Understanding the Timing and Consequences of Migration Events for Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in a Wilderness System

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Abstract

Juvenile Chinook salmon (*Onchorhynchus tshawytscha)* migrate from their natal spawning grounds in cold freshwater streams, where opportunities for growth are limited, to the more productive Pacific Ocean. The early life history decisions made by individuals during this time have significant impacts on survival to the ocean and later life stages. The expression of these life histories can be highly variable within and among closely related populations of Chinook due in part to the heterogeneity of habitats in which they evolved. Ongoing research in the Snake River basin indicates general patterns in migration that may be related to site specific survival trends. Of 12 sites studied, upper and lower Big Creek (UBC and LBC) sites span the lowest to highest survival patterns respectively during this period (Achord et al. 2008, Zabel and Achord 2004). Considering these apparent survival differences between upper and lower Big Creek, we sought to determine whether basin wide patterns in migration timing were also expressed at the scale of a single large sub-basin (Big Creek). Furthermore, with multiple opportunities for recapturing out migrating fish, we wished to determine whether there were growth differences based upon when and where fish existed at different time points along their migration. We found that fish outmigration from Big Creek is not uniform across summer and fall months with peak migration occurring in fall months. There is a basin wide relationship between tagging size and arrival date to the Lower Granite juvenile salmon bypass system (LGBPS), being that larger fish tended to arrive earlier. However, this relationship did not exist when the population was studied at smaller spatial and temporal scales. Growth between tagging in UBC and recapture in LBC depended upon year, with 2008 being greater than 2007. Similarly, growth rates of fish overwintering upstream of LGBPS varied across years. Fish overwintering in Big Creek experience significantly lower growth rates than those fish presumably leaving earlier and overwintering downstream in bigger rivers.

Introduction

Diadromy evolved in Chinook salmon (*Oncorhynchus tshawytscha)* as a strategic life history. In an ecological context a strategy is defined as a genetically determined life history resulting from both intraspecific competition and environmental pressures (Gross 1987). Over evolutionary time scales these life history strategies developed repeatedly as a means to maximize reproductive fitness (Gross 1987). Diadromy entails a seaward migration from freshwater as a juvenile and a return migration as adults to natal streams to spawn and die (Gross 1987). Migratory behavior in animals occurs in response to habitats that vary temporally in their suitability and therefore we can assume that more suitable habitat exists beyond natal spawning grounds (Zabel 2002). In fact, productivity in the ocean is much greater than that of cold freshwater streams in northern latitudes in which juvenile Chinook emerge. Consequently, opportunities for growth are higher in the ocean and migration from these nursery habitats is advantageous for this species so long as the benefits outweigh the costs of migration (Zabel 2002).

Although opportunities for growth in the ocean are greater, migration is a risky strategy. Individuals must make trade off's between reaching their destination quickly or choosing to maximize short term comfort and moving downstream more slowly (Zabel 2002). Migration costs for Chinook include the energetic demands of swimming, the physiological cost of changing osmoregulation, and increased risk of exposure to predators (Gross 1987). Costs are important when considering the early life history decisions of salmon because the condition of individuals during one life stage may impact survival at a later life stage (Zabel and Achord 2004). The duration of migration time or "travel time" for this species can be an important variable in determining the cost of seaward migration (Zabel 2002.) Research has shown that timing of seaward migration plays an important role in juvenile to adult survival in Chinook salmon (Scheuerell et al. 2009).

While the cues of migration timing have been intensively studied in this species in the past, the connection between life history diversity and quantitative details of movements during the early life stage are not well documented (Zabel 2002). Salmon exhibit a diversity of behaviors and morphologies as a result of the physical variation in freshwater rearing habitats in which they evolved. Factors such as flow conditions, temperature regimes, and geomorphic complexity vary across systems and therefore great variation exists in the way in which life history is expressed at the sub-population level (Scheuerell et. al 2009). Therefore, the timing of migration can have important consequences for population demographics (Connor et al. 2005, Kennedy et al. 2008). Even closely related populations of Chinook salmon show considerable variation in the timing of seaward migration both within and among populations (Sheuerell et. al 2009).

Study System

Ongoing research in the Snake River basin indicates general patterns in migration that may be related to site specific survival trends (Achord et al. 2008, Zabel and Achord 2004). However this work underscores the complex interrelationships between variation in environmental factors and the annual timing of juvenile Chinook salmon migration (Achord et al. 2008). Within the Salmon basin there is a trend for larger smolts (juvenile salmon making a seaward migration) to arrive earlier at fixed sites along the main stem Snake River (Fig. 1).

