

VALIDATING THE USE OF NON-INVASIVE ENERGY SAMPLING TECHNIQUES TO  
DIFFERENTIATE WILD AND ENHANCED SKEENA SOCKEYE SALMON (*Oncorhynchus  
nerka*) POPULATIONS

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VALIDATING THE USE OF NON-INVASIVE ENERGY SAMPLING TECHNIQUES TO DIFFERENTIATE WILD AND ENHANCED SKEENA SOCKEYE SALMON (*Oncorhynchus nerka*) POPULATIONS

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## ABSTRACT

Sockeye salmon (*Oncorhynchus nerka*) is a key species to nearly every community existing within the Skeena River Watershed. Spawning enhancement programs within the Babine sub-watershed have enabled two sockeye populations at Pinkut Creek and Fulton River to increase in abundance over several decades and now comprise the majority (> 75%) of the Skeena River sockeye aggregate stock, amidst a long-term decline for wild populations. Mixed-stock harvests without means to differentiate wild from enhanced populations have contributed to overexploitation of wild sockeye populations. This study used a microwave energy meter (Distell Fat Meter, Model FFM 692) to examine if populations could be differentiated based on energy reserves. At a full-span, salmon counting fence located along the migration route of Lake Babine sockeye populations, I externally tagged and assessed energy status of 2,056 sockeye, using tag recoveries ( $n = 252$ ) on spawning grounds to infer population identification. I found that the energy meter was able to differentiate enhanced Babine sockeye (pooled between the two enhanced populations) from wild Babine sockeye (all wild populations pooled; Mann-Whitney U-test;  $P < 0.001$ ). An established model from Crossin and Hinch (2005) was used to estimate gross somatic energy (GSE) from energy meter readings and enabled the comparison of this metric among populations. Previous literature has suggested that energy stores will be the highest among populations with the longest remaining migration distance at the time of sampling, but I did not find this to be the case. The two enhanced populations had higher GSE than wild populations despite not having the longest migration distance remaining following sampling. The results of my thesis have begun to validate the use of the energy meter to differentiate wild and enhanced sockeye within the Skeena River system and have the potential to contribute to and inform a shift towards more sustainable terminal, known-stock fishing practices. Finally, my

tagging results enabled a re-examination of the run timing of wild and enhanced populations as they enter the Lake Babine system which has not been examined for several decades and is important information for considering and strategizing sustainable terminal fisheries in this system.

## **LAY SUMMARY**

In the Skeena River Watershed, most of our sockeye salmon are from two abundant and “enhanced” populations called Pinkut Creek and Fulton River within the Babine Watershed. These fish are considered “enhanced” because their spawning grounds were artificially built of cement and have controlled water flows and conditions. Because these populations are so abundant, fisheries all throughout the Skeena River target these fish, and any wild sockeye population swimming alongside, is then exposed to higher fishing pressure. Wild sockeye are not as abundant and have been declining through time; therefore, it’s important for wild sockeye conservation to find ways to protect those wild fish swimming alongside the enhanced fish throughout Skeena fisheries. With this research, I tested the potential for a tool that estimates fat content of fish to differentiate wild and enhanced sockeye. Results were promising and show the tool could be used to selectively harvest just enhanced fish in terminal areas.

## **PREFACE**

My name is Taylor Wale (Luu'maja), wilps xGwoimtxw, Lax Gibuu Pdeek'y from the Gitxsan community of Gitanmaax. My community sits at the confluence of the Skeena and Bulkley Rivers, just downstream of the Babine Watershed where this research is situated. All of our Gitxsan communities harvest from and subsist on the salmon (hon) of the Skeena River ('xsan) since time immemorial. A large number of wild Skeena sockeye (miso'o) populations return to our territories each year, and as such, our culture and livelihoods are centered around the salmon run. Our health and wellness as Gitxsan is inherently tied to the health and wellness of the wild salmon that feed us, feed our forests and wildlife, teach us our values and indicate to us the health status of the ecosystems we all rely on. Wild sockeye is our primary food source, just as it always has been for the people of the Lake Babine Nation upstream.

The Lake Babine Nation (LBN) sits in a very important place within this Skeena River system, as a large majority of all of our Skeena First Nations' collective sockeye return to their territories each year, making LBN the primary stewards for this food source. The LBN has given a great deal to the collective fight to protect wild salmon in our Skeena Watershed, to which this research is a small contribution. This work was born out of specific inquiry posed by the LBN in their efforts to again thrive off of the sockeye populations they have been cared by and cared for since before colonization, while concurrently protecting the wild sockeye returning to their territories. I hold a deep reverence for the communities of the LBN and the work they have done to pick up the pieces of our watershed that settler governments have fragmented without considering future generations, and work to put them back together in ways that honour their traditions and modern rights to subsist on their unceded lands.

This research was conducted on the traditional territories of the Lake Babine Nation and in close collaboration with Lake Babine Nation Fisheries (LBNF) and LBN's commercial fishing enterprise, Talok Fisheries LP. Greg Taylor in association with Talok's board of directors played a major role in conceptualizing the questions that guided this research as well as helped guide future directions and applications of this research. The study design was collaboratively created between Dr. Scott Hinch, Dr. Katrina Cook with substantial inputs from David Patterson and myself. I held the primary responsibility for field work (with assistance from Dr. Katrina Cook, Fern Marlowe, Christie Whess, Donna Macintyre and all LBNF creek-walking crews), data collection and management, and preparation of this thesis. Data analysis was completed collaboratively between myself, Dr. Katrina Cook and Dr. Eduardo Martins. Substantial guidance and invaluable expertise were contributed by my supervisor Dr. Scott Hinch throughout the entire process, as well as field planning guidance and organization from Andrew Lotto, Donna Macintyre, and Andy Rosenberger. All fish capture, tagging and handling procedures were done in accordance with protocols defined by the Canadian Council of Animal Care and approved by the Animal Ethics Committee (A15-0205) as well guided by the expertise of Lake Babine Nation leadership.

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**DEDICATION**

*To the wild miso' o of 'xsan*

# 1 INTRODUCTION

## 1.1 Background

Wild Pacific salmon (*Oncorhynchus* spp.) in British Columbia, Canada, have been in a state of decline for several decades (Price et al. 2017). Despite this, Pacific salmon are still heavily relied upon as critical food sources, particularly for Indigenous peoples (Price et al. 2017). While it is acknowledged that the causes of this decline are multi-factor with complex interactions to consider, aspects of fisheries management which have led to the overharvest of some populations through time, remains a major concern (Berringer 1974; Argue and Shepard 2005; Price et al. 2017). Following European colonization, fisheries maintained by Indigenous communities within their traditional territories were displaced by industrial fisheries systems, which deemed salmon a common property resource harvestable by license holders (Harper et al. 2018; Newell 2016; Haggan and Brown 2002), further disrupting traditional subsistence economies (Haggan and Brown 2002). A major change stemming from this imposed regime, was that non-Indigenous fisheries became concentrated into fewer sites rather than spread out throughout the watershed, across a variety of locations in time and space (Haggan and Brown 2002). Pacific salmon have the highest commercial value when they are intercepted in the marine environment prior to the onset of upstream migration, which is associated with a depletion of fat reserves as a process of maturation and change in physical colouration progresses (Ando 1986; Wood 2001).

By concentrating fisheries into fewer locations, most often coastal marine areas, commercial Pacific salmon fisheries became ‘mixed-stock’ in that multiple species and populations are harvested at the same time from these single locations (Atlas et al. 2020). A major conservation concern associated with mixed-stock salmon fisheries was the application of Maximum

Sustainable Yield management regimes. This involved using a harvest rate applied uniformly to all populations at a place in time and space that was inevitably excessive for the smaller populations which were co-migrating with the abundant ones (Fujita and Bonzon 2006; Plate et al. 2009; Strobele and Wacker 1990). This change in the late 19<sup>th</sup> century coupled with a top-down management regime, has not only removed communities and fishers from the system (Berringer 1974), but has further allowed for unprecedented exploitation and overharvest of salmon in British Columbia (Wood 2001). Overall, the commodification of Pacific salmon in the commercial fishing industry has contributed to an irreparable loss in salmon biodiversity and abundance (Argue and Shepard 2005; Zhou et al. 2010).

Managing mixed-stock coastal fisheries can be challenging because of conflicting objectives of fisheries management agencies to help maximize profits for commercial fisheries from the abundant populations while also needing to protect biodiversity and smaller, more vulnerable populations. One approach to remedy this issue is to allow populations to migrate upstream and begin to physically separate from one another in their specific quests for natal areas, and then conduct fisheries at more 'terminal' locations during their migration where stocks can be better differentiated from one another. However, as fish begin migrating up-river and lipid reserves decline in somatic tissues, the economic value of migrants also declines, which means that terminal fisheries are presumably less profitable and thus less desirable to operate (Walters et al. 2008).

Fisheries focused on terminal migratory areas, and/or on individual populations are not new. Inland Indigenous communities have been conducting and managing their own salmon fisheries

within their traditional territories since before the imposition of the industrialization of fisheries on the Pacific Ocean coast (Atlas et al. 2019). Terminal, known-stock fisheries were and are still common practice despite the imposition of colonial management regimes which have sought to monopolize the commercial fishing industry and remove Indigenous leadership from salmon and water management throughout the province. Although these fisheries have not been fully erased through acts of colonization, the impacts of mixed-stock marine commercial fisheries in tandem with a myriad of pressures that habitats and salmon are subject to through time, have in many cases, severely impacted the ability of communities to harvest sufficient numbers of fish for food, let alone allowing subsisting communities to bolster local economies through their fisheries. The precision and selectivity of some Indigenous fisheries for particular attributes of a salmon run, such as oil content or targeting abundant stocks, presents a sustainable and resilient fishery model for broader fisheries managers to learn from (Menzies and Butler 2007).

One of the most relevant and key features to learn from these types of inland fisheries is the aspect of selectivity of particular populations which are abundant enough to sustain a fishery. Allowing abundant populations to migrate upstream far enough to physically separate from less abundant ones not only relieves the mixed-stock harvest issue presented on the coast, but further distributes benefits of fisheries throughout the watershed to the communities that have been maintaining salmon populations for millennia. This initiative to support more terminal, known-stock salmon fisheries in order to reduce the impacts of mixed-stock commercial fisheries has become a focal point for fisheries managers throughout the province (Beacham et al. 2014), yet balancing the trade-offs for harvesting commercially viable species that are sustainably managed for protection through time remains a challenge.

## **1.2 Study area**

The Skeena River (Figure 1) is the second longest river in British Columbia and an important lifeline for Indigenous peoples in the northwest region of the province. It flows from the Skeena mountains within the traditional territories of the Tahltan people, 400 kilometers downstream to the Pacific Ocean at Chatham Sound on British Columbia's north coast within the traditional territories of the Tsimshian people situated near Prince Rupert (Walters et al. 2008). Babine Lake in the upper Skeena watershed is largest natural lake in British Columbia (500 km<sup>2</sup>; Wood 2001). The Skeena River is a substantial salmon producer for the province, second only to the Fraser River, Canada's largest producer of wild Pacific salmon (Beacham et al. 2014; Wood 2001). Sockeye salmon (*O. nerka*) in the Skeena River system are a critical species to the sustenance and economies of numerous Indigenous communities, as well as an important species economically and recreationally for settler governments and communities. The commercial harvest of Skeena River sockeye salmon predominantly occurs on the coast near the river mouth in mixed-stock fisheries, although smaller inland commercial fisheries are conducted throughout the watershed, extending to the eastern and most terminal portions of the watershed, within the Babine-Nilkitkwa Lake system (Figure 1).

