1 presented evidence of at least two coordinated spring movements: movement from overwintering habitats and migration to spawning habitats. In this chapter I will apply an information theoretic approach to examine how a set of biological and abiotic factors may have influenced these two behaviours.

METHODS

Fish Sampling and Tracking

Methods employed to sample, radio tag and relocate radio tagged CCT are described in Chapter 1.

Environmental Data Collection

Water temperature was monitored throughout the Kitimat watershed using HOBO Data Loggers (Onset Computer Corporation). HOBO loggers were encapsulated within a perforated ABS pipe attached to a concrete cinder block that was submerged and anchored to shore. Each recorder measured water temperature on 4 hour intervals. A total of nineteen temperature loggers were distributed throughout the watershed: four throughout the mainstem of the Kitimat River; nine in major tributaries, and; six in minor tributaries (Figure 2.1). Eight HOBO loggers were deployed into suspected spawning tributaries in 2012 and an additional 8 were deployed into confirmed tributaries in 2013. To assess how mainstem water temperature varied throughout the study area, temperature loggers were deployed at 11.2 rkm and 38.3 rkm in 2012. In 2013, additional mainstem loggers were deployed at a key overwintering area (30.4 rkm) as well as within the upper watershed at 48.3 rkm. However, the logger at 48.3 rkm was displaced by ice, resulting in unreliable temperature metrics and has not been included. Tributary water temperatures are summarized in Table A2.3, but tributary temperatures were not included in either analyses as temperature was not recorded in all spawning tributaries nor was it available for both years of the study. Mean daily mainstem water temperatures (collected at 11.2 rkm) were summed for the period from November 15 of each year to calculate the thermal experience, or accumulated thermal units (ATU) in each year. Thermal experience was calculated from November 15 as it was roughly the date when water temperatures first approached 0 °C in each year.

Discharge data was collected by Environment Canada and downloaded from the website of the Water Survey of Canada (https://wateroffice.ec.gc.ca/). Environment Canada operates three stations within the Kitimat watershed, however, data was only collected from the station that operated on the Kitimat River, downstream of Hirsch Creek (Station 08FF001). Hydrometric data was collected continuously at a 5-minute interval and are reported as mean daily values.

Photoperiod was calculated as the duration of time (hr) between civil twilight (sun 6° above and below the horizon). Daily estimates of civil twilight were downloaded from the National Research Council of Canada website (http://www.nrc-cnrc.gc.ca/eng/services/sunrise), and were calculated for Kitimat BC (Longitude = 128° 39' West, Latitude = 54° 13.2' North).

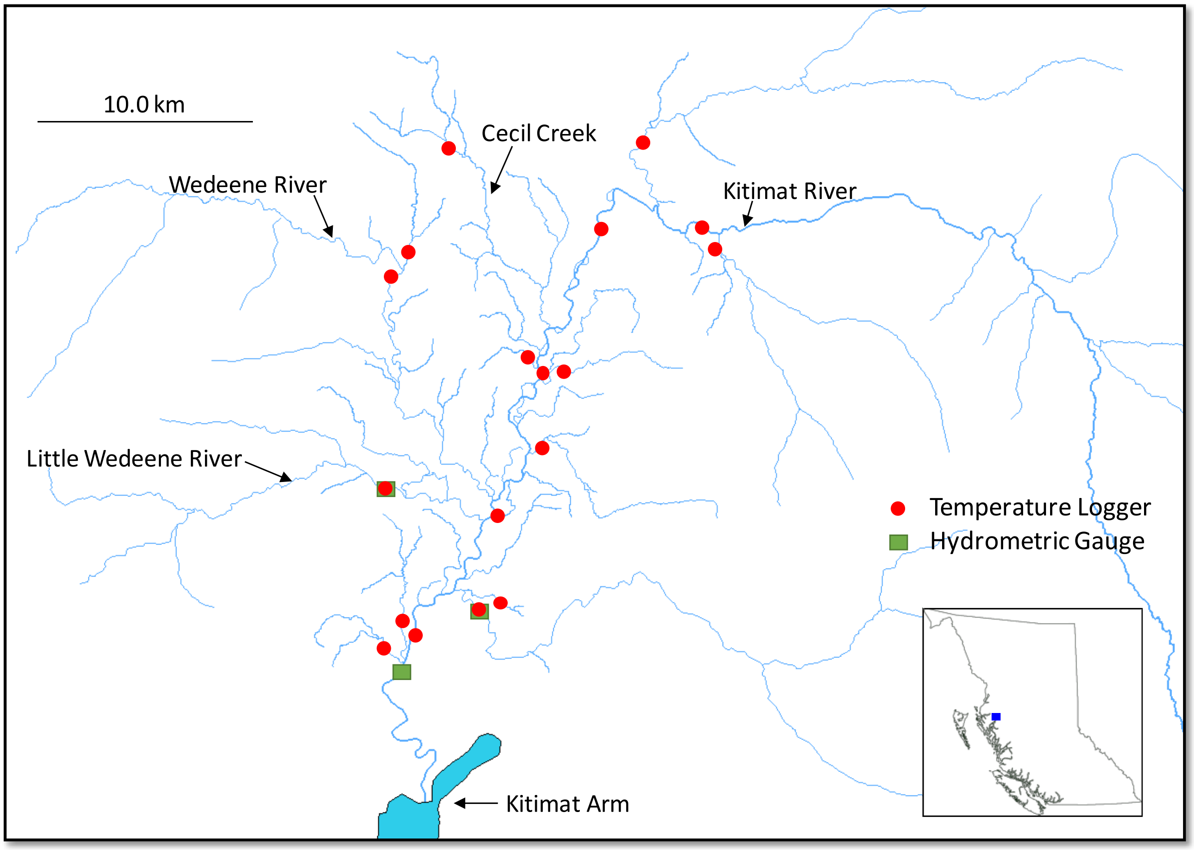

Figure 2.1. Map of the Kitimat Watershed. Red circles indicate the position of temperature loggers; green squares indicate the position of Environment Canada hydrometric gauges.

Statistical Analyses

Welch's two sample t-test was used to compare measures of mean daily water temperature and discharge between years. Discharge and water temperature were tested for the tracking period (October to June) as well as for the period when CCT were observed moving out of overwintering habitats and into spawning habitats (March to June). Analysis of variance (ANOVA) was applied when more than two groups were compared and was used to test for differences in mainstem flow between years and for differences in temperature between mainstem logger sites and years. Tukey's test was used to compare means when significant differences were identified. Variance in temperature was assessed for normality and homogeneity using Bartlett's and Levene's tests prior to analyses. For all tests, alpha values less than 0.05 were deemed significant. Summary values for all measures are presented as mean ± SD.

Modelling

An information theoretic approach (Burnham and Anderson 2002) was applied to assess how a suite of biotic and abiotic metrics influenced two observed life history behaviours: movement out of overwintering habitats, and; movement into spawning habitats. Candidate models were developed using parameters identified from previous research and were ranked using Akaike's Information Criterion (AIC). The factors influencing the life history behaviours of CCT are understudied consequently research was expanded to include other cold water salmonids with similar life history behaviours. Species reviewed include westslope cutthroat trout (WCT; *O. clarkii lewisi*), Brook trout, Brown trout, Rainbow trout / Steelhead, Bull trout, and Atlantic salmon. This review identified four abiotic (photoperiod, discharge, water temperature, and thermal experience) and three biotic parameters (fork length, sex, and distance from overwintering to spawning habitats) that have been shown to influence life history behaviours. An additional biotic metric, migration type, was included to distinguish between CCT displaying mobile and stationary behaviours during each winter. Due to limitations in sample size, year was not differentiated within candidate models.

Mobile and stationary relocation data was used to identify the median date that behaviours were completed by each CCT. Median departure dates from overwintering habitats were calculated as the median date between the final relocation within overwintering habitats and the first observation outside of overwintering habitats. Similarly, the date of spawning tributary arrival was calculated as the median date between the last observation outside of, and the first relocation within a spawning tributary. To account for variability in the frequency that each CCT was relocated, date was broken into 27, 4-day temporal periods from February 15 to June 1 of each year. A binary metric was then calculated to identify whether each CCT did (1), or did not (0) complete movements within a given temporal period. For each CCT, a minimum of 4 consecutive periods were included in the analysis and once a behaviour was observed no further periods were included. Mean values of the abiotic variables were calculated for each temporal period. Measures of water temperature and discharge were calculated using data collected in the mainstem of the Kitimat River. Sex and migration type were included as categorical variables. Distance to spawn was calculated as the total absolute distance CCT travelled from final overwintering habitats to maximum upstream spawning positions. Separate longitudinal datasets comprised of repeated measures of each CCT were prepared for the overwintering and spawning analyses.

In each candidate model, biotic and abiotic measures were treated as predictor variables and event (indicating either overwinter departure, or spawning arrival) was treated as the response variable. Candidate models were assessed by standard logistic regression, however standard errors were clustered by individual fish. Models were evaluated by examining coefficient estimates, standard errors and confidence intervals. Multicollinearity was assessed by visually inspecting Spearman correlations between metrics and by calculating variance inflation factors and tolerance values for each variable. Logistic regressions were performed in STATA (StataCorp 2015), two-sample t-tests, ANOVA's and Tukey's tests were performed using R (R Core Team 2016). All figures were prepared using the ggplot2 package in R (Wickham 2009).

Overwintering departure and spawning arrival models were assessed on independent data sets. Models in each candidate set were ranked by AIC, corrected for small sample size (AICc) (Burnham and Anderson 2002, Symonds and Moussalli 2011). Models with the lowest AICc value were deemed to be the best fit of the data. Competing models with AICc values < 2 were considered to be as good as the top model. The receiver operating characteristic (ROC) curve, relates the relative proportions of correctly and incorrectly classified predictions. The area under the ROC curve is an index of model performance and was calculated to assess the predictive ability of each model (Hanley and McNeil 1982).

RESULTS

Summary of Abiotic Conditions

Overwintering and spawning migrations occurred when photoperiod was increasing in the spring (Figure 2.2). Mainstem water temperatures declined rapidly in the late fall, remained cool through the winter and warmed again in the spring (Figure 2.3). Temperatures did not differ significantly among mainstem logger sites during either year; nor was a difference apparent between years when mainstem temperature was compared from October to June. Mean temperatures recorded in tributaries ranged from 1.6 to 5.4 °C during the winter and 2.9 to 5.8 °C throughout the spawning period (Table A2.3). The number of CCT observed in temperature monitored tributaries and the temperatures during their use are presented in Table A2.4. Tributary temperatures were not included in any additional analyses. Extended periods of sub-zero air temperatures were associated with extensive ice formation throughout the Kitimat watershed and resulted in mean daily water temperatures below 0 °C (Figure 2.3). The timing of ice events differed between years. Major ice events occurred from December 22 to 30 and January 10 to 14 in year 1 and from December 6 to 9 and February 1 to 13 in year 2. Subsurface and frazil ice were observed during the longer ice events in each year.

Historic mean ± SD annual discharge in the Kitimat River is 132 ± 116 m^3/s, calculated from 1965 to 2012 and show that peak flows primarily occur with the spring freshet (Figure 2.4). The Kitimat River typically remains low and clear throughout the winter, although short duration high flow events frequently occur following rain on snow events (Figure 2.4). Flows in year 1 did not differ from historic flows, however flows in year

2 were significantly greater than flows in year 1 and historic flows (Table 2.2). The increased variability in flows recorded during year 2 was likely due to differences in snow pack between years. Indeed, snow levels in year 1 were minimal compared to year 2 (personal observation).

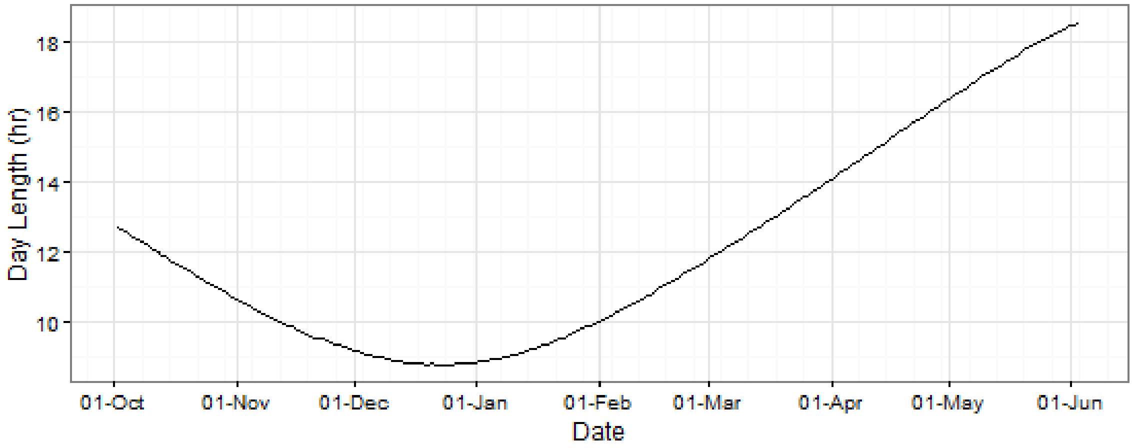

Figure 2.2. Trends in daily measures of day length recorded in Kitimat BC, from October 1 to June 1.

Table 2.1. Summary of grand mean and minimum water temperatures recorded at mainstem temperature logging sites in year 1 and year 2 from November 1 to May 31.

Year	**rkm**	**Mean**			**Minimum**		
		Mean	**SD**	**Range**	**Mean**	**SD**	**Range**
1	11.2	2.98	2.19	0.0 - 8.0	2.33	1.76	0.0 - 6.3
1	38.3	2.89	2.07	0.0 - 7.9	2.22	1.65	0.0 - 6.0
		t(420.6) = 0.44, p = 0.66			t(420.4) = 0.70, p = 0.49		
2	11.2	2.81	2.13	0.0 - 8.3	2.28	1.95	0.0 - 6.8
2	30.4	2.8	2.40	0.0 - 8.2	2.18	1.97	-0.1 - 6.6
2	38.3	2.72	2.13	0.0 - 7.7	2.16	1.75	0.0 - 6.2
		$F_{[2, 633]} = 0.95$, $p = 0.91$			$F_{[2, 633]} = 0.21$, $p = 0.81$		

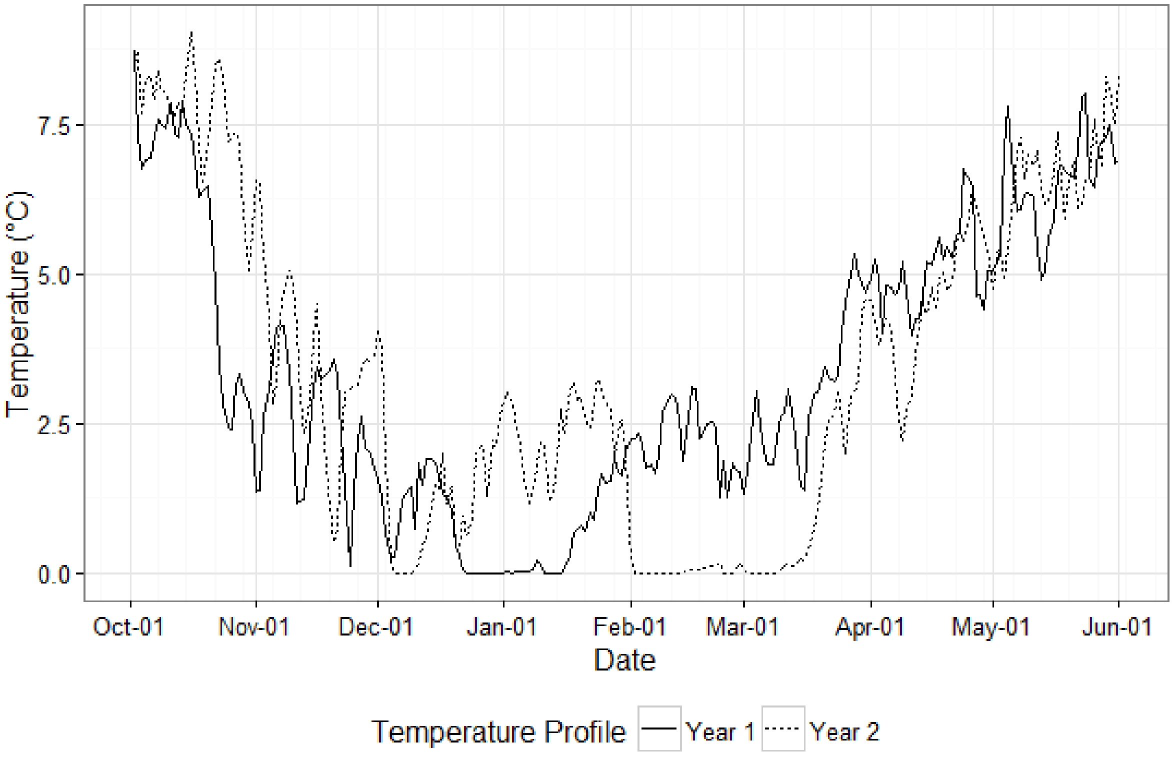

Figure 2.3. Profile of mean and minimum daily mainstem water temperature from October 1 to May 31 of year 1 and year 2. Temperatures recorded at 11.2 rkm on the Kitimat River.

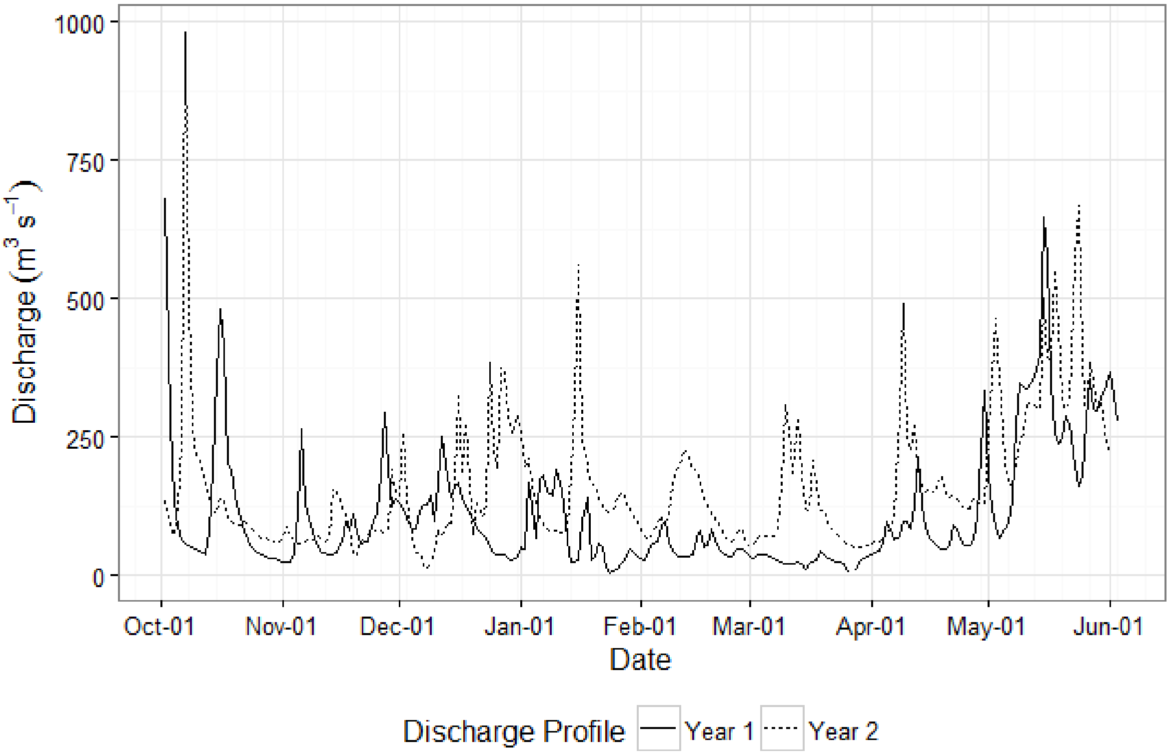

Figure 2.4. Profile of mean and minimum daily discharge in the Kitimat River in year 1 and year 2.

Table 2.2. Summary of ANOVA and Tukey multiple comparison tests comparing mean mainstem discharge from October to May in year 1 and year 2 to mean daily historic flows from 1965 to 2012.

Raw Summary				Tukey's Post-hoc Comparison	
Year	**Mean**	**SE**	**Range**	**Comparison**	**P-value**
1	109.7	7.2	3.1 - 681.3	Year 1 - Year 2	< 0.001
2	161.7	8.1	12.5 - 979.7	Year 1 - Historic	0.97
Historic	111.8	3.6	47.5 - 253	Year 2 - Historic	< 0.001
ANOVA:	F[2, 725] = 19.93, p < 0.001			-	

Correlations and Collinearity

Strong correlations were observed between the abiotic variables in both the overwintering departure (Table 2.3) and spawning arrival datasets (Table 2.4). Correlations were strongest between water temperature and photoperiod ($r \geq 0.80$). In the spawning analysis, a correlation of moderate strength (r = 0.66, p < 0.001) was also observed between photoperiod and discharge, though this correlation was considerably weaker in the overwinter data set (r = 0.30, p < 0.001). Strong, significant correlations were also observed between accumulated thermal units and discharge (r = 0.65, p < 0.001) and temperature (r = 0.78, p < 0.001) in the spawning analysis (Table 2.4); these correlations were weaker in the overwintering analysis (Table 2.3). The strength of the relationship between water temperature and discharge was similar in both analyses, however the relationship was negative in the overwintering analysis (r = -0.21, p < 0.001) and positive in the spawning analysis (r = 0.21, p < 0.001). A negative correlation of moderate strength was observed between discharge and fork length in the analysis of movement out of overwintering habitats (r = -0.44, p < 0.001), and into spawning tributaries (r = -0.40, p < 0.001).

Analysis of VIF scores for the global overwintering and spawning models demonstrated that collinearity was a serious issue between water temperature and photoperiod. Thus, to reduce collinearity, water temperature and photoperiod parameters were not included in the same candidate models. Quadratic terms for each abiotic variable were tested; however, they did not significantly improve model fit and were not included in any of the candidate models.

Table 2.3. Correlations between metrics included in the analysis of departure from overwintering habitats.

Parameter		Photoperiod	Discharge	Temperature	ATU	Fork Length	Distance	Sex	Mig.Type	
Photoperiod		1	0.30	0.83	0.90	-0.09	-0.10	0.07	0.02	
Discharge		< 0.001	1	-0.21	0.49	-0.25	-0.06	0.10	0.25	
Temperature		< 0.001	< 0.001	1	0.57	0.10	-0.06	0.00	-0.16	
ATU		< 0.001	< 0.001	< 0.001	1	-0.2	-0.11	0.1	0.15	
Fork Length	**P-Value**	0.055	< 0.001	0.030	< 0.001	1	0.09	0.25	-0.44	**Correlation**
Distance		0.030	0.174	0.219	0.020	0.049	1	0.03	0.07	
Sex		0.128	0.026	0.918	0.030	< 0.001	0.462	1	-0.08	
Mig.Type		0.596	< 0.001	< 0.001	< 0.001	< 0.001	0.125	0.084	1	

Table 2.4. Correlations between metrics included in the analysis of arrival in to spawning tributaries.

Parameter		Photoperiod	Discharge	Temperature	ATU	Fork Length	Distance	Sex	Mig.Type	
Photoperiod		1	0.66	0.80	1.00	-0.17	0.04	0.09	0.19	
Discharge		< 0.001	1	0.21	0.65	-0.24	0.01	0.08	0.23	
Temperature		< 0.001	< 0.001	1	0.78	-0.03	0.03	0.05	0.05	
ATU		<0.001	< 0.001	< 0.001	1	-0.18	0.04	0.10	0.20	
Fork Length	**P-Value**	< 0.001	0.000	0.516	< 0.001	1	0.05	0.20	-0.40	**Correlation**
Distance		0.437	0.827	0.475	0.430	0.295	1	-0.07	0.14	
Sex		0.059	0.111	0.340	0.040	< 0.001	0.124	1	-0.07	
Mig.Type		< 0.001	< 0.001	0.254	< 0.001	< 0.001	0.003	0.137	1	

Overwintering Departure Models

A total of 47 candidate models for CCT were included in the overwintering analysis to characterize departure from overwintering habitats between March 13 to May 7 (median = April 7) (Figure 2.5). The number of temporal periods included in the analysis for each fish ranged from 4 to 18, with an overall mean of 10.1 ± 3.0. Mean values of day length recorded in each period ranged from 12.8 to 17.1 hr. Mean temperature and discharge values ranged from 0.2 to 7.0 °C and 8.5 to 309.8 $m^3 s^{-1}$, respectively (Table 2.5; Figure 2.5). Accumulated thermal units experienced by CCT during periods when movements were completed ranged from 177.6 to 427.3 ATU. Measures of water temperature, discharge and ATUs differed significantly between years during intervals when CCT moved out of overwintering habitats (Table 2.5; Figure 2.5). Cutthroat included in the overwintering and spawning analysis were primarily female (60%) and ranged in fork length from 331 to 460 mm (395.3 ± 34.9 mm). The mean ± SD total absolute distance radio tagged CCT travelled from overwintering to spawning habitats was 9.7 ± 7.9 km, though this ranged from 1.1 to 37.0 km.

