Fisheries and Oceans Canada | Pêches et Océans Canada
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Canadian Science Advisory Secretariat (CSAS)

Research Document 2017/074

National Capital Region

Summary of Fraser River Sockeye Salmon (*Oncorhynchus nerka*) ecology to inform pathogen transfer risk assessments in the Discovery Islands, BC

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March 2018

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Grant, S.C.H., Holt, C., Wade, J., Mimeault, C., Burgetz, I. J., Johnson, S. and Trudel, M. 2018. Summary of Fraser River Sockeye Salmon (*Oncorhynchus nerka*) ecology to inform pathogen transfer risk assessments in the Discovery Islands, BC. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/074. v + 30 p.

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ABSTRACT

This paper describes the biology and ecology of the Fraser River Sockeye Salmon (*Oncorhynchus nerka*) relevant to assessments of the risks to wild salmon due to pathogen transfer from salmon farms located in the Discovery Islands area of British Columbia. The spatial and temporal presence of the Fraser River Sockeye Salmon in the Discovery Islands area for out-migrating juveniles is based on data from the timing when they exit the Fraser River from mid-April to late-May, the estimated 20 to 59 days spent migrating through the Strait of Georgia, and catch data from the Discovery Islands. Juvenile lake-type Fraser River Sockeye Salmon tend to migrate through the Discovery Islands from mid-May to mid-July, with peak catches in early-to-mid June. The residence time for juvenile Fraser River Sockeye Salmon in the Discovery Islands is estimated to range between 5 to 14 days. Adult Sockeye Salmon return to the Fraser River via either the northern or southern route, with 52% diverting through Johnstone Strait in recent years. In-season test fishery data shows that adult Sockeye Salmon are present in the Discovery Islands from at least mid-July to the beginning of September. Back calculations based on swimming speed and arrival time at Mission estimate that adult Sockeye Salmon could be in the Discovery Islands from late-June to early-October assuming no residence time in the Strait of Georgia. Based on these same estimates, Fraser River Sockeye Salmon could spend approximately three days swimming through the Discovery Islands.

Résumé de l’écologie du saumon rouge du fleuve Fraser (*Oncorhynchus nerka*) visant à éclairer les évaluations du risque de transfert d'agents pathogènes dans les îles Discovery, Colombie-Britannique

RÉSUMÉ

Le présent document décrit les caractéristiques biologiques et écologiques du saumon rouge du fleuve Fraser (*Oncorhynchus nerka*) pertinentes pour les évaluations des risques pour les populations de saumons sauvages en raison du transfert d'agents pathogènes provenant des élevages de saumons situés dans la région des îles Discovery de la Colombie-Britannique. La présence spatiale et temporelle du saumon rouge du fleuve Fraser dans la région des îles Discovery pour la migration des juvéniles s’appuie sur les données recueillies à partir du moment où ils quittent le fleuve Fraser entre la mi-avril et la fin-mai, la période estimative de 20 à 59 jours passés à migrer par le détroit de Georgie, et les données sur les prises dans les îles Discovery. Des saumons rouges juvéniles du fleuve Fraser de type lac ont tendance à migrer par les îles Discovery de la mi-mai à la mi-juillet, avec un pic de prises entre le début et le milieu du mois de juin. La durée de séjour des saumons rouges juvéniles du fleuve Fraser dans les îles Discovery est estimée à une période de 5 à 14 jours. Le saumon rouge adulte retourne dans le fleuve Fraser en passant soit par le Nord, soit par le Sud, et 52 % empruntent le détroit de Johnstone ces dernières années. Les données en cours de saison issues des pêches d'essai indiquent que le saumon rouge adulte est présent dans les îles Discovery au moins de la mi-juillet au début septembre. Des calculs rétrospectifs fondés sur la vitesse de nage et l'heure d'arrivée à Mission indiquent de façon estimative que des saumons rouges adultes pourraient se trouver dans les îles Discovery de la fin-juin au début octobre, en supposant qu'ils ne séjournent pas dans le détroit de Georgie. Selon ces mêmes estimations, le saumon rouge du fleuve Fraser pourrait passer environ trois jours de nage dans les îles Discovery.

INTRODUCTION

Fisheries and Oceans Canada (DFO) has a regulatory role to ensure the protection of the environment while creating the conditions for the development of an economically, socially and environmentally sustainable aquaculture sector. Restoring funding to support federal ocean science programs to protect the health of fish stocks, to monitor contaminants and pollution in the oceans, and to support responsible and sustainable aquaculture industries in Canada was identified as a top priority for the Minister of Fisheries, Oceans and the Canadian Coast Guard in 2016.

It is recognized that there are interactions between aquaculture operations and the environment (Grant et al., 2010; Foreman et al., 2015). One interaction is the risk to wild salmon populations resulting from the potential spread of infectious diseases from Atlantic Salmon (*Salmo salar)* farms in British Columbia (BC) (Cohen, 2012). In BC, many of the Atlantic Salmon farms are located within the migratory routes of Pacific salmon species (*Oncorhynchus* spp.). However, no risk assessment has been conducted to specifically determine the risk to wild fish populations associated with pathogens released from Atlantic Salmon farms.

DFO Aquaculture Management Division requested formal science advice on the risks of pathogen transfer from Atlantic Salmon farms to wild fish populations in BC. Given the complexity of interactions among pathogens, hosts and the environment, DFO will deliver the science advice through a series of pathogen-specific risk assessments followed by a synthesis.

PURPOSE OF THIS DOCUMENT

The information summarized in this document will assist in assessments of the risk to Fraser River Sockeye Salmon (*O. nerka*) due to interactions with Atlantic Salmon farms located in the Discovery Islands area of British Columbia. This document focuses on three aspects of the ecology and biology of Fraser River Sockeye Salmon that pertain to: (1) their spatial and temporal presence in the Discovery Islands area; (2) ecological interactions with other species also found in the Discovery Islands area; and (3) population attributes such as abundance and diversity. The first aspect is important for the risk assessment in determining direct spatial and temporal overlap between migrating Sockeye Salmon and Atlantic Salmon farms located in the Discovery Islands area. The second relates to evaluating indirect impacts associated with other species that are critical to survival of Sockeye Salmon (e.g., prey and predator species) that may also interact with Atlantic Salmon farms. Lastly, the risk assessment endpoints are consequences to the abundance and diversity of Sockeye Salmon.

BIOLOGY

DISTRIBUTION

Fraser River Sockeye Salmon (*Oncorhyncus nerka*) are one of the largest spawning complexes of this species in North America (Burgner, 1991). The Fraser River watershed covers more than 230,000 km^2 and extends more than 1,600 km from its headwaters in the Rocky Mountains to the Strait of Georgia (Killick and Clemens, 1963) (Figure 1). Sockeye Salmon spawn in over 150 natal areas throughout the Fraser River watershed (Pestal et al., 2012).

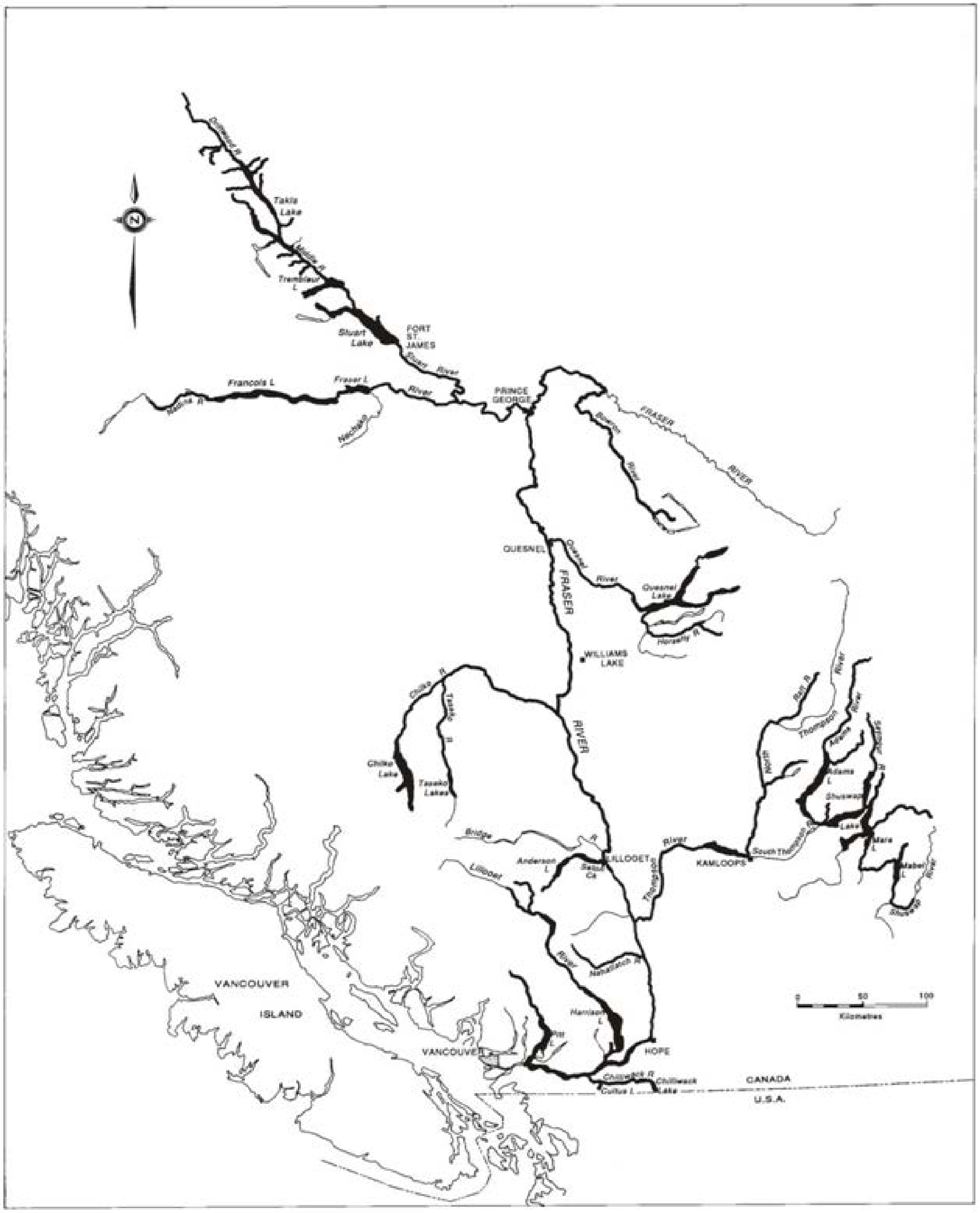

Figure 1. Map of the spawning distribution (darkened black lines) of Fraser River Sockeye CUs in south-western British Columbia.Source: Grant and Pestal (2013).