## **1.3 Study Context**

Management activities over the past 60 years have led to abundant Skeena sockeye salmon populations occurring in the Babine-Nilkitkwa Lake system, situated a few hundred kilometres inland and upstream from the mouth of the Skeena (Fisheries and Oceans Canada, 2019). The most significant factor of this redistribution was the construction of sockeye spawning enhancement channels created as a part of the Babine Lake Development Project in the 1960s

(West 1978; Beacham et al. 2014). This project sought to increase the number of juvenile sockeye utilizing Babine Lake for rearing, which was found to be a limiting factor of the system's productivity at the time (West 1978; Wood et al. 1998; Beacham et al. 2014). To reach this goal, spawning channels with flow controls were constructed for Babine Lake's two most productive and abundant populations at Fulton River and another 80 km south at Pinkut Creek (West 1978; Wood et al. 1998; Beacham et al. 2014). These spawning enhancement facilities were loaded with naturally produced fertilized eggs from their respective natal areas in advance of construction and maintained with flow controls conducive to good alevin survival (West 1978). The progeny fry rear in Babine Lake, sharing space and resources with numerous wild populations (Price and Connors 2014). The first significant adult returns of Fulton River and Pinkut Creek spawning enhancement occurred in 1975 (Wood et al. 1998; Cox-Rogers and Splisted 2012) and have since then comprised the largest sockeye populations for the entire system, producing on average 75% of all Babine sockeye salmon collectively each year (Cox-Rogers and Splisted 2012). At present, approximately 90% of all Skeena River sockeye salmon originate from Babine Lake and this lake system now supports the largest individual sockeye stock in all of Canada (Cox-Rogers and Splisted 2012).

Skeena River sockeye salmon are intensively assessed during the adult migration. In the lower river near the ocean at a location known as Tyee (Figure 1), gillnet test fisheries have been in operation since 1955 (Fisheries and Oceans Canada, 2019) examining in-season return abundances. The Tyee test fishery is currently operated by the North Coast Skeena Stewardship Society by way of a collaborative agreement with Fisheries and Oceans Canada (Fisheries and Oceans Canada, 2020). In-season daily escapement estimates from the test fishery are

corroborated with direct counts of migrants upstream at the Babine River Counting Fence (Figure 1), which was established in 1946. The Counting Fence is situated at the entrance of Babine Lake, 360 km upriver from the commercial fishing boundary near the mouth of the Skeena (Fisheries and Oceans Canada, 2019). The Lake Babine First Nation is responsible for managing salmon within their traditional territories, which includes the counting fence that they operate in collaboration with Fisheries and Oceans Canada. The Fulton River and Pinkut Creek spawning channels are also managed by Fisheries and Oceans Canada.

There are 15 major stocks of sockeye salmon within the Babine Lake system with adult spawning migrations largely passing through the Babine River Counting Fence from the end of July to early September (Smith and Jordan 1973). Tagging studies have revealed three clear runs that are distinct, yet slightly overlap through time and space (Cox-Rogers and Splisted 2012). The early-timed run is comprised solely of wild sockeye spawning largely in small tributaries to the main arm of Babine Lake (Cox-Rogers and Splisted 2012). The mid-timed run is almost entirely comprised of enhanced sockeye returning to Fulton River and Pinkut Creek, migrating approximately one week apart in succession of one another and known to overlap with less abundant wild stocks. Lastly, the late-timed run is comprised of wild sockeye stocks that spawn in the upper and lower reaches of Babine River (Cox-Rogers and Splisted 2012). Wood et al. (1998) noted that the wild populations within the three run timing groups have declined over time as harvesting pressures increased on the enhanced populations. Thus, there are wild, small populations co-migrating with larger, enhanced ones throughout the run, possibly overlapping for large portions of the migration.

In recent years, it has been observed that on average, 75% of adult returns in Lake Babine originate from the enhanced spawning channels, compared to 20-40% prior to the completion of the channels (Cox-Rogers and Splisted 2012). There have been several assessments on Babine Lake sockeye examining timing of the various run components through the commercial fishing areas (Aro and McDonald 1968), timing in spawning areas throughout the lake system (Takagi and Smith 1973), as well as an examination of management of fisheries targeting harvests on enhanced Babine stocks (Sprout and Kadowaki 1987). But through all of this, the emerging concern is that most of the Skeena River sockeye are now coming predominantly from two enhanced populations, which has serious implications for fisheries management, the commercial fishery economy, and the resilience of the ecological system. It has been shown that greater salmon diversity provides greater food security for the peoples within a watershed, and thus this lack thereof, raises great concern (Nesbitt 2014).

The legacy of the spawning channels has been an increase in overall productivity and abundance, to an extent, for the enhanced stocks, but this appears to have increased the likelihood of over-exploitation of the smaller wild sockeye populations in coastal mixed-stock fisheries (Walters et al. 2008; Wood 2001). Despite complete closures of commercial fisheries in recent years associated with expected low sockeye salmon returns, and a general decline in exploitation rates over time, sockeye salmon abundance for most wild populations in the Skeena River system continue to decline (Price et al. 2014; Cox-Rogers and Splisted 2012). In a previous study by Beacham et al. (2014), it was shown that ten of the Babine sockeye populations clustered together during upstream migrations in 91% of all dendograms evaluated, highlighting the risk associated with mixed-stock harvesting in downstream locations without being able to

differentiate stocks. This overlapping of returns for smaller and declining wild populations with larger enhanced ones, makes mixed-stock marine fisheries with set exploitation rates difficult to implement when trying to conserve wild stocks (Beacham et al. 2014; Wood 2001; Cox-Rogers and Splisted 2012). This situation points to a need to alter the way fisheries are conducted.

#### **1.4 Potential transitions to more terminal harvests**

Current shortcomings of mixed-stock fishery management in coastal areas is re-emphasizing a need to transition towards more sustainable fisheries in order to protect salmon biodiversity as well as to assist fragile commercial fishing economies threatened by low returns. One such approach would be to shift large segments of harvest on the enhanced stocks to terminal areas where population selectivity is possible (Walters et al. 2008; Plate et al. 2009). Cox-Rogers and Splisted (2012) concluded that escapements to the two enhanced populations in the Babine lake system are projected to continue to surpass spawning escapement requirements amidst long-term declining trends in total production. Thus, given the forecast of enhanced populations being able to sustain a targeted fishery, the question we now face is what are the most appropriate strategies for harvesting surplus fish from enhanced populations while prioritizing the conservation of wild stock biodiversity. There are myriad assumed benefits that would stem from a larger proportion of the commercial sockeye fishery being moved into terminal areas, beyond the preservation of biodiversity and the sustainability of a healthier fishing industry. Conducting fisheries upstream allows for more thorough monitoring of a wider variation of stocks leading to more comprehensive estimates of relative abundance, while also facilitating the distribution of monetary and social benefits coming from commercial harvests to the communities that primarily subsist and protect these valuable species through time (Walters et al. 2008). Upstream

known-stock harvests also have the potential to enhance salmon diversity and consequently strengthen Indigenous communities' food security (Nesbitt 2014).

There are ongoing initiatives for shifting towards more terminal fisheries in the Skeena (Walters et al. 2008; Plate et al. 2009), yet there still remain gaps in our understanding of the system as to the precise timing of each of the run components, updated abundance metrics of each of the wild Babine stocks, and identification of where wild stocks are overlapping with enhanced sockeye (Smith and Jordan 1973; Beacham et al. 2014; Price and Connors 2014). Most importantly, in order to successfully conduct a profitable terminal fishery, it is crucial to find solutions to balance the trade-off presented by harvesting fish of a perceived lower value at a point in their migration where lipid and energy content are likely to be nearly exhausted.

Because the Babine Lake system is the migratory terminal location characterized by maintaining the largest salmon return in the whole Skeena region, there are special opportunities for harvesting larger numbers of salmon here than in other areas of the watershed. The Indigenous communities of this region, now known as the aggregate Lake Babine Nation (LBN), have built thriving societies upon this abundance, which is now reflected in the contemporary fisheries they maintain. Because of the terminal nature of this system, First Nations such as LBN have access to commercial harvest opportunities under the Economic Salmon to Spawning Requirements (ESSR) Fisheries umbrella. ESSR fisheries occur where spawner abundance of a particular system is in excess of the spawning requirement for that system, which allows for the selective harvest of individuals theoretically unable to spawn that year based on channel capacity (Fisheries and Oceans Canada, 2020). ESSR fisheries also provide a unique opportunity to First

Nations communities such as LBN, enabling the commercial sale of fish that contributes to the economic self-sufficiency of participating communities (Fisheries and Oceans Canada, 2020).

Since 2006, terminal ESSR sockeye fisheries have been conducted on surplus spawners arriving at the enhancement channels in Babine Lake through LBN's privately owned commercial fishing company, Talok Fisheries LP (Plate et al. 2009). Although this fishery is able to avoid harvesting wild populations, the economic value of these fish is reduced because they are captured at spawning grounds and their flesh quality is diminished due to maturation. Being able to harvest earlier in their migration, for example at the Babine River Counting Fence, would increase their economic value. However, because they co-migrate with wild populations at that location, and they also look physically similar to them, a non-invasive and rapid means of identifying population origin is needed in order to facilitate a more economical and conservation-oriented fishery. Population identification has traditionally relied on a combination of run timing details and DNA approaches. However, DNA approaches have not been reliable for population identification for Babine Lake sockeye (Beacham et al. 2000). My study builds on the traditional-run timing research (e.g. Smith and Jordan 1973; Takagi and Smith 1973) and examines a new approach for differentiating wild populations from enhanced ones during the spawning migration for Babine Lake sockeye salmon.

### **1.5 Energy expenditure of migrating sockeye salmon**

A central piece of this study is the examination of the energy content and energy use by migrating sockeye salmon. Adult sockeye salmon cease feeding prior to initiating upriver migration and rely on lipid reserves to fuel upstream swimming and production of reproductive

tissues (Crossin et al. 2004; Gilhousen 1980). Gilhousen (1980) demonstrated that the energy derived from lipid stores in the body results in a decrease in mass by way of the oxidation of proteins. Water replaces the utilized lipids in somatic tissues. By the time salmon reach spawning grounds and are reproductively mature, somatic lipid levels are nearly depleted and somatic tissues have gained a large proportion of water (Crossin et al. 2004).

Sockeye salmon populations in the Fraser River start their upriver migrations with levels of energy reflective of their migration journey (Crossin et al. 2004). Long distance migrating populations (e.g. spawning grounds ~ 1000 km from the ocean) start the river migration with high densities of tissue lipids whereas shorter distance migrants start their migration with low densities (Crossin et al. 2004). A similar relationship between upriver migration distance and energy density has also been observed in populations of adult Fraser River pink salmon (*O. gorbuscha*; Crossin et al. 2003). Energy-use during upriver migration is affected by behaviour and environmental factors like water temperature and hydrology (Brownscombe et al. 2017; Kinnison et al. 2001; Rand and Hinch 1998; Gilhousen 1980; Crossin et al. 2004). Crossin et al. (2004) found that despite substantial among-population differences in somatic energy levels at the onset of up-river migration, once on spawning grounds following completed maturation and spawning, populations had similarly low levels of energy. Although it is uncertain if populations remain energetically different from one another throughout the entirety of the migration prior to reaching spawning grounds, it is possible that within a terminal range, downstream terminal fishing locations, that populations could still be energetically differentiated from one another.