The results of the overwintering analysis are summarized in Table 2.6. Models that included photoperiod primarily had lower AICc values than models that did not include photoperiod; photoperiod was included in 9 of the top 10 models and the model with only photoperiod was ranked 6th. The model with the lowest overall AICc value (AICc = 236.89) consisted of photoperiod and fork length. This model indicates that photoperiod ($\beta = 1.442$, SE = 0.248, $P < 0.001$) and fork length ($\beta = 0.011$, SE = 0.004, P = 0.003) significantly influence when CCT depart from overwintering habitats (Table 2.7). An additional 3 models had AICc values that differed by less than 2 and are considered to be probable candidate models. The model with the second lowest AICc value (Δ AICc = 0.16) included photoperiod (β = 1.413, SE = 0.198, $P < 0.001$) and distance travelled from overwintering to spawning habitats (β = 0.060, SE = 0.024, P = 0.024). Confidence intervals of the top 2 models did not include zero and all parameters were shown to have a significant effect. Together these two models account for a total accumulated Akaike weight of 0.44. The third and fourth ranked models were more complicated versions of the second and first ranked models, respectively, and both contained negative, non-significant coefficient estimates for discharge. Including the third and fourth ranked models increased the total accumulated Akaike weight of the top models to 0.65. The area under the receiver operating curve was greater than 0.86 for all four of the top ranked models, indicating that they had good predictive ability.

Table 2.5. Summary of abiotic measures calculated for temporal intervals included in the overwintering analysis. Tests for differences between years are presented in the final column.

	Combined			**Year 1**			**Year 2**			**Two-Sample T-Test**
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	
Photoperiod	14.8	0.8	12.8 - 17.1	14.6	0.7	13.2 - 15.9	15.1	0.9	12.8 - 17.1	t(466.6) = -1.31, p = 0.19
Temperature	4.4	1.1	0.2 - 7.0	4.7	0.7	2.5 - 5.8	4.1	1.4	0.2 - 7.0	t(428.0) = 9.59, p < 0.001
ATU	276.0	50.8	177.6 - 427.3	258.2	46.1	177.6 - 343.2	296.3	49.2	204.5 - 427.3	t(447.3) = -8.31, p < 0.001
Discharge	112.9	80.6	8.5 - 309.8	56.9	25.2	8.5 - 81.4	176.4	74.4	59.0 - 309.8	t(343.3) = -17.91, p < 0.001

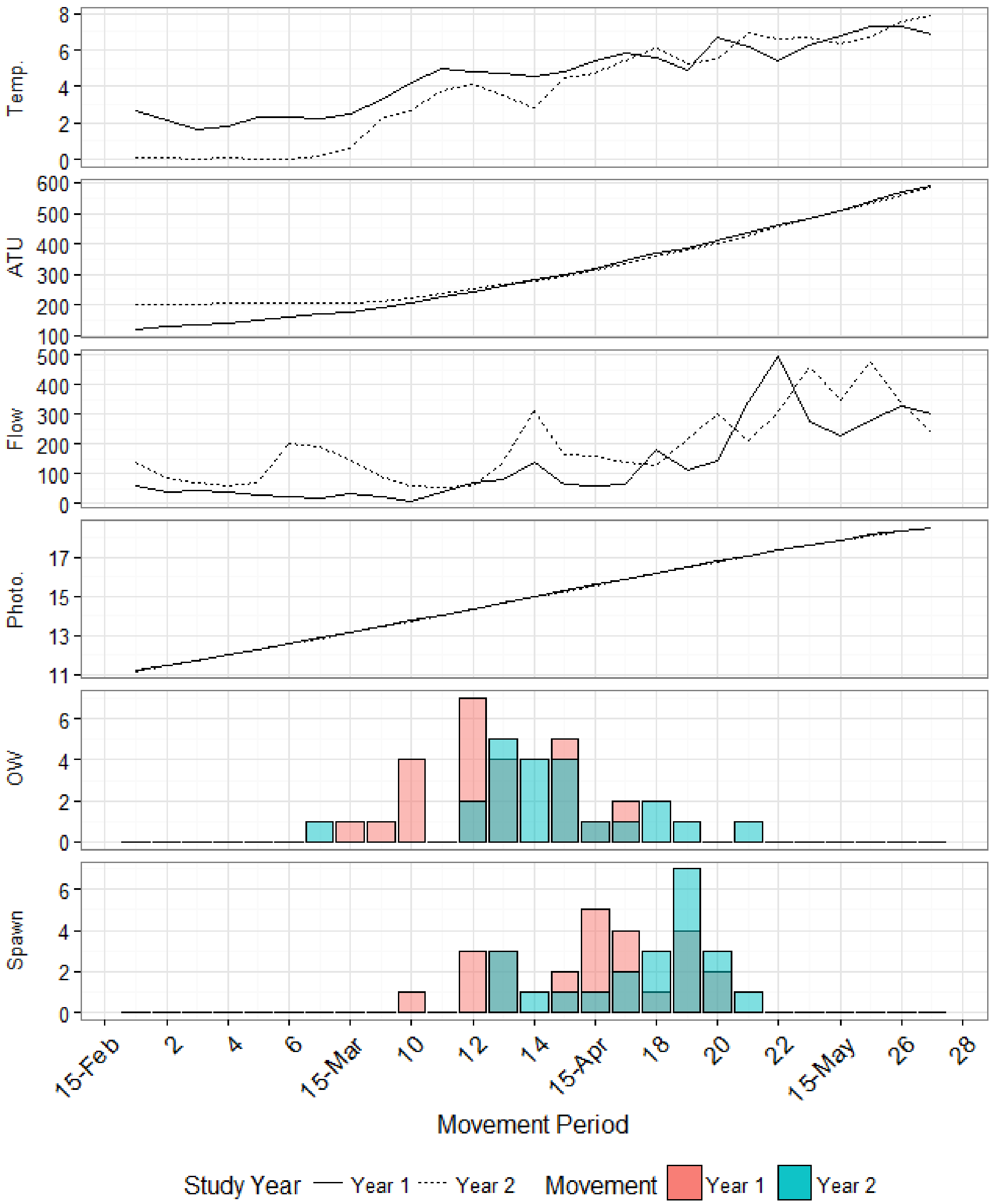

Figure 2.5. Environmental conditions and count of the number of fish moving per period in year 1 and 2. Each period represents 4 days, starting on February 15. Line plots compare mean water temperature (Temp., °C), accumulated thermal units (ATU, sum of mean daily temperature), discharge (Flow, m^3s^{-1}), and day length (Photo, hr) per period in year 1 and year 2. Histograms summarize the total number of CCT observed moving out of overwintering habitats (OW) and into spawning tributaries (Spawn) during each period.

Table 2.6. Set of logistic regression candidate models used to estimate likelihood of movement out of overwintering habitats for CCT radio tagged in the Kitimat River in year 1 and year 2. Standard errors in each model were clustered by individual CCT. Fixed effect variables include: Photoperiod, a continuous measure of mean civil day length (hr); Temperature and Discharge, measures of mean mainstem water temperature and discharge, respectively; ATU, running sum of mean daily mainstem water temperature; Distance, measure of the total absolute distance (km) each CCT travelled to spawn from final overwintering habitats; Mig.Type, a dichotomous measure identifying mobile (1) and stationary CCT (0); Sex, a dichotomous variable identifying male (0) and female (1) CCT, and; FL, a measure of the fork length (mm) of individual CCT.

Rank	Model	LL	n	df	k	ROC	AICc	Δ AICc	Wi	Acc. Wi
1	Photoperiod + FL + Constant	-114.404	473	2	4	0.86	236.89	0.00	0.23	0.23
2	Photoperiod + Distance + Constant	-114.485	473	2	4	0.87	237.06	0.16	0.21	0.44
3	Photoperiod + Discharge + Distance + Constant	-114.152	473	3	5	0.87	238.43	1.54	0.11	0.55
4	Photoperiod + Discharge + FL + Constant	-114.238	473	3	5	0.86	238.60	1.71	0.10	0.65
5	Photoperiod + Sex + Constant	-115.766	473	2	4	0.87	239.62	2.72	0.06	0.71
6	Photoperiod + Constant	-116.799	473	1	3	0.86	239.65	2.75	0.06	0.77
7	Temperature + Discharge + Distance + Constant	-114.973	473	3	5	0.85	240.07	3.18	0.05	0.81
8	Photoperiod + Mig.Type + Constant	-116.169	473	2	4	0.86	240.42	3.53	0.04	0.85
9	Photoperiod + Discharge + Constant	-116.384	473	2	4	0.85	240.85	3.96	0.03	0.88
10	Photoperiod + Discharge + Sex + Constant	-115.450	473	3	5	0.86	241.03	4.13	0.03	0.91
11	Temperature + Discharge + Constant	-116.886	473	2	4	0.85	241.86	4.96	0.02	0.93
12	Temperature + Discharge + FL + Constant	-115.897	473	3	5	0.85	241.92	5.03	0.02	0.95
13	Photoperiod + Discharge + Mig.Type + Constant	-115.934	473	3	5	0.86	242.00	5.10	0.02	0.97
14	Temperature + Discharge + Sex + Constant	-116.067	473	3	5	0.85	242.26	5.37	0.02	0.99
15	Temperature + Discharge + Mig.Type + Constant	-116.811	473	3	5	0.85	243.75	6.86	0.01	0.99
16	ATU + FL + Constant	-119.055	473	2	4	0.84	246.19	9.30	0.00	1.00
17	ATU + Discharge + FL + Constant	-118.746	473	3	5	0.84	247.62	10.73	0.00	1.00
18	ATU + Distance + Constant	-119.864	473	2	4	0.84	247.81	10.92	0.00	1.00
19	ATU + Discharge + Distance + Constant	-119.314	473	3	5	0.85	248.76	11.86	0.00	1.00
20	ATU + Mig.Type + Constant	-120.855	473	2	4	0.83	249.79	12.90	0.00	1.00
21	ATU + Sex + Constant	-120.952	473	2	4	0.84	249.99	13.09	0.00	1.00
22	ATU + Constant	-121.976	473	1	3	0.83	250.00	13.11	0.00	1.00
23	ATU + Discharge + Sex + Constant	-120.450	473	3	5	0.85	251.03	14.13	0.00	1.00
24	ATU + Discharge + Mig.Type + Constant	-120.517	473	3	5	0.83	251.16	14.27	0.00	1.00
25	Temperature + Distance + Constant	-121.961	473	2	4	0.82	252.01	15.11	0.00	1.00
26	Temperature + Constant	-123.041	473	1	3	0.82	252.13	15.24	0.00	1.00
27	Temperature + Sex + Constant	-122.654	473	2	4	0.82	253.39	16.50	0.00	1.00
28	Temperature + Mig.Type + Constant	-122.880	473	2	4	0.82	253.85	16.95	0.00	1.00
29	Temperature + FL + Constant	-122.948	473	2	4	0.82	253.98	17.09	0.00	1.00
30	Discharge + Constant	-149.425	473	1	3	0.65	304.90	68.01	0.00	0.00
31	Discharge + FL + Constant	-148.579	473	2	4	0.65	305.24	68.35	0.00	1.00
32	Discharge + Distance + Constant	-148.965	473	2	4	0.64	306.02	69.12	0.00	1.00
33	Discharge + Sex + Constant	-149.015	473	2	4	0.63	306.12	69.22	0.00	1.00
34	Discharge + Mig.Type + Constant	-149.055	473	2	4	0.64	306.20	69.30	0.00	1.00
35	Distance + Constant	-152.804	473	1	3	0.52	311.66	74.77	0.00	1.00
36	FL + Constant	-152.914	473	1	3	0.53	311.88	74.99	0.00	1.00
37	Sex + Constant	-152.923	473	1	3	0.52	311.90	75.00	0.00	1.00
38	Mig.Type + Constant	-153.090	473	1	3	0.51	312.23	75.34	0.00	1.00
39	Sex + FL + Distance + Constant	-152.360	473	3	5	0.55	314.85	77.95	0.00	1.00
40	Mig.Type + FL + Distance + Constant	-152.655	473	3	5	0.53	315.44	78.54	0.00	1.00

Table 2.7. Diagnostic summary of overwintering candidate models with AICc values less than 2. Fixed effect variables include: Photoperiod, a continuous measure of mean civil day length (hr); Discharge, a measure of mean mainstem discharge; Distance, measure of the total absolute distance (km) each CCT travelled to spawn from final overwintering habitats, and; FL, a measure of the fork length (mm) of individual CCT.

Rank	**Parameter**	**β**	**Std. Err.**	**z**	**P>|z|**	**C.I. (2.5, 97.5)**		**Odds Ratio**	**Log Likelihood**	**n**	**df**	**k**	**χ^2**	**Prob > χ^2**	**Pseudo R^2**	**ROC**	**AICc**	**Δ AICc**	**Wi**	**Acc. Wi**
1	Photoperiod	1.442	0.248	5.82	0.000	0.957	1.927	4.229	-114.404	473	2	4	35.8	0.00	0.253	0.862	236.89	0.00	0.23	0.23
	FL	0.011	0.004	2.97	0.003	0.004	0.018	1.011												
	Constant	-26.927	4.198	-6.41	0.000	-35.156	-18.698	0.000												
2	Photoperiod	1.413	0.198	7.14	0.000	1.025	1.800	4.107	-114.485	473	2	4	61.7	0.00	0.252	0.866	237.06	0.16	0.21	0.44
	Distance	0.060	0.024	2.51	0.012	0.013	0.106	1.062												
	Constant	-22.728	2.771	-8.20	0.000	-28.159	-17.297	0.000												
3	Photo	1.493	0.202	7.40	0.000	1.098	1.888	4.449	-114.152	473	3	5	67.73	0.00	0.254	0.866	238.43	1.54	0.11	0.55
	Discharge	-0.002	0.003	-0.73	0.462	-0.008	0.003	0.998												
	Distance	0.059	0.024	2.41	0.016	0.011	0.106	1.060												
	Constant	-23.655	2.766	-8.55	0.000	-29.076	-18.234	0.000												
4	Photo	1.498	0.247	6.05	0.000	1.013	1.983	4.471	-114.238	473	3	5	38.14	0.00	0.254	0.861	238.60	1.71	0.10	0.65
	Discharge	-0.002	0.003	-0.50	0.620	-0.008	0.004	0.998												
	FL	0.011	0.004	2.92	0.004	0.003	0.018	1.011												
	Constant	-27.405	4.203	-6.52	0.000	-35.644	-19.167	0.000												

Spawning Models

The same 47 CCT in the overwintering analysis were also included in the spawning analysis. The median date that CCT arrived in spawning tributaries ranged from April 6 to May 11, with peak spawning (median) occurring on April 27. Abiotic metrics were calculated for a total of 15 four-day temporal periods encompassing March 11 to May 9. Mean measures of day length calculated in each period ranged from 12.9 to 16.8 hr. The mean values of mainstem water temperature, accumulated thermal units and discharge ranged from 12.9 to 17.1 °C, 177.6 to 427.3 ATU and 8.5 to 309.8 $m^3 s^{-1}$, respectively. In year 1, movements into spawning tributaries occurred at significantly lower values of photoperiod, accumulated thermal units and discharge (Table 2.8; Figure 2.5). Abiotic metrics are the same as those used in the overwintering model.

Candidate models tested in the spawning analysis are summarized in Table 2.9 and Table 2.10. Accumulated thermal units dominated the top spawning models; ATU was included in 7 of the top 10 models and the model with only ATU ranked 5th. The spawning model with the lowest AICc value had an Akaike weight of 0.25 and suggests that movement into spawning tributaries is influenced by accumulated thermal units ($\beta = 0.027$, SE = 0.003, $P < 0.001$) and migration type ($\beta = - 0.781$, SE = 0.347, $P < 0.024$) (Table 2.10). Two additional models had Δ AICc values less than 2 and are considered as good as the top model. The second ranked model (Δ AICc = 1.66) also included migration type ($\beta = -0.771$, SE = 0.335, $P = 0.021$), though ATU was replaced by photoperiod ($\beta = 1.677$, SE = 0.209, $P < 0.001$). The final model had a Δ AICc value of 1.82 and contained accumulated thermal units ($\beta = 0.028$, SE = 0.004, $P < 0.001$), migration type ($\beta = - 0.747$, SE = 0.350, $P = 0.033$) and discharge. Except for discharge in the third model, all parameters were significant and did not include zero within their confidence intervals. Area under the ROC curves for all three top models were greater than 0.85, indicating that they were of high predictive value.

Table 2.8. Summary of measures of photoperiod (hr), temperature (°C), thermal experience (ATU, °C) and discharge (m/s^3) calculated for temporal intervals included in the spawning analysis.

	Combined			Year 1			Year 2			Two-Sample T-Test
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	
Photoperiod	15.8	0.8	13.7 - 17.1	15.5	0.9	13.7 - 16.8	16.0	0.8	14.6 - 17.1	t(426.4) = -7.39, p < 0.001
Temperature	5.2	0.8	2.9 - 7	5.3	0.6	4.2 - 6.7	5.1	1.0	2.9 - 7	t(415.9) = 0.43, p = 0.67
ATU	335.4	55.2	205 - 427.3	321.6	57.6	205 - 410.7	351.1	48.9	268.1 - 427.3	t(431.4) = -7.98, p < 0.001
Discharge	136.1	75.9	8.5 - 309.8	82.9	36.7	8.5 - 181.7	196.6	62.2	126.9 - 309.8	t(263.8) = 12.87, p < 0.001

Table 2.9. Set of logistic regression candidate models used to estimate likelihood of movement into spawning tributaries for CCT radio tagged in the Kitimat River in year 1 and year 2. Standard errors in each model were clustered by individual CCT. Fixed effect variables include: Photoperiod, a continuous measure of mean civil day length (hr); Temperature and Discharge, measures of mean mainstem water temperature and discharge, respectively; Distance, measure of the total absolute distance (km) each CCT travelled to spawn from final overwintering habitats; Mig.Type, a dichotomous measure identifying mobile (1) and stationary CCT (0); Sex, a dichotomous variable identifying male (0) and female (1) CCT, and; FL, a measure of the fork length (mm) of individual CCT.

Rank	Model	LL	n	df	k	ROC	AIC_c	Δ AICc	W_i	Acc. W_i
1	ATU + Mig.Type + Constant	-108.34	473	2	4	0.85	224.76	0.00	0.25	0.25
2	Photoperiod + Mig.Type + Constant	-109.17	435	2	4	0.85	226.42	1.66	0.11	0.36
3	Discharge + ATU + Mig.Type + Constant	-108.22	473	3	5	0.85	226.57	1.82	0.10	0.46
4	ATU + FL + Constant	-109.57	473	2	4	0.85	227.23	2.47	0.07	0.53
5	ATU + Constant	-110.63	473	1	3	0.84	227.30	2.54	0.07	0.60
6	ATU + Sex + Constant	-109.67	473	2	4	0.84	227.42	2.66	0.07	0.66
7	Photo + Discharge + Mig.Type + Constant	-109.03	435	3	5	0.85	228.20	3.44	0.04	0.71
8	Photoperiod + FL + Constant	-110.17	435	2	4	0.85	228.44	3.68	0.04	0.75
9	ATU + Distance + Constant	-110.25	473	2	4	0.84	228.58	3.82	0.04	0.78
10	Discharge + ATU + Sex + Constant	-109.29	473	3	5	0.85	228.70	3.94	0.03	0.82
11	Photoperiod + Constant	-111.43	435	1	3	0.85	228.91	4.15	0.03	0.85
12	Discharge + ATU + FL + Constant	-109.40	473	3	5	0.85	228.93	4.17	0.03	0.88
13	Photoperiod + Sex + Constant	-110.58	435	2	4	0.85	229.24	4.48	0.03	0.91
14	Discharge + ATU + Distance + Constant	-109.85	473	3	5	0.85	229.83	5.08	0.02	0.93
15	Photoperiod + Discharge + Constant	-111.00	435	2	4	0.85	230.09	5.33	0.02	0.94
16	Photo + Discharge + FL + Constant	-109.99	435	3	5	0.85	230.12	5.36	0.02	0.96
17	Photoperiod + Distance + Constant	-111.08	435	2	4	0.85	230.25	5.49	0.02	0.98
18	Photo + Discharge + Sex + Constant	-110.16	435	3	5	0.85	230.46	5.70	0.01	0.99
19	Photo + Discharge + Distance + Constant	-110.65	435	3	5	0.85	231.44	6.68	0.01	1.00
20	Temperature + Discharge + Mig.Type + Constant	-115.33	435	3	5	0.83	240.80	16.04	0.00	1.00
21	Temperature + Discharge + Constant	-117.07	435	2	4	0.82	242.24	17.48	0.00	1.00
22	Temperature + Discharge + FL + Constant	-116.10	435	3	5	0.82	242.34	17.58	0.00	1.00
23	Temperature + Discharge + Sex + Constant	-116.56	435	3	5	0.82	243.27	18.51	0.00	1.00
24	Temperature + Discharge + Distance + Constant	-116.85	435	3	5	0.82	243.84	19.08	0.00	1.00
25	Temperature + Constant	-122.75	435	1	3	0.80	251.56	26.80	0.00	1.00
26	Temperature + Mig.Type + Constant	-122.37	435	2	4	0.81	252.83	28.07	0.00	1.00
27	Temperature + Sex + Constant	-122.46	435	2	4	0.80	253.02	28.26	0.00	1.00
28	Temperature + Distance + Constant	-122.61	435	2	4	0.81	253.30	28.55	0.00	1.00
29	Temperature + FL + Constant	-122.63	435	2	4	0.81	253.36	28.60	0.00	1.00
30	Discharge + Constant	-140.87	435	1	3	0.72	287.80	63.04	0.00	1.00
31	Discharge + Mig.Type + Constant	-140.11	435	2	4	0.72	288.31	63.56	0.00	1.00
32	Discharge + FL + Constant	-140.20	435	2	4	0.71	288.50	63.74	0.00	1.00
33	Discharge + Sex + Constant	-140.73	435	2	4	0.73	289.56	64.80	0.00	1.00
34	Discharge + Distance + Constant	-140.80	435	2	4	0.72	289.70	64.94	0.00	1.00
35	Distance + Constant	-148.89	435	1	3	0.51	303.84	79.09	0.00	1.00
36	Sex + Constant	-148.92	435	1	3	0.51	303.89	79.14	0.00	1.00
37	Mig.Type + Constant	-148.92	435	1	3	0.51	303.90	79.14	0.00	1.00
38	FL + Constant	-148.94	435	1	3	0.51	303.93	79.17	0.00	1.00
39	Sex + FL + Distance + Constant	-148.84	435	3	5	0.52	307.82	83.06	0.00	1.00
40	Mig.Type + FL + Distance + Constant	-148.87	435	3	5	0.52	307.89	83.13	0.00	1.00

Table 2.10. Diagnostic summary of spawning candidate models with AICc values less than 2. Standard errors in each model were clustered by individual CCT. Fixed effect variables include: Photoperiod, a continuous measure of mean civil day length (hr); ATU, a measure of cumulative mean daily mainstem water temperature; Discharge, measure of mean mainstem discharge, and; Mig.Type, a dichotomous measure identifying mobile (1) and stationary CCT (0).

Rank	Parameter	β	SE	z	P>|z|	C.I. (2.5, 97.5)		Odds Ratio	Log Likelihood	n	df	k	χ^2	Prob > χ^2	Pseudo R^2	ROC	AIC_c	Δ AICc	W_i	Acc. W_i
1	ATU	0.027	0.003	8.60	0.000	0.021	0.033	1.027	-108.337	473	2	4	74.04	0.00	0.273	0.850	224.76	0.00	0.25	0.25
	Mig.Type	-0.781	0.347	-2.25	0.024	-1.461	-0.101	0.458												
	Constant	-9.613	1.059	-9.08	0.000	-11.688	-7.538	0.000												
2	Photoperiod	1.677	0.209	8.01	0.000	1.266	2.088	5.349	-109.165	435	2	4	64.2	0.00	0.267	0.852	226.42	1.66	0.11	0.36
	Mig.Type	-0.771	0.335	-2.30	0.021	-1.428	-0.114	0.463												
	Contstant	-27.116	3.310	-8.19	0.000	-33.603	-20.629	0.000												
3	ATU	0.028	0.004	7.38	0.000	0.020	0.035	1.028	-108.223	473	3	5	75.95	0.00	0.273	0.852	226.57	1.82	0.10	0.46
	Discharge	-0.001	0.003	-0.51	0.613	-0.007	0.004	0.999												
	Mig.Type	-0.747	0.350	-2.13	0.033	-1.432	-0.061	0.474												
	Constant	-9.710	1.099	-8.83	0.000	-11.865	-7.556	0.000												

DISCUSSION

The overwintering and spawning analyses demonstrate that both abiotic and biotic factors influence migratory behaviours of CCT. Additionally, responses to environmental stimuli appeared to differ between migration from overwintering habitat and migration to spawning areas. Spawning migrations were initiated when CCT depart from overwintering habitats and the results of this analysis demonstrated that photoperiod and fork length were the primary variables which correlate when movements occur. In contrast, the results suggest that arrival in spawning tributaries is most strongly influenced by thermal experience and migration type. Collinearity between environmental variables was a serious issue in this study and the influence of abiotic effects must be considered cautiously.