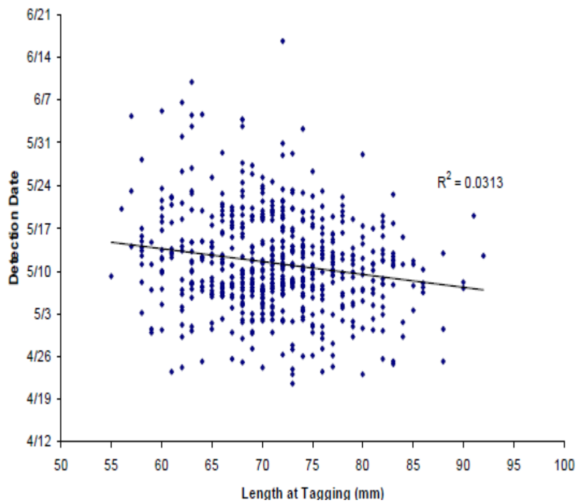

Figure 1. Relationship between fork length of parr at tagging (in 2007) and detection at Lower Granite Dam in 2008. (Achord et al. 2008)

Additionally, based upon long term monitoring of juvenile Chinook survival within specific study reaches, there is high spatial variability in survival from late summer (at which point they receive an individually coded tag, or Passive Integrated Transponder (PIT tag) to when they are resampled with antennas at the major hydropower facilities in the Snake River (when their PIT tags are detected). Of 12 sites studied, Upper and Lower Big Creek sites span the lowest to highest survival patterns respectively during this period (Achord et al. 2008) (Fig. 2).

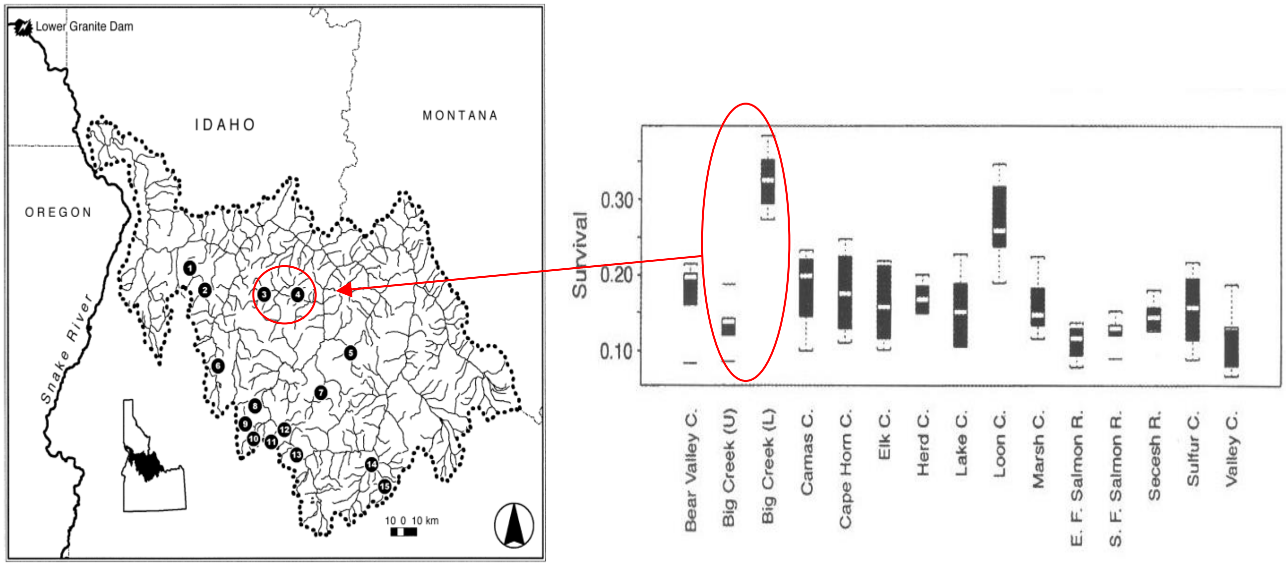

Figure 2. Spatial relationship between Upper and Lower Big Creek with survival patterns over 6 six years of study plotted against other study sites in the Salmon River basin (Zabel and Achord, 2004).

Considering the apparent survival differences between upper and lower Big Creek, we sought to determine whether the patterns in migration timing seen in the Snake River basin were also expressed at the scale of a single large sub-basin (Big Creek). Furthermore, with multiple opportunities for recapturing out migrating fish, we wished to determine whether there were growth differences based upon when and where fish existed at different time points along their migration. We attempted to find if significant differences exist in individual size, growth and migration timing of groups of fish from Upper Big Creek and Lower Big Creek and if these vary across years. To accomplish this, our objectives were to (1) attempt to identify overall trends in the migration timing of juvenile Chinook from Big Creek and how they relate to environmental variables, flow and stream temperature respectively, (2) to quantify the effects of size and individual movements of juveniles from throughout the basin, and finally (3) to determine if patterns exist between growth and timing of outmigration and whether these patterns exist within the single sub-basin of Big Creek.

Methods and Materials

Study Area

Juvenile Salmon were studied in Big Creek for the summers of 2007 through 2009. A major attraction for studying life history variation on Big Creek and comparing it to other sites throughout the Salmon River basin is its relative pristine quality. Though there has been some human settlement in the valley, particularly in the last 100 years, the watershed remains relatively untouched from a chemical, biological and geomorphologic perspective. There has been little to no direct impact from hatcheries on Big Creek. However, portions of upper Big Creek have seen colonization by non-native brook trout.