Most of the research examining Pacific salmon lipid levels have utilized full body constituent analyses which requires sacrificing fish and considerable time with laboratory chemical assays. Ways to rapidly and non-lethally assess fish energy content in migrating adult Pacific salmon have been explored by examining somatic water concentrations using electric conductivity (e.g. Crossin and Hinch 2005; Hendry and Beall 2004). Crossin and Hinch (2005) found that indices of somatic tissue water concentration derived from a commercially produced hand-held microwave energy meter were strongly correlated with somatic lipid concentrations, which were assessed on the same fish from constituent analyses. Recently, the microwave energy meter revealed consistent differences in water content among some populations of Fraser River sockeye at a mid-point (~ 400 km upriver from the ocean) in their spawning migration, and these differences were confirmed with DNA analyses (Harrower et al 2019).

Given the need in the Babine Lake system to protect wild stocks exhibiting decreasing trends in abundance and diversity, meanwhile looking to increase the allocation and selectivity of the commercial terminal fishery here, this study seeks to examine non-invasive energetic sampling as a technique of stock differentiation at a downstream location (e.g. the Babine Lake Counting Fence). It is becoming increasingly relevant to explore new methods for in-field stock differentiation within this system, as Indigenous communities further increase access to and participation within terminal economic fisheries (Plate et al. 2009). This further emphasizes the need to test methods for balancing trade-offs between stock selectivity and value harvested. My research involves an examination of timing and run-components of all Babine-origin sockeye, as well as the application of the microwave energy meter to differentiate wild stocks from enhanced stocks coming from the spawning enhancement facilities at Fulton River and Pinkut Creek. This

work hypothesizes that Babine-origin sockeye stocks will differ in arrival timing and lipid content at the Babine River Counting Fence, and thus can be differentiated non-invasively using a handheld microwave energy meter in the field.

## **2 METHODS**

### **2.1 Study site and sampling design**

Sockeye salmon were collected at the Babine River Counting Fence (Figures 1 and 2), which is operated by LBN Fisheries technicians to control fish passage and provides a unique opportunity to intercept and monitor salmon en route to terminal spawning grounds. The fence is installed each summer following spring freshet once water levels have sufficiently dropped. Installation timing is an important factor because precise enumeration requires that the fence be installed prior to the onset of upstream migration of salmonids returning into this system. During 2017, the year of study, the fence was installed and operational by July 17, which is only slightly behind regular timing, typically complete in early July. The fence is 100.6 meters wide and is comprised of seven holding traps used intermittently to collect a complete count of all migrating salmon returning to this system (Figure 2). Each holding trap is approximately 1.8 m x 2.5 m positioned on the upstream side of the fence, which are equipped with manually-operated sliding trap doors on either end of each holding trap and a viewing box to enable visibility and control the flow of individuals counted through (Figure 2).

There are 11 main populations of sockeye salmon that pass through the fence enroute to their spawning grounds plus the two enhanced populations, Pinkut and Fulton (Cox-Rogers and Splisted 2012). My approach was to use the fence as a means to rapidly and with relatively little stress to salmon migrants, access adult sockeye for purposes of bio-assessments and tagging, over the course of their run into the Lake Babine system. I sampled sockeye across most of the known run timing window – though I was not able to access the earliest fish because the fence could not be installed due to high water.

Tagging and sampling was conducted off one of the seven holding-trap platforms, chosen each day based on which traps were holding the greatest number of fish. The sampling set up was portable to enable moving to another trap that may have a steadier stream of fish ready to sample. At the chosen platform, each day a standing sampling trough (96 cm long X 26 cm wide, X 12 cm deep) was set up equipped with features to minimize harm and stress on individuals undergoing sampling and tagging. The sampling trough interior was lined with rubber matting and had a constant flow of cold water being diverted from the river through a battery-powered bilge pump. For ease of data collection and sampling, the upper edge of the trough was bordered with a ruler for recording measurements and a screen was installed across the top surface of one side of the trough to cover the head of each individual during sampling and reduce visible stressors. Other precautions were taken to ensure minimal damage and stress was inflicted on each fish, including floor matting should a fish be mis-handled or dropped, and a padded release chute attached to the trough outflow directing released fish to the surface of the river. On each of the seven platforms, the holding traps are at the centre and covered by a hinged door that is lifted to access fish for sampling from above. The sampling trough was set up directly adjacent to the holding trap to minimize air exposure. Fish could be dip-netted from a trap to the trough in approximately 5s. All fish were handled and sampled in accordance with animal use protocols (A15-0205) approved through the University of British Columbia.

Sockeye were individually dip-netted at random from the holding traps. Once in the trough, I collected the following information: fork length, sex, external injuries, maturity state (classified as silver, silver bright, mature, and very mature), and estimates of tissue lipids and gross somatic energy (GSE). External injuries were estimated using a scoring system following methodology from Cook et al. (2018), which classified and scored observed injuries based on scale loss, skin

loss, wound depth, fin damage and severity of fin damage. Maturity state was a relative measure based on the level of visible scale absorption and colour change through the maturation process, as well as the apparent level of gonad development for the more mature individuals. Gross somatic energy content was estimated using a handheld microwave energy meter (Distell Fat Meter, Model FFM 692) that rapidly and non-invasively provides a measurement of somatic tissue water content. Water content measures can be converted to estimates of somatic lipid content and total GSE through previous calibrations on sockeye salmon between microwave energy meter readings and whole body and tissue specific lipid measures from chemical constituent analyses (Crossin and Hinch 2005). The microwave energy meter is used extensively in aquaculture as a means for 'grading' the fat content of fish. Two microwave energy meter readings were collected at a single body position centered between the back of the operculum and the dorsal fin, directly above the lateral line (see Crossin and Hinch 2005). For the first 100 fish, three energy meter readings were taken per individual along the lateral line; however, energy meter index values were consistently similar and so we moved to two readings per individual in order to minimize handling time per individual. Energy meter assessments took less than 10 seconds per fish.

Because my goal was to determine if GSE content estimated at the fence was a good indicator of population of origin, and there are no accurate ways at present to utilize DNA procedures for population identification in this system, I needed to be able to track the final spawning locations of my sampled fish. To accomplish this, I externally tagged fish using 1-2 coloured spaghetti tags (FT-4 Spaghetti Tags, Floy Tags) each with a unique ID. Within each 2-3 day tagging block, external tags were colour-coded so that each tagging block was visibly distinguishable in the

case that tagged fish could not be physically recovered on spawning grounds but could at minimum be visually identified to provide coarse information on migration timing through the fence. Two tags were used for certain tagging blocks to increase the number of colour combinations for visually identifying fish relevant to the time they were tagged.

To insert a spaghetti tag, each was partially threaded over a stainless-steel hollow needle (covering ~10% of the needle's length). The needle was pierced through the body less than 3 centimetres behind the dorsal fin and just below the arch of the back, exiting the body through the other side. A spaghetti tag was pulled through about half of the tag length and the needle attached to the leading end was removed before securing both ends of the tag with a metal crimp using pliers. One or two tags were attached per fish, depending on the tagging block to increase the colour combinations. Tags were secured along the top ridge of the back without excess tag looping to avoid individuals getting snagged, however tags needed to be loose enough to avoid skin pulling or any injury that may facilitate wounding or infections. Prior to insertion, the needles were disinfected using diluted 90% proof ethanol, diluted bleach and thoroughly rinsed with water. Following sampling and tagging protocols, fish were slid backwards from under the head screen and gently directed head-first into a release chute with water outflow.

Main sockeye salmon spawning streams were surveyed on ten-day intervals throughout the spawning period by Lake Babine Nation Fisheries (LBNF) technicians. On spawning grounds, LBNF technicians primarily collected tags on spawned out carcasses recording date and location of encountering the tagged carcass to derive coarse run timing, population of origin, and match the coded tag to its respective line of data collected at the Counting Fence. Technicians also recorded observations of tag colours on live tagged individuals on creeks, and of carcasses that

were not possible to recover because of water depth. I was not able to assess lipid concentrations from tagged fish recovered from spawning grounds because tissues have such high volumes of water that the energy meter's output becomes unreliable (Crossin and Hinch 2005).

## **2.2 Data Analyses**

Population of origin for fish sampled at the counting fence was derived from tagged carcasses encountered on spawning grounds. Because all analyses relied on the numbers of individuals recovered, sample sizes limited interpretation of run timing for several wild populations. To address the main objectives of differentiating wild populations from enhanced populations temporally, data were grouped according to this binary to allow for comparisons between both enhanced populations grouped together, and all wild populations grouped together. To examine important interactions amongst populations, wild populations with less than 30 recovered individuals (Table 1) were grouped together to facilitate analyses. Examining run timing components of the system set up the foundation for further analyses into how timing interacts with energy and other variables for the populations sampled. Run timing curves were produced for each population to examine overlap between stocks of interest. Logistic regression was used to assess temporal variation in the probability of encountering a migrant at the counting fence that was destined for one of the enhanced populations.

Previous studies done by Smith and Jordan (1973) and Takagi and Smith (1973) primarily relied on run timing of the three distinct 'runs' of Babine sockeye for their analysis. For this study however, my objectives were to differentiate the enhanced sockeye from wild stocks throughout

the entirety of the run, accounting for the known overlap between these two groups in time and space, falling largely within the mid-timed portion of the run. Because sampling likely missed some of the early-run wild stocks due to late fence installation, it was not justified to group populations according to the three distinct yet overlapping run timing groups as has been previously used by earlier studies.

Energy meter readings were averaged to get a single value for each individual fish. Following the methods in Crossin and Hinch (2005), average energy meter values were natural log transformed so that they could be used as an independent variable in linear regression models which were developed on Fraser River sockeye in order to predict GSE (Figure 3). This energy model was derived and validated using full body constituent analyses on migrating Fraser River sockeye (Crossin and Hinch 2005). Estimates of GSE for Babine Lake sockeye, based on this model, were non-normally distributed thus requiring non-parametric analyses in subsequent comparisons.

To examine the question of whether or not the microwave energy meter can be used to distinguish enhanced sockeye populations from wild sockeye populations in Babine Lake sockeye salmon, I used a Mann-Whitney U-test (non-parametric Wilcoxin Rank Sum Test) with a correction for continuity. To examine if GSE estimates differed among the broader set of populations, I used a Kruskal-Wallis test (non-parametric ANOVA). To examine arrival timing as a predictor of GSE for fish encountered at the Babine River Counting fence, linear regression was used with sampling date as a predictor of GSE for the various populations. This linear model

required that all populations be pooled and compared against the enhanced Fulton population which had the largest sample size. All analyses were performed in R software (version 1.4.1103).

### 3 RESULTS

#### 3.1 Population-specific run timing

Run timing at the Babine Lake Counting Fence was determined for populations of wild and enhanced sockeye using tag recoveries from spawning creeks ( $n = 252$ ). The early portion of the sockeye run was dominated by wild populations whereas the latter portion consisted primarily of sockeye from enhanced populations (Figure 4). Examinations of individual populations occurred if tag recoveries were sufficient ( $n > 30$ , see Table 1), otherwise populations were pooled and looked at as one group. In particular, populations from Four Mile and Pierre were the most abundant of the wild sockeye, which were passing through the counting fence at the beginning of study in mid-July, with their migrations continuing through to early August where they overlapped with fish from the enhanced Pinkut population and the arrival of the enhanced Fulton population. Throughout much of August, the run was comprised primarily of migrants from the Fulton population (Figure 5). Daily population proportions at the fence revealed Fulton fish comprised the large majority from the point of their arrival, overlapping only slightly with a few wild fish and some from the Pinkut population near mid-August (Figure 5).