Overwinter Analysis

The overwintering analysis identified 4 top candidate models that were able to explain when CCT would depart overwintering habitats. Photoperiod, distance to spawn, fork length and discharge were identified as the most influential variables. Photoperiod was the most important variable and appeared in each of the top 4 models, however, it was strongly correlated with thermal experience and water temperature. Thus, the effect of photoperiod should be considered cautiously.

Photoperiod dominated the top models and was clearly the single abiotic variable that best predicted when CCT would move out of overwintering habitats. Models that included photoperiod consistently ranked higher (had lower AICc values) than models that did not, including when photoperiod was modelled independently. The results of this study are novel because they suggest that photoperiod was a better predictor of when CCT would move out of overwintering habitats than other variables that have commonly been linked with migratory movements such as water temperature and discharge. Photoperiod has been shown to influence migratory behaviour by cueing physiological changes associated with sexual maturation and smolting and by promoting positive rheotaxis (Dodson and Young 1977, Duston and Bromage 1986, Duston and Saunders 1990, Björnsson et al. 1994, Martin et al. 2012). However, it is difficult to link physiological changes associated with photoperiod to the migratory behaviours that were observed. Sexual maturation is not an immediate process and will have been initiated several months before the earliest movement dates included in the analysis. Additionally, CCT moved both up and downstream from overwintering to spawning habitats suggesting that rheotaxis alone did not induce the observed migrations. Thus, if photoperiod is having a direct effect on movements out of overwintering habitats it is having an effect that has not been previously described. Additional research focusing specifically on overwintering behaviours, and which includes physiological as well as biological measures is likely to provide greater insight into this phenomenon.

Collinearity between abiotic variables is often recognized as one of the greatest factors limiting the ability to interpret environmental influences on migratory behaviours (Trepanier et al. 1996). Indeed, collinearity was a serious issue in my study. Photoperiod changes were highly correlated with temperature (r = 0.83) and even more highly correlated with thermal experience (r=0.90); a weaker, but still significant correlation was observed between photoperiod and discharge (r=0.30). A substantive argument could be made that water temperature rather than photoperiod may have been driving the observed behaviours.

Models containing water temperature and photoperiod were of similar predictive ability, as evidenced by similar ROC values. Additionally, the steady nature by which day length increased during, and leading up to the period when movements were observed suggests that CCT responded to a threshold rather than a specific change in photoperiod. Threshold responses to day length have not been described for salmonids; however, they have been well documented in response to water temperature. In fact, water temperature is often recognized as a primary trigger initiating short duration spawning migrations among salmonids (e.g. Jensen et al. 1986, Swanberg 1997, Stephan and Zurstadt 2004, Svendsen et al. 2004). It is therefore a very real possibility that CCT responded to water temperature rather than photoperiod, but that the strong progressive nature of photoperiod promoted its significance within the models and resulted in photoperiod being the best predictor of movement from overwintering habitats.

Fork length was also identified as a variable that influenced the timing that CCT moved out of overwintering habitats. In my study, larger CCT initiated movements out of overwintering habitats earlier during each winter. In year 1, radio tagged CCT were significantly larger and spawned earlier than CCT in year 2, however, it is unlikely that fork length appeared in the top models due to these differences between years. Indeed, a visual examination of the data demonstrated that the relationship was clear in each year and similar size gradients have been recorded for CCT as well as other salmonids and charr. Yanusz (1997) observed a similar pattern among CCT emigrating from Sitkoh Lake to spawn in small coastal streams of SE Alaska. Size gradients have also been described during studies of the migratory behaviours of steelhead, bull trout, brook trout and Atlantic salmon (Swanberg 1997, Curry et al. 2002, Dahl et al. 2004, McLean et al. 2005). Early arrival of larger fish may promote size assortative mating (Hanson and Smith 1967). However, more recent studies employing genetics have demonstrated that size may have less of an effect on reproductive success than previously believed (Garant et al. 2001, Seamons et al. 2004, Dickerson et al. 2005, Costello 2006). Indeed, precocious stream resident male CCT have been shown to successfully reproduce with larger, migratory female CCT (Costello 2006).

In my study, early departure from overwintering habitats did not confer earlier arrival within spawning tributaries. Radio tagged CCT that departed overwintering habitats earlier took relatively longer to enter spawning tributaries. This suggests that larger, earlier departing CCT either travelled further to spawn, and/or travelled to staging positions prior to spawning. The significant positive correlation between fork length and distance travelled to spawn ($r = 0.09$, $p = 0.049$, Table 2.3) demonstrates that larger CCT generally travelled further. The fact that the second-top overwintering model identified distance as a significant predictor of overwintering departure timing further reinforces this observation. In addition, the relocation data described in chapter 1 provides considerable evidence that CCT used staging habitats prior to spawning. Staging may be preferred by larger CCT to ensure that final movements into spawning tributaries occur under suitable stream conditions. For instance, selection of higher, more turbid flows may reduce predation during migrations (Svendsen et al. 2004 and references within). Movements out of overwintering habitats roughly coincide with the April emigration of coho and Chinook salmon smolts (Macdonald and Shepherd 1983). It is therefore also possible that larger, presumably more piscivorous CCT move out of overwintering habitats earlier to capitalize upon this important seasonal food source prior to spawning. Finally, given that female CCT were significantly larger than males, the observed size gradient may be due to differences in the date that male and female CCT departed overwintering areas. Sex did appear in the 5th ranked overwintering model (Δ $AIC_c = 2.72$), however it's effect was non-significant and weakly negative suggesting that males moved earlier than females.

The second ranked overwintering model suggests that the absolute total distance CCT travelled to spawn had a significant positive effect on the likelihood that an individual would move out of an overwintering habitat. Date when fish initiate movements toward spawning areas was described in an earlier study on fall spawning bull trout. Bahr and Shrimpton (2004) found that adult bull trout initiated a directed movement earlier in the season if they were further from spawning locations. To my knowledge, my study is the first to find that distance from spawning locations was associated with timing of overwintering departure for a spring spawning salmonid. As described earlier, the relationship may be associated with larger fish overwintering in locations further from the spawning locations. Consequently, CCT travelling further to spawn are more likely to move out of overwintering habitats at an earlier date than CCT that overwintered closer to spawning habitats, a relationship observed during both years. Early departure from overwintering habitats did not confer early spawning and many CCT travelled great distances to staging habitats prior to spawning. Thus, it is likely that CCT travelling further initiated migrations earlier to be situated closer to spawning habitats in the period immediately prior to spawning. Moving close to spawning tributaries would ensure that CCT are better able to respond to the conditions of the spawning stream and may also increase the likelihood of finding a mate, particularly if spawning populations are low.

The final parameter that appeared within the top set of overwintering models was discharge. In the two models that included discharge, it had a weakly negative effect suggesting that CCT are moving as discharge declines; the confidence intervals however were large and overlapped zero indicating that discharge had little informative power. Thus, even though discharge did appear within the top-ranking models, it's effect appears to be small. Given that the longest distance migrations were from overwintering to staging and spawning habitats a response to flow should be expected. Indeed, a visual examination of the discharge profile shows that movements out of overwintering habitats were initiated after flows began to increase in the spring. However, from overwintering habitats CCT primarily moved through the mainstem and major tributaries and it is likely that migrations through these relatively large waterbodies are possible at a wide range of flows. Evidence that CCT can complete overwintering migrations at a wide range of flows is provided by the fact that CCT completed movements out of overwintering habitats at significantly higher flows in year 2. This discrepancy between years may also explain the insignificant effect of discharge as an elevated response in one year may have been muted by a reduced response in the second year. It is also possible, however, that flows throughout the study period did not restrict movements out of overwintering habitats. Longer term datasets are likely necessary to fully understand how CCT are responding to flow.

Spawning Analysis

Three top models were identified as being able to explain when CCT would arrive in spawning tributaries. These three models identified thermal experience, migration type, photoperiod and discharge as the variables having the strongest effect on spawning migrations. As with the overwintering analysis, collinearity between thermal experience, water temperature and photoperiod require that interpretation of the effects of these variables be considered with caution.

Thermal experience appeared in 2 of the 3 top spawning models and was identified as the primary abiotic variable influencing migrations into spawning habitats. The inclusion of thermal experience in the top models indicates that CCT are more likely to move into spawning tributaries as cumulative degree-days increase. This suggests that spawn timing is influenced by prevailing environmental conditions and may explain why CCT moved into spawning habitats significantly earlier in year 1. Thermal experience is likely to affect migration timing by influencing when CCT mature. Certainly, water temperature has been shown to influence rates of sexual maturation (Hokanson et al. 1973) and warmer antecedent temperatures have been associated with early seaward migration (Holtby 1988) and spawn timing (Dahl et al. 2004). Along with photoperiod, water temperature functions to synchronize the timing of important life history events with environmental conditions (Hoar et al. 1983). For instance, changes in day length have been shown to control the timing of annual life history events, such as spawning, by initiating important physiological processes, such as gametogenesis. However, it is water temperature that controls the rate at which maturation occurs and which therefore ensures that life history events, such as spawning, occur under favorable conditions during a given season. The fact that water temperatures were warmer and that fish spawned earlier in year 1 reinforces the likelihood that thermal experience influenced spawn timing by affecting maturation rates. Future research that applies bio-tracking technologies is required to better understand how thermal experience influences migration behaviours.

During each winter, radio tagged CCT displayed one of two overwintering behaviours. They either remained stationary within a single overwintering habitat, or were mobile and moved between multiple aggregations. Migration type appeared in the top two spawning models and was identified as the most important biological parameter for predicting when CCT would arrive in spawning tributaries. Coefficient estimates of migration type were consistently negative and of moderate strength, indicating that stationary CCT were more likely to move into spawning tributaries earlier than mobile CCT in each temporal period. Migration type appeared within each of the top spawning models, demonstrating that CCT in each behavioural group showed differing responses to thermal experience, photoperiod and discharge. This discrepancy in behavioural responses between groups adds additional support to the notion that CCT in each group are displaying unique behavioural strategies.

The mechanisms contributing to the behavioural differences between groups are not clear and require further research. However, there is evidence to suggest that physical characteristics, age, and/or life experience may have contributed to the observed behavioural differences. Stationary CCT were significantly larger and older than mobile CCT. The difference in age and size may indicate that stationary CCT were repeat spawners and/or had greater experiential knowledge. If this is the case then the observed discrepancy in behaviours may exist along a size gradient. Further research is required to assess the perceived size gradient and to better understand how and why observed differences in behaviour exist.

Photoperiod was shown to have a significant positive effect on spawning timing within one of the three top candidate models, suggesting that the likelihood CCT will move into spawning tributaries increases with longer day length. Photoperiod has been shown to affect the timing of spawning migrations by stimulating rheotaxis and/or by cueing physiological processes related to sexual maturation. For the reasons described in the overwintering analysis, however, it is unlikely that these processes had a direct effect on the timing of CCT movement into spawning habitats. Furthermore, if photoperiod had a direct effect on the timing of spawning it should be expected that spawning movements would not differ between years. Movement times differed in this study between years and suggests that photoperiod either had a novel influence on spawning behaviours, or more likely, that the nature by which photoperiod increased throughout the study period promoted its significance within the model.

Collinearity between water temperature and photoperiod was a serious issue in this study and has been shown to greatly complicate, and limit the strength of interpretations of environmental influences on behaviour. Given the collinearity observed in this study, it cannot be ruled out that the fish may in fact be responding to changes in parameters that are associated with photoperiod, such as water temperature and thermal experience. Certainly, the importance and prevalence of thermal experience within the top model set suggests that water temperature is having a significant effect on when CCT are arriving in spawning tributaries.

Discharge was the only parameter included in the top set of models that was not significant, suggesting that movements into spawning tributaries were not influenced by flow. A stronger response to flow was certainly expected in this study given that CCT are known to, and were observed to, spawn in the upper most accessible reaches of small first and second order tributaries. Flow may have had an insignificant effect on spawning behaviour for several reasons. First, flows in year 1 were significantly lower than in year 2 and it is possible that behavioural responses varied between years. Indeed, a visual examination of the data reveals that flows were more variable in year 2 and that CCT in that year completed migrations during high flow events. Flows during year 1, however, were more stable and the primary movement of CCT into spawning tributaries occurred between flow events. Therefore, if CCT showed a strong response in one year, but not both years, it is possible that the lack of response would reduce the significance of flow within the model.

It is also possible that flows in each year were above a threshold required to access spawning habitats. In this study, CCT were observed travelling to spawning habitats in the upper most accessible reaches of first and second order tributaries during each year. The geography of the Kitimat River may also permit CCT to move to the upper most accessible spawning habitats at a wide range of flows. In both years of the study, the majority of spawning was observed within the lower and middle reaches of the Kitimat watershed, where the valley is at its widest and accessible reaches of tributaries are relatively short, low gradient and influenced by groundwater (Macdonald and Shepherd 1983, Reese-

Hansen 2004). If flows did not restrict access to spawning habitats, then a minimal response to flow should be expected.

Finally, this study used mainstem discharge as a surrogate of flows within small tributaries. It is possible that a stronger response to flow would have been observed if flows had been measured directly within tributaries. Mainstem discharge should reflect the general behaviour of tributary flows; however, a temporal lag will certainly exist between tributary and mainstem flows. Previous research has demonstrated that responses to flows vary between years, populations and species. Given this variability, the appearance of flow within the top ranked model set should be considered to indicate that flow may have an effect on the spawning behaviours of CCT. To better understand how flow affects spawning behaviour research that applies a longer-term dataset is recommended.

Implications

The results of the overwintering and spawning analyses demonstrate that factors influencing migrations from overwintering to spawning habitats were complex and influenced by both biotic and abiotic variables. Coastal cutthroat trout are arguably the least understood species of salmonid (Trotter 2008) and the results of this study provide insight into some of the variables that appear to be structuring migratory behaviours within the Kitimat River. Previous research into the migratory behaviours of salmonids have demonstrated that responses to biotic and abiotic cues are highly variable within and among species as well as over time. Thus, the results presented in this study should be regarded as a point of reference and are not likely to reflect range wide trends for the subspecies.

In addition to the metrics that were included in this analysis, strong correlations are likely to exist among unmeasured/unmodeled environmental variables which may influence movement. Movement studies often focus upon flow and temperature while ignoring covariates that may also have a strong influence on movement (Trepanier et al. 1996). For instance, rising flows generally increase turbidity which may reduce predation during spawning migrations (Gregory and Levings 1998). Additionally, flows may promote movement towards foraging habitats if they increase invertebrate drift (Romero et al. 2005), or to off-channel cover habitats if they are suitably high (Harper and Farag 2004). Thus, although these factors were not assessed in my study, it is possible that they too may have influenced behaviours.

Due to the collinearity among environmental parameters the results of this analysis should not be considered to reflect cause and effect. This should not be implied to underscore the presented results but rather to ensure that they are interpreted with caution and an understanding that changes in modelled environmental parameters will influence a variety of additional unmodeled environmental metrics. Thus, changes in day length stimulate migratory behaviours of CCT in the Kitimat River, but migration may or may not be in direct response to photoperiod.

EPILOGUE

Coastal cutthroat trout are not fished commercially and the recreational fishery for the subspecies is limited, relative to other Pacific salmonids. As a result, there has been minimal systematic research into their ecology and behaviour. All too often, stream-specific information is anecdotal or has been collected indirectly during studies of other species (e.g. McCubbing 2002). The diverse array of habitats occupied by coastal cutthroat trout and the varied life history strategies displayed by the subspecies have added to the challenges in extrapolating range-wide trends. For these reasons, watershed-specific, or at least regional evaluations of CCT are required to assess and manage stocks appropriately. This is particularly important in British Columbia, which contains the majority of the species native range. To date, however, the research on the migration patterns and movement behaviours has occurred overwhelmingly at the extremities of the subspecies range (specifically, in Washington, Oregon and Alaska).

Patterns of trophic migrations, however, found for other species of salmonids may be applicable to CCT. As individual fish move through different life history stages they are not only capable of, but also require, access to different types of habitats and food sources. The movement patterns exhibited by salmonids can, therefore, be considered as variations on a theme that ensures the successful linking of spawning and rearing habitats with areas for feeding and overwintering. Northcote's (1997b) migratory/residency spectrum model, for example, provides a functional description of general migratory behaviours that may be applied to CCT from all life history strategies and suggests that CCT migrate between feeding, wintering and spawning habitats to meet their foraging, refuge and reproductive requirements. The movements and behaviours observed throughout this study fit within the migratory/residency spectrum model developed by Northcote (1997b). Refuge migrations were completed in the fall when CCT moved from mainstem and estuarine foraging habitats to overwintering habitats. In the spring, reproductive migrations from overwintering to spawning habitats were followed by trophic migrations to mainstem and estuary foraging habitats. Although Northcote's model provides a functional overview of general movement patterns, it is unable to account for the complexity and diversity of individual trout movement.

Behaviours observed in this study can be generally characterized as either synchronous movements within the population, or individual movements. Synchronized behaviours fit within Northcote's model and were associated with life history events, occurring when tagged CCT exhibited movements of similar purpose, magnitude and timing. Synchronized movements were most apparent in the spring when CCT moved from overwintering habitats to spawn, and from spawning tributaries to the estuary. In contrast, individual movements cannot be accounted for by Northcote's model, and may be opportunistic or responsive to environmental cues. Individual movements were most apparent throughout the winter, by mobile CCT that made frequent up- and downstream movements. The duration of time that CCT spent in marine environments and the timing that they returned to fresh water was also individual, varying considerably among sea-run CCT.

Distinguishing between synchronous and individual behaviours is important. Understanding the factors influencing individual behaviours will contribute to our understanding of whether the inherent individuality of CCT is a product of, or reason for, the species' unique and diverse life history behaviours. Movement studies, however, that focus on ecologically sensitive time periods, when movements are often synchronized, are more likely to identify significant biological relationships (Tetzlaff et al. 2005). It is recommended, therefore, that future research on CCT focus on synchronized, life history associated behaviours as they are most likely to be predictable and consistent among populations. Once our understanding of the factors shaping the basic life history behaviours of CCT are better understood it is likely that the stimuli influencing individual behaviours will become clearer.

Recent evidence suggesting that individuals may switch between migratory strategies in response to variable environmental conditions has led Johnson et al. (2010) to suggest that there may be a certain degree of phenotypic plasticity associated with life history form. These authors have proposed that sympatric populations of migratory and stream resident CCT may exist along a life history continuum rather than in fixed, predetermined states. A flexible life history strategy that has permitted individuals to modify their behaviours in response to environmental stochasticity may act to increase the resiliency of CCT populations and may have contributed to the diverse array of habitats they are currently found within (Northcote 1997b).

My research has provided evidence that CCT can, and do, shift behavioural strategies. Indeed, a portion of CCT tracked throughout both winters displayed stationary behaviours in year 1 and mobile behaviours in year 2. Though limited in number, the behavioural shift between years was clear and is further supported by the significant difference in the relative proportion of CCT displaying stationary and mobile behaviours in each year. Certainly, Westslope cutthroat trout have been documented to display similar stationary and mobile overwinter behaviours which may indicate that these strategies are more common than has been previously recognized (Brown 1999). In my study, stationary CCT were significantly larger than mobile CCT. It is unlikely however, that size was the primary factor structuring the proportion of CCT displaying each overwintering strategy given that relatively larger year 1 stationary CCT were observed to display mobile behaviours in year 2. Thus, it was more likely that environmental conditions, or some other external stimuli (i.e. environmental, or competition/resource related) influenced overwinter behaviours. To better understand the prevalence of stationary and migratory winter behavioural strategies, and to gain insight into the factors that may stimulate shifts between strategies will require additional research. The observed shift and change in proportion of CCT that displayed different behaviours in each year, however, suggest that these strategies are plastic, rather than fixed traits.

It is likely that the wandering, individual nature of CCT may have influenced the subspecies current distribution, and likely facilitated use of the full range of available habitats within a watershed. The recolonization of previously inaccessible habitats was directly observed in my study. Indeed, multiple CCT were observed spawning upstream of a highway crossing that had recently been modified to permit fish passage. Additionally, spawning within multiple streams occurred within 100 m of impassable barriers suggesting that CCT were moving as far upstream as physically possible. These observations demonstrate the benefits that will be realized by management activities that aim to maximize habitat availability. Indeed, Magee et al. (1996) report that cutthroat trout redd density is correlated with the quantity and quality of spawning habitats. Effective population size is an indicator of resiliency to stochastic events (Newman and Pilson 1997). A strong positive correlation between available spawning area and effective population size in Chinook salmon (*O. tshawytscha*) was reported by Shrimpton and Heath (2003). These findings demonstrate the benefits that will be realized by management activities that aim to maximize available habitat for spawning.

Conservation Concerns

The exposure of CCT to recreational fisheries in the Kitimat watershed is a conservation concern. Arguably, CCT are most vulnerable to angling throughout the winter, when aggregated in overwintering habitats. Salmon and steelhead bait fisheries, however, also pose considerable risk to CCT. Bait fisheries for CCT have been associated with high mortality due to "deep hooking" (Mongillo 1984, Pauley and Thomas 1993, Gresswell and Harding 1997) and incidental mortality was observed during this study when artificially scented plastic worms were used as bait. Deep hooking was observed when angling with roe; however, it was less frequent and no mortalities were directly attributed to the use of roe. To reduce mortality associated with "deep hooking" the use of artificial plastic worms is discouraged. Relative to bait, angling by lure and fly should reduce capture rates and mortality of CCT (Schisler and Bergersen 1996). Additional research (i.e. angler surveys) is recommended to quantify the exposure of CCT to recreational fisheries and assess the risks to CCT associated with varying angling methods.

As with other species, CCT continue to feed throughout the winter and are particularly vulnerable to angling as they aggregate within deep, slow moving pools (Cunjak and Power 1987, White and Harvey 2007). Habitats with these characteristics are few and far between within the Kitimat watershed. Thus, CCT aggregated in the same locations during both winters and occupied all habitats with these characteristics. Of concern, however, is the fact that these overwintering habitats are known, readily accessible and frequently targeted by anglers. Thus, the seasonal dependence on these habitats has indirectly increased angling pressure and efficiency. Presumably, CCT aggregate in overwintering habitats to mitigate the stresses associated with winter environmental conditions. However, capture by hook and line is a physiologically stressful event (Ferguson and Tufts 1992, Bartholomew and Bohnsack 2005) and CCT that remain in aggregations are likely to be captured more than once in a single winter (personal observation). Angling activities that increase stress to aggregated CCT therefore diminish the functionality of overwintering habitats to provide refuge. It is also possible that angling has affected behaviours and that mobile CCT move between habitats in response to, or to escape from angling.

Angling pressure on overwintering CCT is likely to vary with environmental conditions. Relatively warm winters may increase angling pressure on CCT as ice cover will be minimal and feeding rates will be elevated. Conversely, cooler winters may decrease angling success due to the combination of reduced feeding rates and increased ice cover, although evidence of ice fishing was apparent at multiple overwintering habitats used by CCT. Thus, uncharacteristically warm winters may warrant consideration of additional angling regulations specific to CCT. The relative ease at which aggregated CCT are captured is attractive, particularly to new anglers. Conversations with recreational anglers targeting overwintering CCT indicated that catching multiple CCT in an area over a short period contributed to the belief that Kitimat River CCT were abundant. The status of CCT populations in the Kitimat River, however, is unknown; this false assumption may promote illegal harvesting of CCT (personal observation). Tools that increase awareness of CCT behaviours and promote self-regulation of harvesting guidelines are recommended as a means of mitigating the potential for illegal harvesting of overwintering CCT.