The major impacts that are likely to influence Salmonids in this wilderness system are those occurring at extremely large spatial scales (e.g. along the migration corridor) or broad temporal scales (e.g. changing climatic conditions). Hydroelectric dams on the Columbia River impact this population as they must pass through them to complete their life history (Berggren1993). Once a free flowing river system it has been transformed into a series of large reservoirs, significantly altering the historical hydraulic regimes. This has major implications for migratory behavior and can further jeopardize at-risk populations (Scheuerell et al 2009). Interestingly enough, The Big Creek population must achieve viable status in order for the Middle Fork Salmon MPG to be considered viable. Climate change has also influenced environmental conditions in these systems through its influence on summer temperatures and the rate and timing of spring runoff, impacting spawning and rearing habitat as well as further complicating the effects of river impoundment (Berggren 1993, Crozier and Zabel 2006).

Fish Collection and Handling

During this time individual fish were caught, measured, and implanted with PIT tags that would permit the individual identification of these fish when recaptured and scanned. The PIT tag is an invaluable resource in monitoring juvenile migration as it allowed us to monitor downstream movements, survival, and growth of these individuals. PIT tag information Systems (PTAGIS) reports provided recapture data for emigrating juveniles PIT tagged by either NOAA shocking efforts or IDFG screw trap tagging operations. NOAA conducts sampling and PIT tagging in late summer at both upper and lower portions of Big Creek (UBC and LBC respectively). In 2008 NOAA also tagged individuals in Cabin Creek which flows into Big Creek approximately 7 miles upstream of the lower site at TWRS. The Idaho department of Fish and Game operates a rotary screw trap to sample out migrating Salmonids in lower Big Creek at Taylor Wilderness Research Station (TWRS).

Rotary Screw traps are placed in the fastest part of the stream channel where the capture rate of juveniles is maximized (Volkhardt et al. 2007). The assumption made in this report is that fish caught in the screw trap are in this channel because they are actively out migrating from the Big Creek basin. The screw trap consists of a large rotary cone with a live box at the back. Juveniles are swept into the large portion of the cone and led to the back where they remain in the live box until collections. Small debris was placed in the box to minimize predation from piscivorous fish such as bull trout that occasionally get swept into the cone (Volkhardt et al. 2007).

Each morning the live box at the back of the screw trap was checked for captured juveniles. This work was always conducted in the morning in an effort to process fish when temperatures were lowest and stress could be avoided. A work station is located nearby with processing and PTAGIS equipment. Each smolt was initially anesthetized with Tricaine Methanesulfionate (MS222) (Volkhardt et al. 2007). This makes the fish easier to handle and helps minimize stress while being processed. During the course of handling a proportion of smolts were injected with a PIT tag with a unique code which was then scanned into the PTAGIS database. We then weighed and measured each individual and recorded those measurements in PTAGIS. Length and weight measurements are important in determining the age structure of out migrating juveniles as well as to allow us to quantify growth of individuals from initial tagging to recapture sites.

PTAGIS reports were accessed via the internet to retrieve detection data for fish that were tagged within Big Creek and re-sampled at a different location in the system. This data reflects the passage of tagged individuals as they pass through the screw trap in place at TWFS as well as all individuals from throughout the basin as they are detected at the Lower Granite juvenile salmon Bypass system (LGBPS).

Outmigration timing and environmental Variables

The tagging season in this drainage lasts from May through November and is dependent on a number of variables including flow and stream temperatures. For each month we calculated the number of fish passing through the screw trap and the average fork length of those fish. Flow data was provided from the efforts of an ongoing study of streams within the Big Creek basin conducted by ISU. This provided us with daily discharge (cms) at TWFS. Temperature data was taken at the time of tagging and recorded on PTAGIS where it was later retrieved and compared to numbers of out migrating juveniles at LBC.

Movements and Effects of Size

To determine how individual size influenced individual movements within Big Creek we used data from 2007 and 2008 for fish tagged in UBC and arriving at LBC. We then attempted to find if individual size influences the timing and strategies expressed by juveniles at a larger basin wide scale. To do this we separated juveniles from Big Creek into five groups by year and tag origin. In 2007 fish were placed into two groups; upper Big Creek and lower Big Creek. In 2008 tag origins consisted of three sites; upper Big Creek, Cabin Creek and lower Big Creek. Recapture data provided us with the arrival dates of these individuals at LGBPS

Growth and Outmigration

To quantify how the growth of individuals related to the timing of out migrating juveniles at two spatial scales we again grouped fish by year and tag origin. Individuals traveling from UBC to LBC were separated into two groups by year, 2007 and 2008 respectively. For analysis of a larger special scale we grouped fish into four groups; UBC 07, LBC 07, UBC 08 and LBC 08 and calculated length growth from initial tagging to recapture at LGBPS. Additionally, a small portion of fish was known to have overwintered in Big Creek and we combined those individuals from 2007 and 2008 to make up a fifth group.

Statistical Analysis: size and migration timing

We performed an ANOVA to determine if there were significant differences in numbers of out migrating individuals across summer and fall months. We then plotted numbers of fish passing through the screw trap during this time against daily mean discharge (cms) at TWFS and daily temperatures taken at tagging to see if we could find general patterns in relation to these changing environmental variables.