Run timing curves used the total daily proportion of recovered fish migrating through the fence to compare migration timing patterns between wild ( $n = 139$  individuals recovered) and enhanced ( $n = 113$  individuals recovered) populations (Figures 6 and 7). Fish from the enhanced populations arrived at the fence in late July in moderate abundances which rapidly increased to peak abundance in early August, with a more gradual decline in abundance at the fence throughout the remainder of the study period (Figure 6). Wild fish populations, when grouped together as a single aggregate, arrived in a series of four distinct peaks, the first had peak abundance dense near mid-July, with a rapid decline in abundance to near zero by the end of

July. Smaller peaks appeared at the start of August, and towards the end of August (Figure 6). Wild fish population peak arrivals at the fence appear to be linked to arrivals of fish from the Four Mile and Pierre populations though smaller contributions from other wild populations appear to be important (Figure 7). Peaks in these figures are also informed by the sampling design, whereby fish were sampled at the fence in blocks of days, rather than sampled consecutively throughout the sockeye run, which may have revealed a smoother and more consistent run timing curve. The enhanced Pinkut population arrived at the fence in peak numbers from mid July to early August, ahead of the enhanced Fulton population with high abundances throughout much of August (Figure 7). The wild populations (Four Mile, Pierre, and others) exhibited migration timing patterns at the fence most similar to, and overlapped with, that of the enhanced Pinkut population (Figure 7). There were very few wild migrants that overlapped in timing later in the study coincident with the timing of the enhanced Fulton population, according to these recovery results. Importantly, this lack of visibility for the late-run wild populations are not indicative of their absence, but rather limitations to our study design and lack access to wild tributaries to enable tag recoveries from these populations.

### **3.2 Population-specific energy content**

The microwave energy meter was able to differentiate enhanced fish (pooled between the two enhanced populations) from wild fish (all populations pooled) (Mann-Whitney U-test;  $P < 0.001$ ,  $W = 9514$ ). I therefore proceeded to use the calibrations in Crossin and Hinch (2005) to estimate GSE and compared this metric among populations. By converting energy meter readings to GSE, it enables comparisons of population energetics from the Babine study system to GSE studies in other systems and to better define trends. There were significant differences among populations

in energy meter readings and hence in estimates of GSE (Kruskal-Wallis test,  $P < 0.001$ , chi-squared = 51.99). Pinkut and Fulton had the highest GSE values (Figure 8). Pairwise comparisons between the individual enhanced and wild populations revealed significant differences in GSE (all  $P < 0.05$ ) between the two enhanced populations, as well as both enhanced populations compared to the all the wild populations (Figure 8). Pinkut had higher GSE than Fulton however there were no differences in GSE between any of the wild populations (all  $P > 0.05$ ).

Enhanced populations from Pinkut and Fulton not only had the highest energy meter indices, but the greatest number of silver and silver-bright fish (categories representing lowest maturity) as compared to all other populations. The only fish categorized as silver upon sampling at the counting fence ultimately returned to Fulton River. Fish categorized as silver-bright also returned to wild natal streams at Four Mile Creek and Pierre Creek, but in smaller numbers compared to the enhanced silver-bright fish (Figure 9). Linear models reveal how wild and enhanced populations relate to GSE through time, and further defined the periods of significant difference in energy between populations and the smaller period of overlap in mid- to late-August (Figure 10). These results reveal a much steeper downward slope for GSE of enhanced sockeye through time, compared to the relatively stable and flat slope for GSE of wild sockeye populations across tagging dates (Figure 10). The same linear model relating GSE to populations through time was created to further examine populations individually (all populations with  $n > 30$  recovered individuals; populations with  $n < 30$  recovered individuals grouped as one population), firstly revealing a much steeper downward slope in GSE for Pinkut fish as compared with Fulton fish, which maintained a more gradual downward slope in GSE for the duration of the run (Figure

11). Linear regressions to examine if sampling date predicted GSE for the various populations found significant relationships for enhanced populations ( $P < 0.01$ ), but not for wild ones (all  $P > 0.5$ ).

## **4 DISCUSSION**

### **4.1 Salmon run timing**

The population-specific run timing of Babine River sockeye populations were consistent with those of older studies (Takagi and Smith 1973, Smith and Jordan 1973) and further demonstrated the timing similarities and differences among wild and enhanced populations. Enhanced fish arrived at the Babine fence at moderate densities which increased to a maximum and then gradually fell until the end of the run. In contrast, the wild populations arrived at the counting fence in a series of peaks that decreased in density until the end of their run. The peaks in density shown in wild population run timing curves can be explained in part by the number of populations making up the wild grouping ( $n = 11$ ) compared to the enhanced population grouping ( $n = 2$ ). The curvature of the two run timing curves also revealed a potential sampling bias presented through tag recovery, as tag recoveries at the enhanced facilities were more accessible and consistent through time, relative to wild creeks which were surveyed on 10-day intervals over vast geographic ranges with limited access. Relative abundance of these two population groupings were comparable; however, the diversity within each grouping was evident from the run timing curves.

Earlier studies characterized the aggregate Skeena sockeye run to peak at the lower river test fishery during the week of July 22, inferring a peak at the counting fence to be mid-August (Price and Connors 2014). My results showed that the peak of the wild population to have occurred mid-July (around the time of fence installation for this year of study), and the peak of the enhanced run to have occurred in the first week of August, with Pinkut fish arriving a week or two prior to Fulton fish, which is consistent with previous studies (West 1978). Despite this

examination only spanning one year of study, previous research has shown that the Fulton population exhibits remarkable consistency in run timing across years (Smith and Jordan 1973); thus, allowing us to make inference about this major population in relation to other populations within this system.

My research revealed that the enhanced populations comprise the relative majority of the run right from the point of their arrival to terminal areas. Examining run components for this system revealed that, in addition to the Morrison population, wild fish from Pierre Creek were also in a timing overlap with the enhanced-majority run – rendering these two populations inherently vulnerable to over-exploitation. A benefit flowing from this study is the definition of a gradient of time showing when targeted enhanced fisheries are of highest and least risk to co-migrating wild fish. However, without methods in place for differentiating these two populations in the field in real time, applying differential exploitation rates on each population has not been possible; potentially contributing to marked declines in the Morrison population through time since the last examination of this system (Smith and Jordan 1973, Takagi and Smith 1973, Price and Connors 2014). Sample sizes for Morrison fish recovered within this study were insufficient ( $n = 1$ ) to draw larger inference to consequences of this overlap during my study year, but points to a need to further examine the status and relative abundance of this vulnerable wild population.

## **4.2 Salmon energetics**

Upriver migration experiences are population-specific so it is not surprising that energy accrual in the ocean and energy use for upriver migration activities including swimming and gonad development are also population specific (Nadeau et al. 2010; Gilhousen 1980). I found that

enhanced fish arrived at the counting fence with higher GSE content. There are three potential reasons for this, the first is migration distances. Salmon populations that must undertake long-distance migrations typically begin their up-river migration with higher somatic energy reserves and they develop fewer and smaller eggs than populations with shorter distance migrations (Crossin et al. 2003; 2004). The enhanced populations, in particular Pinkut, must travel some of the longest distances of all the populations to spawning grounds so having higher energy content when entering the lake would help individuals to reach spawning areas, however the Fulton population has a shorter distance to its spawning areas than several of the wild populations so other factors must be involved in addition to migratory distance. Because much of the earlier research related energy reserves in upstream migrants to migratory difficulty (Gilhousen 1980; Kinnison et al. 2001; Crossin et al. 2003, 2004; Cooke et al. 2006), my results present a relatively more complex inquiry into population-specific energetic characteristics for populations that have relatable migratory experiences, yet show distinct energetic patterns. Enhanced populations generally arrived at the counting fence with GSE estimates of nearing 6 MJ/kg and sharply declined to below 5.5 MJ/kg, compared to wild fish which arrived at the fence with ~ 5.5 MJ/Kg with these values remaining stable over the run. These results highlight a need to further examine the stock (e.g. genetic) composition and behaviors of the wild fish within Babine Lake, and energy use patterns between the counting fence and terminal spawning grounds.

The second issue involves arrival timing and within-lake behaviour. The higher GSE of enhanced populations could be attributed to a different type of life-history than the wild populations in terms of where gonad and sexual maturation takes place. If they are indeed arriving at the fence well before their spawning time, they are likely milling in the lake and

maturing their gonads with that higher level of reserve energy whereas the wild stocks may have been spending more of their energy maturing their gonads they migrated upriver. This trait is evident in Late-run Fraser River sockeye which mill in the Strait of Georgia for several weeks prior to starting up-river migration where they spend their time maturing their gonads, in contrast to other Fraser River sockeye stocks that migrate directly from the ocean to freshwater and spend a lot of energy maturing gonads during their upriver migration (Hinch et al. 2012). Some pre-spawning sockeye within the Babine Lake system are believed to hold in the lake for up to three weeks prior to ascending natal spawning streams (C.J. West 1978; Beacham et al. 2014). My results suggest that earlier arrivals from the enhanced populations may exhibit some energetically costly behaviours (i.e. milling) in Babine Lake for an extended period of time before approaching spawning grounds, with the amount of time/rigor spent on these behaviors decreasing as the run progresses. Past research also noted that early-run populations may migrate relatively slower yet some travel comparable distances to the mid-timed enhanced/Morrison run (Takagi and Smith 1973) further indicating that migration rates need to be more thoroughly assessed in these Lake Babine populations.

The third issue involves the potential for 'enhancement operations' affecting the energetics of the populations. Salmonid enhancement facilities can lead to selection for particular behavioral and morphological traits (Reisenbichler and McIntyre 1977; Nickelson et al. 1986; Fleming and Gross 1989; Swain and Riddell 1990; Fleming and Gross 1992, 1993, 1994; Flagg et al. 1995). Within the Babine system, it is possible that some form of artificial selection affecting energy utilization may have contributed to the enhanced populations having higher energy densities when they enter the Lake Babine system. Brownscombe et al. (2017) explored the relationship

between energy stores and biological fitness for migrating populations, defining a positive correlation between the two attributes. The optimization of energy allocation throughout migration thus, can be considered a major contributing factor to a population's fitness (Brownscombe et al. 2017). It is possible that enhanced populations exhibit different types of energy allocation and maturation timing attributable to the enhancement operations, however understanding the underlying processes that might lead to behavioural or physiological changes in migrating adults cannot be assessed by this thesis.

### **4.3 Salmon energetics in the broader context**

Estimates of GSE that I obtained for Lake Babine sockeye populations in their terminal natal areas revealed a remarkable consistency with those from terminal areas in other river systems. Crossin et al. (2004) examined GSE of five populations of Fraser River sockeye salmon as they migrated up-river. They found that despite some populations starting their migrations with GSE ranging from 10 MJ/kg (natal areas ~ 1000 km upriver) to 7 MJ/kg (natal areas < 50 km upriver), all populations arrived at spawning grounds with GSE of 5-6 MJ/kg. In my study, most populations arrived at the counting fence with energy levels of 5-6 MJ/kg, which is similar to the Fraser River populations (Crossin et al. 2004). Interestingly, the Lake Babine populations still had several more days to migrate to arrive at spawning grounds yet the Fraser River populations were already at spawning grounds. This suggests that the Lake Babine populations were very close to being ready to spawn despite the additional travel required to get to natal streams.