The steelhead fishery in the Kitimat River runs from late March to mid-May and is primarily concentrated in the mainstem of the Kitimat River and the 3 largest tributaries (Hirsch Creek, Big Wedeene and Little Wedeene). Angling was not conducted during the steelhead fishery and anecdotal information on exposure to, and rates of, bycatch are limited. Mobile tracking occurred frequently during the steelhead fishery and demonstrated that CCT were concentrated in the lower and middle sections of the river. Given that steelhead frequently targeted in this area, it is likely that CCT are also often captured. The steelhead fishery directly coincides with the CCT spawning period and CCT may be removed from the population in critical spawning tributaries (excluding CCT staging in the mainstem and accessible reaches of the 3 largest tributaries). Fluvial CCT are perhaps more exposed to the fishery than sea-run CCT which moved directly towards the estuary after spawning. Thermal experience was identified as a key variable influencing the timing that CCT arrived within spawning tributaries. Thus, exposure to the steelhead fishery may be elevated during warmer years if fluvial CCT spawn and return to the mainstem earlier. Relative to gear that is used during the salmon fishery, angling equipment used for steelhead is typically smaller and more appropriate to CCT. Relative to the salmon fishery, the use of bait in the steelhead fishery is likely to increase incidental mortality of CCT due to the smaller size of hooks that are used.

Research Limitations

Aerial tracking flights were conducted infrequently during the salmon fishery and radio tagged fish provided limited insight into the behaviours of CCT in the late summer and fall. Sampling, however, was conducted extensively during the salmon fishery and demonstrated that CCT were widely distributed throughout the watershed. Although bycatch data was not formally collected from recreational salmon anglers, anglers were frequently questioned about CCT and conversations suggest, anecdotally, that CCT were captured as by-catch but that capture rates were relatively low. Sampling data corroborates this assertion, catch-per-unit-effort (CPUE) was relatively low despite using gear, and targeting habitats, specific to CCT. Thus, it is likely that CPUE of anglers targeting salmon will be further reduced given that they are using larger gear and targeting habitats specific to salmon (though habitat often overlaps, particularly with coho salmon). However, these findings should be interpreted with caution. Despite the reduced CPUE, the salmon fishery is the most popular recreational fishery on the Kitimat River and the sheer volume of recreational anglers in the watershed at this time suggests that a disproportionately large number of CCT are likely to be captured as bycatch.

The status of the Kitimat River CCT population is unknown, and stock assessment activities have been limited by a general lack of knowledge of the timing and location of spawning in the watershed. In my study, radio tagged CCT spawned throughout the lower, middle and upper watershed in April and May. Table A2.4 summarizes the location and timing that radio tagged CCT spawned and should be consulted if stock assessment activities are considered in the Kitimat River watershed. Spawn timing differed between years and thermal experience was identified as a significant predictor of spawn timing. Thus, assessment programs should consider seasonal environmental conditions when defining monitor timing as warmer winters may stimulate CCT to spawn earlier.

Tracking studies, however, assume that tagged individuals will display behaviours that are representative of the greater population (Ramstad and Woody 2003). The surgical implantation of radio transmitters is an invasive procedure and may affect fish behaviour. Once CCT were tagged, the likelihood of recapturing, resampling, or even directly observing an individual was low and there was little opportunity to assess the condition of tagged fish. One advantage of surgical implantation is that deleterious effects of tagging should be observed within a relatively short period (i.e. wounds will heal, or if, infected will likely cause mortality). Thus, the likelihood that tagging affected behaviour should have decreased with time. In my research, radio tagged CCT spawned 3.5 to 8 months after tagging and it was therefore assumed that CCT that survived to spawn were not harmed by the surgical procedure and that their behaviours were representative of the greater population.

Coastal cutthroat trout are often characterized by their ability to adapt to local environments. Likely, this adaptation has contributed to the diverse array of habitats and behaviours exhibited by CCT. The variety of behavioural responses that local adaptation has facilitated, however, hamper our ability as researchers and fisheries biologists, to predict how CCT populations will behave. While broad generalizations can be made, watershed scale research is necessary to understand even basic biological processes. The findings presented in my research will contribute to our ability to make broad generalizations about the species, however specifics, such as the timing of spawning and responses to environmental stimuli should be expected to vary among CCT populations.

Given how little we truly know about CCT, and how vulnerable the species appears to be to overharvesting and habitat degradation it is essential that fisheries managers err on the side of caution when considering future developments that may affect CCT habitat and fisheries regulations that may promote harvesting. This is particularly true for Northwest BC, which is being rapidly developed and likely contains many of the last remaining populations of wild, healthy CCT populations.

My research examined seasonal behaviours of CCT at a scale and scope that had not been completed previously. However, additional research is required to substantiate these findings. Given the metapopulation structure of CCT populations and the seemingly flexible migratory behaviours they exhibit, behaviours should be expected to vary among populations (Wenburg and Bentzen 2001, Costello 2006, Johnson et al. 2010). Thus, our understanding of CCT and factors shaping the subspecies behaviours will improve as more studies are conducted throughout the subspecies' range. Specific recommendations for future research were presented in the discussions of chapters 1 and 2. It is recommended, however, that future studies examining CCT behaviours focus upon life history events as they are most likely to be synchronized, structured and therefore predictable.

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APPENDICES

Chapter 1 Appendix

Table A1.1. Physical characteristics of all male and female CCT sampled during angling.

		Age (y)			**Fork Length (mm)**			**Weight (g)**			**Condition Factor (k)***		
	n	**mean**	**SE**	**range**	**mean**	**SE**	**range**	**mean**	**SE**	**range**	**mean**	**SE**	**range**
Male	80	3.6	0.11	2 - 6	319	7.32	135 - 455	414	23.53	35 - 1020	1.13	0.04	0.84 - 1.67
Female	144	3.9	0.11	2 - 7	335	6.18	110 - 480	500	24.71	45 - 1180	1.13	0.03	0.74 - 1.98
Welch's two sample t:		t(173.79) = -2.33, p = 0.021			t(181.05) = -1.63, p = 0.10			t(198.28) = -2.54, p = 0.012			t(370.0) = -0.048, p = 0.96		

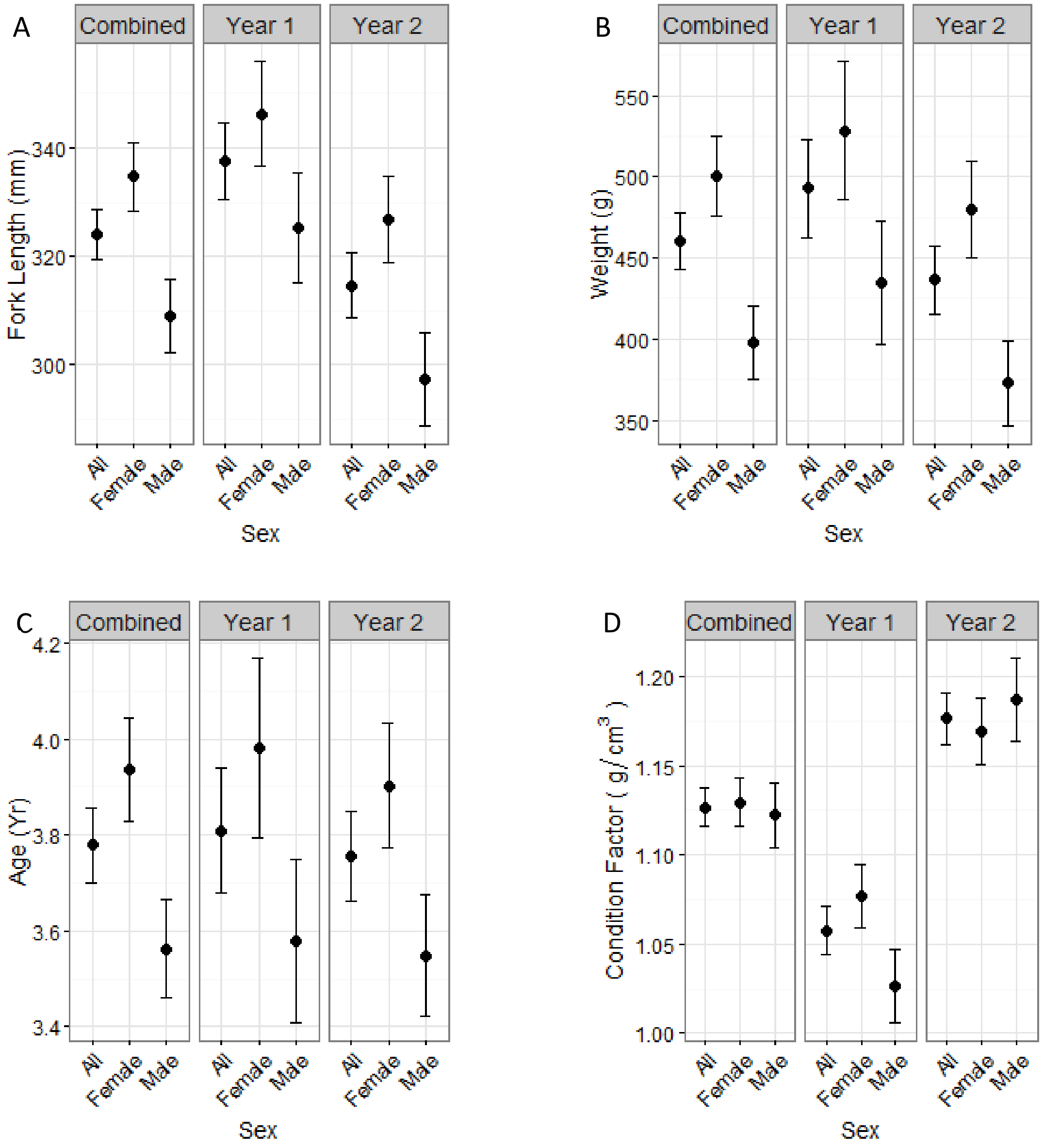

Figure A1.1. Fork length (A), weight (B), age (C) and condition factor (D) of all CCT sampled during angling.

Table A1.2. Summary of the physical characteristics of male and female CCT radio tagged with large transmitters in year 1 and year 2. Significant test results are presented in bold.

			Age (y)			**Fork Length (mm)**			**Weight (g)**			**Condition Factor (g/cm^3)**		
Year	**Sex**	**n**	**Mean**	**SE**	**Range**	**Mean**	**SE**	**Range**	**Mean**	**SE**	**Range**	**Mean**	**SE**	**Range**
Combined	**Male**	31	3.9	0.15	3 - 6	377	5.6	331 - 455	605	23.4	440 - 1020	1.13	0.02	0.92 - 1.45
	Female	62	4.5	0.14	3 - 7	390	5.4	330 - 480	703	29.3	430 - 1180	1.15	0.01	0.93 - 1.37
Welch's two sample t:			t(67.1) = -2.59, p = 0.01			t(78.8) = -1.70, p = 0.09			t(89.5) = -2.59, p = 0.01			t(45.7) = -0.88, p = 0.38		
1	**Male**	14	4.2	0.26	3 - 6	401	6.8	367 - 455	674	36.9	520 - 1020	1.03	0.02	0.92 - 1.10
	Female	26	5.0	0.25	3 - 7	413	8.3	330 - 480	819	45.9	440 - 1180	1.13	0.02	0.94 - 1.34
Welch's two sample t:			t(25.4) = -2.25, p = 0.03			t(37.3) = -1.12, p = 0.27			t(37.6) = -2.45, p = 0.02			**t(34.85) = -4.05, p < 0.001**		
2	**Male**	17	3.8	0.18	3 - 5	357	4.5	331 - 392	557	23.1	440 - 720	1.20	0.03	1.06 - 1.45
	Female	36	4.2	0.15	3 - 6	373	5.9	330 - 446	618	31.9	430 - 1020	1.17	0.02	1.03 - 1.37
Welch's two sample t:			t(35.5) = -1.66, p = 0.11			t(50.3) = -2.25, p = 0.03			t(50.9) = -1.80, p = 0.08			t(25.7) = 1.32, p = 0.20		
1	**Combined**	40	4.6	0.21	2 - 7	409	5.9	330 - 480	768	34.0	440 - 1180	1.09	0.02	0.92 - 1.34
2		53	4.0	0.12	3 - 6	368	4.4	330 - 446	596	23.2	430 - 1020	1.18	0.02	1.03 - 1.39
Welch's two sample t:			t(49.9) = 2.61, p = 0.01			**t(76.4) = 5.57, p < 0.001**			**t(71.9) = 4.18, p < 0.001**			**t(86.6) = -3.88, p < 0.001**		
1	**Male**	14	4.2	0.26	3 - 6	401	6.8	367 - 455	674	36.9	520 - 1020	1.03	0.02	0.92 - 1.10
2		17	3.8	0.18	3 - 5	357	4.5	331 - 392	557	23.1	440 - 720	1.20	0.03	1.06 - 1.45
Welch's two sample t:			t(31.7) = 2.92, p = 0.01			**t(48.1) = 3.91, p < 0.001**			**t(47.1) = 3.57, p < 0.001**			**t(25.7) = -5.20, p <0.001**		
1	**Female**	26	5.0	0.25	3 - 7	413	8.3	330 - 480	819	45.9	440 - 1180	1.13	0.02	0.94 - 1.34
2		36	4.2	0.15	3 - 6	373	5.9	330 - 446	618	31.9	430 - 1020	1.17	0.02	1.03 - 1.37
Welch's two sample t:			**t(25.7) = -5.2, p < 0.001**			t(22.2) = 2.91, p = 0.01			t(19.1) = 1.3, p = 0.21			t(54.4) = -1.26, p = 0.21		

Table A1.3. Physical characteristics, capture summary and fate of all CCT selected for radio tagging in year 1.

ID	Sex	Age	FL (mm)	Capture Date	Final Relocation	Survived Tagging?	Comments
1	M	-	398	8-Aug-12	21-Oct-13	Yes	No upstream movement observed after 6-Sept-2013.
2	F	-	340	10-Aug-12	10-Dec-13	Yes	Fish still alive on 10-Dec-2013 when tag expired.
3	F	4	330	11-Aug-12	17-Dec-12	Yes	Recaptured on 16-Nov-2012. Not observed after 20-Dec-2012
6	F	3	345	22-Aug-12	20-Nov-12	No	No upstream movement after capture.
7	F	-	370	22-Aug-12	30-Oct-12	Unknown***	No upstream movement after moving into Goose OW area.
8	F	5	435	22-Aug-12	12-Aug-13	Unknown**	Insufficient relocation data. Relocated during 1 aerial tracking flight.
9	F	4	385	23-Aug-12	4-Feb-14	Yes	Fish alive when tag expired on 4-Feb-2014. CCT returned to OW habitat used in first winter.
10	M	4	375	23-Aug-12	23-Sep-12	No	No upstream movement after capture.
12	F	-	435	26-Aug-12	1-Feb-13	Yes	No upstream movement observed after moving into Wedeene OW area on 17-Dec-2012.
13	F	6	455	31-Aug-12	4-Feb-14	Yes	Survived spawn. Estuary from 23-May to 1-July. Returned to Goose OW. Tag expired after 4-Feb-2014.
15	M	6	417	1-Sep-12	28-Oct-12	No	No upstream movement observed after tagging.
19	M	-	455	12-Sep-12	17-May-13	Yes	Chicken Ck. spawning mort. Recovered on 17-May-2013.
21	F	4	380	15-Sep-12	8-Mar-13	Yes	Not observed after 8-March-2013 at 16.5 rKM.
29	M	-	435	17-Sep-12	22-Apr-13	Yes	Goose Ck. spawning mort. Recovered on 22-Apr-2013.
34	M	4	432	23-Sep-12	1-May-13	Yes	Upper Big Wedeene spawning mort. No upstream movement after 1-May-2013.
43	F	4	423	26-Sep-12	27-Apr-13	Yes	Cecil Ck. spawning mort. No movement after 27-April-2013.
44	F	-	400	26-Sep-12	17-May-13	Yes	Chicken Ck. spawning mort. Recovered on 17-May-2013.
45	F	4	404	26-Sep-12	1-May-13	Yes	Big Wedeene spawning mort. No movement after 1-May-2013
47	F	6	450	6-Oct-12	10-Mar-14	Yes	Survived spawn. In estuary from 26-May-2013 to 11-July-2013. Tag expired after 4-Feb-2014.
49	F	4	414	8-Oct-12	6-Sep-13	Yes	Survived spawn. Moved to estuary on 23-May-2013, predated on by eagle before 6-Sept-2013.
50	F	7	460	8-Oct-12	4-Feb-14	Yes	Survived spawn. Tag expired after 4-Feb-2014.
51	F	-	438	28-Oct-12	5-Apr-13	Yes	No upstream movement observed after 31-March-2013. Tag recovered on 23-April-2013.
52	F	5	419	2-Nov-12	28-Mar-14	Yes	Survived spawn. In estuary from 3-June to 30-July. No upstream movement after 15-Jan-2014.
53	F	-	348	2-Nov-12	25-Feb-13	Yes	No upstream movement observed after 25-Feb-2013.
54	F	6	465	3-Nov-12	9-Dec-12	Unknown**	Not observed during any aerial relocation flights.
67	F	7	480	7-Nov-12	6-Apr-13	Yes	Killed by angler on 6-April-2013.
69	F	5	384	8-Nov-12	21-Oct-13	Yes	Survived spawn. In estuary 20-May to 13-Aug-2013. No upstream movement after 21-Oct-2013.
74	M	4	380	10-Nov-12	13-May-13	Yes	Predated upon by eagle on 13-May-2013. Tag expired 5-May-2014.
77	F	5	409	16-Nov-12	21-Mar-14	Yes	Survived spawn. In estuary 22-May to 23-July-2013. Mortality between 23-July and 10-Dec-2013.
87	F	5	408	19-Nov-12	17-Dec-13	No	No upstream movement observed after tagging.
88	M	5	404	19-Nov-12	27-Apr-13	Yes	Chicken Ck. spawning mort after 27-April-2013.
91	F	6	424	24-Nov-12	28-Apr-14	Yes	Survived spawn. Overwintered in Wedeene OW area. Tag expired on 28-April-2014.
92	M	4	396	24-Nov-12	24-May-13	Yes	Big Wedeene spawner. Not observed after 24-May-2013.
93	F	4	447	10-Dec-12	14-Apr-13	Yes	KTR Trib spawning mort. No upstream movement after 14-April-2013.
94	F	5	454	11-Dec-12	1-May-14	Yes	Little Wedeene spawning mort - after 1-May-2013.
95	M	3	367	11-Dec-12	1-May-13	Yes	Predated upon by eagle between 27-April and 1-May-2013.
96	M	5	399	12-Dec-12	6-May-13	Yes	Cecil Ck. spawning mort. No upstream movement after 14-April-2013. Recovered on 6-May-13.
97	M	3	376	12-Dec-12	27-Apr-13	Yes	Deception Ck. spawning mort. No upstream movement after 27-April-2013. Recovered on 3-May-2013.
99	M	4	398	12-Dec-12	6-May-13	Yes	McNeil Ck. spawning mort. No upstream movement after 6-May-2013. Recovered on 17-May-2013.
100	M	4	384	12-Dec-12	17-Apr-13	Yes	Survived spawn and second winter. Estuary28-May to 17-July-2013. Tag expired on 17-April-2014.
102	F	6	448	15-Dec-12	1-Feb-13	No	No upstream movement observed after tagging.

Unknown* = Fish moved directly out of system following tagging.

Unknown** = Fish not relocated sufficiently to determine fate.

Unknown*** = Fish not observed departing from OW habitat occuppied within 6 weeks of tagging.

Table A1.4. Physical characteristics, capture summary and fate of all CCT selected for radio tagging in year 2.

Fish ID	Sex	Age	FL (mm)	Capture Date	Final Relocation	Survived Tagging?	Comments
118	M	5	380	20-Jun-13	6-Sep-13	Yes	Last observed on 6-Sept-2013 at 11.2 rKM. Possibly captured.
123	M	5	363	9-Jul-13	13-May-14	Yes	Duck Ck. spawning mort. No upstream movement after 5-May-2014. Recovered on 13-May-2014.
132	M	3	342	13-Jul-13	16-Dec-13	Yes	Last moving past receiver at 2.2 rKM on 6-Sept-2013.
134	F	5	435	14-Jul-13	28-Jun-14	Yes	Survived spawn (Cecil Ck.), in estuary from 3-June to 28-June-2014. Not observed after 28-June-2014
141	F	4	388	18-Jul-13	22-Nov-13	No	No movement observed after tagging.
143	F	-	369	21-Jul-13	21-Oct-13	No	No upstream movement observed after tagging.
146	M	4	390	21-Jul-13	TAGGING	No	Did not survive surgery.
147	F	5	392	21-Jul-13	18-Sep-13	Yes	Last observed on 18-Sept-2013 at 16.5 rKM. Possibly captured.
148	F	4	389	21-Jul-13	27-May-14	Yes	Survived spawn (Chicken Ck.), last observed 15-May-2014 in Hirsch Ck.
149	F	4	391	22-Jul-13	TAGGING	No	Did not survive surgery.
151	F	4	338	25-Jul-13	27-May-14	Yes	Spawned (Nalbeelah Ck.), last observed near mouth of Nalbeelah, 29-May-2014.
152	F	5	418	23-Jul-13	10-May-14	Yes	Cecil Ck. spawning mort between 11-April and 5-May-2014. Recovered on 10-May-13.
154	F	5	350	23-Jul-13	9-Sep-13	Unknown*	Last observed moving out of system on 9-Sept-2013.
155	F	3	297	25-Jul-13	25-Jul-13	Unknown**	Not observed after tagging.
156	F	4	349	25-Jul-13	16-May-14	Yes	Powerline Ck. spawning mort. No upstream movement after 9-May-2014.
157	F	6	440	25-Jul-13	27-May-14	Yes	Survived spawn (McKay Ck.). Not observed after 27-May-2014.
158	F	5	371	25-Jul-13	9-May-14	Yes	Nalbeelah Ck. spawning mort.No upstream movement after 9-May-2014.
159	F	-	446	29-Jul-13	18-Jul-14	Yes	Survived spawn (McNeil Ck.), in estuary 1-June to 18-July-2014. Not observed after 18-July-2014.
161	F	3	336	12-Aug-13	21-Oct-13	No	No upstream movement after 6-Sept-2013. Not observed after 22-Nov-2013.
162	-	-	388	12-Aug-13	13-Jul-14	Yes	Survived spawn (Upper Kitimat), in estuary 1-June to 13-July-2014. Not observed after 13-July-2014.
163	F	5	333	12-Aug-13	4-Feb-14	Yes	Not observed after 4-Feb-2014. Likely captured near 19.6 rKM.
166	F	4	387	15-Aug-13	21-Aug-13	No	No upstream movement after tagging.
169	M	3	287	17-Aug-13	25-Aug-13	Unknown*	Last observed moving out of system on 25-Aug-2013 at 8.3 rKM.
170	M	3	346	17-Aug-13	13-Apr-14	Unknown*	Last observed moving out of system on 20-Aug-2013 at 8.3 rKM.
171	F	3	333	17-Aug-13	4-Feb-14	No	No upstream movement after tagging.
172	F	3	338	17-Aug-13	TAGGING	No	Did not survive surgery.
173	M	3	335	18-Aug-13	4-Sep-13	No	No upstream movement after tagging.
174	M	3	335	18-Aug-13	30-Aug-13	Unknown*	Last observed moving out of system on 30-Aug-2013 at 8.3 rKM.
175	F	3	341	18-Aug-13	6-Sep-13	Unknown*	Last observed moving out of system on 6-Sept-2013.
176	M	3	350	18-Aug-13	10-Feb-14	Unknown**	Not observed after 6-Sept-2013.
177	-	4	293	18-Aug-13	6-Sep-13	No	No upstream movement after tagging.
179	F	3	283	21-Aug-13	11-Sep-13	Unknown**	Not observed after 11-Sept-2013.
180	F	3	276	21-Aug-13	6-Feb-14	Unknown**	Not observed during any aerial relocation flights.
181	F	3	359	5-Sep-13	8-Sep-13	No	No upstream movement after tagging.
182	F	5	399	9-Sep-13	10-Dec-13	Unknown***	No upstream movement observed after entering Goose overwinter area on 10-Dec-2013.
185	F	5	435	9-Sep-13	3-May-14	Yes	Powerline Ck. spawning mort. No upstream movement after 3-May-2014.
187	M	3	345	13-Sep-13	22-Nov-13	Unknown***	No upstream movement after 22-Nov-2013.
189	F	5	338	15-Sep-13	27-Sep-13	Unknown*	Last observed on 27-Sept-2013 at 2.2 rKM moving out of system.
195	M	4	340	17-Sep-13	10-Dec-13	Yes	Moved continuously downstream after tagging, last observed in system on 10-Dec-2013.
200	F	3	344	18-Sep-13	8-Oct-13	No	No upstream movement after tagging.
206	F	3	366	21-Sep-13	10-Dec-13	No	No upstream movement after tagging.
207	F	3	332	24-Sep-13	28-Mar-14	Yes	Not observed in spawning habitat. Last relocated on 28-March-2014.
208	M	4	392	24-Sep-13	5-May-14	Yes	Cecil Ck. spawning mort. No upstream movement after 5-May-2014. Tag recovere on 15-May-2014.
209	F	5	436	25-Sep-13	27-May-14	Yes	Survived spawn (Cecil Ck.), last observed 27-May-2014 entering estuary.
211	F	4	364	25-Sep-13	27-May-14	Yes	Big Wedeene spawner. Fate unclear. Last observed 27-May-2014.
212	M	5	331	25-Sep-13	27-May-14	Yes	Survived spawn (Nalbeelah Ck.). Last observed on 27-May-2014.
217	F	4	374	26-Sep-13	29-Apr-14	Yes	Goose Ck. spawning mort. Recovered on 29-April-2014.
218	F	4	372	26-Sep-13	14-Jul-14	Yes	Survived spawn (Chicken Ck.), in estuary 8-June to 14-July-2014.
220	F	4	346	27-Sep-13	15-Jan-14	Yes	Moved continuously downstream after tagging, no movement after 21-March-2014.
222	F	-	344	28-Sep-13	15-Jan-14	Yes	Last observed on 7-April-2014 in Goose Pool OW area
224	F	5	430	29-Sep-13	11-Apr-14	Yes	Predated upon by eagle between 2-April-2014 and 11-April-2014.
225	M	4	368	7-Oct-13	5-May-14	Yes	Duck Ck. spawning mort. No upstream movement after 5-May-2014. Tag recovered 6-May-2014.
227	F	4	353	7-Oct-13	29-May-14	Yes	Fate unclear. No upstream movement observed after 11-April-2014. Fish may have moved to estuary on 29-May-2014.
231	F	4	365	9-Oct-13	21-Oct-13	Unknown**	Not observed after 21-Oct-2013.
232	M	4	416	9-Oct-13	30-Jun-14	Yes	Survived spawn (upper Kitimat), in estuary 22-May to 30-June-2014. Last observed 30-June-2014.
233	M	4	355	9-Oct-13	10-Dec-13	No	Fish moved continuously downstream after tagging.
234	M	5	320	9-Oct-13	4-Mar-14	Yes	Last observed on 4-March-2014 in McNeil Ck. No upstream movement after 15-Jan-2014.
235	F	5	380	9-Oct-13	9-Oct-13	Unknown**	Not observed after tagging.
236	F	4	350	9-Oct-13	14-May-14	Yes	Not observed in spawning habitat but likely spawned near Airpark. Last observed moving into estuary 14-May-2014.
240	M	4	345	10-Oct-13	30-Mar-14	Yes	Last observed on 30-March-2014 at 16.5 rKM
241	F	5	376	10-Oct-13	24-May-14	Yes	Survived spawn (Big Wedeene), last observed moving into estuary on 24-May-2014.
242	F	4	357	10-Oct-13	27-May-14	Yes	Not observed in spawning habitat. Last relocated on 27-May-2014.
245	F	4	330	11-Oct-13	4-Feb-14	Yes	No upstream movement observed after 4-Feb-2014.
249	M	4	371	14-Oct-13	27-May-14	Yes	Big Wedeene spawning mort. No upstream movement after 9-May-2014.
250	M	3	357	14-Oct-13	15-Jan-14	Yes	Not observed departing Cable Car OW area. No movement after 15-Jan-2014.
251	M	4	358	15-Oct-13	19-Jun-14	Yes	Survived spawn (Little Wedeene), in estuary from 1-June to 19-June-2014.
252	F	4	335	15-Oct-13	4-Mar-14	Yes	Not observed leaving Goose overwintering area. No movement after 4-March-2014.
255	M	4	355	18-Oct-13	17-Apr-14	Yes	Deception Ck. spawning mort. No upstream movement after 28-April-2014.