To assess the relationship between size and migration timing we performed regression analysis comparing patterns observed in the groups from different year and tag origins. We attempted to find if there was a significant relationship between initial tag size and arrival at LGBPS and if the strength of the relationship is influenced by year or source habitat. Using length at tagging and length at recapture we calculated the instantaneous rates of growth for individuals. Instantaneous rate of growth (%length increase/day) was calculated for the groups of fish using the following equation:

Instantaneous rate of growth (% length increase/day) = ((ln(recap length) – ln(tag length))/time (days)*100

We performed a student t- test between the growth rates of individuals traveling from Upper Big Creek to Lower Big Creek in 2007 and 2008. To compare growth rates and travel timing from all years and tag origins traveling to LGBPS, statistical analyses consisted of ANOVA followed by Fisher's LSD multiple comparisons with Bonferroni correction.

Results

Outmigration Timing and Environmental Variables

Fish outmigration from Big Creek is not uniform across summer and fall months. Additionally we observed general patterns between the number of individuals passing through the screw trap at TWFS and flow and temperature regimes within Big Creek. There are significant differences (Fig. 4, $p < 0.0001$) in numbers of outmigrating individuals across summer and fall months. A general pattern can be seen between fish migration timing and temperature and flow regimes within Big Creek where fish outmigration is concentrated during the fall months as temperatures cool (Fig. 2, Fig. 3).

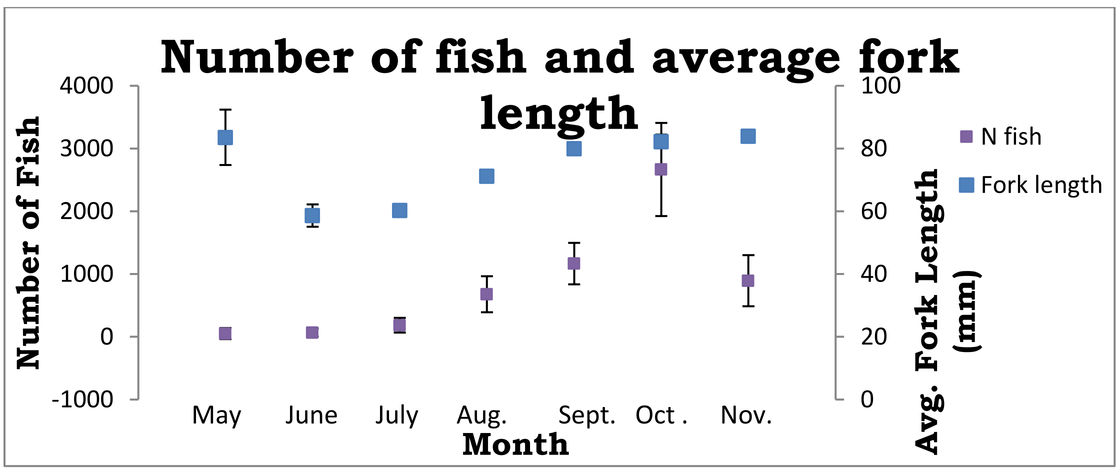

Figure 4. Outmigration patterns of fish passing through the IDFG rotary screw trap at Taylor Wilderness Field Station.

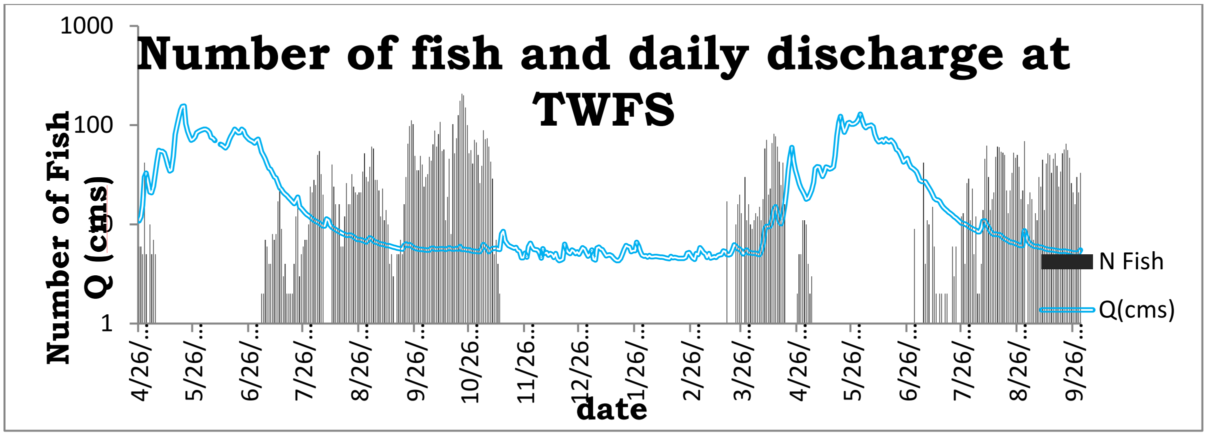

Figure 5. Daily number of fish passing through the IDGF rotary screw trap and daily mean discharge (cms) at Taylor Wilderness Field Station.