LIFE HISTORY

Fraser River Sockeye Salmon exhibit two key anadromous life-history types: lake-type and river-type. Lake-type Sockeye Salmon rear in a nursery lake for at least one year before migrating to the ocean. River-type Sockeye Salmon migrate to the ocean shortly after they emerge from the gravel. River-type is synonymous with ocean-type (Holtby and Ciruna, 2007). Non-anadromous kokanee will not be discussed in this publication since they do not migrate to the ocean, and therefore, would not be exposed to salmon farms in the Discovery Islands.

For both life-history types, Fraser River Sockeye Salmon adults spawn from mid-summer to late-autumn in streams, rivers and lakes. Eggs incubate over the winter and fry emerge from the gravel in early spring. Most lake-type Fraser River Sockeye Salmon fry/parr rear in lakes for one year, although a small percentage (~ 5%) rear in a lake for two years (Burgner, 1991). Lake-type smolts begin their downstream migration to the Strait of Georgia in the early spring (April/May), with some small amounts of variability in timing by stock and year. In contrast, river-type Fraser River Sockeye Salmon do not remain freshwater as juveniles, but migrate downstream after gravel emergence and their entry into the Strait of Georgia appears to be later (June/July) than lake-type Sockeye Salmon (Birtwell et al. 1987; Beamish et al. 2016).

Once in the Strait of Georgia, lake-type Fraser River Sockeye Salmon migrate primarily north, exit the Strait of Georgia via the Johnstone Strait, continue north following the continental shelf, and subsequently enter the Gulf of Alaska in the northeast Pacific Ocean (Tucker et al., 2009). An unknown proportion of river-type Fraser River sockeye salmon (predominantly Harrison River derived) migrate north through the Strait of Georgia; they spend considerably longer in the Strait of Georgia ecosystem (July to September) compared to lake-type (Tucker et al., 2009; Beacham et al., 2014a, b; Beamish et al., 2016). In the ocean, Fraser River Sockeye Salmon feed, grow and mature for generally two years (and up to four) before they return to the Fraser River to begin their upstream migration to their natal streams where they spawn and die (Burgner, 1991). Most Fraser River Sockeye Salmon return to spawn as four-year-olds (two winters in freshwater and two winters in the ocean) (Grant et al., 2011); however, smaller proportions return as five-year-olds and three-year-olds (Pestal et al., 2012). The predominant age classes for returning river-type Fraser River Sockeye Salmon are three- and four-year-olds (one winters in freshwater and two to three winters in the ocean) (Grant et al., 2011).

GROUPING TERMINOLOGY

Sockeye Salmon populations have a complex hierarchical structure that extend from groups of salmon at individual spawning sites (demes), to populations, and conservation units (CUs). The CU is a fundamental unit of biodiversity described in DFO's Wild Salmon Policy (WSP), which can include one or more populations (DFO, 2005). The WSP defines a CU as "a group of wild salmon sufficiently isolated from other groups that, if extirpated is very unlikely to recolonize naturally within an acceptable timeframe, such as a human lifetime or a specified number of salmon generations" (DFO, 2005). Lake-type Fraser River Sockeye Salmon CUs are characterized by their rearing lakes and adult return timing, which are supported by genetics (Holtby and Ciruna, 2007). River-type CUs are classified by their joint (freshwater and marine) adaptive zone, genetics, and adult spawn timing (Holtby and Ciruna, 2007). There are currently 24 Fraser River Sockeye Salmon CUs (Table 1).

Stocks and management units are other salmon groupings used for the management of fisheries. For Fraser River Sockeye Salmon, stocks are largely equivalent to CUs with the exception of the Scotch and Seymour stocks that are grouped into a single Shuswap-ES CU. Management units are comprised of single stocks/CUs (i.e., Early Stuart management group) or aggregates of stocks/CUs (Early Summer, Summer, and Late management groups), and are used to manage fisheries in the coastal marine and Fraser River ecosystems (Pestal et al., 2012) (Table 1). The remainder of this document will focus on CUs.

Table 1. Grouping of Fraser River Sockeye Salmon by stock and conservation unit (CU) (DFO (2013). Type refers to life-history type which can be either lake type or river type.

Management Timing Group	Stock	Conservation Unit	Type
Early Stuart	Early Stuart	Takla-Trembleur	Lake
Early Summer	Nadina	Nadina-Francois	Lake
	Miscellaneous Early Summers	Taseko	Lake
	Miscellaneous Early Summers	Nahatlatch	Lake
	Bowron	Bowron	Lake
	Miscellaneous Early Summers	Chilliwack	Lake
	Fennel & Miscellaneous Early Summers	North Barriere	Lake
	Gates	Anderson-Seton	Lake
	Raft & Miscellaneous Early Summers	Kamloops	Lake
	Scotch, Seymour, Miscellaneous Early Summers	Shuswap	Lake
	Chilko	Chilko	Lake
	Pitt	Pitt	Lake
Summer and Early Summer	Chilko	Chilko (S) and Chilko (ES) aggregate	Lake
Summer	Stellako	Francois-Fraser	Lake
	Quesnel	Quesnel	Lake
	Late Stuart	Takla-Trembleur-Stuart	Lake
Late	Cultus	Cultus	Lake
	Miscellaneous Lates	Widgeon-River	River
	Weaver	Harrison U/S	Lake
	Birkenhead	Lillooet-Harrison	Lake
	Miscellaneous Lates	Harrison D/S	Lake
	Late Shuswap	Shuswap Complex	Lake
	Harrison	Harrison River	River
	Seton	Seton	Lake

MIGRATION

Fraser River Sockeye Salmon may encounter Atlantic Salmon farms in the Discovery Islands in both their juvenile and adult life-history stages. The timing, duration, extent or proximity of this interaction can be estimated by synthesizing the available information for both juvenile and adult migrations through the Discovery Islands and Strait of Georgia.

Given the complexity of the Discovery Island area and limited data on salmon migration routes through that area, the proportion of Fraser River Sockeye Salmon that will directly encounter a farm is highly uncertain, but is the subject of on-going research. The purpose of this section is to characterize the time of year and duration that juveniles and adults spend in and around the Discovery Islands.

JUVENILE MIGRATION

Little is known about the migration timing or duration of juvenile Sockeye Salmon in the Discovery Islands area. Therefore, data on ocean entry and migration through the Strait of Georgia were used as proxies for juvenile Fraser River Sockeye Salmon migration timing through the Discovery Islands.

Downstream migration

The timing of ocean entry into the Strait of Georgia can be estimated from two smolt surveys conducted in the Lower Fraser River at Mission, B.C., and located 60 km upstream of the Fraser River outlet to the southern Strait of Georgia. Because of the location of the monitoring station at Mission, only lake-type stocks that spawn upstream of Mission (all stocks except Pitt-ES CU) were assessed in these surveys. The timing of the smolt surveys largely excluded assessing river-type stocks (Harrison-river-type and Widgeon river-type).

From 1976 to 2008, DFO conducted Pink Salmon (*Oncorhynchus. gorbuscha*) smolt surveys in even years that incidentally caught Fraser River Sockeye Salmon smolts (Preikshot et al., 2012). Based on these surveys, the timing of the Fraser River Sockeye Salmon (aggregate) passage at the Mission site ranged from mid-April to late-May (peak in the first week of May), covering a four to five week period (Preikshot et al., 2012). However, as Pink Salmon smolts were the target species of this program, the sampling gear, and time period were selected to capture Pink Salmon not Sockeye Salmon. Therefore, these data only provide a relatively uncertain measure of Fraser River Sockeye Salmon outmigration.

Building on this long-term Pink Salmon smolt monitoring project, in 2012 a similar project was initiated to specifically target Fraser River Sockeye Salmon smolts migrating past Mission, in both even and odd years. This project used a rotary screw trap (RST) and an inclined plane trap (IPT) mounted on a vessel operating in the Fraser River at Mission. Results of this survey (2012 to 2014) show that the aggregate outmigration time period for Fraser River Sockeye Salmon smolts at Mission occurred from mid-April to mid-to-late May (Joe Tadey, DFO, 3-100 Annacis Parkway, Annacis Island, Delta, BC, Canada V3M 6A2, pers. comm.). This is consistent with the conclusions of previous studies (Barraclough and Phillips, 1978; Groot and Cooke, 1987; Preikshot et al., 2012).

In addition to providing information for the Fraser River Sockeye Salmon aggregate, the Sockeye Salmon smolt surveys also inform outmigration timing among CUs. While there are differences in smolt outmigration timing among CUs, this varies by year and no clear annual patterns of consistent timing for particular stocks have been identified (DFO, 2014, 2015, 2016; Neville et al., 2016). For example, the 50% migration date for Chilko-S/Chilko-ES CUs, which contributes a large proportion to the total Fraser River Sockeye Salmon return, and, therefore to smolt composition, was April 29 in 2012, May 5 in 2013, and May 1 in 2014 (DFO 2014, 2015, 2016, respectively). The Shuswap-ES and Shuswap Complex–L CUs are dominant every four years (i.e., 2008, 2012, 2016… smolt outmigration years) and in the 2012 smolt out-migration year, these CUs had a slightly later 50% migration date than most other CUs, which ranged from May 14 to 18 (DFO, 2014). Currently, there is insufficient resolution in the data to differentiate ocean entry timing between CUs.

River-type CUs are largely undetected at Mission, mostly due to the timing of the project as it is misaligned with out-migrating sub-yearling smolts, as opposed to lake-type yearling smolts. The only published information on ocean entry of river-type CUs is based on trawl surveys conducted in the Strait of Georgia from 1998 to 2010, where river-type (Harrison) Sockeye Salmon entered the ocean about eight weeks after the average lake-type Fraser River Sockeye

Salmon, peaking in mid-July (Beamish et al., 2010; Beamish et al., 2016). This is consistent with the understanding that river-type stocks take longer to reach the ocean from their spawning grounds, possibly delaying in sloughs in the Fraser River (Birtwell et al. 1987).