Unknown* = Fish moved directly out of system following tagging.

Unknown** = Fish not relocated sufficiently to determine fate.

Unknown*** = Fish not observed departing from OW habitat occuppied within 6 weeks of tagging.

Table A1.5. Summary of the behaviours of CCT tracked into overwintering habitats in year 1 and 2.

Fish #	Sex	Age (y)	FL (mm)	Summary of winter movement behaviours
#002	F	-	340	Mobile, captured in Nalbeelah. Overwintered near Airpark, Deception and Cecil in first winter. Spawned in McNeil and then returned to Nalbeelah area. In second winter, was first relocated near Cecil Ck. on 22-Nov-2013. Tag expired on 10-Dec-2013.
#009	F	4	385	Stationary in both winters, occupied same overwintering area during both winters. Occupied overwintering area from 20-Nov-2012 to during the first winter. Spawned and then went to estuary. Returned to initial overwintering area and occupied it from 22-Nov-2013 to 4-Feb-2014 during the second winter. Suspect that tag expired while still in overwintering area.
#013	F	6	455	Stationary in both winters, occupied same overwintering area during both winters. Captured near initial overwintering area on 31-Aug-2013 and remained until 9-April-2013. Spawned in spring and then moved into estuary. Relocated in initial overwintering area on 21-Oct-2013. Final relocation was on 4-Feb-2014, while still in overwintering area.
#050	F	7	460	Stationary in both winters, occupied different overwintering areas in first and second winter. In first winter, CCT remained in initial overwintering area (Deception) from 20-Nov-2012 to 28-March-2013. CCT spawned in the Big Wedeene and then moved throughout watershed during summer/fall. During the second winter it was relocated in a new overwintering area (mouth of Wedeene) on 21-Oct-2013. Tag expired after 4-Feb-2014, fish may have died previously.
#052	F	5	419	Stationary in 2012, mobile in 2013. Overwintered in upper Big Wedeene from 2-Nov-2012 to 14-April-2013. Spawned (19-April-2013) and then moved downstream to the estuary. Relocated in lower Big Wedeene (22-Nov-2013 to 10-Dec-2013) and then moved into the Big Wedeene side channel until tag expired on 28-March-2014.
#091	F	6	424	Captured in upper watershed and primarily overwintered near Cecil Ck in first winter. Spawned (Chist Ck.) and remained in upper watershed through summer. Overwintered in Clay Banks side channel through second winter. Last relocated on 28-April-2014, may have died previously.

Table A1.6. Physical characteristics of stationary and mobile CCT radio tagged with large transmitters in year 1 and year 2. Significant tests results are bold.

			Age (y)			**Fork Length (mm)**			**Weight (g)**			**Condition Factor (g/cm^3)**		
Year	**Winter Behaviour**	**n**	**Mean**	**SE**	**Range**	**Mean**	**SE**	**Range**	**Mean**	**SE**	**Range**	**Mean**	**SE**	**Range**
Combined	**Stationary**	23	4.8	0.2	3 - 7	417	6.1	368 - 460	833	41.1	540 - 1180	1.13	0.02	0.92 - 1.38
	Mobile	34	4.3	0.1	3 - 7	385	6.7	330 - 480	659	34.1	430 - 1050	1.13	0.02	0.93 - 1.37
Welch's two sample t:			t(66) = 2.45, p = 0.02			**t(110.7) = 5.07, p < 0.001**			**t(97.6) = 4.67, p < 0.001**			t(90.2) = 0.05, p = 0.96		
1	**Stationary**	18	4.8	0.30	3 - 7	419	6.6	376 - 460	826	48.0	540 - 1180	1.11	0.02	0.92 - 1.25
	Mobile	12	4.4	0.38	3 - 7	407	11.3	340 - 480	734	60.8	440 - 1050	1.07	0.02	0.93 - 1.18
Welch's two sample t:			t(17.1) = 0.71, p = 0.49			t(18.5) = 0.91, p = 0.38			t(23.1) = 1.18, p = 0.25			t(26.8) = 1.19, p = 0.24		
2	**Stationary**	5	4.8	0.37	4 - 6	411	16.2	368 - 440	862	85.5	620 - 1020	1.23	0.04	1.17 - 1.38
	Mobile	22	4.3	0.14	3 - 5	373	7.3	330 - 446	618	39.3	430 - 1000	1.17	0.02	1.03 - 1.37
Welch's two sample t:			t(5.2) = 1.37, p = 0.23			t(5.7) = 2.14, p = 0.08			t(5.8) = 2.60, p = 0.04			t(6.0) = 1.49, p = 0.19		
1	**Combined**	30	4.7	0.23	3 - 7	414	6.0	340 - 480	789	37.9	440 - 1180	1.09	0.02	0.92 - 1.25
2		27	4.4	0.14	3 - 6	380	7.1	330 - 446	663	39.6	430 - 1020	1.18	0.02	1.03 - 1.38
Welch's two sample t:			t(36.5) = 1.08, p = 0.29			**t(52.4) = 3.68, p < 0.001**			t(54.5) = 2.30, p = 0.03			**t(54.4) = -3.72, p < 0.001**		
1	**Stationary**	18	4.8	0.30	3 - 7	419	6.6	376 - 460	826	48.0	540 - 1180	1.11	0.02	0.92 - 1.25
2		5	4.8	0.37	4 - 6	411	16.2	368 - 440	862	85.5	620 - 1020	1.23	0.04	1.17 - 1.38
Welch's two sample t:			t(9.6) = -0.03, p = 0.98			t(5.4) = 0.46, p = 0.67			t(6.8) = -0.37, p = 0.72			t(7.0) = -2.79, p = 0.03		
1	**Mobile**	12	4.44	0.38	3 - 7	407	11.3	340 - 480	734	60.8	440 - 1050	1.07	0.02	0.93 - 1.18
2		22	4.25	0.14	3 - 5	373	7.3	330 - 446	618	39.3	430 - 1000	1.17	0.02	1.03 - 1.37
Welch's two sample t:			t(10.4) = 0.48, p = 0.64			t(20.2) = 2.55, p = 0.02			t(20.3) = 1.61, p = 0.12			**t(25.2) = -3.4, p = 0.002**		

Table A1.7. River position (km) of initial and final overwintering habitats used by male and female CCT in year 1 and 2. Significant tests results are presented in bold.

Year	**Sex**	**Initial OW Position**				**Final OW Position**				**Welch's two sample t: Initial vs Final**
		n	**Mean**	**SD**	**Range**	**n**	**Mean**	**SE**	**Range**	
Combined	Male	22	24.4	1.7	10.8 to 36.9	20	24.0	1.8	10.8 to 32.1	t(54.6) = -0.19, p = 0.85
	Female	47	24.5	1.2	10.8 to 37.1	32	24.2	1.5	10.8 to 35.7	t(105.8) = 0.31, p = 0.76
Welch's two sample t:		t(53.3) = -0.51, p = 0.61				t(49.3) = -0.03, p = 0.97				-
1	Male	12	25.8	2.3	10.8 to 36.9	12	24.4	2.2	10.8 to 32.1	t(16.5) = 0.65, p = 0.53
	Female	19	24.4	2.0	10.8 to 35.7	16	24.1	2.4	10.8 to 35.7	t(22.0) = 0.46, p = 0.65
Welch's two sample t:		t(25.6) = 0.05, p = 0.96				t(17.6) = -0.2, p = 0.84				-
2	Male	10	22.7	2.5	10.8 to 34.6	8	23.3	3.1	10.8 to 31.9	t(5.7) = -0.21, p = 0.84
	Female	29	24.7	1.5	10.8 to 37.1	15	24.0	1.8	11 to 33.5	t(25.2) = -0.09, p = 0.93
Welch's two sample t:		t(14.6) = -0.81, p = 0.43				t(4.0) = -0.36, p = 0.74				-
1	Combined	31	24.9	1.5	10.8 to 36.9	28	24.3	1.7	10.8 to 35.7	t(60.3) = 0.54, p = 0.59
2		37	24.1	1.3	10.8 to 37.1	24	24.0	1.5	10.8 to 33.5	t(70.1) = -0.00, p = 0.99
Welch's two sample t:		t(73.6) = 0.05, p = 0.62				t(56.8) = -0.16, p = 0.87				-
1	Male	12	25.8	2.3	10.8 to 36.9	12	24.4	2.2	10.8 to 32.1	-
2		10	22.7	2.5	10.8 to 34.6	8	23.3	3.1	10.8 to 31.9	-
Welch's two sample t:		t(19.6) = 0.71, p = 0.49				t(6.5 = -0.20, p = 0.85				-
1	Female	19	24.4	2.0	10.8 to 35.7	16	24.1	2.4	10.8 to 35.7	-
2		29	24.7	1.5	10.8 to 37.1	15	24.0	1.8	11 to 33.5	-
Welch's two sample t:		t(31.6) = -0.03, p = 0.98				t(18.2) = -0.57, p = 0.58				-

Table A1.8. River position of initial and final overwintering habitats used by mobile and stationary CCT in year 1 and 2. Significant tests results are presented in bold.

Year	Winter Behaviour	Initial OW Position				Final OW Position				Welch's two sample t: Initial vs Final
		n	**Mean**	**SD**	**Range**	**n**	**Mean**	**SE**	**Range**	
Combined	Stationary	25	23.7	1.9	10.8 to 35.7	25	23.7	1.9	10.8 to 35.7	t(43.7) = 0.76, p = 0.45
	Mobile	40	25.1	1.1	10.8 to 37.1	27	24.5	1.3	10.8 to 32	t(110.3) = -0.2, p = 0.84
Welch's two sample t:		t(36.2) = -0.33, p = 0.74				t(31.4) = -1.33, p = 0.19				-
1	Combined	30	25.2	1.5	10.8 to 36.9	28	24.3	1.7	10.8 to 35.7	t(64.8) = 0.52, p = 0.6
2		34	24.0	1.3	10.8 to 37.1	24	24.0	1.5	10.8 to 33.5	t(66.2) = -0.36, p = 0.72
Welch's two sample t:		t(77.6) = 0.44, p = 0.66				t(60.7) = -0.46, p = 0.65				
1	Stationary	19	24.0	2.2	10.8 to 35.7	19	24.0	2.2	10.8 to 35.7	-
	Mobile	11	27.4	1.7	15.7 to 36.9	9	24.9	2.5	10.8 to 30.7	t(21) = -0.23, p = 0.82
Welch's two sample t:		t(26.1) = -0.61, p = 0.55				t(21) = -1.85, p = 0.08				
2	Stationary	6	22.8	3.9	10.8 to 33.5	6	22.8	3.9	10.8 to 33.5	-
	Mobile	30	24.3	1.3	10.8 to 37.1	17	24.1	1.7	10.8 to 32	t(33.4) = -0.08, p = 0.94
Welch's two sample t:		t(6.2) = -0.33, p = 0.75				-				
1	Stationary	19	24.0	2.2	10.8 to 35.7	19	24.0	2.2	10.8 to 35.7	-
2		6	22.8	3.9	10.8 to 33.5	6	22.8	3.9	10.8 to 33.5	-
Welch's two sample t:		t(8.8) = 0.31, p = 0.77				-				
1	Mobile	11	27.4	1.7	15.7 to 36.9	9	24.9	2.5	10.8 to 30.7	-
2		30	24.3	1.3	10.8 to 37.1	17	24.1	1.7	10.8 to 32	-
Welch's two sample t:		t(26.6) = 0.83, p = 0.41				t(21.9) = 0.89, p = 0.39				-

Table A1.9. Median date male and female CCT arrived in, and were captured in, initial overwintering habitats in year 1 and year 2. Note that 1 CCT captured in an overwintering habitat in year 1 was excluded from this analysis (Fish#003). Significant tests results are bold.

Year	Sex	Observed in Overwintering Habitats				Captured in Overwintering Habitats				NOT Captured in Overwintering Habitats			
		n	Median	SD	Range	n	Median	SD	Range	n	Median	SD	Range
Combined	Male	22	20-Nov	28.0	12-Sep to 17-Dec	11	19-Nov	35.8	12-Sep to 17-Dec	11	20-Nov	18.6	21-Oct to 17-Dec
	Female	46	21-Oct	24.7	11-Aug to 17-Dec	15	21-Oct	31.2	11-Aug to 11-Dec	31	30-Oct	20.5	06-Sep to 17-Dec
Two Sample KS Test		**H_o**: Male > Female; d = 0.22, p = 0.233				**H_o**: Male > Female; d = 0.35, p = 0.221				**H_o**: Male > Female; d = 0.21, p = 0.477			
1	Male	12	22-Nov	26.0	12-Sep to 17-Dec	7	11-Dec	33.7	12-Sep to 17-Dec	5	20-Nov	12.1	20-Nov to 17-Dec
	Female	19	20-Nov	27.7	11-Aug to 17-Dec	7	8-Nov	41.2	11-Aug to 11-Dec	12	20-Nov	16.7	06-Oct to 17-Dec
Two Sample KS Test		**H_o**: Male > Female; d = 0.34, p = 0.182				**H_o**: Male > Female; d = 0.43, p = 0.280				**H_o**: Male > Female; d = 0.25, p = 0.639			
2	Male	10	21-Oct	18.5	24-Sep to 22-Nov	4	10-Oct	9.4	24-Sep to 14-Oct	6	23-Oct	16.1	21-Oct to 22-Nov
	Female	27	21-Oct	18.6	06-Sep to 22-Nov	8	21-Oct	14.7	09-Sep to 21-Oct	19	21-Oct	18.9	06-Sep to 22-Nov
Two Sample KS Test		**H_o**: Male < Female; d = 0.29 p = 0.301				**H_o**: Male < Female; d = 0.75, p = 0.050				**H_o**: Male > Female; d = 0.24, p = 0.601			
1	Combined	31	20-Nov	27.2	11-Aug to 17-Dec	14	22-Nov	37.4	11-Aug to 17-Dec	11	20-Nov	16.6	21-Oct to 17-Dec
2		37	21-Oct	18.3	11-Aug to 17-Dec	12	14-Oct	13.1	09-Sep to 21-Oct	31	30-Oct	18.1	06-Sep to 17-Dec
Two Sample KS Test		**H_o: 2012 > 2013; d = 0.71, p < 0.001**				**H_o: 2012 > 2013; d = 0.85, p < 0.001**				**H_o: 2012 > 2013; d = 0.66, p < 0.001**			
1	Male	12	22-Nov	26.0	12-Sep to 17-Dec	7	11-Dec	33.7	12-Sep to 17-Dec	5	20-Nov	12.1	20-Nov to 17-Dec
2		10	21-Oct	18.5	24-Sep to 22-Nov	4	10-Oct	9.4	24-Sep to 14-Oct	6	23-Oct	16.1	21-Oct to 22-Nov
Two Sample KS Test		**H_o: 2012 > 2013; d = 0.72, p = 0.004**				**H_o**: 2012 > 2013; d = 0.86, p = 0.023				**H_o**: 2012 > 2013; d = 0.67, p = 0.089			
1	Female	19	20-Nov	27.7	11-Aug to 17-Dec	7	8-Nov	41.2	11-Aug to 11-Dec	12	20-Nov	16.7	06-Oct to 17-Dec
2		27	21-Oct	18.6	06-Sep to 22-Nov	8	21-Oct	14.7	09-Sep to 21-Oct	19	21-Oct	18.9	06-Sep to 22-Nov
Two Sample KS Test		**H_o: 2012 > 2013; d = 0.71, p < 0.001**				**H_o: 2012 > 2013; d = 0.86, p = 0.004**				**H_o: 2012 > 2013; d = 0.65, p =0.002**			

Table A1.10. Median date mobile and stationary CCT arrived in, and were captured in, initial overwintering habitats in year 1 and year 2. Note that 1 CCT captured in an overwintering habitat in year 1 was excluded from this analysis (Fish#003). Significant tests results are presented in bold.

Year	**Winter Behaviour**	**Observed in Overwintering Habitats**				**Captured in Overwintering Habitats**				**NOT Captured in Overwintering Habitats**			
		n	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**
1	Combined	30	20-Nov	20.6	11-Aug to 17-Dec	13	22-Nov	26.4	11-Aug to 17-Dec	17	20-Nov	15.6	06-Oct to 17-Dec
2		34	21-Oct	18.4	06-Sep to 22-Nov	12	14-Oct	13.1	09-Sep to 21-Oct	22	21-Oct	16.5	06-Sep to 22-Nov
Two Sample KS Test		**H_o: 2012 > 2013; d = 0.71, p < 0.001**				**H_o: 2012 > 2013; d = 0.86, p < 0.001**				**H_o: 2012 > 2013; d = 0.66, p < 0.001**			
1	Stationary	18	20-Nov	22.7	12-Sep to 17-Dec	7	20-Nov	33.5	12-Sep to 17-Dec	11	20-Nov	13.5	30-Oct to 17-Dec
	Mobile	12	20-Nov	18.0	06-Oct to 12-Dec	6	2-Dec	14.6	07-Nov to 12-Dec	6	20-Nov	18.4	06-Oct to 20-Nov
Two sample KS Test:		H_o: Stationary > Mobile; d = 0.17, p = 0.665				H_o: Stationary < Mobile; d = 0.29, p = 0.588				H_o: Stationary > Mobile; d = 0.18, p = 0.770			
2	Stationary	6	21-Oct	24.0	09-Sep to 22-Nov	2	23-Sep	19.8	09-Sep to 07-Oct	4	21-Oct	16.0	21-Oct to 22-Nov
	Mobile	28	21-Oct	17.3	06-Sep to 22-Nov	10	18-Oct	8.7	24-Sep to 21-Oct	18	21-Oct	19.4	06-Sep to 22-Nov
Two sample KS Test:		H_o: Stationary < Mobile; d = 0.23, p = 0.597				H_o: Stationary < Mobile; d = 0.80, p = 0.118				H_o: Stationary < Mobile; d = 0.083, p = 0.960			
1	Combined	30	20-Nov	20.6	11-Aug to 17-Dec	13	22-Nov	26.4	11-Aug to 17-Dec	17	20-Nov	15.6	06-Oct to 17-Dec
2		34	21-Oct	18.4	06-Sep to 22-Nov	12	14-Oct	13.1	09-Sep to 21-Oct	22	21-Oct	16.5	06-Sep to 22-Nov
Two Sample KS Test		**H_o: 2012 > 2013; d = 0.71, p < 0.001**				**H_o: 2012 > 2013; d = 0.86, p < 0.001**				**H_o: 2012 > 2013; d = 0.66, p < 0.001**			
1	Stationary	18	20-Nov	22.7	12-Sep to 17-Dec	7	20-Nov	33.5	12-Sep to 17-Dec	11	20-Nov	13.5	30-Oct to 17-Dec
2		6	21-Oct	24.0	09-Sep to 22-Nov	2	23-Sep	19.8	09-Sep to 07-Oct	4	21-Oct	16.0	21-Oct to 22-Nov
Two sample KS Test:		**H_o: 2012 > 2013; d = 0.78, p = 0.004**				H_o: 2012 > 2013; d = 0.86, p = 0.102				H_o: 2012 > 2013; d = 0.75, p = 0.037			
1	Mobile	12	20-Nov	18.0	06-Oct to 12-Dec	6	2-Dec	14.6	07-Nov to 12-Dec	6	20-Nov	18.4	06-Oct to 20-Nov
2		28	21-Oct	17.3	06-Sep to 22-Nov	10	18-Oct	8.7	24-Sep to 21-Oct	18	21-Oct	19.4	06-Sep to 22-Nov
Two sample KS Test:		**H_o: 2012 > 2013; d = 0.74, p < 0.001**				**H_o: 2012 > 2013; d = 1.0, p < 0.001**				H_o: 2012 > 2013; d = 0.56, p = 0.062			

Table A1.11. Absolute distance male and female CCT travelled to initial overwintering areas. Note that CCT captured within overwintering areas have been excluded. Summary includes distance travelled in mainstem (rkm), tributaries (tkm) and in total (rkm + tkm).