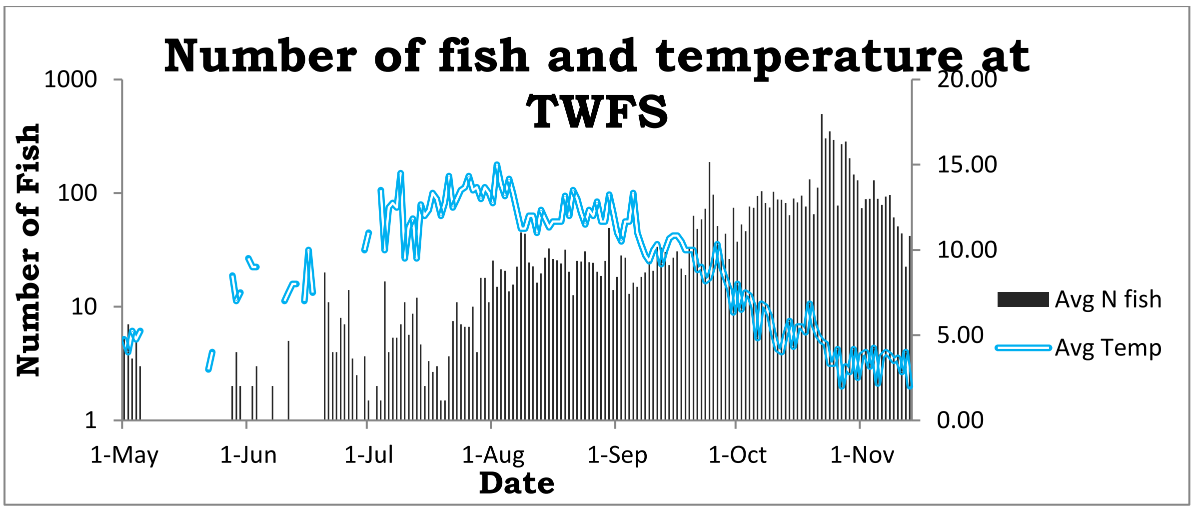

Figure 6. Daily Average number of fish and tag temperature at the IDFG rotary screw trap at Taylor Wilderness Field Station for the years of 2007 through 2009.

More detailed analyses of outlier flow or thermal events that might occur unpredictably over the course of a single day and could influence within-week outmigration would be interesting, but was beyond the scope of this study. A more significant correlation can be drawn provided more detailed observations particularly during peak flow events.

Movements and Effects of Size

We found a basin wide relationship between initial tag size and migration in that larger individuals from Big Creek tended to arrive earlier at LGBPS. However, when fish were grouped by year and source habitat we found that the strength of this relationship varied. We also found that on a smaller scale, UBC to LBC this trend was not apparent.

When all origin locations and years were combined there is a significant relationship between initial tag size and arrival at LGBPS (Fig. 8, $p < 0.0001$) with larger fish tending to show up earlier. However, the strength of the relationship between size and outmigration timing depended upon on year and source habitat. First, within Big Creek there does not appear to be a significant relationship between the size at tagging in Upper Big Creek and the arrival date at the screw trap in Lower Big Creek (Fig. 7, $p > 0.05$). Similarly the length at tagging did not affect the arrival date at LGPS for fish leaving UBC in 2007 or LBC and Cabin Creek in 2008 (Fig. 8, $p > 0.05$). However, for fish leaving LBC in 2007 and UBC in 2008 and arriving at LGBPS we did find significant results (Fig. 8, $p = 0.03$).

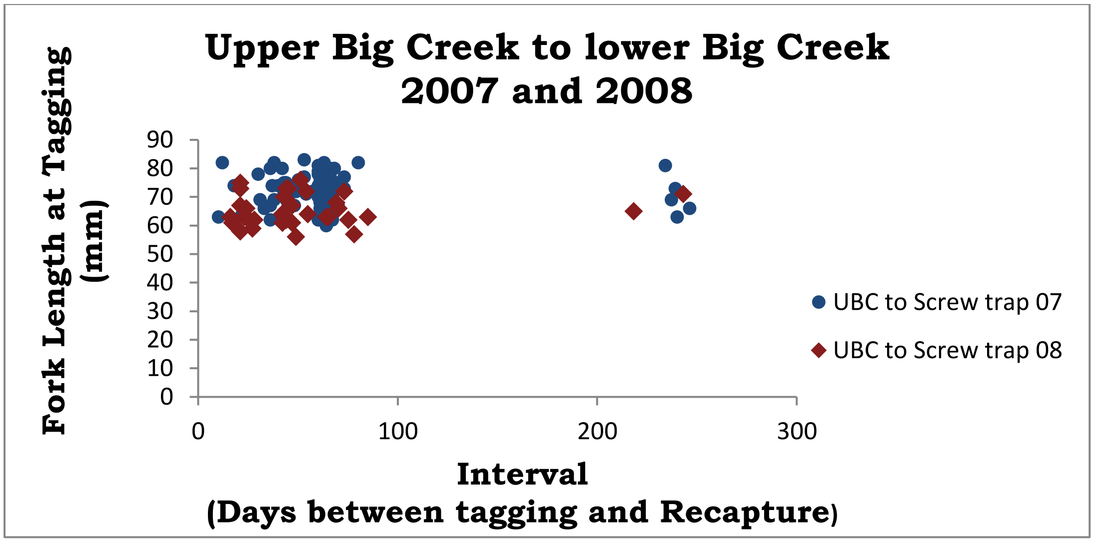

Figure 7. Relationship between fork length at tagging in UBC and arrival date at the IDFG screw trap in LBC.