In summary, most Fraser River Sockeye Salmon smolts leave the Fraser River and enter the Strait of Georgia from mid-April to late-May. One major exception is the Harrison Sockeye Salmon, which migrates to the ocean between early-June and late-July peaking mid-July (Birtwell et al. 1987; Beamish et al. 2016).

Migration through the Strait of Georgia

Combining information on timing of ocean entry from the Mission smolt programs and information on migration through the Strait of Georgia can provide an indication of timing through the Discovery Islands. Information on the migration route and timing into and through the Strait of Georgia and residence time for juvenile Fraser River Sockeye Salmon has been estimated by numerous authors over three decades using trawl and purse seine surveys (Groot and Cooke, 1987; Preikshot et al., 2012; Neville et al., 2013; Beacham et al., 2014a; Beamish et al., 2016; Neville et al., 2016), modeling (Peterman et al., 1994), and acoustic implants of two-year-old Sockeye Salmon smolts (Welch et al., 2009; Clark et al., 2016).

After exiting the Fraser River, lake-type Sockeye Salmon juveniles migrate both along the mainland coast in a northerly direction (Groot and Cooke, 1987; Welch et al., 2009; Clark et al., 2016) as well as move across the Strait of Georgia and migrate north along the east side of the Gulf Islands (Groot and Cooke, 1987; Neville et al., 2013). The primary exit route for the Harrison CU has not been determined as previous trawl studies suggested that they migrated out of the Strait of Georgia primarily through Juan de Fuca Strait (Tucker et al., 2009), but more recently juvenile Harrison Sockeye Salmon have been observed both in Johnstone Strait and Juan de Fuca Strait, suggesting that they may be migrating out of the Strait of Georgia through both the southern and northern routes (Beacham et al., 2014a).

The timing of juvenile Sockeye Salmon migration through the Strait of Georgia is estimated from purse and trawl surveys conducted from 1982-1984 (Groot and Cooke, 1987), trawl surveys conducted by DFO and the National Oceanographic and Atmospheric Administration (NOAA) from the Oregon coast to Kodiak Island, Alaska between 1996 and 2011 (Tucker et al., 2009; Beacham et al., 2014a) and changes in catch per unit effort (CPUE) from 2011 and 2012 purse seine and trawl surveys conducted in the Strait of Georgia in collaboration with the Pacific Salmon Commission (PSC) (Neville et al., 2013).

The 2011 and 2012 purse seine surveys indicated that lake-type Fraser River Sockeye Salmon were present in the southern part of the Strait of Georgia in mid-May shifting northward in June (Neville et al., 2013). This is consistent with surveys conducted in 1982-1984, which indicated that Fraser River Sockeye Salmon had left the Fraser River and entered into the Strait of Georgia starting in mid-April, and were caught through to the end of June when the survey ended (Groot and Cooke, 1987). Results from the 1996-2011 surveys indicate that Fraser River Sockeye Salmon were present in the Strait of Georgia from May to November (Beacham et al., 2014a) (Table 2). The composition of stocks in May and June was almost exclusively of non-Harrison River origin with an increasing proportion of Harrison River origin fish in July and August (Table 2). Almost all fish sampled from September to November in the Strait of Georgia were of Harrison River origin (Table 2). Based on these samples, the majority of non-Harrison Fraser River Sockeye Salmon appear to migrate through the Strait of Georgia in June.

Table 2. Percent (%) composition of juvenile Fraser River Sockeye Salmon in the Strait of Georgia from May to November from samples collected between 1996 and 2011 (Beacham et al., 2014a). Harrison River contribution is reported separately from Fraser River.

Month	Number of juvenile Fraser River Sockeye Salmon collected	Percent composition in the Strait of Georgia		
		Fraser River Origin	Harrison River Origin	Total Fraser River Origin
May	66	97.0	-	97.0
June	1,201	97.7	0.8	98.5
July	291	54	45	99
August	119	23.5	75.6	99.1
September	597	-	96.1	>96.1
October	66	-	98.5	>98.5
November	209	-	98.6	>98.6

Residence time is the average time a Sockeye Salmon spends migrating though a particular habitat or area (Preikshot et al., 2012) and has been estimated using different methods. Preikshot et al. (2012) summarized more than ten years of data and estimated that residence time of juvenile Fraser River Sockeye Salmon in the Strait of Georgia ranged from 45 to 59 days. The remainder of estimates are all based on fewer years of data (ranging from a single year to four years), either with acoustic tagging of two-year-old smolts (Welch et al., 2009) or surveys (Healey, 1980; Groot and Cooke, 1987; Neville et al., 2016) and range from 20 days (Healey, 1980; Clark et al., 2016) to 56 days (Neville et al., 2016). These estimates are not applicable to juvenile Harrison River Sockeye Salmon as the studies were completed in the Strait of Georgia in the spring and summer, when few Harrison River Sockeye Salmon juveniles are present (Beacham et al., 2014a; Beamish et al., 2016).

Beacham et al. (2014a) showed that some CUs moved rapidly through the Strait of Georgia to begin their northward migration, while others did not, suggesting that the residence time of juvenile Fraser River Sockeye Salmon varied among CUs. In particular, they observed that larger individuals from the same CU are caught in more northerly locations compared to those in the Strait of Georgia, and that CUs that produced larger smolts initiated their northward migration earlier (Beacham et al., 2014a, b). This pattern was confirmed by Freshwater et al. (2016a, 2016b) who used otolith microstructure to reconstruct the growth and migration history of juvenile Fraser River Sockeye Salmon. In contrast, Neville et al. (2016) did not observe any differences in the migration timing of different stocks of juvenile Fraser River Sockeye Salmon in the Discovery Islands in 2014, though they recognized that these results were for a single year and that they did not catch all stocks.

In summary, the peak of juvenile Fraser River Sockeye Salmon migration through the Strait of Georgia occurs in June, but ranges between May and August, albeit in lower numbers. This is consistent with the estimates of total residence time ranging from 20-59 days, depending on CU, size of fish, and methodology.

Migration through the Discovery Islands

The Discovery Islands area is a complex network of islands, narrow channels and deep fjords (Chandler et al., 2017), northwest of the Strait of Georgia and southeast of the Johnstone Strait. Little is known about the migration timing or residence time of juvenile Sockeye Salmon in the Discovery Islands area after they exit the Strait of Georgia. What is known is based on a few purse seine and trawl surveys on the migration or presence of Sockeye Salmon, specifically in the Discovery Islands area, conducted in the 1980's and from 2011 to 2015. These studies mainly pertain to lake-type Sockeye Salmon.

Juvenile Sockeye Salmon have been found in the Discovery Islands area in a number of different locations in several studies throughout many years (Levings and Kotyk, 1983; Brown et al., 1984; Groot and Cooke, 1987; Neville et al., 2013; Beacham et al., 2014a; Johnson, 2016; Neville et al., 2016).

Migration timing through the Discovery Islands has been the focus of recent studies, which have included weekly purse seine surveys in the lower Johnstone Strait and the Discovery Islands (Neville et al., 2013; Neville et al., 2016), and the Hakai Institute's Salmon Early Marine Survival Program (SEMSP) (Johnson, 2016).

In 2011 and 2012, Neville et al. (2013) reported comparatively high CPUE of juvenile Fraser River Sockeye Salmon in purse seine surveys in the Discovery Islands and Johnstone Strait in mid-June compared to mid-May, both during a low (2011) and a high (2012) years of juvenile Sockeye Salmon abundance. Additionally, as a part of an integrated study to determine the residence time and migration timing of juvenile Sockeye Salmon from the Fraser River through coastal BC, weekly purse seine surveys were conducted between May 15 and July 22, 2014 in the lower Johnstone Strait with additional fishing in the Discovery Islands (Neville et al., 2016). From May 15 to July 11, a total of 298 juvenile Sockeye Salmon were captured; approximately 81% of Sockeye Salmon were caught between June 12 and June 19 (Neville et al., 2016). Johnson (2016) reported that peak migration through the Discovery Islands was approximately one week earlier (May 23 to May 27, 2015) than reported by Neville et al. (2016), and Groot and Cooke (1987) caught juvenile Sockeye Salmon in the Discovery Islands from May 15 to June 30 when sampling stopped.

River-type juvenile Sockeye Salmon are not expected to be captured in high abundance between May and July in the Discovery Islands (Neville et al., 2016) but can migrate through the northern route in the autumn (Beacham et al., 2014a; Beamish et al., 2016). There is currently no estimate of the migration timing of river-type Harrison Sockeye Salmon through the Discovery Islands.

The residence time of juvenile Fraser River Sockeye Salmon in the Discovery Islands provides an indication of the duration of time that juvenile Fraser River Sockeye Salmon may be in proximity to Atlantic salmon farms in this area, assuming swimming speed or route is not affected by the presence of farms. While farms are distributed through the region, there are many passages where there are no farms so fish may transit in Discovery Islands without passing a farm. The residence time of juvenile Fraser River Sockeye Salmon in the Discovery Islands is relatively uncertain, being estimated using peak migration timing, acoustic tagging studies and theoretical optimal cruising speeds for juvenile salmon. These estimations do not account for any influence of the oceanographic conditions or presence of Atlantic Salmon farms on the migration behaviour or overall residence time in the area.

One and a half year old hatchery Sockeye Salmon (length range 159-189 mm) from Cultus Lake were implanted with a transponder tag and tracked from the lake to Queen Charlotte Sound (Welch et al., 2009). Of those that survived, the mean speed in the Fraser River was 15.5 km/day in 2004 and 25.8 km/day in 2007 and in the marine environment this ranged from 15-30 km/day (Welch et al., 2009). In the northern Strait of Georgia and Queen Charlotte Sound, mean speeds were reported to range between 15 km/day and 26 km/day (Welch et al., 2009). A similar study was conducted using the same transponders in two-year old Chilko Lake Sockeye Salmon (length range 111 to 130 mm). They were reported to swim up to 220 km/day in the

Fraser River mainstream and between 10 and 25 km/day in the coastal regions (Clark et al., 2016).