Crossin et al. (2004) also discovered that 4 MJ/kg is the life-or-death threshold for sockeye salmon, which suggests how close the Lake Babine populations, in particular the wild ones, were

to energy exhaustion and death. In particular, wild fish from Four Mile creek were the closest to this threshold followed by Pierre with the second lowest GSE measurement. In sum, the broad similarity in GSE patterns between Lake Babine and Fraser River populations demonstrates the reliability and utility of the energy meter and this non-invasive approach to addressing energy use in migrating Pacific salmon.

#### **4.4 Maturation status in relation to population-specific energy**

As fish approach migration terminus and energy stores are near depletion, maturation is visible through a change in skin colour and the creation of secondary sexual reproductive tissues (Groot and Margolis 1991). Maturation status, much like energy content, should logically represent the time, difficulty and distance remaining for an individual to reach spawning grounds (Gilhousen 1980; Kinnison et al. 2001, Crossin et al. 2003, 2004) assuming that the population exhibits no further diversions (i.e. milling behaviors beyond point of interception). In this study, I observed the enhanced fish arriving visibly less mature, which we were able to relate to higher measured energy content for enhanced fish. The least mature class, being '*silver*', was only observed for fish of Fulton origin, which consequently also had the highest energy index values. Results displayed through this study defined ranges of measured energy content for each of the maturity status categories (four levels), in relation to each of the 5 major populations sampled and recovered through this study. Both Pinkut and Fulton fish exhibited a wide range of energy meter index values for fish categorized as '*silver-bright*' (level 2) upon sampling, with fish from those categories showing the highest median values for '*silver-bright*' fish compared to all other populations, as well as much higher maximum energy values compared to all other populations. Fish categorized as '*mature*' (level three) were observed in Pinkut, Fulton and Pierre, with

similar ranges in energy meter indices across the three populations, but with the highest measure energy content identified to the Pinkut population for ‘*mature*’ fish. There were no enhanced fish categorized to the ‘very mature’ level throughout this study, and the fish that did arrive with that maturity status had the lowest marked energy levels across the board.

#### **4.5 Relevance to fisheries management and conservation**

Examining population-specific metrics of energy and run timing throughout the Babine sockeye migration provides valuable information for management of the fisheries within Lake Babine Nation territories and potentially the entire Skeena River. The most practical application of these findings is to inform the timing and effort of fisheries conducted at the Babine River Counting Fence, which potentially has the ability to selectively target enhanced individuals using the microwave energy meter in accordance with these timing results. Models produced herein show periods of time at the fence when GSE is significantly different between the two population groupings of interest and therefore, defines a range of dates where energy sampling could be applied to differentiate fish for selective harvests. Once methods are further validated within this system there is large potential for these tools to be applied throughout the watershed and possibly beyond. This future application could involve the utilization of fishing structures along the migration, akin to the Babine River Counting Fence, as harvest locations that time fisheries according to specific run timing results for each location. During times of uncertainty, managers could apply the microwave energy meter to select for enhanced fish. This exploratory research into examining tools for in-field energy measurement as a means to differentiate sockeye populations of interest, has vast application and relevance to fisheries management. Beyond

application to the Skeena River region, this tool has potential to be significant to many systems aiming to conduct more precise selective fisheries.

The majority of the sockeye salmon in the Lake Babine system are from the two enhanced populations. Given that the juveniles from all the populations rear in a common environment (e.g. Lake Babine), the smaller wild populations are likely facing heavy competition for space and resources (Heino and Godø 2002, Rand et al. 2012). Rand et al. (2012) noted a negative correlation between wild salmon survival and high abundance of hatchery-origin fish coexisting in the same system. Relative to studies on consequences of hatcheries on wild salmon populations, much less is known about the influence of artificial spawning enhancement facilities on systems maintained by wild salmon (Price and Connors 2014). Increased abundance in the Skeena sockeye stemming primarily from artificial enhancement, could create a scenario where biodiversity and resilience of smaller wild populations are slowly diminished over time (Price and Connors 2014).

#### **4.6 Balancing trade-offs presented in terminal fisheries**

A large portion of commercially harvested fish stocks are held in a state of depletion, over-exploitation, or are working towards recovery (FAO, IFAD & WFT, 2014). Known-stock terminal fisheries are heralded as a primary sustainable solution to the issues presented by mixed-stock fisheries held on Canada's western coast, however, the value of harvested flesh largely decreases as distance migrated increases, as it is implied that tissue lipids decrease (Gilhousen 1980; Kinnison et al. 2001; Plate et al. 2009). Despite my results challenging assumptions of migration distance relating directly to population-specific energy content, the

economies surrounding commercial salmon harvest rely on perceived energy content as part of their pricing structures (Routledge 2001). Thus, although an obvious path towards protecting declining wild salmon populations is to harvest only in locations where population status can be monitored on or near terminal spawning grounds (Plate et al. 2009), terminal or known-stock fisheries are presented with many barriers to competing economically with coastal mixed-stock fisheries. Under the current management regime, profit margins are heavily incentivized rather than whole-system health, which creates a substantial barrier to transitioning away from this failing system (Routledge 2001, Heino and Godø 2002). Because fisheries are pushed to over-exploit stocks to a point of near extinction through disconnected licensing regimes (Routledge 2001), the ability to selectively harvest abundant populations often comes at the cost of value harvested (Routledge 2001; Plate et al. 2009). Within the current dominant regime guided by the salmon processing industry, more sustainable harvesting practices are not rewarded as heavily and fishers are forced to compete with one another to maximize profits by maximizing quantity and efficiency of the harvest (Plate et al. 2009).

Reiterating these well-known issues with mixed-stock commercial fishing is necessary to continually challenge and confront the assumed authority of capitalist fishing industries extracting from systems they do not reciprocate within. Ideas around transitioning a larger proportion of fisheries upstream to more terminal locations to ensure stock selectivity has been an emerging theme for decades (Routledge 2001). Ultimately, this points to a re-acknowledgement of Indigenous expertise in fisheries methodology, which had previously been disrespected through the hyper-commodification and globalization of salmon products (Strobele and Wacker 1990). Logical next steps to addressing mixed stock fishery concerns would involve

a transfer of capacity to upstream Indigenous communities that subsist on and maintain salmon tributaries (Plate et al. 2009; Routledge et al. 2001), should solutions to the reduced marketability of fish harvested near terminus be well-defined and implemented.

For communities looking to commercially harvest fish near terminus, it is important to understand mechanisms contributing to value of harvested fish. Relevant to the commercial sale of salmon, the key attributes of a fish that change as fish migrate further upstream (according to energy/distance studies, Gilhousen 1980; Kinnison et al. 2001; etc.) and endogenous energy reserves are utilized and depleted (up to as much as 20% of initial energy reserves; Crossin and Hinch 2005; Rand and Hinch 1998), are a decrease in tissue lipids and protein, increase in water levels (Gilhousen 1980; Crossin and Hinch 2005) and a decrease in overall mass (Gilhousen 1980). Gilhousen (1980) found that when sockeye began upstream migration near the coast, approximately two thirds of their total mass could be harvested as fillets, as compared to a decreased one third of total mass which could be harvested near spawning grounds. This relationship between migration status and fillet size is more severe for females, which put more energy towards gonad production (Rand and Hinch 1998) and experience greater decreases in fillet size (Gilhousen 1980). Trade-offs presented in this scenario emphasize the need to explore options for harvesting fish farther downstream along their migration route while still ensuring the selective harvest of specific abundant stocks.

Common solutions to the trade-offs presented within the context of terminal salmon harvests suggest that supplementing harvest of predominantly filleted fish with the additional harvest of roe for each individual can increase profits (Ando 1986). As fish near terminus and gonads are

nearly fully developed, the transfer of energy, lipids and carotenoids from the flesh to the gonads can shift the marketability of terminally harvested products (Ando 1986). In addition to a more wholesome harvest of parts for each individual, value can be added to products through specialized processing methods such as smoking, canning or simply marketing products as known-stock (Plate et al. 2009). Generally, the processing industry invests more effort and funds into farmed salmon rather than wild salmon, yet the industry is on a trajectory that better honours quality and price grading (Plate et al. 2009).

#### **4.7 Limitations of study**

Several caveats exist for this body of work which emphasize the need for further exploration into these methodologies in order to validate within this system. Most notably, due to unusually high water levels in the early season which did not allow for timely fence installation, the late onset of tagging and sampling did not fully encompass the early-run wild populations. Thus, results are biased with very few early-wild fish tagged and an insufficient number of early-wild fish recovered on creeks. Similarly, due to limited access and limitations of the study design, late-run wild fish are also not represented in these data. The results are further biased by tag recovery limitations on all wild population tributaries, many of which had difficult or impossible access for tag recovery, hindering statistical analyses. Implications of these limitations are seen in the interpretation of using sample date as a predictor for GSE between the wild and enhanced population groupings. Tag recovery data for this study were intended to be complemented by tag observation data recording place and time of sightings of live swimming tagged individuals. Should these data have been reliable they would have informed some of the behavioral information gaps regarding which behaviors wild and enhanced fish exhibited in Babine Lake

prior to completing migration onto natal spawning streams. Additionally, tag observation data between the points of tagging at the counting fence and recovery on spawning grounds would have better informed rate of travel and behavioral attributes like milling, data that are especially relevant for analyzing within population variation for GSE and lipid content.

Further exploration and validation of these methods within the Babine system would benefit from expanding upon the range of sampling dates to fully encompass the entire Babine sockeye run through the fence, focusing more effort on the earliest wild and latest wild populations (ascending and descending tails of the sockeye run). Analyses from this study were limited by sample numbers for tagged individuals on wild tributaries with confirmed population of origin. Thus, it is recommended that beyond increasing tagging efforts on wild populations on either end of the enhanced run, it is needed to also greatly increase tag recovery efforts on wild tributaries, especially for populations co-migrating alongside enhanced populations. External tag mark-recapture studies will generally present the same limitations if repeated in this system due to difficulty in accessing many of the wild tributaries for tag recoveries and an inability to gain precise travel rate and timing of arrival to spawning grounds data using these methods. For these reasons it is suggested to explore the use of electronic telemetry (e.g. radio or acoustic) coupled with energy sampling within this system to enable the tracking of energetically costly behaviors and rate of travel to inform the knowledge gaps found within this study.

Because these methods showed the microwave energy meter as a promising tool for in-field population differentiation within the Skeena River watershed, the entire system would benefit from the exploration of these methods throughout the entire migration as a means to bolster

abilities for selective harvests. As fisheries managers in the Skeena region explore new genetic tools to better differentiate populations, a process which requires further validation of results, a collaborative effort between sampling for energy and new genetic identification methods (e.g. SNPs) throughout the physical distance of the Skeena sockeye migration route would support all fisheries' ability to harvest more sustainably and more informed. If these methods were successfully employed in the approach waters of the lower Skeena River, this could re-shape all sockeye fishing sectors within the region (Routledge 2001); reducing the tragedy of the commons scenario whereby fishers' need to compete for profits supersedes fishers' investment in protecting wild sockeye co-migrating alongside targeted enhanced Babine sockeye.