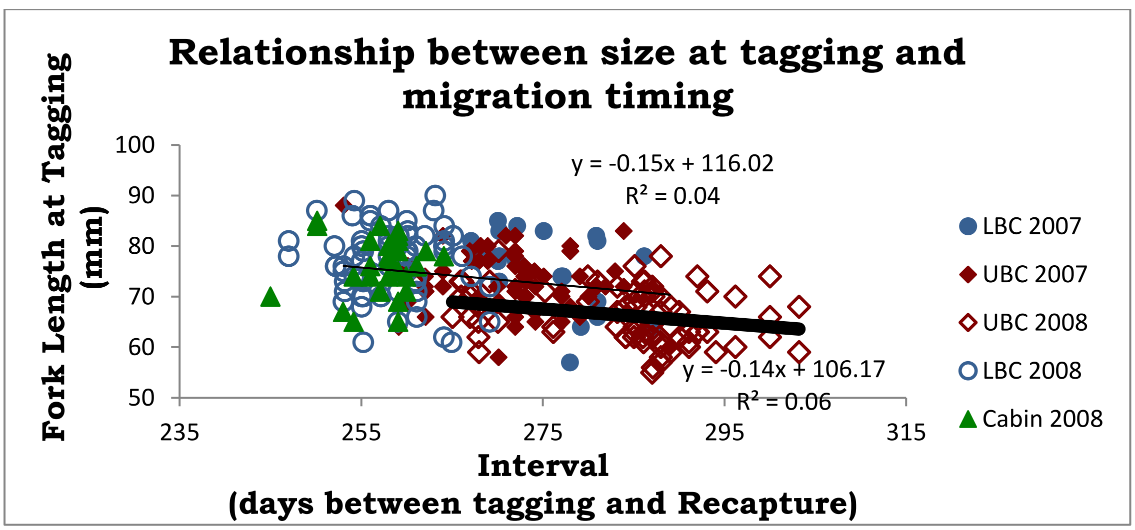

Figure 8. Relationship between fork length at tagging and arrival date at LGBPS

Growth and Outmigration (Time and Space)

Growth between tagging in UBC and recaptured in LBC was dependent upon year. Growth within Big Creek was significantly higher in 2008 for out migrants from UBC to LBC than for those in 2007(Fig. 9a, $p < 0.0001$). Growth rates between initial tagging in fall and recapture the following spring depended upon year, origin (UBC or LBC) and recapture site (LBC vs. LGBPS) (Fig. 9b, $p < 0.0001$).

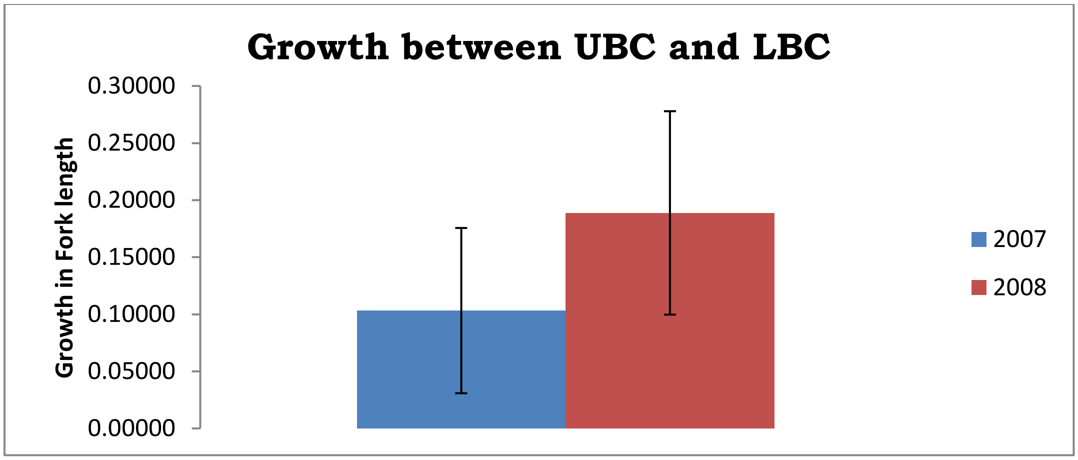

Figure 9a. Mean growth of fish tagged in UBC and arrival at the IDFG screw trap at TWFS.