The estimated distance from the southeastern limit of the Discovery Islands north of Texada Island to the northwestern limit in Johnstone Strait is approximately 140 km (see Chandler et al. (2017) for a description of the oceanographic conditions of the region). Recognizing that Cultus Lake Sockeye Salmon are longer at tagging (average fork length from 159 to 189 mm (Welch et al., 2009)) than the average juvenile Sockeye Salmon caught in the Discovery Islands (average fork length from 124 to 129 mm (Neville et al., 2016)) and based on an average swimming speed of 10 to 30 km/day (based on Welch et al. (2009) and Clark et al. (2016)), it would take a minimum of 5 to 14 days for juvenile Fraser River Sockeye Salmon to migrate through the Discovery Islands. This is a similar estimate that Neville et al. (2016) calculated based on CPUE data in 2015, where peak migration through the Discovery Islands occurred during a two week period. These estimates are likely minimum durations that juvenile Fraser River Sockeye Salmon may spend migrating through the Discovery Islands, as the calculations do not directly take into account any periods where fish are not actively migrating, the effect of tides or currents on swimming behaviour, nor if their migratory behaviour is altered by the presence of farms in this area.

There is currently no estimate of the residence time of river-type Harrison Sockeye Salmon in the Discovery Islands.

In summary, there continues to be some uncertainty as to when lake-type juvenile Fraser River Sockeye Salmon exit the Strait of Georgia and migrate through the Discovery Islands and into the Johnstone Strait. The limited numbers of studies suggest that while lake-type juvenile Fraser River Sockeye Salmon are found in the Strait of Georgia starting in May, they may also be found further north in the Discovery Islands area from late May through to July, though residence time for individual fish may be much shorter (~1-2 weeks).

Vertical distribution

Beamish et al. (2007) summarize trawl survey results from June/July and September 1997 to 2005 based on methods described in Beamish et al. (2000) and report that the majority of juvenile Sockeye Salmon were caught in 0-15 m depth in the Strait of Georgia. This data set was further expanded to include 1997 to 2010 where it was stated that 99.8% of all juvenile Sockeye Salmon were caught in the 45 m depth zone (Beamish et al., 2016). Fishing at these depths for juvenile Sockeye Salmon is consistent with other studies in different regions and with different fishing gear including purse seining in Strait of Georgia and Johnston Strait (Neville et al., 2013; Neville et al., 2016); surface trawl in the Discovery Islands (Levings and Kotyk, 1983) and northern Gulf of Alaska to California (Brodeur et al., 2007); midwater rope trawl in the eastern Bering Sea (Farley et al., 2007); and beach seines in Discovery Passage (Brown et al., 1984).

ADULT MIGRATION

Once juvenile Fraser River Sockeye Salmon reach the Gulf of Alaska (Walter et al., 1997), they are presumed to spend winters south of Alaska and migrate to areas further offshore for the summer (Figure 2) where they feed and grow for up to three years before migrating to their natal spawning grounds in the Fraser River watershed.

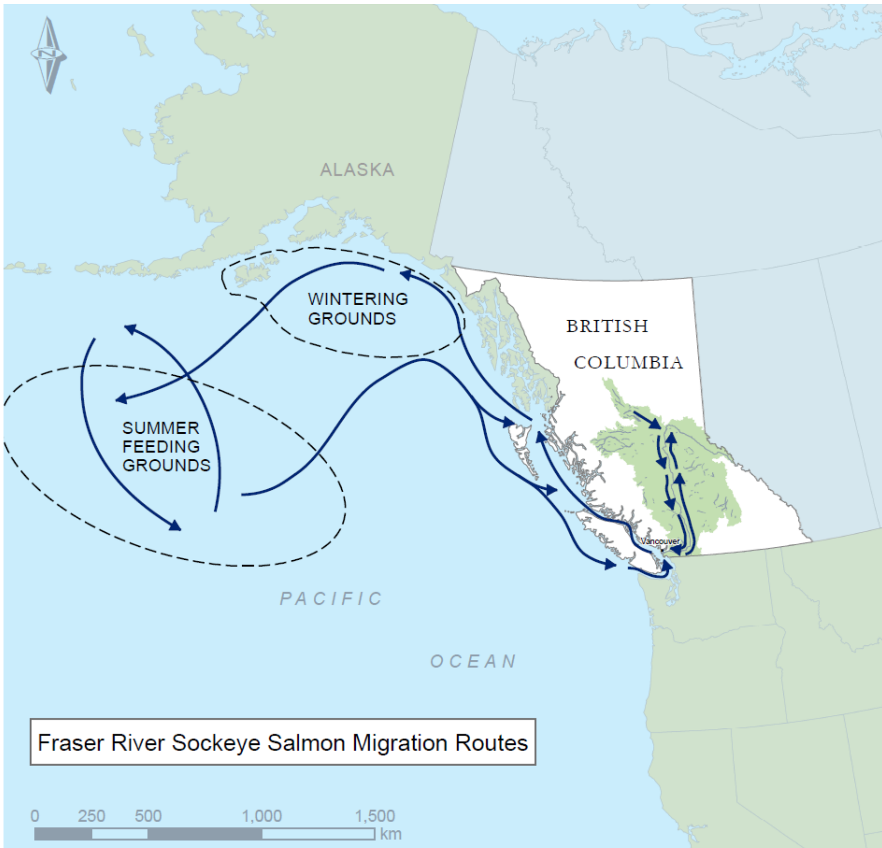

Figure 2. Presumed Fraser River Sockeye Salmon migration routes. Source: Cohen (2012).

Diversion rates

Sockeye Salmon return to the Fraser River either through the northern route (Johnstone Strait) or the southern route (Strait of Juan de Fuca). The proportion of Sockeye Salmon that migrate through the northern route is called the northern diversion rate, or simply the diversion rate.

Estimates of diversion rates have been made using different datasets and methods and can therefore be difficult to interpret and compare. A summary of the potential reasons for either a northern or southern diversion is provided in Lapointe et al. (2015) and Folkes et al. (2017). The information about diversion rates has been included here to give an indication of the proportion of returning adult Sockeye Salmon swimming through the Discovery Islands.

Estimates of annual diversion rates are highly variable. Based on data provided by the PSC, the average diversion rate through Johnstone Strait between 1980 and 2015 has been 52% ± 22%. During this time, 2008 marked the lowest proportion (10%) of adult Fraser River Sockeye Salmon returning via the northern route and 2014 the highest (96%) (Figure 3). Estimates of diversion rates from 1998-2011 are more dependent on the relative catches in marine test fisheries (Lapointe et al., 2015). Because the test fishery harvests a small fraction of the annual return (1-2%), daily diversion rate estimates can be variable. Annual estimates of diversion rate are buffered as they are based on the cumulative sum of daily abundance estimates migrating through each route. Diversion rates are most accurate when migration is strong through one route or the other and less accurate when the fraction is approximately equal (Lapointe et al., 2015).

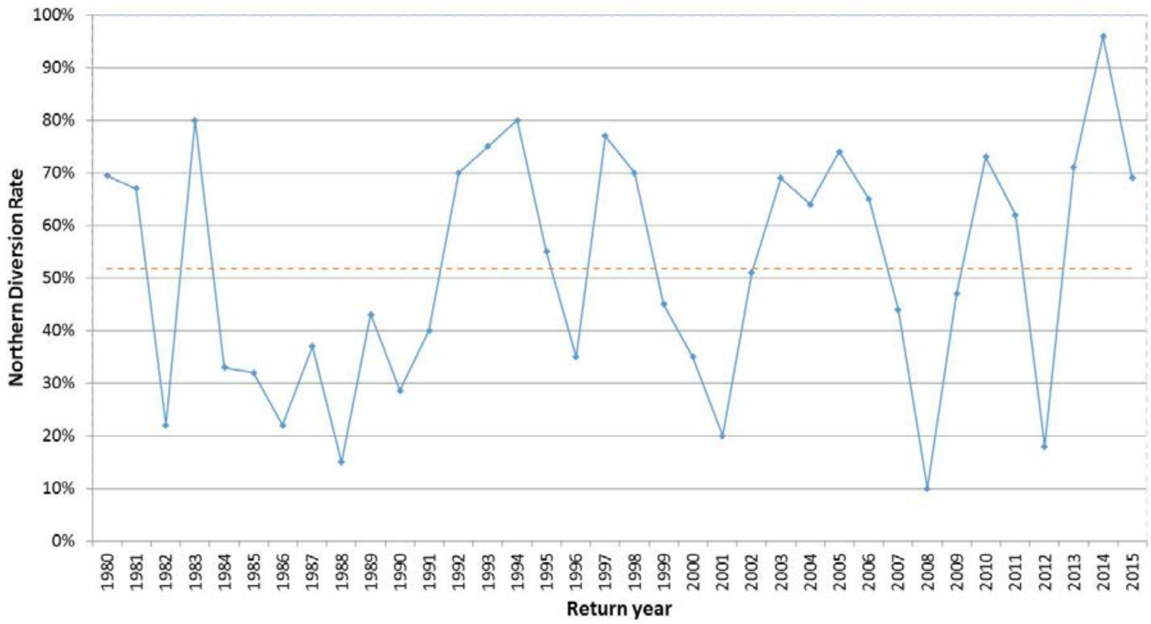

Figure 3. Northern diversion rate of returning Fraser River Sockeye Salmon. The dashed line represents the average percentage (52% ± 22%, average ± standard deviation) of northern diversion between 1980 and 2015. Data provided by the Pacific Salmon Commission, 2015.

The diversion rate is also variable over time within any given year, generally shifting from the southern to northern route within a season. CUs such as Takla-Trembleur-Early Stuart generally have lower northern diversion rates while CUs that migrate later, like Shuswap-L, will have higher northern diversion rates (Lapointe et al., 2015). Therefore, the diversion rate may be skewed based on the relative proportion of each stock.

Migration through the Discovery Islands

Returning adult Fraser River Sockeye Salmon migrate through the Discovery Islands as indicated by the PSC test fishery data (Table 3) and traditional ecological knowledge (Harold Sewie, Mamalilikulla-Qwe'Qwa'Sot'Em Band, *pers. comm*.).

The migration timing of returning adult Fraser River Sockeye Salmon in the Discovery Islands can be estimated based on data from test fisheries and the arrival timing of returning adults at Mission combined with the average swimming speed of adult Sockeye Salmon.