## 5 CONCLUSIONS

I found that enhanced fish arrived at terminal areas with higher GSE than wild fish, despite one of the populations having a shorter migration distance to travel from the point of sampling than several wild populations. We also found that enhanced fish arrived at terminal areas visibly less mature as compared to wild fish, which was again related to higher GSE. Energetically, enhanced fish were significantly different than wild fish throughout this portion of the migration, which presents an opportunity for fisheries managers to target enhanced fish for harvests using the microwave energy meter as a tool for selectivity. My research confirmed that GSE could be assessed using Distell's non-invasive microwave energy meter and it allowed me to draw comparisons between my results and other studies from different systems with terminal-bound sockeye salmon, revealing consistent patterns with sockeye salmon sampled in the Fraser River system (Crossin et al. 2004). These results present an opportunity for further research to examine how far downstream in the Skeena River system energetic differences are evident, which has the potential to inform selective or known-stock harvests further downstream. More generally, the proportion of abundant enhanced fish arriving at terminal areas relative to wild fish suggests a multitude of negative ecological interactions and influences burdening the wild fish within this system through time. Physiological characteristics and genetics of wild sockeye in relation to enhanced sockeye need to be studied closely through time to better understand the implications of enhanced fish becoming the majority of the Skeena sockeye aggregate.

## TABLES

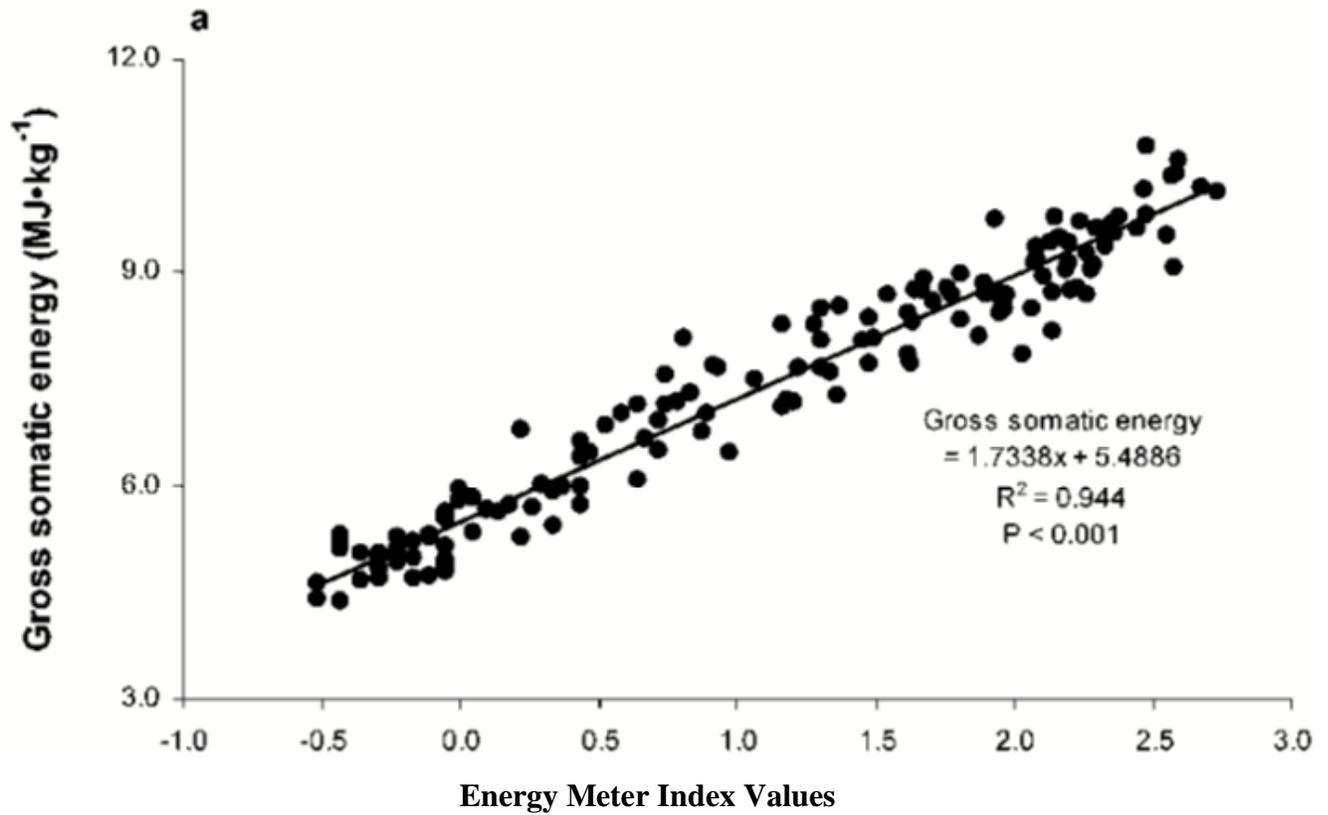
**Table 1.** Summary of data for all populations sampled at the Babine River Counting Fence, including the sample size of recovered individuals, average values for Energy Meter Index and gross somatic energy (GSE) and the average date individuals from each population were sampled at the Counting Fence. Enhanced populations are identified using \*.

Creek Name	Sample Size	Average Energy Meter Index	Average GSE	Average Fence Date
4-mile	33	1.03	3.98	July 23
6-mile	2	1.07	4.07	July 21
9-mile	6	0.97	3.9	July 20
Cross	3	1	3.95	July 27
Fulton *	90	1.27	4.29	August 18
Morrison	1	1.05	4.04	August 24
Pierre	71	1.09	4.08	July 24
Pinkut *	23	1.44	4.53	July 30
Sockeye	1	1	3.96	July 22
Tachek	12	0.97	3.91	July 22
Tsezakwa	1	1	3.96	July 23
Twain	9	1.03	4.01	July 21

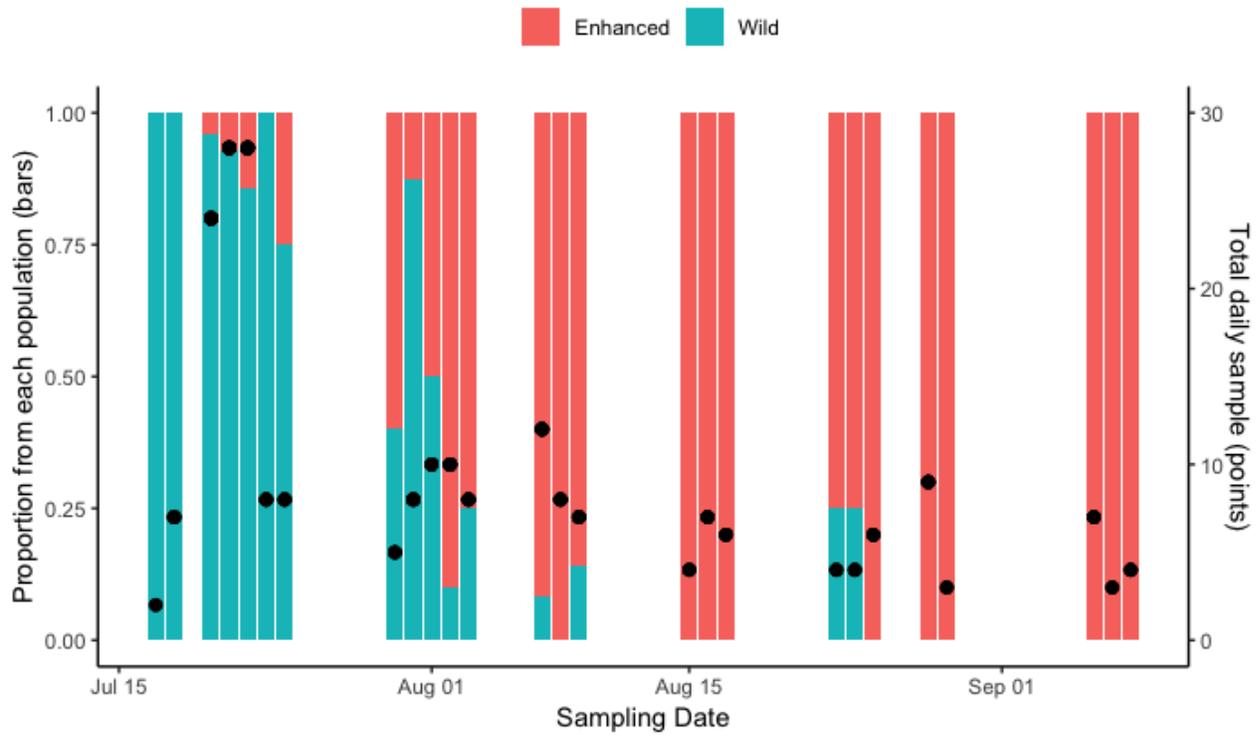




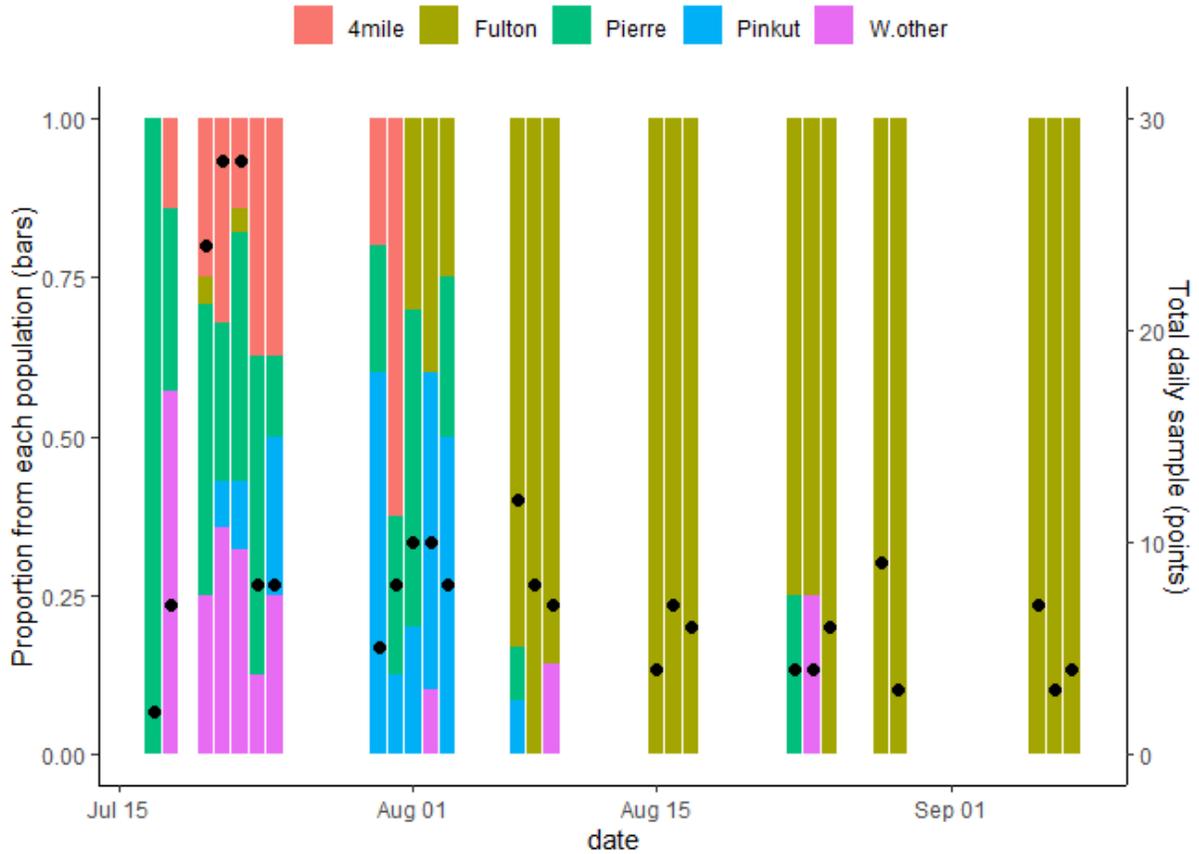
**Figure 2.** Photo of the Babine River Counting Fence showing two of the seven counting platforms with holding traps in the middle of each, on the downstream side of the fence where tagging and sampling was conducted from. (Photo taken by Taylor Wale, July 2017)