Year	**Sex**	**Absolute Distance (rkm)**				**Absolute Distance (tkm)**				**Absolute Distance (rkm + tkm)**			
		n	**Mean**	**SE**	**Range**	**n**	**Mean**	**SE**	**Range**	**n**	**Mean**	**SE**	**Range**
Combined	**Male**	11	6.2	1.8	0.0 - 19.2	11.0	1.5	0.7	0.0 - 6.1	11	7.7	1.6	0.8 - 19.2
	Female	31	9.2	1.2	0.0 - 22.0	31.0	0.8	0.4	0.0 - 12.0	31	10.1	1.1	1.0 - 22.0
Welch's two sample t:		t(40.2) = -2.00, p = 0.05				t(36.3) = 1.18, p = 0.25				t(76.7) = -2.21, p = 0.03			
1	**Male**	5	2.6	1.0	0.0 - 5.0	5	1.8	1.1	0.0 - 5.9	5	4.4	1.0	1.9 - 7.0
	Female	12	8.8	1.7	0.0 - 20.8	12	0.4	0.2	0.0 - 2.6	12	9.2	1.7	1.0 - 20.8
Welch's two sample t:		**t(15.0) = -3.18, p = 0.006**				t(4.3) = 1.28, p = 0.27				t(15.0) = -2.46, p = 0.03			
2	**Male**	6	9.3	2.7	0.0 - 19.2	6	1.2	1.0	0.0 - 6.1	6	10.5	2.4	0.8 - 19.2
	Female	19	9.5	1.6	0.0 - 22.0	19	1.1	0.6	0.0 - 12.0	19	10.6	1.5	1.0 - 22.0
Welch's two sample t:		t(8.8) = -0.07, p = 0.94				t(9.7) = 0.094, p = 0.93				t(9.1) = -0.043, p = 0.97			
1	**Combined**	17	7.0	1.4	0.0 - 20.8	17	0.8	0.4	0.0 - 5.9	17	7.8	1.3	1.0 - 20.8
2		25	9.5	1.4	0.0 - 22.0	25	1.1	0.5	0.0 - 12.0	25	10.6	1.2	0.8 - 22.0
Welch's two sample t:		t(78.3) = -1.82, p = 0.07				t(79.6) = -0.68, p = 0.50				t(42.0) = -1.72, p = 0.09			
1	**Male**	5	2.6	1.0	0.0 - 5.0	5	1.8	1.1	0.0 - 5.9	5	4.4	1.0	1.9 - 7.0
2		6	9.3	2.7	0.0 - 19.2	6	1.2	1.0	0.0 - 6.1	6	10.5	2.4	0.8 - 19.2
Welch's two sample t:		t(6.3) = -2.31, p = 0.06				t(8.6) = 0.41, p = 0.69				t(6.7) = -2.34, p = 0.05			
1	**Female**	12	8.8	1.7	0.0 - 20.8	12	0.4	0.2	0.0 - 2.6	12	9.2	1.7	1.0 - 20.8
2		19	9.5	1.6	0.0 - 22.0	19	1.1	0.6	0.0 - 12.0	19	10.6	1.5	1.0 - 22.0
Welch's two sample t:		t(26.8) = -0.3, p = 0.76				t(21.6) = -1.03, p = 0.31				t(25.3) = -0.63, p = 0.53			

Table A1.12. Absolute distance mobile and stationary CCT travelled to initial overwintering areas. Note that CCT captured within overwintering areas have been excluded. Summary includes distance travelled in mainstem (rkm), tributaries (tkm) and in total (rkm + tkm). Significant tests results are presented in bold.

Year	**Winter Behaviour**	**Absolute Distance (rkm)**				**Absolute Distance (tkm)**				**Absolute Distance (rkm + tkm)**			
		n	**Mean**	**SE**	**Range**	**n**	**Mean**	**SE**	**Range**	**n**	**Mean**	**SE**	**Range**
Combined	**Stationary**	25	7.2	1.5	0.0 - 20.8	25	1.0	0.4	0.0 - 5.9	25	8.2	1.4	1.0 - 20.8
	Mobile	15	9.4	1.4	0.0 - 22.0	15	1.1	0.5	0.0 -12.0	15	10.5	1.3	0.8 - 22.0
Welch's two sample t:		t(69.5) = -1.25, p = 0.22				t(82.0) = -1.0, p = 0.31				t(76.7) = -2.07, p = 0.041			
1	**Stationary**	11	7.3	2.0	0.0 - 20.8	11	0.9	0.5	0.0 - 5.9	6	8.2	1.8	1.0 - 20.8
	Mobile	6	6.4	1.9	0.5 - 11.1	6	0.6	0.4	0.0 - 2.6	11	7.0	2.1	1.1 - 13.1
Welch's two sample t:		t(13.5) = 0.32, p = 0.76				t(14.9) = 0.50, p = 0.62				t(11.9) = 0.45, p = 0.66			
2	**Stationary**	4	7.2	2.5	1.9 - 13.4	4	1.2	0.9	0.3 - 3.9	4	8.4	2.4	2.2 - 13.7
	Mobile	19	10.5	1.7	0.0 - 22.0	19	1.2	0.7	0.0 - 12.0	19	11.7	1.5	0.8 - 22.0
Welch's two sample t:		t(6.3) = -0.89, p = 0.40				t(7.4) = -0.21, p = 0.84				t(5.6) = -1.06, p = 0.33			
1	**Combined**	17	7.0	1.4	0.0 - 20.8	17	0.8	0.4	0.0 - 5.9	17	7.8	1.3	1.0 - 20.8
2		23	9.9	1.5	0.0 - 22.0	23	1.2	0.6	0.0 -12.0	23	11.1	1.3	0.8 - 22.0
Welch's two sample t:		t(79.4) = -1.56, p = 0.12				t(77.9) = -0.47, p = 0.64				t(68.8) = -1.56, p = 0.12			
1	**Stationary**	11	7.3	2.0	0.0 - 20.8	11	0.9	0.5	0.0 - 5.9	11	8.2	1.8	1.0 - 20.8
2		4	7.2	2.5	1.9 - 13.4	4	1.2	0.9	0.3 - 3.9	4	8.4	2.4	2.2 - 13.7
Welch's two sample t:		t(7.0) = 0.03, p = 0.98				t(5.2) = -0.26, p = 0.81				t(6.6) = -0.06, p = 0.95			
1	**Mobile**	6	6.4	1.9	0.5 - 11.1	6	0.6	0.4	0.0 - 2.6	6	7.0	2.1	1.1 - 13.1
2		19	10.5	1.7	0.0 - 22.0	19	1.2	0.7	0.0 - 12.0	19	11.7	1.5	0.8 - 22.0
Welch's two sample t:		t(13.9) = -1.35, p = 0.20				t(22.8) = -1.03, p = 0.31				t(10.7) = -1.72, p = 0.11			

Table A1.13. Summary of the number of overwintering habitats (OW) mobile CCT occupied; the mainstem river position (rkm) of final overwintering habitats for mobile CCT relative to initial overwintering habitats; the mean distance separating overwintering habitats, and; the total absolute distance male and female CCT moved between overwintering habitats. Significant tests results are presented in bold.

Year	**Sex**	**Number of OW habitats Occupied**				**Relative Position of OW**				**Mean Distance of**				**Total Absolute Distance Moved (rkm +**			
		n	**Mean**	**SE**	**Range**	**n**	**Mean**	**SE**	**Range**	**n**	**Mean**	**SE**	**Range**	**n**	**Mean**	**SE**	**Range**
Combined	Male	12	2.6	0.2	2 - 4	12	-0.9	2.3	-12.1 to 12.3	21	6.8	0.9	2.1 - 15.0	12	10.4	1.6	2.9 to 23
	Female	17	2.7	0.2	2 - 5	17	-2.3	1.4	-17.9 to 6.2	39	4.8	0.5	1.1 - 11.6	17	8.2	1.7	1.4 to 31.3
Welch's two sample t:		t(21.2) = -0.29, p = 0.77				t(19.0) = 0.53, p = 0.60				t(30.0) = 1.90, p = 0.07				t(26.8) = 0.98, p = 0.34			
1	Male	10	2.6	0.2	2 - 4	5	-5.2	2.8	-12.1 to 4.4	10	5.8	1.4	2.1 - 15.0	5	12.6	3.3	5 to 23.5
	Female	19	2.7	0.2	2 - 5	5	-3.6	2.3	-10.4 to 1.3	7	5.5	1.4	1.3 - 10.7	5	6.3	2.0	1.3 to 11
Welch's two sample t:		t(26.6) = -0.43, p = 0.67				t(7.8) = -0.42, p = 0.68				t(14.1) = 0.16, p = 0.88				t(6.7) = 1.65, p = 0.15			
2	Male	5	3.0	0.3	2 - 4	7	2.1	2.9	-9.3 to 12.3	11	7.6	1.3	2.7 - 13.4	7	11.8	2.4	3 to 22.2
	Female	5	2.2	0.2	2 - 3	12	-1.8	1.7	-17.9 to 6.2	32	4.6	0.5	1.1 - 11.6	12	9.4	2.6	2.2 to 33.4
Welch's two sample t:		t(6.8) = 2.14, p = 0.07				t(10.4) = 1.15, p = 0.28				t(12.8) = 2.14, p = 0.05				t(15.9) = 0.68, p = 0.51			
1	Combined	7	2.3	0.2	2 - 3	10	-4.4	1.7	-12.1 to 4.4	17	5.7	1.0	1.3 - 15.0	10	9.5	2.1	1.3 to 23.5
2		12	2.9	0.3	2 - 5	19	-0.3	1.6	-17.9 to 12.3	43	5.4	0.5	1.1 - 13.4	19	10.3	1.8	2.2 to 33.4
Welch's two sample t:		t(17.0) = -1.98, p = 0.06				t(22.1) = -1.73, p = 0.10				t(26.0) = 0.32, p = 0.75				t(21.5) = -0.3, p = 0.76			
1	Male	5	3.0	0.3	2 - 4	5	-5.2	2.8	-12.1 to 4.4	10	5.8	1.4	2.1 - 15.0	5	12.6	3.3	5 to 23.5
2		7	2.3	0.2	2 - 3	7	2.1	2.9	-9.3 to 12.3	11	7.6	1.3	2.7 - 13.4	7	11.8	2.4	3 to 22.2
Welch's two sample t:		t(6.7) = 1.95, p = 0.09				t(9.7) = -1.79, p = 0.10				t(18.9) = -0.93, p = 0.37				t(8) = 0.2, p = 0.85			
1	Female	5	2.2	0.2	2 - 3	5	-3.6	2.3	-10.4 to 1.3	7	5.5	1.4	1.3 - 10.7	5	6.3	2.0	1.3 to 11
2		12	2.9	0.3	2 - 5	12	-1.8	1.7	-17.9 to 6.2	32	4.6	0.5	1.1 - 11.6	12	9.4	2.6	2.2 to 33.4
Welch's two sample t:		t(14.2) = -2.18, p = 0.05				t(8.9) = -0.64, p = 0.54				t(7.4) = 0.62, p = 0.55				t(13.9) = -0.96, p = 0.35			

Table A1.14. Timing that staging and non-staging male and female CCT departed from final overwintering habitats in year 1 and year 2. Significant tests results are presented in bold.

Year	Sex	Staging & Non-Staging				Non-Staging				Staging				Two-sample KS test: Non-Staging vs Staging CCT
		n	Median	SD	Range	n	Median	SD	Range	n	Median	SD	Range	
Combined	Male	20	31-Mar	13.1	04-Mar to 28-Apr	10	1-Apr	4.5	15-Mar to 28-Apr	10	30-Mar	3.6	04-Mar to 09-Apr	Ho: Non Stage < Stage; p = 0.78, D = 0.07
	Female	33	07-Apr	11.3	06-Mar to 05-May	17	5-Apr	2.6	06-Mar to 19-Apr	16	8-Apr	3.0	20-Mar to 05-May	Ho: Non Stage < Stage; p = 0.78, D = 0.07
Two sample KS test:		Ho: Male < Female; p = 0.11, D = 0.30				Ho: Male < Female; p = 0.48, D = 0.24				Ho: Male < Female; p = 0.08, D = 0.45				-
1	Male	12	28-Mar	10.0	13-Mar to 14-Apr	5	23-Mar	5.1	15-Mar to 14-Apr	7	28-Mar	3.6	13-Mar to 09-Apr	Ho: Non Stage < Stage; p = 0.30, D = 0.46
	Female	16	05-Apr	12.0	06-Mar to 19-Apr	9	5-Apr	4.5	06-Mar to 19-Apr	7	5-Apr	4.2	20-Mar to 19-Apr	Ho: Non Stage < Stage; p = 0.79, D = 0.17
Two sample KS test:		Ho: Male < Female, p = 0.49, D = 0.23				Ho: Male < Female; p = 0.22, D = 0.49				Ho: Male < Female; p = 0.87, D = 0.14				-
2	Male	8	02-Apr	16.6	04-Mar to 28-Apr	5	7-Apr	5.6	31-Mar to 28-Apr	3	1-Apr	9.3	04-Mar to 01-Apr	Ho: Non Stage > Stage; p = 0.09, D = 0.8
	Female	17	08-Apr	9.7	28-Mar to 05-May	8	7-Apr	2.3	28-Mar to 17-Apr	9	11-Apr	3.9	28-Mar to 05-May	Ho: Non Stage < Stage; p = 0.66, D = 0.22
Two sample KS test:		Ho: Male < Female; p = 0.30, D = 0.33				Ho: Male > Female; p = 0.37, D = 0.4				Ho: Male < Female; p = 0.03, D = 0.89				-
1	Combined	28	28-Mar	11.3	06-Mar to 19-Apr	14	28-Mar	3.4	06-Mar to 19-Apr	14	1-Apr	2.7	13-Mar to 19-Apr	Ho: Non Stage < Stage; p = 0.56, D = 0.14
2		25	07-Apr	12.2	04-Mar to 05-May	13	7-Apr	2.6	28-Mar to 28-Apr	12	6-Apr	4.4	04-Mar to 05-May	Ho: Non Stage < Stage; p = 0.42, D = 0.19
Two sample KS test:		**Ho: Year 1 < Year 2; p < 0.001, D = 0.42**				**Ho: Year 1 < Year 2; p = 0.001, D = 0.49**				Ho: Year 1 < Year 2; p = 0.05, D = 0.35				-
1	Male	12	28-Mar	10.0	13-Mar to 14-Apr	5	23-Mar	5.1	15-Mar to 14-Apr	7	28-Mar	3.6	13-Mar to 09-Apr	-
2		8	02-Apr	16.6	04-Mar to 28-Apr	5	7-Apr	5.6	31-Mar to 28-Apr	3	1-Apr	9.3	04-Mar to 01-Apr	-
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.06, D = 0.54				Ho: Year 1 < Year 2; p = 0.04, D = 0.8				Ho: Year 1 > Year 2; p = 0.46, D = 0.43				-
1	Female	16	05-Apr	12.0	06-Mar to 19-Apr	9	5-Apr	4.5	06-Mar to 19-Apr	7	5-Apr	4.2	20-Mar to 19-Apr	-
2		17	08-Apr	9.7	28-Mar to 05-May	8	7-Apr	2.3	28-Mar to 17-Apr	9	11-Apr	3.9	28-Mar to 05-May	-
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.19, D = 0.32				Ho: Year 1 < Year 2; p = 0.42, D = 0.32				Ho: Year 1 < Year 2; p = 0.26, D = 0.41				-

Table A1.15. Timing that staging and non-staging mobile and stationary CCT departed from final overwintering habitats in year 1 and year 2. Significant tests results are presented in bold.

Year	**Migration Type**	**Staging & Non-Staging**				**Non-Staging**				**Staging**				**Two-sample KS test: Non-Staging vs Staging CCT**
		n	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**	
Combined	Stationary	24	05-Apr	10.6	06-Mar to 19-Apr	12	04-Apr	13.1	06-Mar to 19-Apr	12	08-Apr	7.35	21-Mar to 19-Apr	Ho: Non Stage > Stage; p = 0.42, D = 0.19
	Mobile	29	02-Apr	13.6	04-Mar to 05-May	15	07-Apr	10.9	21-Mar to 28-Apr	14	30-Mar	16.2	04-Mar to 05-May	Ho: Non Stage > Stage; p = 0.56, D = 0.14
Two sample KS test:		Ho: Stationary > Mobile; p = 0.41, D = 0.18				Ho: Stationary < Mobile; p = 0.59, D = 0.2				Ho: Stationary > Mobile; p = 0.14, D = 0.39				-
1	Stationary	18	05-Apr	11.5	06-Mar to 19-Apr	9	28-Mar	13.7	06-Mar to 19-Apr	9	09-Apr	8.24	21-Mar to 19-Apr	Ho: Non Stage < Stage; p = 0.37, D = 0.33
	Mobile	10	28-Mar	10.5	13-Mar to 19-Apr	5	28-Mar	12.3	21-Mar to 19-Apr	5	28-Mar	6.77	13-Mar to 28-Mar	Ho: Non Stage > Stage; p = 0.45, D = 0.4
Two sample KS test:		Ho: Stationary > Mobile; p = 0.11, D = 0.41				Ho: Stationary < Mobile; p = 0.73, D = 0.22				Ho: Stationary > Mobile; p = 0.02, D = 0.78				-
2	Stationary	6	09-Apr	5.89	01-Apr to 17-Apr	3	11-Apr	7.0	03-Apr to 17-Apr	3	07-Apr	5.03	01-Apr to 11-Apr	Ho: Non Stage = Stage; p = 0.72, D = 0.33
	Mobile	19	07-Apr	13.8	04-Mar to 05-May	10	7-Apr	10.0	28-Mar to 28-Apr	9	05-Apr	17.7	04-Mar to 05-May	Ho: Non Stage = Stage; p = 0.8, D = 0.16
Two sample KS test:		Ho: Stationary > Mobile; p = 0.53, D = 0.26				Ho: Stationary > Mobile; p = 0.54, D = 0.37				Ho: Stationary > Mobile; p = 0.61, D = 0.33				-
1	Combined	28	28-Mar	11.3	06-Mar to 19-Apr	14	28-Mar	12.8	06-Mar to 19-Apr	14	01-Apr	10	13-Mar to 19-Apr	Ho: Non Stage > Stage; p = 0.41, D = 0.25
2		25	07-Apr	12.2	04-Mar to 05-May	13	07-Apr	9.2	28-Mar to 28-Apr	12	06-Apr	15.3	04-Mar to 05-May	Ho: Non Stage = Stage; p = 0.47, D = 0.25
Two sample KS test:		**Ho: Year 1 < Year 2; p < 0.001, D = 0.42**				**Ho: Year 1 < Year 2; p = 0.001, D = 0.49**				Ho: Year 1 < Year 2; p = 0.05, D = 0.35				-
1	Stationary	18	05-Apr	11.5	06-Mar to 19-Apr	9	28-Mar	13.7	06-Mar to 19-Apr	9	09-Apr	8.24	21-Mar to 19-Apr	-
2		6	09-Apr	5.89	01-Apr to 17-Apr	3	11-Apr	7.0	03-Apr to 17-Apr	3	07-Apr	5.03	01-Apr to 11-Apr	-
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.26, D = 0.39				Ho: Year 1 < Year 2; p = 0.25, D = 0.56				Ho: Year 1 < Year 2; p = 0.80, D = 0.22				-
1	Mobile	10	28-Mar	10.5	13-Mar to 19-Apr	5	28-Mar	12.3	21-Mar to 19-Apr	5	28-Mar	6.77	13-Mar to 28-Mar	-
2		19	07-Apr	13.8	04-Mar to 05-May	10	7-Apr	10.0	28-Mar to 28-Apr	9	05-Apr	17.7	04-Mar to 05-May	-
Two sample KS test:		**Ho: Year 1 < Year 2; p = 0.004; D = 0.64**				Ho: Year 1 < Year 2; p = 0.19, D = 0.5				Ho: Year 1 < Year 2; p = 0.02, D = 0.78				-

Table A1.16. Summary of absolute distances travelled by male and female CCT from overwintering to spawning habitats, from overwinter to staging habitats, and from staging to spawning habitats in year 1 and year 2. Significant tests results are presented in bold.

Year	Sex	OW to Stage				Stage to Spawn			
		n	Mean	SE	Range	n	Mean	SE	Range
Combined	Male	10	6.2	3.5	0.1 - 36.2	10	3.2	0.5	0.8 - 5.7
	Female	16	4.5	1.2	0.1 - 14.8	14	5.7	1.0	1.7 - 14.0
Welch's two sample t:		t(11.0) = 0.47, p = 0.65				t(-2.3) = 19.06, p = 0.04			
1	Male	7	3.5	1.2	0.1 - 9.5	7	3.2	0.6	0.8 - 5.2
	Female	7	4.4	1.9	0.2 - 14.8	6	4.2	0.9	1.7 - 8.1
Welch's two sample t:		t(10.3) = -0.42, p = 0.68				t(-1.0) = 8.27, p = 0.37			
2	Male	3	12.7	11.8	0.7 - 36.2	3	3.1	1.4	0.8 - 5.7
	Female	9	4.6	1.5	0.1 - 14.0	8	6.9	1.5	2.4 - 14.0
Welch's two sample t:		t(2.1) = 0.68, p = 0.56				t(-1.8) = 6.82, p = 0.12			
1	Combined	14	4.0	1.1	0.1 - 14.8	13	3.6	0.5	0.8 - 8.1
2		12	6.6	2.9	0.1 - 36.2	11	5.8	1.3	0.8 - 14.0
Welch's two sample t:		t(14.0) = -0.85, p = 0.41				t(-1.6) = 13.42, p = 0.13			
1	Male	7	3.5	1.2	0.1 - 9.5	7	3.2	0.6	0.8 - 5.2
2		3	12.7	11.8	0.7 - 36.2	3	3.1	1.4	0.8 - 5.7
Welch's two sample t:		t(2.0) = -0.78, p = 0.52				t(0.01) = 2.64, p = 0.99			
1	Female	7	4.4	1.9	0.2 - 14.8	6	4.2	0.9	1.7 - 8.1
2		9	4.6	1.5	0.1 - 14.0	8	6.9	1.5	2.4 - 14.0
Welch's two sample t:		t(12.4) = -0.07, p = 0.94				t(-1.5) = 11.03, p = 0.17			

Table A1.17. Summary of absolute distances travelled by stationary and mobile CCT from overwintering to spawning habitats, from overwinter to staging habitats, and from staging to spawning habitats in year 1 and year 2. Significant tests results are presented in bold.

Year	Migration Type	OW to Stage				Stage to Spawn			
		n	Mean	SE	Range	n	Mean	SE	Range
Combined	Stationary	12	2.6	0.6	0.1 - 5.8	11	3.6	0.6	0.8 - 8.1
	Mobile	14	7.4	2.6	0.1 - 36.2	13	5.5	1.1	0.8 - 14.0
Welch's two sample t:		t(14.5) = -1.80, p = 0.09				t(-1.5) = 18.94, p = 0.16			
1	Stationary	9	2.6	0.8	0.1 - 5.8	8	3.3	0.8	0.8 - 8.1
	Mobile	5	6.3	2.6	1.4 - 14.8	5	4.2	0.6	2.9 - 5.6
Welch's two sample t:		t(4.7) = -1.39, p = 0.23				t(-1.0) = 10.97, p = 0.33			
2	Stationary	3	2.6	1.0	1.2 - 4.6	3	4.7	1.0	2.7 - 5.7
	Mobile	9	8.0	3.9	0.1 - 36.2	8	6.3	1.7	0.8 - 14
Welch's two sample t:		t(9.0) = -1.35, p = 0.21				t(-0.8) = 8.97, p = 0.44			
1	Combined	14	4.0	1.1	0.1 - 14.8	13	3.6	0.5	0.8 - 8.1
2		12	6.6	2.9	0.1 - 36.2	11	5.8	1.3	0.8 - 14.0
Welch's two sample t:		t(14.0) = -0.85, p = 0.41				t(-1.6) = 13.42, p = 0.13			
1	Stationary	9	2.6	0.8	0.1 - 5.8	8	3.3	0.8	0.8 - 8.1
2		3	2.6	1.0	1.2 - 4.6	3	4.7	1.0	2.7 - 5.7
Welch's two sample t:		t(4.6) = 0.02, p = 0.99				t(-1.1) = 4.77, p = 0.32			
1	Mobile	5	6.3	2.6	1.4 - 14.8	5	4.2	0.6	2.9 - 5.6
2		9	8.0	3.9	0.1 - 36.2	8	6.3	1.7	0.8 - 14.0
Welch's two sample t:		t(12) = -0.35, p = 0.73				t(-1.1) = 8.38, p = 0.29			

Table A1.18. Median timing that male and female CCT arrived in, and departed from, pre-spawn staging habitats in year 1 and year 2. Significant tests results are presented in bold.

Year	Sex	Arrival to pre-spawn staging				Departure from pre-spawn staging			
		n	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**
1	Combined	12	11-Apr	10.5	28-Mar to 01-May	11	19-Apr	10.0	28-Mar to 06-May
2		10	12-Apr	7.1	07-Apr to 28-Apr	10	27-Apr	6.0	14-Apr to 01-May
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.023, D = 0.42				**Ho: Year 1 < Year 2; p < 0.001, D = 0.61**			
Combined	Male	9	9-Apr	8.9	28-Mar to 23-Apr	8	17-Apr	6.7	05-Apr to 28-Apr
	Female	13	14-Apr	9.1	28-Mar to 01-May	13	23-Apr	9.9	28-Mar to 06-May
Two sample KS test:		Ho: Male < Female; p = 0.061, D = 0.51				Ho: Male < Female; p = 0.184, D = 0.41			
1	Male	6	7-Apr	9.0	28-Mar to 19-Apr	5	14-Apr	6.5	05-Apr to 22-Apr
	Female	6	14-Apr	11.7	28-Mar to 01-May	6	19-Apr	12.6	28-Mar to 06-May
Two sample KS test:		Ho: Male < Female; p = 0.51, D = 0.33				Ho: Male < Female; p = 0.68, D = 0.27			
2	Male	3	9-Apr	8.7	07-Apr to 23-Apr	3	17-Apr	6.4	17-Apr to 28-Apr
	Female	7	14-Apr	6.7	11-Apr to 28-Apr	7	28-Apr	5.6	14-Apr to 01-May
Two sample KS test:		Ho: Male < Female; p = 0.15, D = 0.67				Ho: Male < Female; p = 0.32, D = 0.52			
1	Male	6	7-Apr	9.0	28-Mar to 19-Apr	5	14-Apr	6.5	05-Apr to 22-Apr
2		3	9-Apr	8.7	07-Apr to 23-Apr	3	17-Apr	6.4	17-Apr to 28-Apr
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.37, D = 0.5				Ho: Year 1 < Year 2; p = 0.26, D = 0.6			
1	Female	6	14-Apr	11.7	28-Mar to 01-May	6	19-Apr	12.6	28-Mar to 06-May
2		7	14-Apr	6.7	11-Apr to 28-Apr	7	28-Apr	5.6	14-Apr to 01-May
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.49, D = 0.33				Ho: Year 1 < Year 2; p = 0.046, D = 0.69			

Table A1.19. Median timing that mobile and stationary CCT arrived in, and departed from, staging habitats in year 1 and year 2. Significant tests results are presented in bold.