The PSC has conducted daily Sockeye Salmon test fisheries every year since 2000 to collect in-season data and provide updates for the management of the fishery. There is a test fishery location in the Discovery Islands (Area 13, Lower Johnstone Strait) that is sampled for an average of 40 consecutive days every year from approximately mid-July to early September (Table 3). Returning Sockeye Salmon have been caught in 98% of the sets conducted in this area between 2000 and 2015 providing evidence of their presence in the Discovery Islands from mid-July to mid-September (Table 3).

Table 3. Duration and timing of Sockeye Salmon test fisheries in Area 13 conducted by the Pacific Salmon Commission (PSC) from 2000 to 2015. Data provided by the Pacific Salmon Commission (2016).

From	To	Total days fished
18 July 2000	20 August 2000	32
18 July 2001	23 August 2001	29
21 July 2002	4 September 2002	46
22 July 2003	9 September 2003	50
19 July 2004	25 August 2004	38
20 July 2005	10 September 2005	53
20 July 2006	9 September 2006	52
3 August 2007	9 September 2007	38
21 July 2008	25 August 2008	36
26 July 2009	3 September 2009	40
27 July 2010	3 September 2010	39
25 July 2011	7 September 2011	45
20 July 2012	17 August 2012	29
24 July 2013	5 September 2013	44
27 July 2014	8 September 2014	44
23 July 2015	31 August 2015	40

However, these data do not provide an estimation of the total migration period of returning Sockeye Salmon in the Discovery Islands as fishing is not conducted to identify the timing of arrival and departure of Sockeye Salmon in the area. Additionally, the rare instances when Sockeye Salmon were not caught (2%) were not at the beginning or end of the sampling period suggesting that fish could have been present before and after the sampling periods.

The residence time of adult Fraser River Sockeye Salmon in the Discovery Islands is currently unknown but may be inferred from studies that estimate adult Fraser River Sockeye Salmon swimming speed. By combining when the earliest and latest returning adult Sockeye Salmon migrate past Mission with the average swimming speed and the distance from the northwestern and southwestern limits of the Discovery Islands, an estimate of the total time period that adult Sockeye Salmon are likely to be in the Discovery Islands can be made.

Returning adult Sockeye Salmon were estimated to swim at 2.4 km/h (n=25 fish) during day time between the Vancouver Island and the coastal mainland of BC (Quinn, 1987). Madison et al. (1972) report that night time swimming speeds of adult Sockeye Salmon north of Dundas Island BC were half that recorded during the day. Assuming that swimming speed are similar in the different studies, adult Sockeye Salmon can therefore be estimated to travel approximately 43 km per day ((2.4 km/h x 12 hrs) + (1.2 km/h x 12 hrs)).

The distance between the northwestern limit of the Discovery Islands (in the Johnstone Strait) and Mission is approximately 290 km, a distance that could be traveled by returning Sockeye Salmon adults in six to seven days. As adults from the Early Stuart CU can return to Mission at the beginning of July, based on the above estimated traveling rates, the first returning adult Sockeye Salmon can be estimated to enter the Discovery Islands in late-June to early-July.

The distance between the southeastern limit of the Discovery Islands (north of Texada Island) and Mission is approximately 150 km which can be traveled in three to four days. As adults from the Summer and Late Management Groups can return to Mission as late as mid-October, based on the above estimated traveling rates, the last returning adult Sockeye Salmon can be estimated to leave the Discovery Islands in early-October.

Based on the above, the returning migration window for adult Fraser River Sockeye Salmon in the Discovery Islands could range from late-June to early-October. These estimates assume constant travel of the returning adults and no residence time in the Strait of Georgia. Earlier migration through the Discovery Islands could be possible if fish arrive in the Discovery Islands earlier or reside in the Discovery Islands for a period of time before migrating to the Strait of Georgia.

Finally, with an estimated length of 140 km for the Discovery Islands, it would take approximately three days for an individual adult Fraser River Sockeye Salmon to migrate through the Discovery Islands swimming both day and night.

Upstream migration

Timing of Fraser River Sockeye Salmon adult migration in the Fraser River, en-route to their spawning ground, is available from various test fisheries in the Fraser River and the Mission hydroacoustic program. The PSC operates a hydroacoustic facility at Mission to enumerate the returning fish migrating past the sensors.

Most Fraser River Sockeye Salmon return to spawn mid-summer to late autumn (Pestal et al., 2012). Generally speaking, the Early Stuart Management Group begins returning to the Fraser River first at the beginning of July, followed by the Early Summer and Summer Management Groups which begin returning mid-July and finally the Late Management Group begins to return early-August (Figure 4). More specifically, between 1977 and 2015, the medians of the 50% return dates at Mission were July 10 for the Early Stuart, August 1 for Early Summer, August 14 for Summer and September 1 for Late Management Groups (Figure 4). When only considering Harrison, the median was September 14.

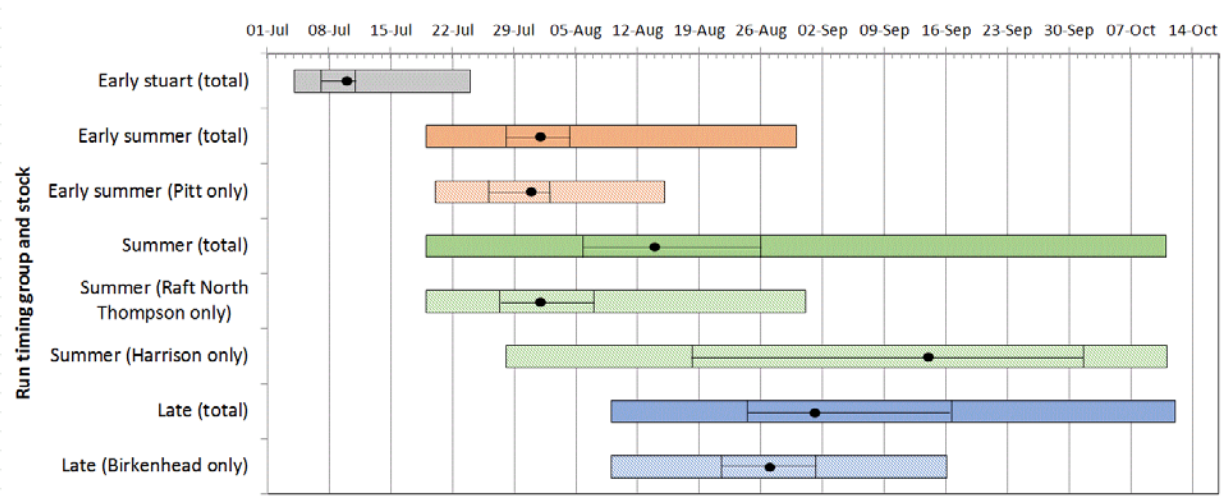

Figure 4. Range at which 50% of the Fraser River Sockeye Salmon Management Groups escaped past Mission (1977 to 2014). The black dots indicate the medians for each Management Group or stock while the vertical bars represent the first and third quartile. Data provided by the Pacific Salmon Commission, 2015.

Some Management Groups or stocks may have a highly protracted period of return to freshwater such as Late Management Group since they are comprised of several stocks; Early Stuart do not as it is made up of a single stock (Figure 4).

The timing of Late Management Group is important as in some years it is the dominant group of Fraser River Sockeye Salmon. Historically, this group would hold up in the estuary at the mouth of the Fraser River for three to six weeks, a behaviour unique among Sockeye Salmon populations (Pacific Salmon Commission, 2009). Since 1995, this group no longer holds in the estuarine area before upstream migration (Pacific Salmon Commission, 2009). The average delay has been five days or less since 2000 with the exception of 2002 (Lapointe in Pacific Salmon Commission (2009)). This early migration phenomenon makes fisheries management difficult as it has been associated with high en-route and pre-spawn mortality in Late Management Group stocks. No single process has been discovered which appears to govern entry timing (Pacific Salmon Commission, 2009).

SUMMARY

Adult and juvenile Fraser River Sockeye Salmon migrate through the Strait of Georgia and the Discovery Islands through to Johnstone Strait in the late-spring though early fall, and while the weight of evidence from stock surveys, telemetry and fisheries management activities provides some precision on the timing, there is inter-annual variability in migration timing.

ECOLOGICAL INTERACTIONS

Risk assessments of Atlantic Salmon farms to Fraser River Sockeye Salmon should consider potential indirect risks resulting from an impact of Atlantic Salmon farms on species interacting with Fraser River Sockeye Salmon such as a change in prey composition, predator abundance, or any species co-occurring with Fraser River Sockeye Salmon during their marine life-history stage. A short summary of the species and their direct interactions with Fraser River Sockeye Salmon, particularly with those species that are known to occur or migrate through the Discovery Islands, is presented below to support analyses of potential interactions with Atlantic Salmon farms in the Discovery Islands.

PREY

There have been a number of studies that have examined the species on which juvenile and adult Sockeye Salmon feed in the marine environment. Adult Sockeye Salmon prey items are very similar to those of juveniles, and while different studies have found different relative proportions and dietary components, these may be more reflective of ocean conditions and species availability. The range of food and species they have been reported to consume includes copepods, euphausiids, amphipods, pteropods, ascidiacea, crustacean larvae and many fish species such as Pacific Herring (*Clupea pallasii*) and rockfish (*Sebastes* spp.) (Healey, 1976, 1978; Burgner, 1991; Healey, 1991; Brodeur et al., 2007).

PREDATORS

Many fish species have been identified as predators or potential predators of Fraser River Sockeye Salmon in the marine environment. Christensen and Trites (2011) reviewed the scientific literature and reported several species of predators including invertebrates, fish, birds and mammals which prey on either juvenile or adult Sockeye Salmon in the marine environment. Of these, 27 species were considered to potentially impact Sockeye Salmon including one invertebrate, the Humboldt squid (*Doscidicus gigas*), 17 fish species and nine marine mammal species. The authors also ranked spatial and temporal overlap of predators with Fraser River Sockeye Salmon on a gradient from low to high. The species that graded highest for spatial and temporal overlap with Fraser River Sockeye Salmon were Coho Salmon, Chinook Salmon, Pacific Spiny Dogfish (*Squalus suckleyi*), Salmon Shark (*Lamna ditropis*), Blue Shark (*Prionace glauca*), Daggertooth (*Anotopterus nikparini*), common murre (*Uria aalge*), harbour seal *(Phoca vitulina)*, Stellar sea lion *(Eumetopias jubatus)*, Northern fur seal (*Callorhinus ursinus*), killer whale (*Orcinus orca*), Dall's porpoise (*Phocoenoides dalli*), white-sided dolphin (*Lagenorhynchus obliquidens*), harbour porpoise (*Phocoena phocoena*) and humpback whale (*Megaptera novaeangliae*) (Christensen and Trites, 2011).