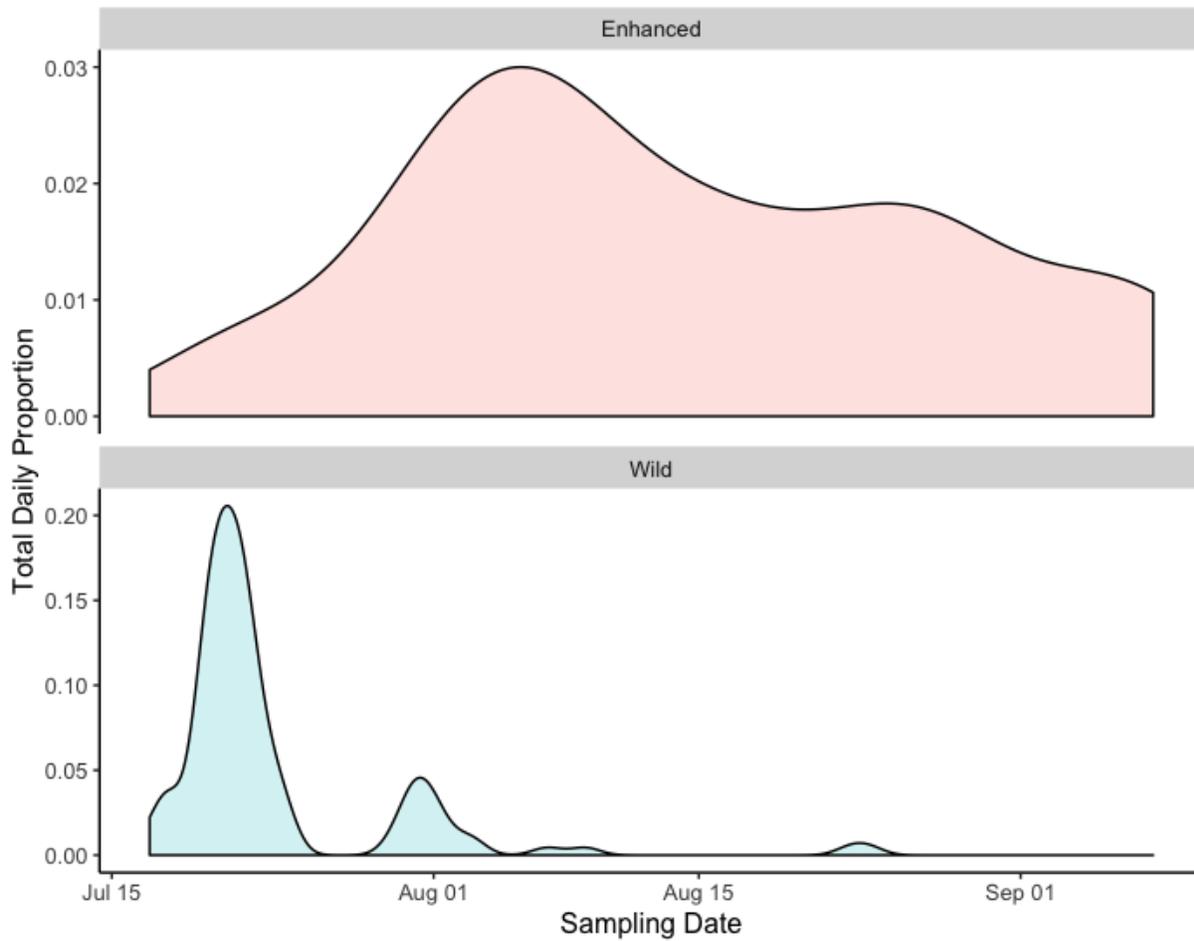
**Figure 3.** Linear relationship between gross somatic energy and natural log-transformed microwave energy meter values for Fraser River sockeye salmon. Each data point represents an individual fish collected at different locales along their freshwater migratory routes. Figure modified from Crossin and Hinch (2005).



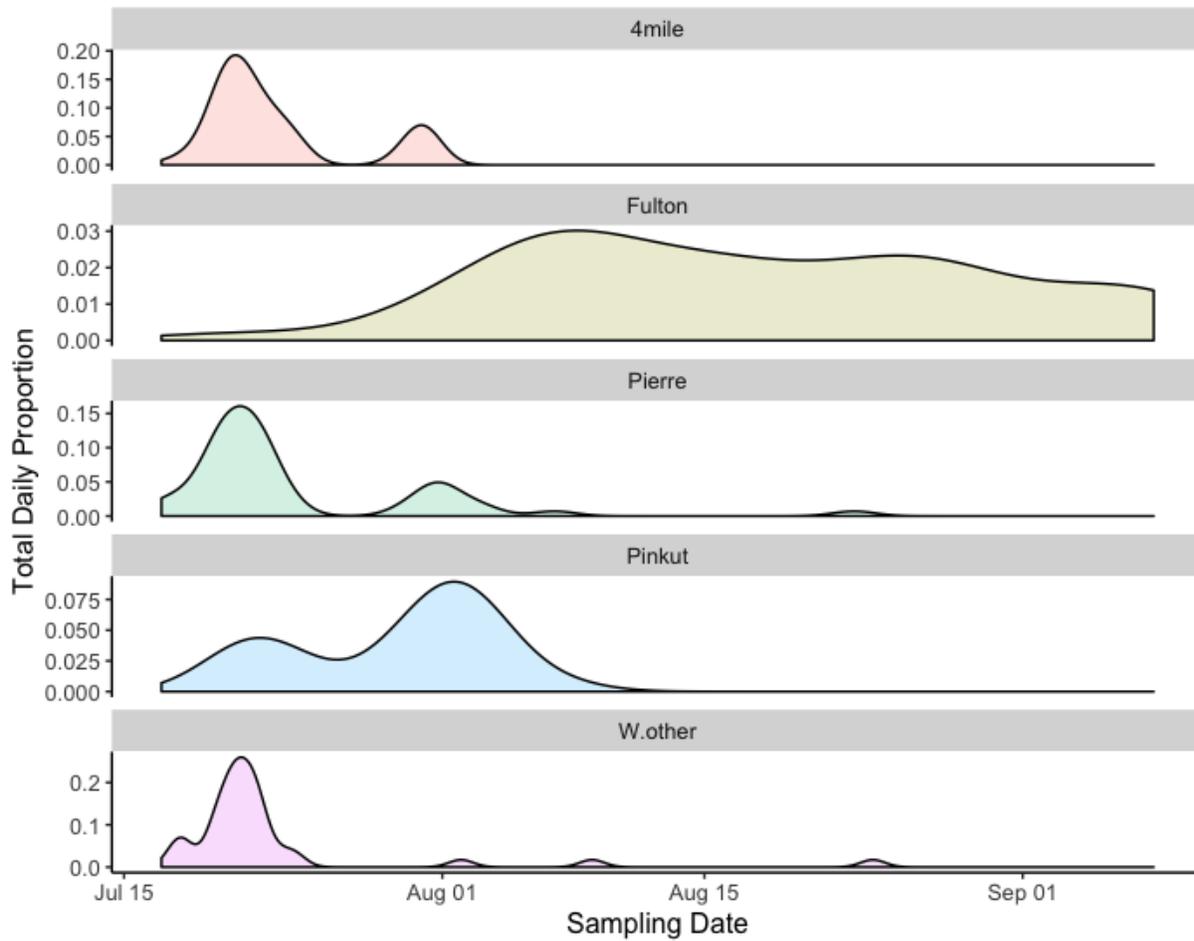
**Figure 4.** Proportions of enhanced (red bars) and wild (blue bars) populations encountered at the Babine fence across sampling dates with the total daily sample size of recovered individuals and therefore population identified individuals shown as points across sampling dates.



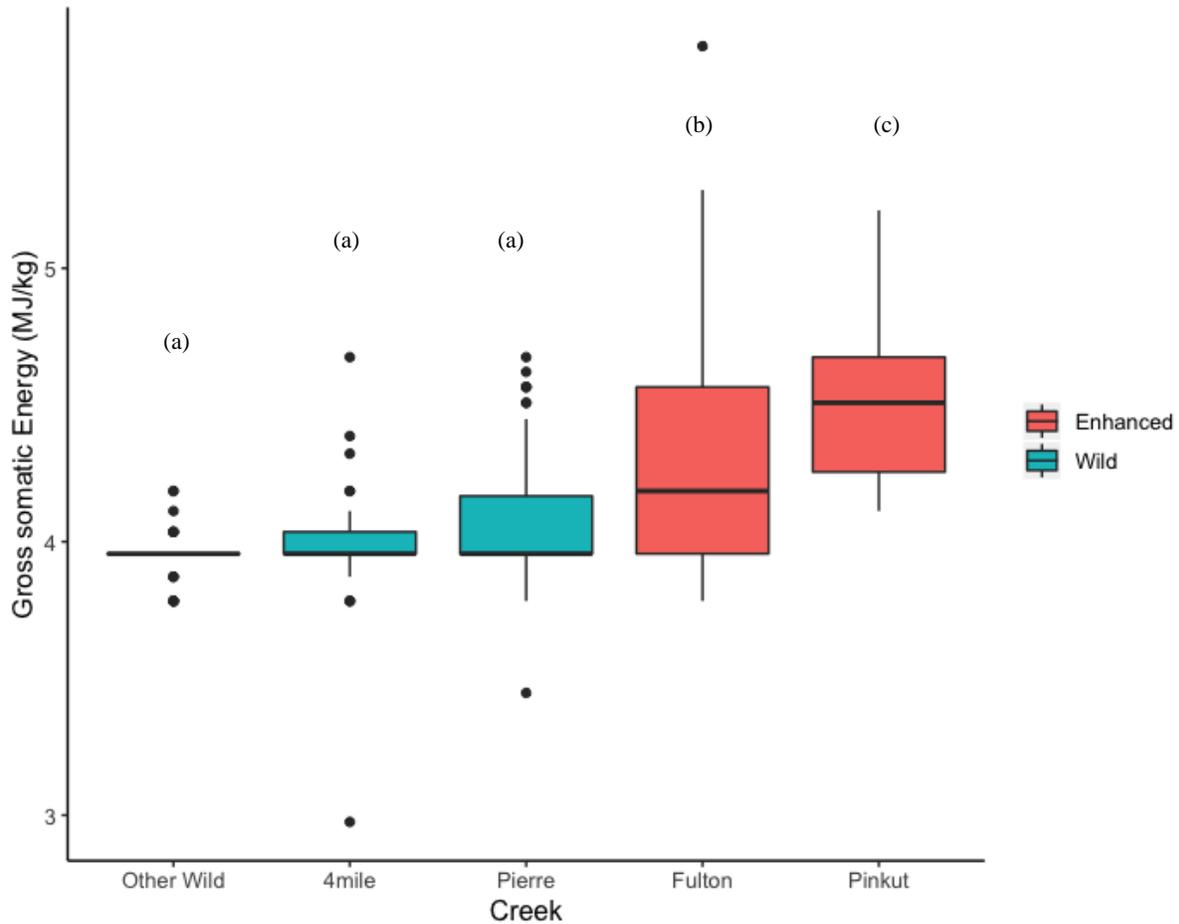
**Figure 5.** Proportions of all populations sampled with greater than 30 individuals recovered on creeks, encountered at the Babine fence across sampling dates with the total daily sample size of recovered individuals and therefore population identified individuals shown as points across sampling dates.