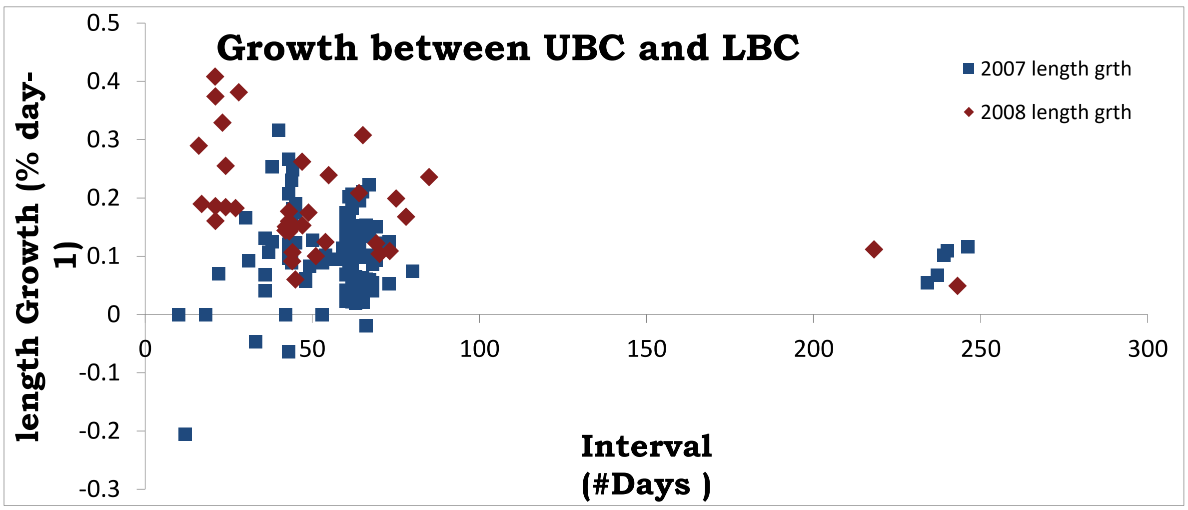

Figure 9b. Relationship between growth rate of fish tagged in UBC and arrival date at the IDFG screw trap at TWFS

Similarly growth rates of fish overwintering upstream of LGBPS varied across years. Of those fish recaptured at LGBPS, growth was lowest for fish tagged in LBC in 2008 (Fig. 10a). Compared to those fish that arrived to LGBPS in spring, growth of fish overwintering in Big Creek (and captured at LBC in spring) was significantly lower (Fig. 10b, Fisher's LSD, $p < 0.001$).

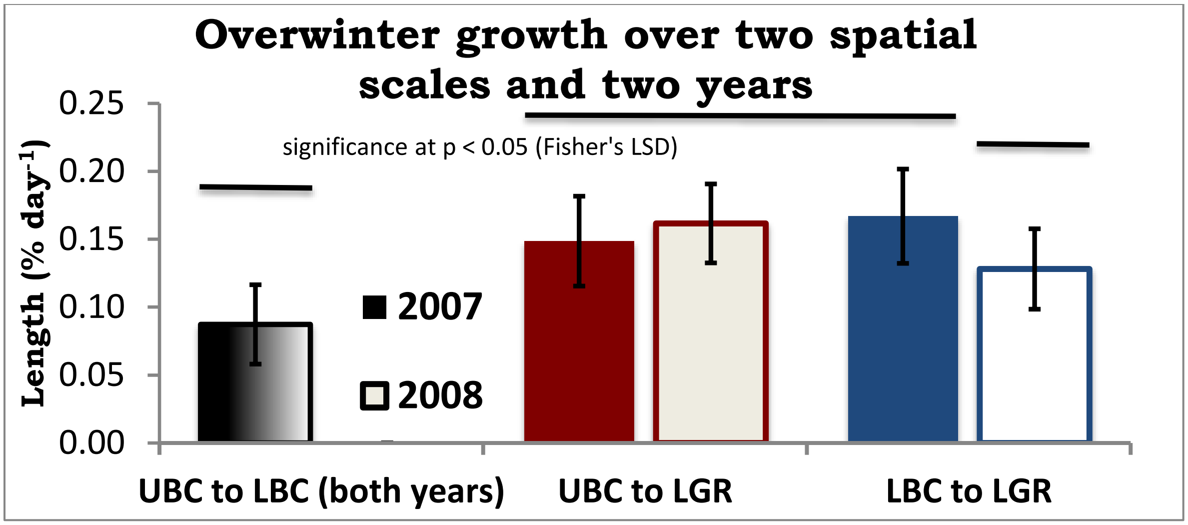

Figure 10a. Mean growth of fish tagged throughout Big Creek and arrival at LGBPS.