CO-OCCURRING SPECIES

Information about species co-occurring with Sockeye Salmon can inform aquaculture interactions risk assessments of potential ecological consequences, including potential pathogen reservoirs. Characterizing the temporal and spatial interactions between co-occurring species and Atlantic Salmon farms in the Discovery Islands can support analyses of the likely scope and scale of these interactions, and subsequently an analysis of the effects of these interactions with co-occurring species on Sockeye Salmon. A summary has been provided in detail due to significant differences in fishing methodologies, depths and locations among studies.

Species co-occurring with juvenile Sockeye Salmon

Juvenile Sockeye Salmon are reported to concentrate with juvenile Chum (*O. keta*) and Pink Salmon in the Gulf Islands (Burgner, 1991). From March to July of the same year, a 50 fathom (91 m) purse seine survey in the nearshore area of Nanaimo did, however, catch Sockeye Salmon juveniles as well as Chum, Chinook and Coho Salmon (Schmidt et al., 1978). When Sockeye Salmon were caught, other species in the set other than salmonids included some or all of the following: Lingcod (*Ophiodon elongatus*), Pacific Herring, Pacific Sandlance, Shiner Perch (*Cymatogaster aggregata*), Pile Perch (*Rhacochilus vacca*), Copper Rockfish (*Sebastes caurinus*), Kelp Greenling (*Hexagrammos decagrammus*).

Continuing these studies in 1976 and 1977, a 120 fathom (220 m) purse seine survey was conducted from April to July (Schmidt et al., 1979b) in the same general area as that reported in Schmidt et al. (1978). All anadromous Pacific salmon species were reported being caught at some point in the survey. When Sockeye Salmon were caught, other species in the set other than salmonids included some or all of the following: kelp greenling, red Irish lord (*Hemilepidotus hemilepidotus*), Pacific Sandlance, Lingcod, Pacific Herring, Stickleback (*Gasterosteus* sp.), Kelp Greenling, and River Lamprey (Schmidt et al., 1979b). Schmidt et al. (1979a) also report on a similar juvenile salmon survey in the nearshore area of Nanaimo using a 50 fathom purse seine from April to July 1976. Again, all anadromous Pacific salmon were caught at some point during the survey. When Sockeye Salmon were caught they were found in sets with one or a combination of species other than other salmonids including: Pacific Herring, Stickleback and Lingcod (Schmidt et al., 1979a).

Surveys using midwater tows in the Strait of Georgia in May and June 1976 caught a total of 28 different species of fish, the most abundant species being Pacific Hake (*Merluccius productus*); Walleye Pollock and Pacific Spiny Dogfish; Northern Lampfish (*Stenobrachius leucopsarus*), Brown Cat Shark (*Apristurus brunneus*), Pacific Herring, Northern Smoothtongue (*Leuroglossus schmidti*) and Sockeye Salmon were also present (Shaw et al., 1983). Other species not mentioned were present in total numbers less than 50.

In Hecate Strait, survey data demonstrates that Sockeye Salmon juveniles are caught in the same sets as Pink, Chum, Coho and Chinook Salmon in July and August (Morris and Healey, 1988). The majority of the sets were composed of Pink and Chum Salmon (*O. keta*) (Morris and Healey, 1988). In the same survey, adult salmon as well as Pacific Herring, Pacific Spiny Dogfish and rockfish (spp.) could be caught in the same sets as juvenile salmon (Morris and Healey, 1988). Data were provided but CPUE was not calculated. Healey (1991) summarizes much of the work conduced in Hecate Strait surveys in 1986 and 1987. It was reported that Pink Salmon were by far the most abundant species (34 fish/set in 1986 and 93 fish/set in 1987) followed by Chum (six fish/set in 1986 and seven fish/set in 1987) and Sockeye Salmon (three fish/set in 1986 and four fish/set in 1987) (Healey, 1991).

DFO conducted trawl surveys in the Discovery Islands on June 3 (n= 9 sets) and July 2, 3 (n=9 sets) 2013 and; June 4, 5 (n=17 sets) and July 5, 6 (n=16 sets) 2014. A preliminary analysis of the total number of fish caught at all depths (0, 15 and 30 m) in all above surveys reported that the Pacific Herring was the predominant species (> 100,000 fish). Catches also included thousands of Chum, Pink and Sockeye Salmon and hundreds of Coho and Chinook Salmon, Walleye Pollock and other fishes (Chrys Neville, DFO, 3190 Hammond Bay Road, Nanaimo, BC, Canada V9T 6N7, pers. comm.).

Species co-occuring with adult Sockeye Salmon

Results of the PSC test fishery for Sockeye Salmon in Area 13 (Lower Johnstone Strait) from mid-July to early September 2000-2015 show that sockeye and Pink Salmon are the two species with the highest annual CPUE. Chum Salmon is occasionally caught while Chinook Salmon, Coho Salmon and Steelhead (*O. mykiss*) are rarely caught (Table 4).

Table 4. Summary of average daily catch-per-unit-effort (CPUE) (count per set) at Lower Johnstone Strait test fishery location (Area 13) (2000-2015). Data provided by the Pacific Salmon Commission.

Year	Sockeye Salmon		Pink Salmon		Chinook Salmon		Coho Salmon		Steelhead		Chum Salmon		Other	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
2000	293.6	426	41.8	63.5	0.9	0.9	0.2	0.3	0	11.3	0.3	0.4	0.4	1.2
2001	112.8	126.2	126.5	138.4	1.3	1	1.6	2.1	0	0	0.4	0.5	0.1	0.2
2002	668.6	927.4	28.7	45.2	0.9	0.7	0.6	0.9	0	0	2.5	4	0	0
2003	235.5	242.6	341.4	462.1	0.9	0.9	0.8	0.9	0	0	11	14.4	0	0
2004	198.1	265.5	16.1	32.9	1.3	1.2	0.5	0.5	0	0.2	4.7	4.8	0.1	0.3
2005	503.8	647.6	296	348.7	0.8	0.6	0.7	0.8	0	0	4.4	5.5	0	0.1
2006	655.9	1225	2.6	3.2	1	1.1	0.3	0.3	0	0	5.8	12.2	1.5	10.8
2007	101.2	109.6	294	471.9	0.9	0.8	2.1	3.5	0	0	2.1	2.1	0.1	0.3
2008	7.4	8.3	7.4	10.7	0.8	1.1	0.4	0.9	0	0	0.8	1.3	0.4	2.1
2009	93.8	122.4	676.7	769.8	1	1	2	4.1	0	0	1.3	1.4	0	0.1
2010	2019.7	2775	68	102.7	0.8	0.8	0.2	0.2	0	0	0.5	0.6	0.3	1.4
2011	467.6	868.9	350.5	480.4	0.8	0.8	0.8	0.9	0	0.1	2.1	2.8	0.1	0.8
2012	33.6	27.5	112.9	135.9	0.6	0.6	0.7	0.6	0	0	1.5	2.1	0.1	0.3
2013	232.5	174.6	1416.7	1665.5	0.8	0.8	2.6	6.3	0	0	5.8	7.9	0.1	0.8
2014	2544.2	3177	161.8	366.1	1.1	0.8	0.4	0.5	0	0	1.9	1.9	0	0
2015	112.1	99.6	286.7	225.2	1	0.8	0.6	0.5	0	0.1	5.3	9	0	0.1

ABUNDANCE

Consequences of interactions with salmon farms in the Discovery Islands can be measured by assessing the impacts on Fraser River Sockeye Salmon abundance. The current trends in abundance and marine survival of Fraser River sockeye provide a baseline to evaluate variability and the potential magnitude of mortality attributable to salmon farms.

ADULTS

Fraser River Sockeye Salmon return abundances, which combine DFO escapement data and catch data with run-size adjustments organized by age, are compiled by the PSC into annual reports. These data are organized by Management Group and stock aggregates used for in-season management purposes (Table 1).

Total adult returns of Fraser River Sockeye Salmon are highly variable ranging from 2 to 28 million, with an average of 9.6 million, between 1980 and 2014 (Figure 5). One factor that contributes to this high variability is that cyclic stocks produce large returns once every four years. Since most Fraser River Sockeye Salmon stocks mature at four years of age, individual years in a four year cycle are somewhat independent of the remaining three years depending on the variation in age of maturity of each cycle year (i.e., there will be some overlap between different cycle return years depending on the contribution of age classes from other cycle years). The high variability in returns for Fraser River Sockeye Salmon is also due to variability in brood year spawner abundances and survival from the egg to adult return stages (Grant et al., 2010).