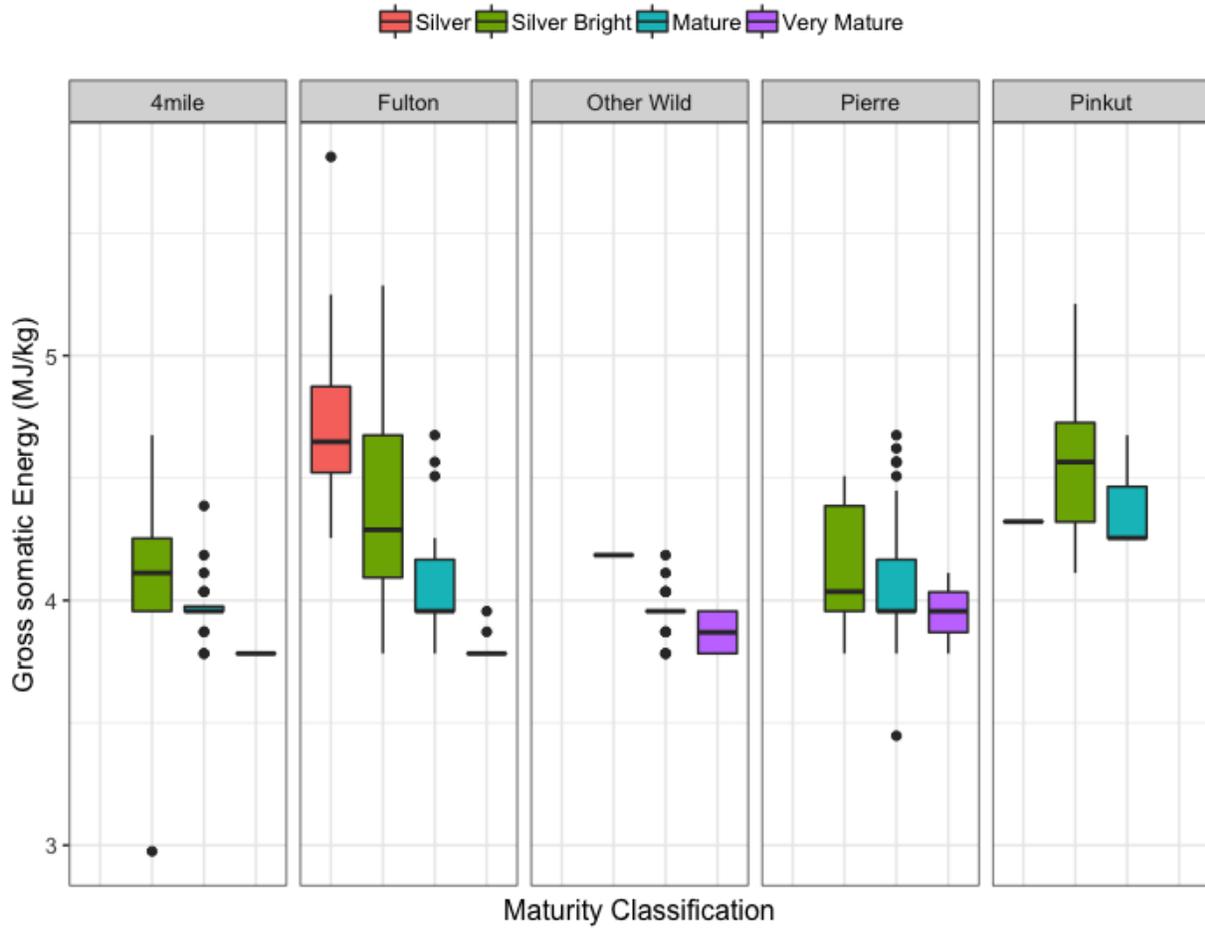
**Figure 6.** Run timing curves for enhanced and wild populations encountered at the Babine River Counting Fence across sampling dates, derived from the total daily proportion (vertical values add up to 1.0) of recovered fish migrating through the Counting Fence.



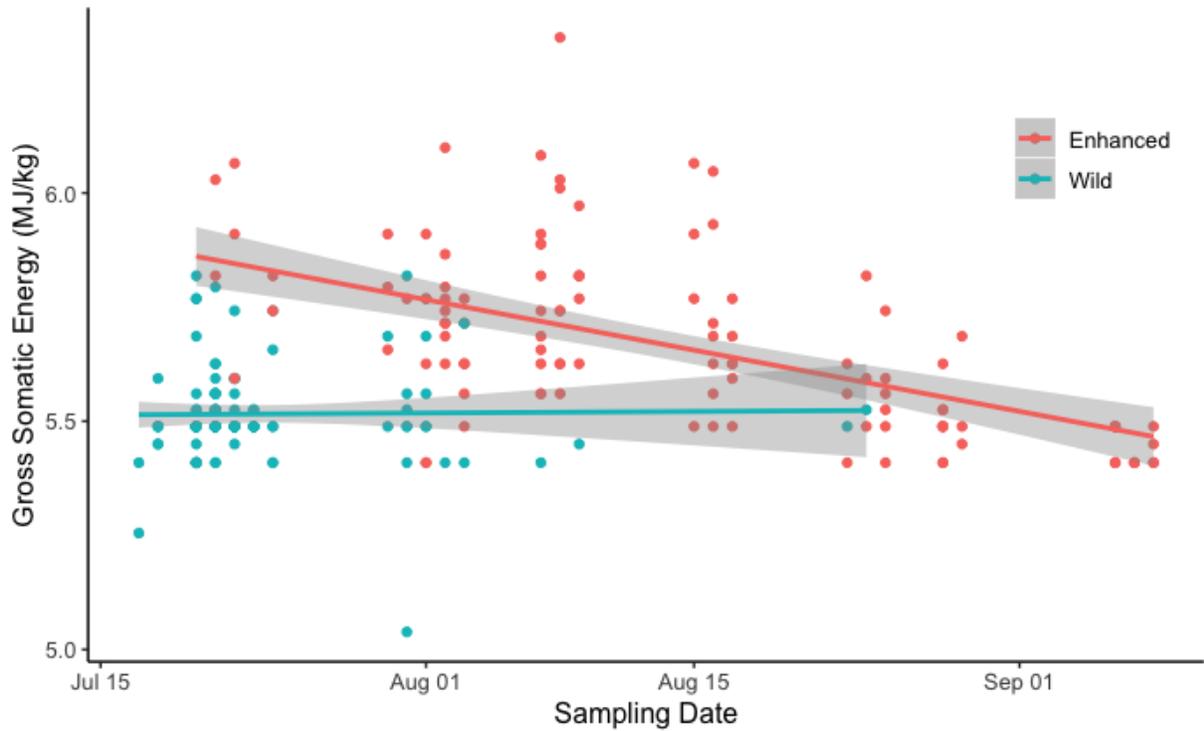
**Figure 7.** Run timing curves for all populations with greater than 30 individuals recovered on creeks encountered at the Babine River Counting Fence across sampling dates, derived from the total daily proportion (vertical values add up to 1.0) of recovered fish migrating through the Counting Fence.



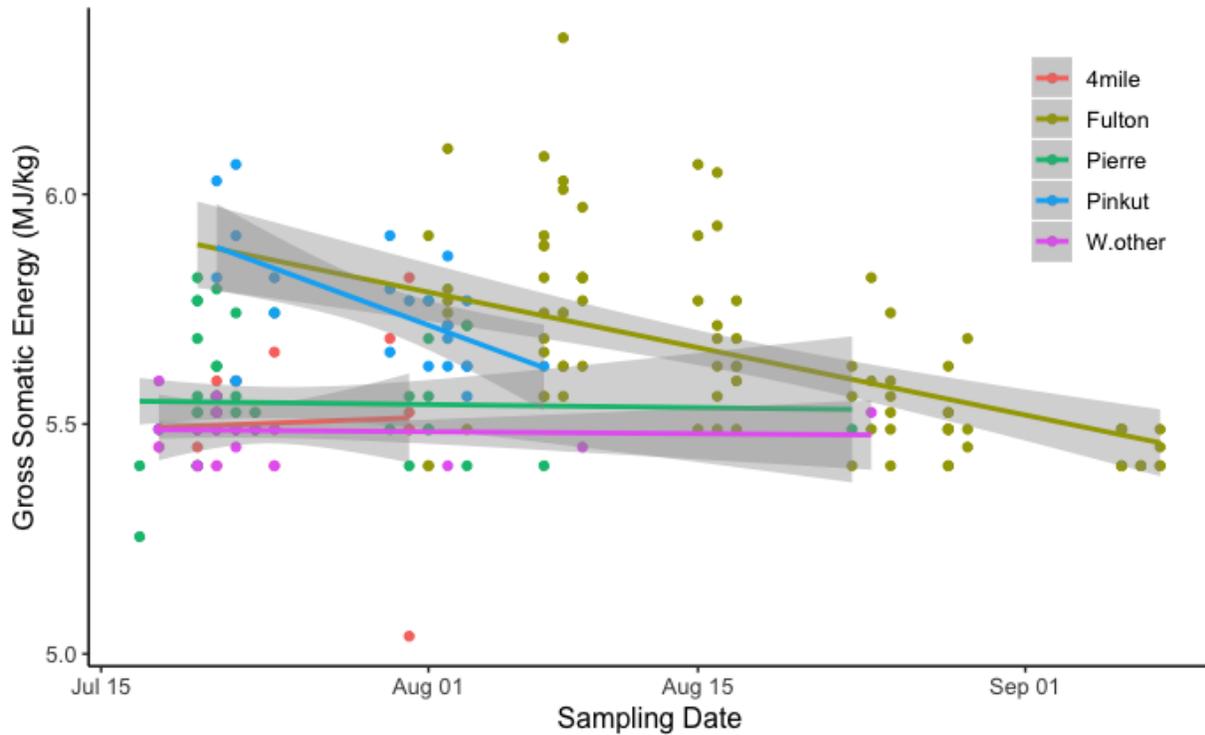
**Figure 8.** Comparison of GSE (MJ/kg) across all populations sampled. Boxes represent data points between the 25<sup>th</sup> and 75<sup>th</sup> percentiles with whiskers representing the minimums (25<sup>th</sup> percentile – 1.5\*Interquartile Range) and the maximums (75<sup>th</sup> percentile + 1.5\*Interquartile Range) of the dataset for each population. Dots are outliers defined by data points beyond the range of the whiskers. Letters in parentheses indicate which comparisons have significantly different means. If bars have different letters, they are significantly different.



**Figure 9.** Comparison of GSE (MJ/kg) and maturity classification (silver, silver-bright, mature, very mature) across all populations sampled with greater than 30 individuals recovered on creeks. Boxes represent data points between the 25<sup>th</sup> and 75<sup>th</sup> percentiles with whiskers representing the minimums (25<sup>th</sup> percentile – 1.5\*Interquartile Range) and the maximums (75<sup>th</sup> percentile + 1.5\*Interquartile Range) of the dataset for each population. Dots are outliers defined by data points beyond the range of the whiskers



**Figure 10.** Linear model comparing gross somatic energy (MJ/kg) between enhanced and wild populations through time using 95% confidence intervals and dots representing individual data points for each of the two population groupings shown here.



**Figure 11.** Linear model comparing gross somatic energy (MJ/kg) among all populations with greater than 30 individuals recovered on creeks through time, using 95% confidence intervals and dots representing individual data points for each of the populations grouping shown here.

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