Year	**Migration Type**	**Arrival to pre-spawn staging**				**Departure from pre-spawn staging**			
		n	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**
1	Combined	12	11-Apr	10.5	28-Mar to 01-May	11	19-Apr	10.0	28-Mar to 06-May
2		10	12-Apr	7.1	07-Apr to 28-Apr	10	27-Apr	6.0	14-Apr to 01-May
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.023, D = 0.42				**Ho: Year 1 < Year 2; p < 0.001, D = 0.61**			
Combined	Stationary	10	14-Apr	10.2	28-Mar to 01-May	9	19-Apr	10.7	28-Mar to 06-May
	Mobile	12	11-Apr	9.0	28-Mar to 28-Apr	12	21-Apr	7.8	05-Apr to 01-May
Two sample KS test:		Ho: Stationary > Mobile; p = 0.69, D = 0.18				Ho: Stationary < Mobile; p = 0.383, D = 0.31			
1	Stationary	7	14-Apr	12.3	28-Mar to 01-May	6	20-Apr	12.8	28-Mar to 06-May
	Mobile	5	5-Apr	6.2	28-Mar to 14-Apr	5	14-Apr	5.7	05-Apr to 19-Apr
Two sample KS test:		Ho: Stationary < Mobile; p = 0.21, D = 0.51				Ho: Stationary < Mobile; p = 0.26, D = 0.5			
2	Stationary	3	11-Apr	2.5	09-Apr to 14-Apr	3	17-Apr	6.8	14-Apr to 27-Apr
	Mobile	7	17-Apr	7.8	07-Apr to 28-Apr	7	28-Apr	4.7	17-Apr to 01-May
Two sample KS test:		Ho: Stationary < Mobile; p = 0.25, D = 0.57				Ho: Stationary < Mobile; p = 0.117, D = 0.71			
1	Stationary	7	14-Apr	12.3	28-Mar to 01-May	6	20-Apr	12.8	28-Mar to 06-May
2		3	11-Apr	2.5	09-Apr to 14-Apr	3	17-Apr	6.8	14-Apr to 27-Apr
Two sample KS test:		Ho: Year 1 > Year 2; p = 0.46, D = 0.43				Ho: Year 1 > Year 2; p = 0.64, D = 0.33			
1	Mobile	5	5-Apr	6.2	28-Mar to 14-Apr	5	14-Apr	5.7	05-Apr to 19-Apr
2		7	17-Apr	7.8	07-Apr to 28-Apr	7	28-Apr	4.7	17-Apr to 01-May
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.081, D = 0.66				Ho: Year 1 < Year 2; p = 0.014, D = 0.86			

Table A1.20. Comparison of the total absolute distance staging and non-staging male and female CCT travelled from overwintering habitats to spawn. Significant tests results are presented in bold.

Year	**Sex**	**OW to Spawn (Staging)**				**OW to Spawn (Non-staging)**				**Welch's two sample t: Staging vs. Non-Staging**
		n	**Mean**	**SE**	**Range**	**n**	**Mean**	**SE**	**Range**	
Combined	Male	10	8.9	3.3	2.5 - 37.0	10	12.5	3.5	2.4 - 33.0	t(18.0) = -0.74, p = 0.47
	Female	14	9.0	1.3	1.9 - 17.8	13	16.5	2.7	2.8 - 35.1	t(17.0) = -2.46, p = 0.02
Welch's two sample t:		t(0.0) = 11.68, p = 0.98				t(18.4) = -0.91, p = 0.38				-
1	Male	7	6.3	1.6	2.5 - 14.0	5	16.7	6.5	2.5 - 33.0	t(4.5) = -1.55, p = 0.19
	Female	6	8.4	2.2	1.9 - 17.8	7	11.4	2.1	2.8 - 17.5	t(10.7) = -1.01, p = 0.33
Welch's two sample t:		t(-0.8) = 9.29, p = 0.46				t(4.8) = 0.77, p = 0.48				-
2	Male	3	15.0	11.0	3.6 - 37.0	5	8.2	1.7	2.4 - 12.7	t(2.1) = 0.61, p = 0.60
	Female	8	9.5	1.6	2.9 - 16.4	6	22.4	4.5	7.1 - 35.1	t(6.3) = -2.69, p = 0.03
Welch's two sample t:		t(0.5) = 2.09, p = 0.67				t(6.3) = -2.94, p = 0.02				-
1	Combined	13	7.3	1.3	1.9 - 17.8	12	13.6	2.9	2.5 - 33.0	t(15.2) = -2.00, p = 0.06
2		11	11.0	2.9	2.9 - 37.0	11	16.0	3.3	2.4 - 35.1	t(19.7) = -1.12, p = 0.28
Welch's two sample t:		t(-1.2) = 13.87, p = 0.26				t(20.3) = -0.53, p = 0.60				-
1	Male	7	6.3	1.6	2.5 - 14.0	5	16.7	6.5	2.5 - 33.0	-
2		3	15.0	11.0	3.6 - 37.0	5	8.2	1.7	2.4 - 12.7	-
Welch's two sample t:		t(-0.8) = 2.08, p = 0.51				t(4.5) = 1.26, p = 0.27				-
1	Female	6	8.4	2.2	1.9 - 17.8	7	11.4	2.1	2.8 - 17.5	-
2		8	9.5	1.6	2.9 - 16.4	6	22.4	4.5	7.1 - 35.1	-
Welch's two sample t:		t(-0.4) = 9.76, p = 0.68				t(7.1) = -2.21, p = 0.06				-

Table A1.21. Comparison of the total absolute distance staging and non-staging mobile and stationary CCT travelled from overwintering habitats to spawn. Significant tests results are presented in bold.

Year	Migration	OW to Spawn (Staging)				OW to Spawn (Non-staging)				Welch's two sample t:
	Type	n	Mean	SE	Range	n	Mean	SE	Range	Staging vs. Non-Staging
Combined	Stationary	11	5.6	0.8	1.9 - 9.4	11	12.9	2.6	2.5 - 32.1	t(11.9) = -2.73, p = 0.02
	Mobile	13	11.9	2.5	2.9 - 37.0	12	16.5	3.4	2.4 - 35.1	t(20.4) = -1.08, p = 0.29
Welch's two sample t:		t(-2.4) = 14.36, p = 0.03				t(19.8) = -0.84, p = 0.41				-
1	Stationary	8	5.3	1.0	1.9 - 9.4	8	12.8	3.4	2.5 - 32.1	t(8.3) = -2.11, p = 0.07
	Mobile	5	10.5	2.4	4.8 - 17.8	4	15.3	6.0	7.6 - 33.0	t(3.9) = -0.73, p = 0.51
Welch's two sample t:		t(-2) = 5.54, p = 0.10				t(5) = -0.35, p = 0.74				-
2	Stationary	3	6.4	1.0	4.5 - 7.4	3	12.9	2.9	7.1 - 16.3	t(2.1) = 0.87, p = 0.47
	Mobile	8	12.8	3.9	2.9 - 37.0	8	17.1	4.5	2.4 - 35.1	t(12.0) = -1.45, p = 0.17
Welch's two sample t:		t(-1.6) = 7.77, p = 0.15				t(8.7) = -0.78, p = 0.46				-
1	Combined	13	7.3	1.3	1.9 - 17.8	12	13.6	2.9	2.5 - 33.0	t(15.2) = -2.00, p = 0.06
2		11	11.0	2.9	2.9 - 37.0	11	16.0	3.3	2.4 - 35.1	t(19.7) = -1.12, p = 0.28
Welch's two sample t:		t(-1.2) = 13.87, p = 0.26				t(20.3) = -0.53, p = 0.59				-
1	Stationary	8	5.3	1.0	1.9 - 9.4	8	12.8	3.4	2.5 - 32.1	-
2		3	6.4	1.0	4.5 - 7.4	3	12.9	2.9	7.1 - 16.3	-
Welch's two sample t:		t(-0.8) = 6.86, p = 0.44				t(7.3) = -0.02, p = 0.98				-
1	Mobile	5	10.5	2.4	4.8 - 17.8	4	15.3	6.0	7.6 - 33.0	-
2		8	12.8	3.9	2.9 - 37.0	8	17.1	4.5	2.4 - 35.1	-
Welch's two sample t:		t(-0.5) = 10.65, p = 0.63				t(6.4) = -0.25, p = 0.81				-

Table A1.22. Date that male and female staging and non-staging CCT arrived in spawning tributaries in year 1 and year 2. Comparisons between staging and non-staging CCT are presented in the final column. Significant tests results are presented in bold.

Year	**Sex**	**Staging & Non-Staging**				**Non-Staging**				**Staging**				**Two sample KS Test:**
		n	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**	**Non-staging vs Staging CCT**
Combined	Male	20	23-Apr	11.0	28-Mar to 05-May	10	16-Apr	12.2	28-Mar to 05-May	10	27-Apr	9.0	05-Apr to 05-May	Ho: Non-Staging < Staging; p = 0.20, D = 0.40
	Female	27	28-Apr	10.2	05-Apr to 09-May	13	27-Apr	9.1	06-Apr to 01-May	14	1-May	11.2	05-Apr to 09-May	Ho: Non-Staging < Staging; p = 0.22, D = 0.34
Two sample KS test:		Ho: Male < Female; p = 0.29, D = 0.23				Ho: Male < Female; p = 0.32, D = 0.32				Ho: Male < Female; p = 0.10, D = 0.44				-
1	Male	12	19-Apr	10.3	28-Mar to 29-Apr	5	14-Apr	9.6	28-Mar to 19-Apr	7	27-Apr	9.0	05-Apr to 29-Apr	Ho: Non-Staging < Staging; p = 0.15, D = 0.57
	Female	13	27-Apr	11.5	05-Apr to 06-May	7	27-Apr	10.4	06-Apr to 01-May	6	26-Apr	13.6	05-Apr to 06-May	Ho: Non-Staging < Staging; p = 0.49, D = 0.33
Two sample KS test:		Ho: Male < Female; p = 0.16, D = 0.38				Ho: Male < Female; p = 0.15, D = 0.57				Ho: Male < Female; p = 0.20, D = 0.50				-
2	Male	8	01-May	9.9	11-Apr to 05-May	5	1-May	11.8	11-Apr to 05-May	3	1-May	3.5	28-Apr to 05-May	Ho: Non-Staging < Staging; p = 0.55, D = 0.40
	Female	14	01-May	8.9	11-Apr to 09-May	6	25-Apr	8.1	11-Apr to 01-May	8	1-May	9.4	11-Apr to 09-May	Ho: Non-Staging < Staging; p = 0.30, D = 0.42
Two sample KS test:		Ho: Male < Female; p = 0.89, D = 0.11				Ho: Male > Female; p = 0.68, D = 0.27				Ho: Male > Female; p = 0.76, D = 0.25				-
1	Combined	25	19-Apr	11.0	28-Mar to 06-May	12	19-Apr	11.0	28-Mar to 01-May	13	27-Apr	10.9	05-Apr to 06-May	Ho: Non-Staging < Staging; p = 0.14, D = 0.28
2		22	01-May	9.0	11-Apr to 09-May	11	28-Apr	9.4	11-Apr to 05-May	11	1-May	8.1	11-Apr to 09-May	Ho: Non-Staging < Staging; p = 0.20, D = 0.27
Two sample KS test:		**Ho: Year 1 < Year 2; p < 0.001, D = 0.44**				Ho: Year 1 < Year 2; p = 0.04, D = 0.38				**Ho: Year 1 < Year 2; p = 0.002, D = 0.51**				-
1	Male	12	19-Apr	10.3	28-Mar to 29-Apr	5	14-Apr	9.6	28-Mar to 19-Apr	7	27-Apr	9.0	05-Apr to 29-Apr	-
2		8	01-May	9.9	11-Apr to 05-May	5	1-May	11.8	11-Apr to 05-May	3	1-May	3.5	28-Apr to 05-May	-
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.01, D = 0.67				Ho: Year 1 < Year 2; p = 0.17, D = 0.60				Ho: Year 1 < Year 2; p = 0.05, D = 0.86				-
1	Female	13	27-Apr	11.5	05-Apr to 06-May	7	27-Apr	10.4	06-Apr to 01-May	6	26-Apr	13.6	05-Apr to 06-May	-
2		14	01-May	8.9	11-Apr to 09-May	6	25-Apr	8.1	11-Apr to 01-May	8	1-May	9.4	11-Apr to 09-May	-
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.28, D = 0.31				Ho: Year 1 > Year 2; p = 0.59, D = 0.29				Ho: Year 1 < Year 2; p = 0.47, D = 0.33				-

Table A1.23. Date that mobile and stationary staging and non-staging CCT arrived in spawning tributaries in year 1 and year 2. Comparisons between staging and non-staging CCT are presented in the final column. Significant tests results are presented in bold.

Year	**Migration Type**	**Staging & Non-Staging**				**Non-Staging**				**Staging**				**Two sample KS Test: Non-staging vs Staging CCT**
		n	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**	
Combined	Stationary	22	20-Apr	10.6	28-Mar to 01-May	11	19-Apr	10.9	28-Mar to 01-May	11	27-Apr	10.4	05-Apr to 01-May	Ho: Non-Staging < Staging; p = 0.44, D = 0.27
	Mobile	25	01-May	9.7	05-Apr to 09-May	12	27-Apr	10.0	05-Apr to 05-May	13	1-May	8.8	11-Apr to 09-May	Ho: Non-Staging < Staging; p = 0.21, D = 0.35
Two sample KS test:		Ho: Stationary < Mobile; p = 0.07, D = 0.33				Ho: Stationary < Mobile; p = 0.33, D = 0.31				Ho: Stationary < Mobile; p = 0.05, D = 0.5				-
1	Stationary	16	19-Apr	11.1	28-Mar to 01-May	8	16-Apr	11.8	28-Mar to 01-May	8	24-Apr	10.9	05-Apr to 01-May	Ho: Non-Staging < Staging; p = 0.32, D = 0.38
	Mobile	9	27-Apr	10.2	05-Apr to 06-May	4	23-Apr	10.4	05-Apr to 27-Apr	5	29-Apr	10.0	14-Apr to 06-May	Ho: Non-Staging < Staging; p = 0.20, D = 0.60
Two sample KS test:		Ho: Stationary < Mobile; p = 0.45, D = 0.26				Ho: Stationary < Mobile; p = 0.72, D = 0.25				Ho: Stationary < Mobile; p = 0.25, D = 0.48				-
2	Stationary	6	25-Apr	8.1	11-Apr to 01-May	3	23-Apr	8.7	11-Apr to 28-Apr	3	1-May	8.1	17-Apr to 01-May	Ho: Non-Staging < Staging; p = 0.26, D = 0.67
	Mobile	16	01-May	9.4	11-Apr to 09-May	8	1-May	10.0	11-Apr to 05-May	8	1-May	8.4	11-Apr to 09-May	Ho: Non-Staging < Staging; p = 0.61, D = 0.25
Two sample KS test:		Ho: Stationary < Mobile; p = 0.33, D = 0.35				Ho: Stationary < Mobile; p = 0.18, D = 0.63				Ho: Stationary < Mobile; p = 0.54, D = 0.38				-
1	Combined	25	19-Apr	11.0	28-Mar to 06-May	12	19-Apr	11.0	28-Mar to 01-May	13	27-Apr	10.9	05-Apr to 06-May	Ho: Non-Staging < Staging; p = 0.14, D = 0.28
2		22	01-May	9.0	11-Apr to 09-May	11	28-Apr	9.4	11-Apr to 05-May	11	1-May	8.1	11-Apr to 09-May	Ho: Non-Staging < Staging; p = 0.20, D = 0.27
Two sample KS test:		**Ho: Year 1 < Year 2; p < 0.001, D = 0.44**				Ho: Year 1 < Year 2; p = 0.04, D = 0.38				**Ho: Year 1 < Year 2; p = 0.002, D = 0.51**				-
1	Stationary	16	19-Apr	11.1	28-Mar to 01-May	8	16-Apr	11.8	28-Mar to 01-May	8	24-Apr	10.9	05-Apr to 01-May	-
2		6	25-Apr	8.1	11-Apr to 01-May	3	23-Apr	8.7	11-Apr to 28-Apr	3	1-May	8.1	17-Apr to 01-May	-
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.29, D = 0.38				Ho: Year 1 < Year 2; p = 0.47, D = 0.42				Ho: Year 1 < Year 2; p = 0.28, D = 0.54				-
1	Mobile	9	27-Apr	10.2	05-Apr to 06-May	4	23-Apr	10.4	05-Apr to 27-Apr	5	29-Apr	10.0	14-Apr to 06-May	-
2		16	01-May	9.4	11-Apr to 09-May	8	1-May	10.0	11-Apr to 05-May	8	1-May	8.4	11-Apr to 09-May	-
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.08, D = 0.47				Ho: Year 1 < Year 2; p = 0.12, D = 0.63				Ho: Year 1 < Year 2; p = 0.47, D = 0.35				-

Table A1.24. Summary of the date that male and female staging and non-staging CCT arrived at maximum upstream relocation positions in year 1 and year 2. Note that spawn date is estimated as the median date of maximum upstream relocation position. Values presented in the last column of the table compare the arrival timing of staging and non-staging CCT. Significant tests results are presented in bold.

Year	**Sex**	**Staging & Non-Staging**				**Non-Staging**				**Staging**				**Two sample KS Test: Non-staging vs Staging CCT**
		n	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**	
Combined	Male	19	27-Apr	9.7	09-Apr to 15-May	9	19-Apr	12.0	09-Apr to 15-May	10	28-Apr	7.0	14-Apr to 09-May	Ho: Non-Staging < Staging; p = 0.14, D = 0.46
	Female	25	01-May	10.9	06-Apr to 17-May	12	30-Apr	11.5	06-Apr to 17-May	13	5-May	9.9	14-Apr to 15-May	Ho: Non-Staging < Staging; p = 0.03, D = 0.53
Two sample KS test:		Ho: Male < Female; p = 0.61, D = 0.23				Ho: Male < Female; p = 0.53, D = 0.25				Ho: Male < Female; p = 0.18, D = 0.39				-
1	Male	11	27-Apr	7.4	09-Apr to 04-May	4	19-Apr	7.4	09-Apr to 27-Apr	7	27-Apr	6.1	14-Apr to 04-May	Ho: Non-Staging < Staging; p = 0.15, D = 0.61
	Female	12	27-Apr	12.1	06-Apr to 17-May	7	27-Apr	14.2	06-Apr to 17-May	5	27-Apr	9.9	14-Apr to 06-May	Ho: Non-Staging < Staging; p = 0.62, D = 0.29
Two sample KS test:		Ho: Male > Female; p = 0.30, D = 0.33				Ho: Male < Female; p = 0.39, D = 0.43				Ho: Male < Female; p = 0.39, D = 0.40				-
2	Male	8	05-May	10.3	17-Apr to 15-May	5	5-May	12.9	17-Apr to 15-May	3	6-May	2.1	05-May to 09-May	Ho: Non-Staging < Staging; p = 0.55, D = 0.40
	Female	13	05-May	8.4	17-Apr to 15-May	5	1-May	6.8	17-Apr to 05-May	8	7-May	8.4	17-Apr to 15-May	Ho: Non-Staging < Staging; p = 0.06, D = 0.68
Two sample KS test:		Ho: Male < Female; p = 0.69, D = 0.19				Ho: Male > Female; p = 0.45, D = 0.40				Ho: Male < Female; p = 0.76, D = 0.25				-
1	Combined	23	27-Apr	10.0	06-Apr to 17-May	11	19-Apr	12.1	06-Apr to 17-May	12	27-Apr	7.5	14-Apr to 06-May	Ho: Non-Staging < Staging; p = 0.13, D = 0.30
2		21	05-May	8.9	17-Apr to 15-May	10	1-May	9.8	17-Apr to 15-May	11	6-May	7.1	17-Apr to 15-May	**Ho: Non-Staging < Staging; p = 0.004, D = 0.51**
Two sample KS test:		**Ho: Year 1 < Year 2; p < 0.001, D = 0.54**				Ho: Year 1 < Year 2; p = 0.02, D = 0.43				**Ho: Year 1 < Year 2; p < 0.001, D = 0.74**				-
1	Male	11	27-Apr	7.4	09-Apr to 04-May	4	19-Apr	7.4	09-Apr to 27-Apr	7	27-Apr	6.1	14-Apr to 04-May	-
2		8	05-May	10.3	17-Apr to 15-May	5	5-May	12.9	17-Apr to 15-May	3	6-May	2.1	05-May to 09-May	-
Two sample KS test:		**Ho: Year 1 < Year 2; p = 0.005, D = 0.75**				Ho: Year 1 < Year 2; p = 0.2, D = 0.60				Ho: Year 1 < Year 2; p = 0.02, D = 1.0				-
1	Female	12	27-Apr	12.1	06-Apr to 17-May	7	27-Apr	14.2	06-Apr to 17-May	5	27-Apr	9.9	14-Apr to 06-May	-
2		13	05-May	8.4	17-Apr to 15-May	5	1-May	6.8	17-Apr to 05-May	8	7-May	8.4	17-Apr to 15-May	-
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.10, D = 0.43				Ho: Year 1 < Year 2; p = 0.45, D = 0.37				Ho: Year 1 < Year 2; p = 0.21, D = 0.50				-

Table A1.25. Summary of the date that mobile and stationary staging and non-staging CCT arrived at maximum upstream relocation positions in year 1 and year 2. Note that spawn date is estimated as the median date of maximum upstream relocation position. Values presented in the last column of the table compare the arrival timing of staging and non-staging CCT. Significant tests results are presented in bold.