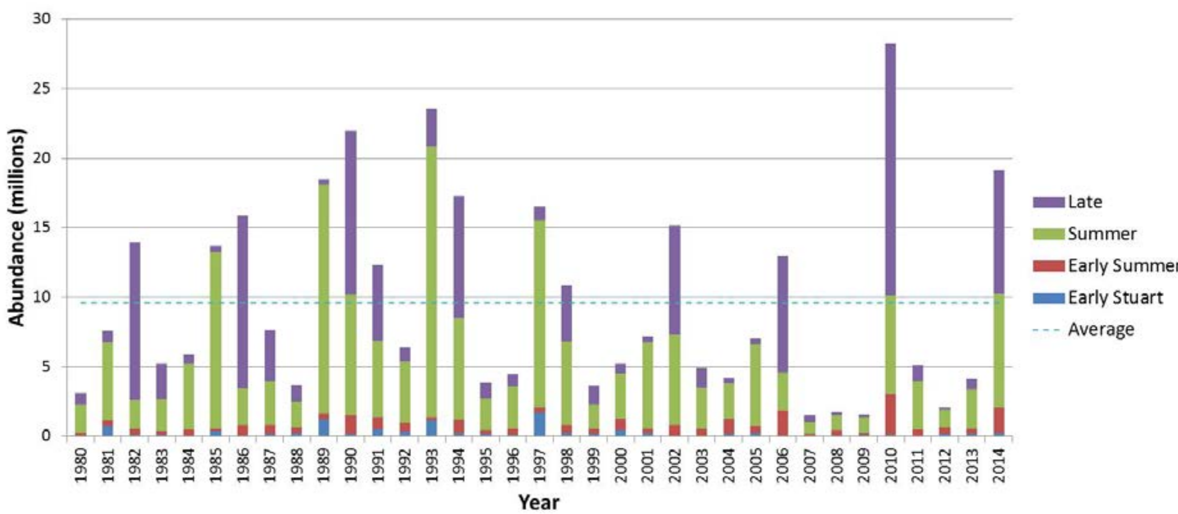

Figure 5. Total abundance of Fraser River Sockeye Salmon returning adults from 1980 to 2014 by Management Group. The dashed line represents the average abundance (9.6 million). Data source provided by the Pacific Salmon Commission, 2015.

Out of the four Fraser River Sockeye Salmon Run Timing Groups, the Summer and Late Run Timing groups are consistently the major contributors to the annual Fraser River Sockeye Salmon return. In contrast, the Early Stuart Management Group contributes very little to the total abundance of Fraser River Sockeye Salmon and has declined in recent decades (Figure 6A). The Early Summer Management Group contributes a small proportion to the total, with variable contributions from the various stocks through time. Historically the major contributors to the Summer Management Group have been Quesnel and/or Chilko stocks (Figure 6C); although in recent years Quesnel has contributed only small proportions to the total. The Late Management Group is the dominant group every four years (such as 2006, 2010, 2014…). Once every four years, the major contributor to the Late Management Group returns is Late Shuswap on its dominant cycle line (2010, 2014…) (Figure 6D).

From 1952 to 2005, Harrison River population represented an average 1.1% of the Fraser River Sockeye Salmon aggregate (Beamish et al., 2016). However, from 2005 to 2011, this percentage has increased to an average of 6.9%, and reached above 27% in both 2009 and 2011 (Beamish et al., 2016).

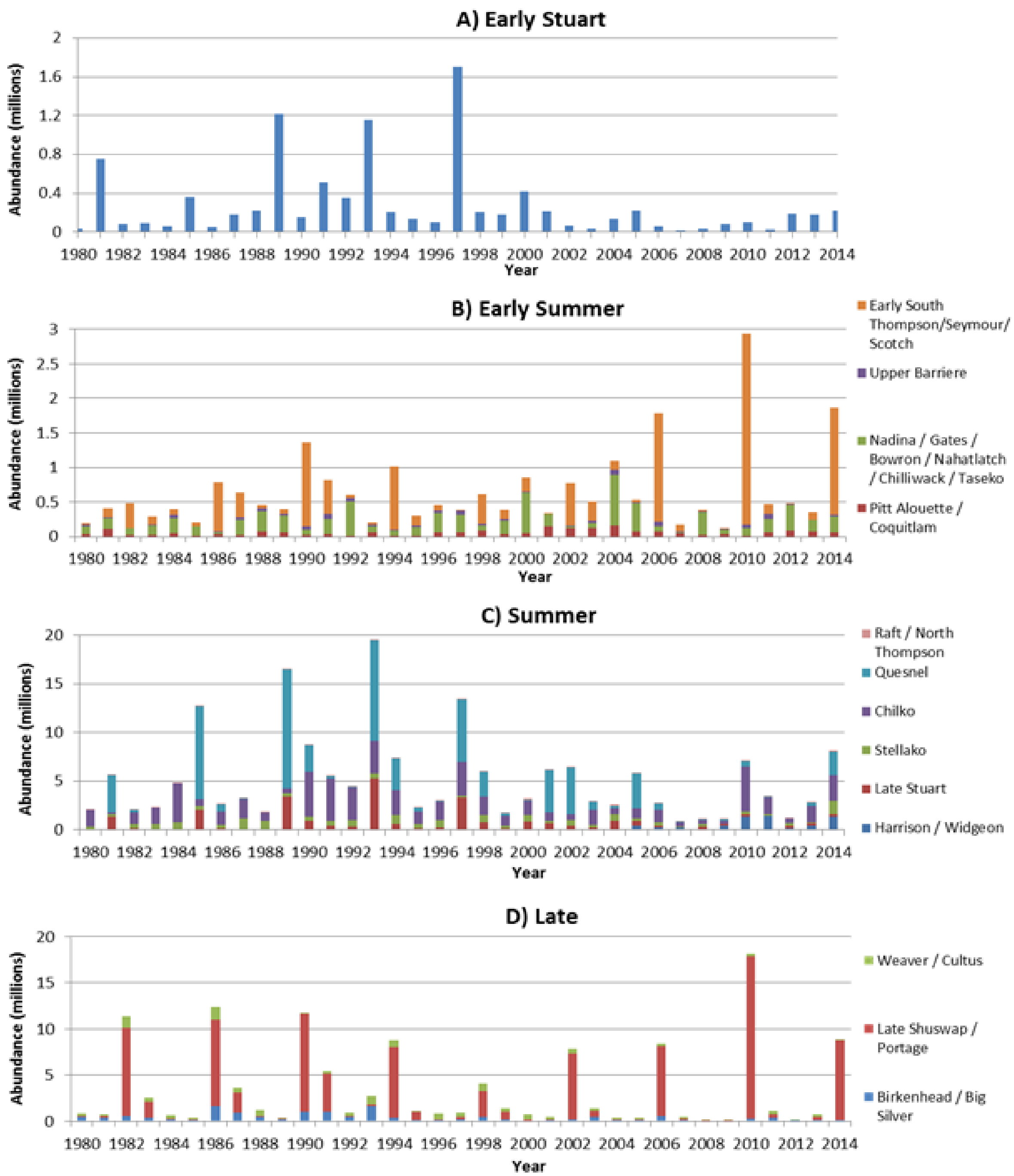

Figure 6. Fraser River Sockeye Salmon returning adult abundance from 1980 to 2014 by Management Group and stock aggregate. Note the change in scale of the Y axis among panels. Data provided by the Pacific Salmon Commission, 2015.

MARINE SURVIVAL

The combination of adult return and smolt data can be used to estimate marine survival. Out of the 27 Fraser River Sockeye Salmon stocks (24 CU's), only Chilko Lake and Cultus Lake have a smolt abundance time series. Therefore, marine survival can only be estimated for these two stocks. Marine survival data for both stocks includes a portion of freshwater survival as smolts are counted at the outlets of their respective lakes. This may be more than 650 km from the mouth of the Fraser River.

The Chilko smolt time series extends from 1949 to 2011 brood years (excluding 1989). Chilko Lake generally contributes a large proportion to the total Fraser River Sockeye Salmon return, with the exception of when Late Shuswap has a dominant cycle year (2010, 2014…). The Chilko stock's marine survival time series is considered an indicator of marine survival for other stocks.

In contrast, the Cultus Lake smolt time series is incomplete throughout the time series (brood years assessed: 1951-1952, 1954-1961, 1965-1972, 1974-1976, 1988-1990 and 1999-2011). Cultus Lake Sockeye Salmon have experienced very low returns in the past few decades, contributing a negligible proportion to the total Fraser River Sockeye Salmon return. Additionally, after the 2000 brood year, Cultus has been enhanced by the hatchery supplementation of fry and smolts. Therefore, given the short and incomplete time series, the poor survival and abundances in recent years, and the high hatchery contributions, the survival time series for the Cultus Lake stock is not considered an indicator for other stocks.

Marine survival is presented in Table 5 for both stocks for the entire time series and a more recent time series (1990-2011 brood years). The recent time series is a low productivity period (Figure 7 and Figure 8) and may be more representative of current conditions.

Table 5. Percent survival of Chilko and Cultus lake Sockeye Salmon stocks (1951-2013 ocean entry year). As of 2000 brood year (2002 ocean entry year) Cultus Lake stock was enhanced by hatchery salmon which are included in the survival data. Data provided by S. Grant (DFO).

Stock	**Descriptive statistics**	**All data (ocean entry years 1951 to 2013)**		**Recent data (ocean entry years 1992 to 2013)**	
		Survival (%)	**N (years)**	**Survival (%)**	**N (years)**
Chilko Lake	Minimum	0.4	62	0.4	22
	Geometric mean	6.9		4.3	
	Maximum	25.1		14.5	
Cultus Lake	Minimum	0.5	36	0.7	13
	Geometric mean	4.0		2.7	
	Maximum	43.9		13.8	

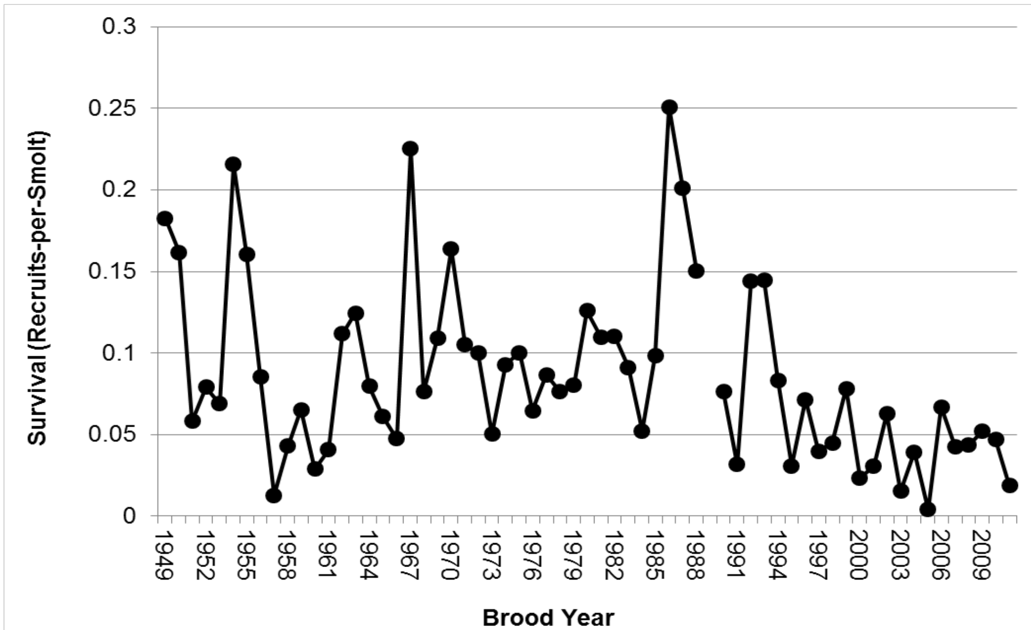

Figure 7. Chilko Lake Sockeye Salmon marine survival (recruits-per-smolt) from the 1949 to 2011 brood year. Data provided by S. Grant (DFO).