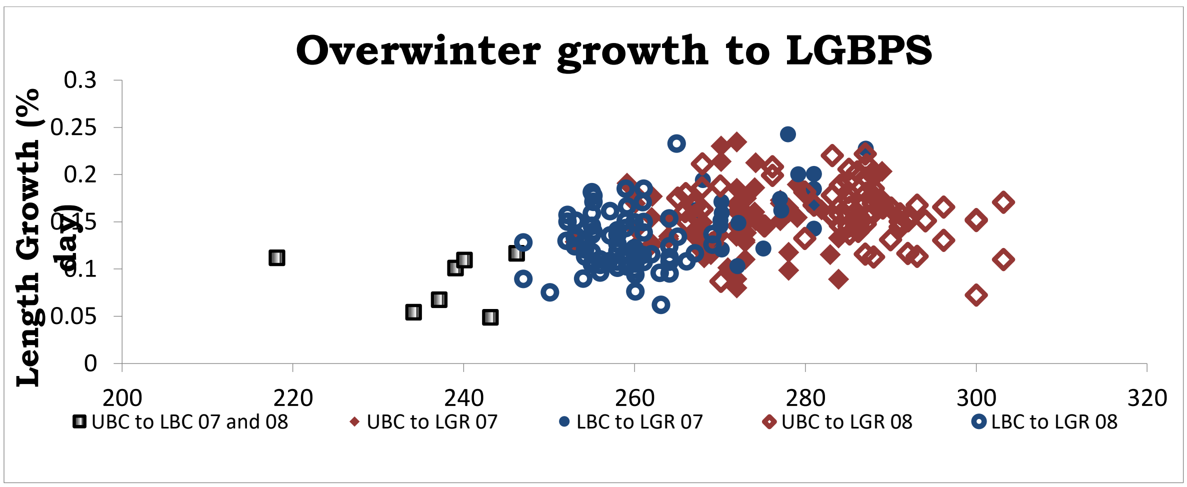

Figure 10b. Relationship between growth rates and arrival at LGBPS

Discussion

Our study demonstrates that although general trends in migration are observed there is also a significant amount of variation occurring within a sub-population of Chinook salmon from within a single large sub basin (Big Creek). We identified several mechanisms responsible for driving these patterns which reflect similar studies of juvenile Chinook outmigration. In Big Creek outmigration peaked in the late summer and fall months when flow is significantly decreased and temperatures are at their peak. This overall pattern follows the typical trend observed in juvenile Chinook emerging in the Salmon River Basin (Crozier et al. 2010, Zabel 2002). In this system fish are assumed to overwinter at sites lower in the tributary where opportunities for growth and quality habitat are less limited by temperature and flow constraints (Crozier and Zabel 2010). Without minimizing the importance of environmental cues we realize that identifying specific relationships between flow, temperature and outmigration is hindered by confounding factors such as fish growth and population dynamics. Therefore, the variation in individual size, travel time, and growth we observed among groups can provide further insights into why these patterns develop in outmigration beyond environmental cues (Zabel 2002).

Since migration evolved as a response to habitats that vary temporally in their suitability, relating migration patterns and individual characteristics to varying habitats allows us to infer what driving forces, constraints and tradeoffs might be. Although we assume the differences we observed between sites and years have links to environmental conditions, it is likely that habitat quality and ecological interactions are responsible for some of the variation in growth rates and travel time across groups. During migration individuals risk exposure to predators and increased bioenergetics costs and therefore must make tradeoffs between reaching the final destination and minimizing these costs. Travel time and individual growth during this period is a direct result of migratory behavior and reflects the consequences of those decisions. This might explain why a small number of individuals remained in the Big Creek watershed overwinter despite growth limitations and why larger fish tended to arrive earlier at LGBPS.

Recent studies of Chinook salmon in Idaho also found that larger fish migrate earlier. Results were expanded to examine survival trends and found that these individuals also exhibit higher survival in the river and in the ocean (Crozier et al. 2010). The same study indicated that population density of conspecifics significantly mediates the relationship between growth and temperature, that at higher temperatures the negative impact of density on growth is intensified (Crozier et al. 2010). This may have important management implications considering changes in climate and the projected rise in temperatures. Under warming climate conditions long-term persistence of populations would most likely require earlier growth and migration (Crozier et al. 2010).

In conclusion, understanding the diversity in which early life history is expressed within and among populations of salmon and the driving forces are key to understanding future risks and mitigation of climate change and anthropogenic impacts. Juvenile survival during the freshwater stages has been identified as the most important stage for recovery of some threatened populations (Sheurell et al. 2009). It has also been shown that migration timing and growth during this period can have significant consequences for survival once fish reach the ocean (Sheurell et al. 2009, Crozier et al. 2010). Although further work needs to be done within Big Creek to identify specific aspects of habitat and population dynamics that significantly influence variation it is important to recognize that from conservation standpoint early life history diversity is important in population stability and viability.

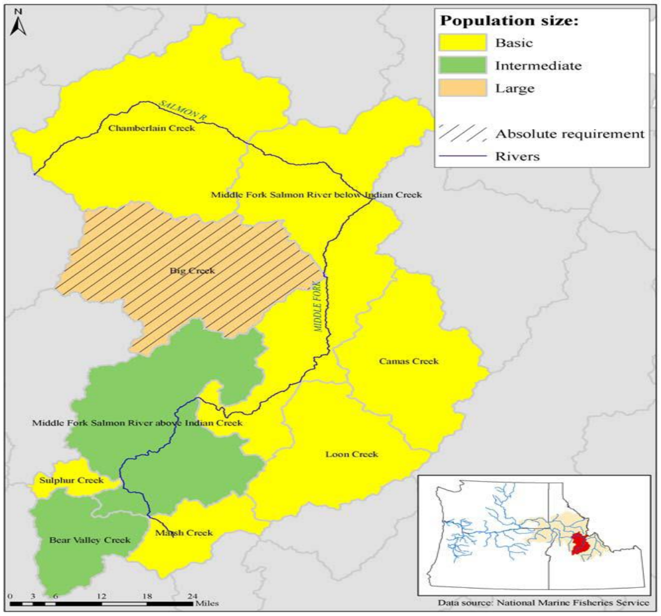

Figure 11. Middle Fork Salmon River spring/summer Chinook salmon Major Population Group and independent populations.
SECTION 5.4 MPG-Level Current Status Assessment Middle Fork Salmon River Spring/Summer Chinook salmon MPG

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