Year	**Migration Type**	**Staging & Non-Staging**				**Non-Staging**				**Staging**				**Two sample KS Test: Non-staging vs Staging CCT**
		n	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**	**n**	**Median**	**SD**	**Range**	
Combined	Stationary	20	27-Apr	9.4	06-Apr to 09-May	9	27-Apr	9.7	06-Apr to 01-May	11	27-Apr	9.2	14-Apr to 09-May	Ho: Non-Staging < Staging; p = 0.27, D = 0.36
	Mobile	24	05-May	10.1	09-Apr to 17-May	12	29-Apr	12.4	09-Apr to 17-May	12	5-May	5.5	27-Apr to 15-May	Ho: Non-Staging < Staging; p = 0.12, D = 0.42
Two sample KS test:		Ho: Stationary < Mobile; p = 0.02, D = 0.43				Ho: Stationary < Mobile; p = 0.17, D = 0.42				Ho: Stationary < Mobile; p = 0.03, D = 0.55				-
1	Stationary	15	27-Apr	9.2	06-Apr to 06-May	7	19-Apr	10.1	06-Apr to 01-May	8	27-Apr	8.4	14-Apr to 06-May	Ho: Non-Staging < Staging; p = 0.54, D = 0.29
	Mobile	8	27-Apr	11.1	09-Apr to 17-May	4	23-Apr	16.1	09-Apr to 17-May	4	28-Apr	4.1	27-Apr to 06-May	Ho: Non-Staging < Staging; p = 0.37, D = 0.50
Two sample KS test:		Ho: Stationary < Mobile; p = 0.57, D = 0.23				Ho: Stationary < Mobile; p = 0.73, D = 0.25				Ho: Stationary < Mobile; p = 0.26, D = 0.50				-
2	Stationary	5	01-May	8.5	17-Apr to 09-May	2	30-Apr	1.4	29-Apr to 01-May	3	6-May	11.9	17-Apr to 09-May	Ho: Non-Staging < Staging; p = 0.34, D = 0.67
	Mobile	16	05-May	9.2	17-Apr to 15-May	8	3-May	11.1	17-Apr to 15-May	8	7-May	3.8	05-May to 15-May	Ho: Non-Staging < Staging; p = 0.14, D = 0.50
Two sample KS test:		Ho: Stationary < Mobile; p = 0.39, D = 0.35				Ho: Stationary < Mobile; p = 0.45, D = 0.50				Ho: Stationary < Mobile; p = 0.62, D = 0.33				-
1	Combined	23	27-Apr	10.0	06-Apr to 17-May	11	19-Apr	12.1	06-Apr to 17-May	12	27-Apr	7.5	14-Apr to 06-May	Ho: Non-Staging < Staging; p = 0.13, D = 0.30
2		21	05-May	8.9	17-Apr to 15-May	10	1-May	9.8	17-Apr to 15-May	11	6-May	7.1	17-Apr to 15-May	**Ho:Non-Staging < Staging; p = 0.004, D = 0.51**
Two sample KS test:		**Ho: Year 1 < Year 2; p < 0.001, D = 0.54**				Ho: Year 1 < Year 2; p = 0.02, D = 0.43				**Ho: Year 1 < Year 2; p < 0.001, D = 0.74**				-
1	Stationary	15	27-Apr	9.2	06-Apr to 06-May	7	19-Apr	10.1	06-Apr to 01-May	8	27-Apr	8.4	14-Apr to 06-May	-
2		5	01-May	8.5	17-Apr to 09-May	2	30-Apr	1.4	29-Apr to 01-May	3	6-May	11.9	17-Apr to 09-May	-
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.12, D = 0.53				Ho: Year 1 < Year 2; p = 0.2, D = 0.71				Ho: Year 1 < Year 2; p = 0.28, D = 0.54				-
1	Mobile	8	27-Apr	11.1	09-Apr to 17-May	4	23-Apr	16.1	09-Apr to 17-May	4	28-Apr	4.1	27-Apr to 06-May	-
2		16	05-May	9.2	17-Apr to 15-May	8	3-May	11.1	17-Apr to 15-May	8	7-May	3.8	05-May to 15-May	-
Two sample KS test:		Ho: Year 1 < Year 2; p = 0.03, D = 0.56				Ho: Year 1 < Year 2; p = 0.47, D = 0.38				Ho: Year 1 < Year 2; p = 0.05, D = 0.75				-

Table A1.26. Summary of the number and spawning position of and the mainstem (rkm) and tributary position (tkm) of spawning habitats within major and minor tributaries of the Kitimat River and their secondary and tertiary channels. Note that major and minor tributaries flow directly into the Kitimat River while secondary and tertiary tributaries confluence with major and minor tributaries, confluence position describes the location that secondary and tertiary tributaries confluence with major and minor tributaries, while spawning position describes the distance CCT travelled within secondary and tertiary tributaries to spawn.

Spawning Water Body	**rkm**	**Main Channel Spawning CCT**				**2° and 3° Spawning CCT**							**All Spawning CCT**			
		Spawning Position (tkm)				**Confluence Position (tkm)**				**Spawning Position (tkm)**			**Spawning Position (tkm)**			
		n	**Mean**	**SE**	**Range**	**n**	**Mean**	**SE**	**Range**	**Mean**	**SE**	**Range**	n	**Mean**	**SE**	**Range**
Hirsch Creek	15.7	0	-	-	-	5	2.5	1.4	0.4 to 7.4	2.0	0.7	0.2 to 3.4	5	4.5	0.8	3.3 to 7.6
Big Wedeene	21.4	2	26.5	4.4	22.1 to 30.9	6	9.5	2.9	5.2 to 23.3	0.8	0.2	0 to 1.1	8	14.3	3.5	6.3 to 30.9
Little Wedeene	20.1	0	-	-	-	2	2.6	0.0	2.6 to 2.6	2.9	0.0	2.9 to 2.9	2	5.4	0.0	5.4
Nalbeelah Creek	24.8	4	4.9	1.0	1.9 to 6.3	0	-	-	-	-	-	-	4	4.9	1.0	1.9 to 6.3
Humphrey Creek	29.7	1	2.4	-	-	0	-	-	-	-	-	-	1	2.4	0.0	2.4
Deception Creek	30.4	2	2.5	0.0	2.5 to 2.5	0	-	-	-	-	-	-	2	2.5	0.0	2.5
Cecil Creek	32.6	5	6.3	2.3	2.5 to 13.2	3	5.6	1.5	2.6 to 7.3	1.4	1.0	0.3 to 3.5	8	6.5	1.4	2.5 to 13.2
Chist Creek	44.2	1	5.8	-	-	1	0.3	-	-	0.2	-	-	2	3.1	2.6	0.5 to 5.8
McKay Creek	48.3	1	2.2	-	-	1	1.0	-	-	0.5	-	-	2	1.8	0.3	1.5 to 2.2
All Major Tributaries	27.2 ± 1.6 *	16	7.4	1.5	1.9 to 30.9	18	5.1	1.3	0.3 to 23.3	1.3	0.3	0 to 3.5	34	7.0	1.1	0.5 to 30.9
Duck Creek	10.6	3	3.0	0.0	2.9 to 3	0	-	-	-	-	-	-	3	3.0	0.0	2.9 to 3.0
Goose Creek	10.8	2	4.9	0.9	3.1 to 6.2	1	5.1	-	-	0.1	-	-	3	4.9	0.9	3.1 to 6.2
McNeil Creek	30.2	2	5.4	1.5	4 to 6.9	0	-	-	-	-	-	-	2	5.4	1.5	4 to 6.9
Powerline Creek	16.5	2	5.4	0.5	5 to 5.9	0	-	-	-	-	-	-	2	5.4	0.5	5 to 5.9
Unnamed Creeks*	41.7 ± 13.3 *	3	1.2	0.2	0 to 3.5	0	-	-	-	-	-	-	3	1.2	0.2	0.8 to 1.7
All Minor Tributaries	21.8 ± 4.5 **	12	6.9	3.8	0.8 to 6.9	1	5.1	-	-	0.1	-	-	13	3.8	0.5	0.8 to 6.9

Note: Table includes position of 4 CCT for which spawning date is unknown.

* Small unnamed tributaries flowing directly into the mainstem of the Kitimat River.

** Mean ± SE

A1. Supplemental Recapture Information

Twelve CCT were recaptured within the Kitimat watershed. This includes four Floy tagged and eight radio tagged CCT. The four Floy tagged (non-radio tagged) CCT were reported by recreational anglers, two of which provided sufficient information to identify the individual and its location of capture. The first of these two individuals, a male captured on September 16, 2012 was recaptured 6.2 km upstream of its initial capture location on October 6, 2012. The second CCT, a female captured on November 7, 2012 was recaptured 5.0 km downstream of its initial capture location on October 29, 2013. The two unidentified CCT were captured by anglers who described catching trout with a yellow tag on their dorsal fin, but did not provide the number on the Floy tag. One CCT sampled and Floy tagged on July 22, 2013 was recaptured in the same location on July 25, 2013 and outfitted with a small radio tag.

Four of the eight radio tagged CCT were recaptured during sampling while the remaining four were captured and reported by recreational anglers. Radio tagged CCT recaptured during sampling were inspected for signs of infection. Two of these fish, CCT #003 and #051, were observed to be in poor condition. Cutthroat #003, initially captured on August 11, 2012 was recaptured on November 16, 2012 within 500 m of its initial capture location. This individual's incision had closed and its sutures were intact though misplaced and cutting through the skin. Discoloration of the skin was apparent at the exit point of the antenna and on the abdomen where the tag appeared to be resting (Figure A1.2). Fish#003 was not observed after December 20, 2012. Fish#051 was radio tagged on October 28, 2012 and was recaptured 11.0 km downstream of its initial location on March 15, 2013. The incision on this CCT appeared to have partially reopened, though no visible signs of infection were apparent (Figure A1.3). Fish#051 was not detected after April 19, 2013, although before this date it appeared to be moving upstream towards a presumed spawning habitat. Fish#134 was recaptured on March 26, 2014, 21.6 km upstream of its location of capture on July 14, 2014. This CCT appeared very healthy, it showed no signs of infection, the sutures had dissolved and the incision had healed cleanly and was almost undetectable (Figure A1.4). Fish#134 survived spawning and then migrated to the estuary where it was last observed on June 28, 2014. A fourth radio tagged CCT, Fish#148 was recaptured by a recreational angler on April 24, 2014 within 500 m of its initial capture location. Fish#148 had a 1.5 x 1.5 cm^2 abscess on the outside of its abdomen, the cause of which was unclear. The incision appears to have healed cleanly and no sutures were present (Figure A1.5). This fish was observed in a spawning tributary from May 9 to May 12, 2014 and was last observed in Hirsch Creek on May 27, 2014. The condition of these four recaptured cutthroat provided insight into the condition and fate of other trout tagged throughout this study and ultimately influenced the criteria used to identifying tagging mortalities. Due to the poor condition of these two fish relative to the condition of Fish#134 and Fish#148, any fish that exhibit no additional movement – regardless of the duration from their initial tagging – were considered tagging mortalities.

Figure A1.2. Condition of CCT ID#3 upon recapture on November 16, 2012. Note the yellow discoloration at the exit point of the antenna as well as on abdomen where transmitter appears to be resting. Fish was not relocated again 1 month after this photo was taken.

Figure A1.3. Condition of CCT ID#51 upon recapture on March 15, 2013. The transmitter in this CCT was recovered on April 19, 2013 and the fish is assumed to have died.

Figure A1.4. Condition of CCT ID#134 upon recapture on July 14, 2014. The incision appears to have healed cleanly and sutures have dissolved.

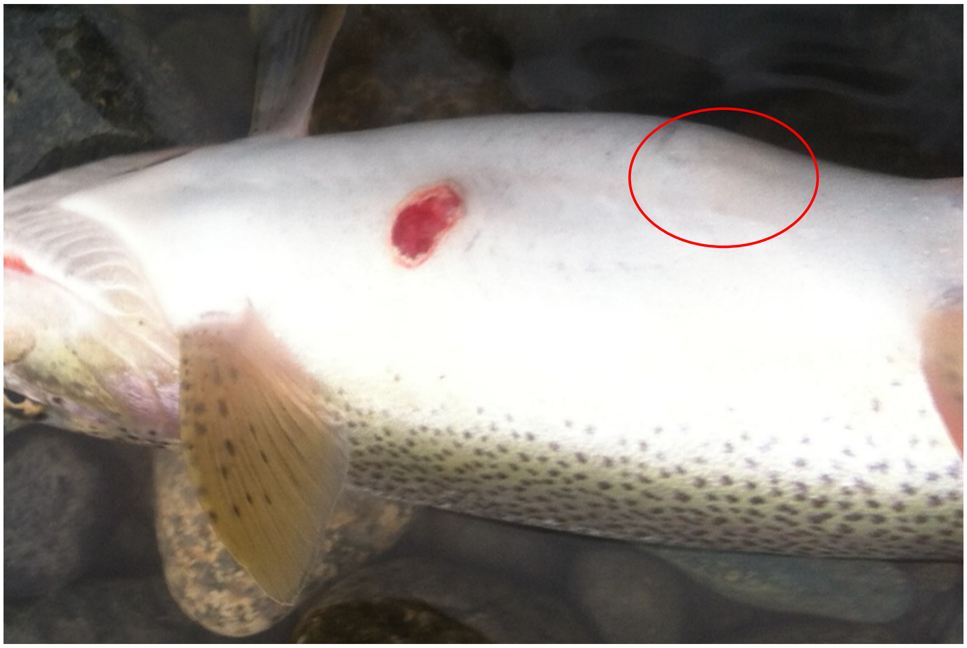

Figure A1.5. Condition of CCT ID#148 upon recapture on April 24, 2014. Note that scar, circled in red has healed cleanly. Abscess is possibly due to wear against the transmitter.

Chapter 2 Appendix

Table A2.1. Observations identified in scientific literature supporting the inclusion of abiotic metrics in the overwintering candidate model set.

Overwintering		
Variable	**Observation**	**Species and Source**
Discharge	Decreased flows reduce winter movement	**CT:** (Gresswell and Hendricks 2007)
	Decreased flows increase winter movement	**Salmonid:** (Jonsson and Jonsson 2002, Krimmer et al. 2011)
	Increased flows influence winter movement.	**CT:** (Waters 1993b, Brown and Mackay 1995a, White and Harvey 2007) **Salmonid:** (Enders et al. 2008)
	Increased flows do not influence winter movement.	**CT:** (Waters 1993b, Brown 1999, Harvey et al. 1999, White and Harvey 2007) **Salmonid:** (Enders et al. 2008)
	Ice formation influences winter movement	**CT:** (Waters 1993b, Jakober et al. 1998, Brown 1999, Harvey et al. 1999, Harper and Farag 2004, Lindstrom and Hubert 2004) **Salmonid:** (Whalen et al. 1999, Huusko et al. 2007, Brown et al. 2011, Linnansaari 2013, Watz et al. 2015)
	Increased flows increase invertebrate drift	**CT:** (Romero et al. 2005)
Water Temperature	Decreased temperature associated with reduced winter movement	**CT**:(Boss 1999, Brown 1999, Harper and Farag 2004, Lindstrom and Hubert 2004, Stephan and Zurstadt 2004, Bryant et al. 2009, Brown et al. 2011) **Salmonid**:(Bustard 1970, Bustard and Narver 1975a, Jakober et al. 1998, Enders et al. 2008, Mollenhauer 2011, Krimmer et al. 2011, Mollenhauer et al. 2013)
	Decreased temperature associated with increased use of overwinter habitats	**CT:** (Brown and Mackay 1995c, Brown 1999, Harper and Farag 2004) **Salmonid:** (Bustard 1970, Bustard and Narver 1975b, Jakober et al. 1998, Mollenhauer 2011, Mollenhauer et al. 2013)
	Movement occurs throughout winter, even at low water temperatures.	**CT:** (Stephan and Zurstadt 2004)
	Increased water temperature in spring associated with increased movement.	**CT:** (Waters 1993b, Stephan and Zurstadt 2004) **Salmonid:** (Bustard and Narver 1975a, Jensen et al. 1986, Swanberg 1997, Albanese et al. 2004, Petty et al. 2012)

Table A2.2. Observations identified in scientific literature supporting the inclusion of abiotic metrics in the spawning candidate model set.

Variable	Observation	Source
Discharge	Rising flows increase spawning movements.	**CT:** (Gresswell and Hendricks 2007, DeRito et al. 2010, Schmetterling 2011, Bennett et al. 2014) **Salmonid:** (Banks 1969, Jensen et al. 1986, van den Berghe and Gross 1989, Økland et al. 2001, Albanese et al. 2004, Svendsen et al. 2004, Mollenhauer 2011, Taylor and Cooke 2012, Malcolm et al. 2012)
	Rising flows reduce spawning movements.	**CT:** (Brown and Mackay 1995a) **Other:** (Jonsson 1991, Jonsson and Jonsson 2002, Svendsen et al. 2004)
	Receding peak flows stimulate spawning movements.	**Salmonid:** (Alabaster 1990, Jonsson 1991, Gresswell et al. 1997, DeRito et al. 2010, Schmetterling 2011)
	Decreased flows increase spawning movement.	**Salmonid:** (Trepanier et al. 1996)
	Variability in flows increases variability in both the response to flows and spawn timing.	**Salmonid:** (Tetzlaff et al. 2005)
	Turbidity increases movement.	**Salmonid:** (Banks 1969, Alabaster 1990, Rakowitz et al. 2008)
Water Temperature	Increased spawning movement associated with rising water temperatures.	**CT:**(Gresswell et al. 1997, Stephan and Zurstadt 2004, DeRito et al. 2010, Bennett et al. 2014) **Salmonid:**(Dodson and Young 1977, Jensen et al. 1986, Swanberg 1997, Albanese et al. 2004, Svendsen et al. 2004, Petty et al. 2012)
	Increased spawning movement associated with decreasing water temperatures.	**Salmonid:** (Trepanier et al. 1996, Young et al. 2010)
	Decreased spawning movement associated with cool water temperatures.	**Salmonid:** (Rustadbakken et al. 2004)
	Spawning movements not influenced by water temperature.	**CT:** (Webb and McLay 1996, Jones and Harding 1998)
	Water temperature influences spawn timing.	**CT:** (Williams et al. 2009, Zeigler et al. 2012, Kovach et al. 2013) **Salmonid:** (Robards and Quinn 2002, Dahl et al. 2004, Juanes et al. 2004, Quinn et al. 2007, Jonsson and Jonsson 2009)

Table A2.2 Continued

Variable	Observation	References
Discharge and water temperature	Increased spawning movement when flow is decreasing and temperature is increasing.	**CT:** (Gresswell and Hendricks 2007) **Salmonid:** (Swanberg 1997, Svendsen et al. 2004, Ringel et al. 2014)
Photoperiod	Day length is proximate factor indicating migration season	**Salmonid:** (Smith 1985)
	Day length influences motivation to spawn.	**Salmonid:** (Banks 1969, Jonsson 1991, Thorstad et al. 2005, 2008)
	Day length influences rheotropic behaviour.	**Salmonid:** (Dodson and Young 1977, Smith 1985)
	Day length acts as cue for physiological changes	**Salmonid:** (Macquarrie et al. 1978, Whitehead et al. 1978, Smith 1985, Carrillo et al. 1989, Fleming 1996, Norberg et al. 2004, Garcia de Leaniz et al. 2007)
Sex	Sex influences timing of migrations	**CT:** (Jones and Yanusz 1998) **Salmonid:** (Morbey 2000, Dahl et al. 2004)
Fork Length	Size influences timing of spawning movements	**CT:**(Jones and Yanusz 1998, Young 2011) **Salmonid:** (Swanberg 1997, Curry et al. 2002)
	Size does not influence movement timing.	**CT:** (Alexiades et al. 2012)
	Size influences distance travelled.	**Salmonid:** (Wenger et al. 2011)
	Size does not influence distance travelled.	**Salmonid:** (Svendsen et al. 2004)
Distance to Spawn	Increased distance to spawn decreases date.	**Salmonid:** (Bahr and Shrimpton 2004)

Table A2.3. Mean water temperature recorded in tributaries of the Kitimat river throughout the overwinter period (October 1 to March 14), spawning period (March 15 to May 31) and combined periods (October 1 to May 31) of each year.

			Winter (Oct. 1 to March 14)			Spawn (March 15 to May 31)			Combined (Oct 1 to May 31)		
Year	**Tributary**	**Deployment Date**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
1	Hirsch	1-Oct-12	1.8	1.9	0 - 8.3	3.1	1.0	0.6 - 4.9	2.2	1.8	0 - 8.3
1	Cecil	1-Oct-12	1.6	1.9	-3 - 6.6	3.7	1.2	-0.3 - 6	2.3	2.0	-3 - 6.6
1	Nalbeelah	6-Oct-12	1.8*	1.9	-0.1 - 8.1	3.6	1.1	0.6 - 5.4	2.4*	1.9	-0.1 - 8.1
1	Little Wedeene	1-Oct-12	1.9*	1.9	0 - 8	3.5	0.9	1.2 - 5.4	2.4*	1.8	0 - 8
1	Humphrey	1-Oct-12	2.7	1.7	0.2 - 8.6	3.4	1.0	1.8 - 5.8	2.9	1.5	0.2 - 8.6
1	McNeil	18-Dec-12	1.7*	0.9	0.1 - 3.4	4.7	1.4	1.6 - 7.6	3.1*	1.9	0.1 - 7.6
1	Big Wedeene	1-Oct-12	2.9	1.7	0.3 - 9	4.1	1.2	2.4 - 6.7	3.3	1.6	0.3 - 9
1	Chicken	12-May-13	-	-	-	7.2*	0.9	6.1 - 8.5	7.2*	0.9	6.1 - 8.5
1	Goose	24-Apr-13	-	-	-	9.1*	2.2	5.3 - 12.1	9.1*	2.2	5.3 - 12.1
2	Lone Wolf	23-Oct-13	1.6*	1.7	0 - 7.5	3.9	2.2	0.1 - 7.5	2.4	2.2	0 - 7.5
2	Hirsch	1-Oct-12	2.3	2.6	0 - 8.2	2.9	1.4	0.2 - 5.5	2.5	2.3	0 - 8.2
2	Chist	12-Oct-13	2.2	2.1	0 - 7.7	3.8	1.6	0.7 - 6.8	2.7	2.1	0 - 7.7
2	Cecil	1-Oct-12	2.2	2.2	-0.1 - 7	3.9	1.3	0.6 - 6.6	2.8	2.1	-0.1 - 7
2	Nalbeelah	6-Oct-12	2.6*	2.7	0.1 - 8.6	3.1	1.5	0.6 - 6	2.8	2.4	0.1 - 8.6
2	Little Wedeene	1-Oct-12	2.4	2.4	0 - 8.1	3.8	1.4	0.8 - 6.9	2.8	2.2	0 - 8.1
2	Humphrey	1-Oct-12	2.9	2.1	0.1 - 7.8	3.3	1.5	0.2 - 6.1	3.0	1.9	0.1 - 7.8
2	Duck	11-Oct-13	2.6*	2.4	0 - 8.9	3.9	1.8	0.5 - 7.4	3.1*	2.3	0 - 8.9
2	Chicken	12-May-13	2.9*	2.8	0 - 9.1	4.0	2.5	0.7 - 8.4	3.3*	2.8	0 - 9.1
2	Big Wedeene	1-Oct-12	3.1	2.1	0.3 - 8	3.9	1.6	0.5 - 6.7	3.4	2.0	0.3 - 8
2	Deception	17-Oct-13	2.1*	2.4	0.1 - 9.1	5.8	3.9	0.1 - 12.1	3.4	3.5	0.1 - 12.1
2	Goose	24-Apr-13	2.6	2.9	0 - 9.4	5.5	3.8	0.1 - 11.4	3.5	3.5	0 - 11.4
2	McNeil	18-Dec-12	5.4	2.0	0.5 - 9.8	3.9	0.7	2.6 - 4.8	5.2	2.0	0.5 - 9.8

* Indicates that temperatures were not collected throughout the entire period.

Table A2.4. Summary of date that radio tagged CCT were first observed in spawning tributaries and the temperature of spawning tributaries upon arrival.

			Date			Water Temperature (°C)		
Tributary	**Year**	**n**	**Median**	**SE**	**Range**	**Mean**	**SD**	**Range**
Big Wedeene	1	5	20-Apr	8.23	07-Apr to 04-May	3.63	0.58	2.85 to 5.24
Cecil	1	4	9-Apr	8.51	26-Mar to 23-Apr	3.71	0.71	2.52 to 5.62
Chicken	1	3	20-Apr	5.34	12-Apr to 29-Apr	n/a	n/a	n/a
Chist	1	2	28-Apr	0.71	28-Apr to 29-Apr	n/a	n/a	n/a
Deception	1	1	17-Apr	NA	17-Apr to 17-Apr	n/a	n/a	n/a
Duck	1	1	18-Apr	NA	18-Apr to 18-Apr	n/a	n/a	n/a
Goose	1	3	3-Apr	1.87	01-Apr to 06-Apr	6.28	1.05	5.26 to 8.47
Hirsch	1	1	23-Apr	NA	23-Apr to 23-Apr	3.75	0.57	2.78 to 5.33
Humphrey	1	0	-	-	-	3.63	0.58	2.85 to 5.24
Little Wedeene	1	1	4-May	NA	04-May to 04-May	3.31	0.56	2.2 to 4.58
Nalbeelah	1	1	1-Apr	NA	01-Apr to 01-Apr	4.37	0.55	3.28 to 5.92
Big Wedeene	2	3	2-May	1.00	01-May to 03-May	3.44	0.86	1.19 to 5.01
Cecil	2	4	11-Apr	3.03	07-Apr to 16-Apr	3.65	0.93	1.1 to 5.27
Chicken	2	2	3-May	2.45	30-Apr to 07-May	3.78	1.13	1.94 to 6.17
Chist	2	0	-	-	-	3.82	0.92	1.6 to 5.54
Deception	2	1	6-Apr	NA	06-Apr to 06-Apr	5.44	2.12	1.4 to 9.24
Duck	2	2	23-Apr	0.71	23-Apr to 24-Apr	3.8	1.01	1.58 to 5.35
Goose	2	1	23-Apr	NA	23-Apr to 23-Apr	4.95	2.38	0.97 to 9.41
Hirsch	2	0	-	-	-	3.7	0.89	1.55 to 5.25
Humphrey	2	1	30-Apr	NA	30-Apr to 30-Apr	3.44	0.86	1.19 to 5.01
Little Wedeene	2	1	27-Apr	NA	27-Apr to 27-Apr	3.49	0.91	1.21 to 5.18
McNeil	2	0	-	-	-	n/a	n/a	n/a
Nalbeelah	2	3	28-Apr	1.29	27-Apr to 30-Apr	4.08	1.05	1.72 to 5.68