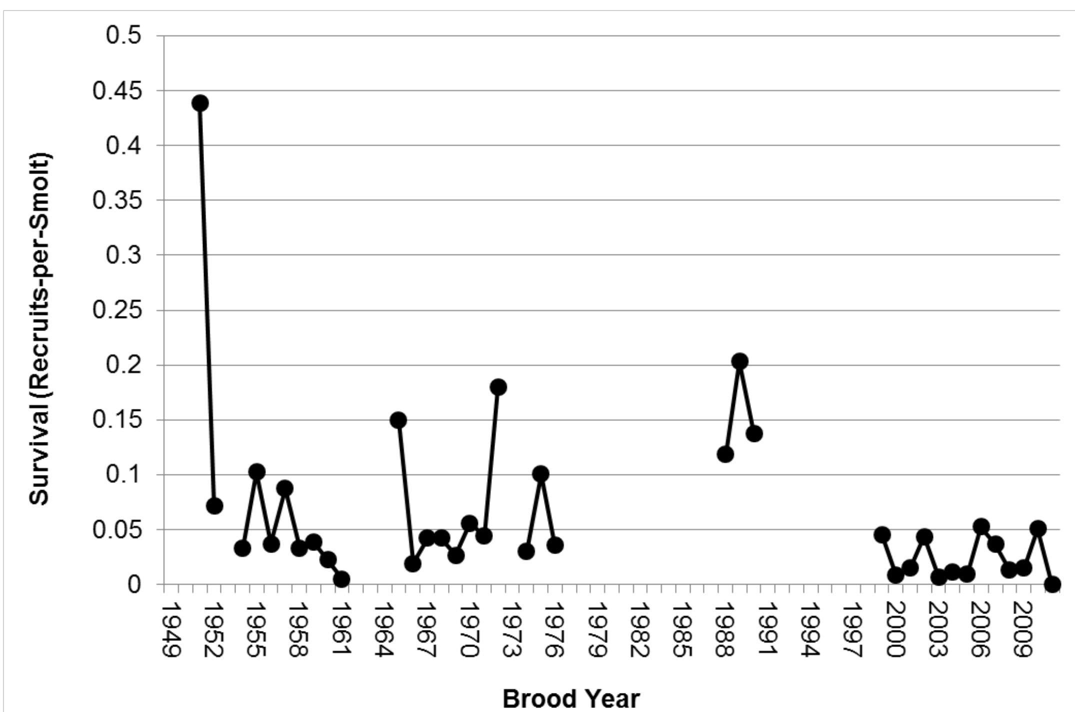

Figure 8. Cultus Lake Sockeye Salmon marine survival (recruits-per-smolt) from 1951 to 2010 brood year. Enhancement by hatcheries began from the 2000 brood year. Data provided by S. Grant (DFO).

The average (geometric) Chilko Lake Sockeye Salmon marine survival from the outlet of Chilko Lake to returning adult over the whole time series is 6.9% (1951-2013 ocean entry years) and decreased in recent years (1992-2013 ocean entry years) to 4.3% (Table 5). The maximum survival calculated for Chilko Lake Sockeye Salmon stocks was in the 1988 ocean entry year and the minimum was in the 2007 ocean entry year (Figure 7).

For Cultus Lake Sockeye Salmon stocks, the average survival from the outlet of Cultus Lake to return adult over the whole time series is 4% and decreased to an average 2.7% in recent years (1992-2013) (Table 5). The maximum survival calculated for Cultus Lake Sockeye Salmon stocks was in the 1953 ocean entry year and minimum in the 1963 ocean entry year (Figure 8).

Marine survival of Chilko Lake Sockeye Salmon, from the outlet of Chilko Lake to the final marine acoustic array in Queen Charlotte Sound (total distance: 1,044 km), has been reported to range from 3 to 10% in acoustic tagging studies (Clark et al., 2016). Welch et al. (2009) reported marine survival of Cultus Lake Sockeye Salmon from the outlet of the Fraser River to the same final acoustic array located in Queen Charlotte Sound to range from 10 to 30%. Differences in survival rates between these studies can be also be attributed to differences in size of fish between the two stocks, hatchery vs. wild origin, and ocean entry timing.

JUVENILES

There are no data available for the total number of out-migrating Sockeye Salmon smolts from the Fraser River. There are very few stocks for which smolt abundance is estimated and only Chilko has a long and complete time series available (1951-present ocean entry year) (DFO, 2015). Chilko has historically contributed the most significant proportion of lake-type Sockeye Salmon to total returns (average 30%) (DFO, 2015). On average, the one-year-old smolt abundance for Chilko has been 20 million, ranging from 1.6 M in 1953 to 77 M in 2007 (Figure 9).

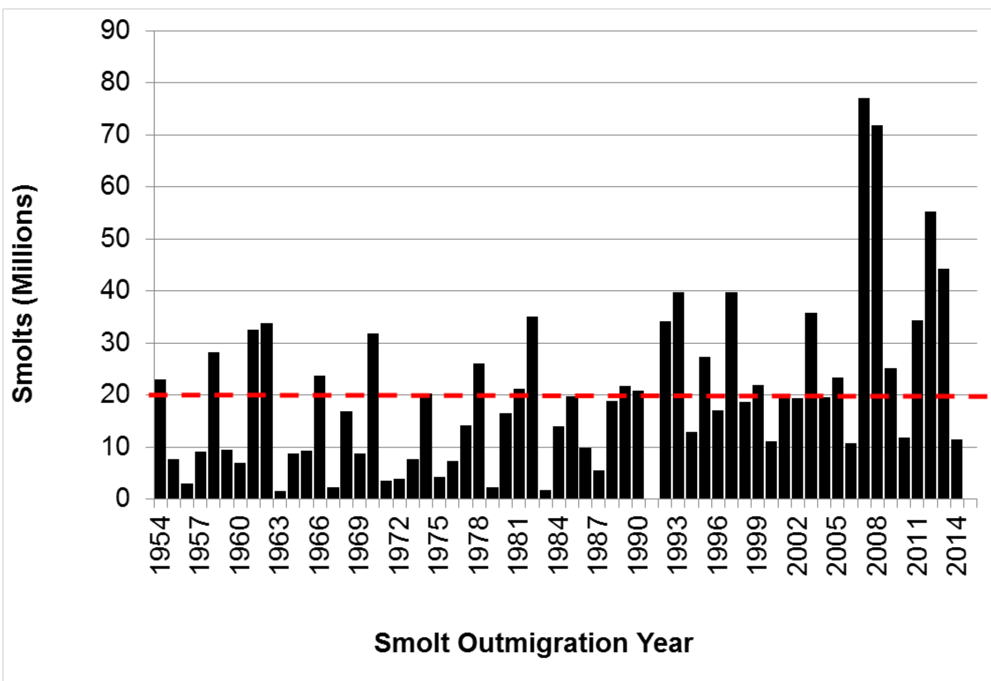

Figure 9. Chilko Lake one-year-old smolt abundances (black bars) from 1954 to 2015. Note: the smolt enumeration fence did not operate in 2015 and no reliable estimate could be produced in this year. The dashed (red) horizontal line represents average smolt abundance (20.2 million) for Chilko. Data provided by S. Grant (DFO).

DIVERSITY

Consequences of interactions with salmon farms in the Discovery Islands can also be assessed by estimating the impacts on Fraser River Sockeye Salmon diversity. Conservation Units are the unit of biodiversity protected under Canada's Wild Salmon Policy, which are required for the health and sustainability of the species as a whole (DFO, 2005; Holtby and Ciruna, 2007). The management of Fraser River Sockeye Salmon is largely aligned with CUs, and so diversity for the purposes of these risk assessments is considered to be equivalent to CUs. A loss of a CU represents a loss in biodiversity of Fraser River Sockeye Salmon.

The current trends in abundance and marine survival provide a baseline to evaluate variability and the potential magnitude of mortality attributable to salmon farms. Consequences on diversity entail a change in risk of extirpation of individual CUs. The current status of CUs provides a background for understanding risk of loss from possible increases in mortality due to interactions with Atlantic Salmon farms.

STATUS OF FRASER RIVER SOCKEYE SALMON CONSERVATION UNITS

An objective of the Wild Salmon Policy (WSP) is to restore and maintain the genetic diversity of wild Pacific salmon through the protection of CUs (DFO, 2005). The WSP outlines action steps for the maintenance of CUs but recognizes that there may be instances when "losses of wild salmon are unavoidable" (DFO, 2005); however, it is identified that the clear intent of the WSP is to prevent losses resulting from management and use.

The WSP defines three zones of biological status: Red, Amber and Green. The zones represent a CU's biological status and the extent of management intervention required (DFO, 2005). CUs in the Red status zone have a higher risk of extirpation and have a loss of ecological benefits and salmon production. CUs in the Red status zone will initiate an immediate consideration of ways to protect the fish, increase their abundance, and reduce their risk of loss (DFO, 2005). A CU in the Amber status zone should be at low risk of loss; however, there could be a degree of lost production. CUs in the Amber status zone will involve broader considerations of biological, social and economic issues and should be managed with caution (DFO, 2005). CUs in the Green status zone are not at a high probability of losing the CU under existing harvesting conditions (DFO, 2005).

There are currently 24 Fraser River Sockeye Salmon CUs (Holtby and Ciruna, 2007; Grant et al., 2011), although the list of CUs is subject to change with new information (Holtby and Ciruna, 2007). The WSP status for each CU has been determined through a Canadian Science Advisory Secretariat workshop during which relevant metrics (e.g., relative abundance, short-term trends in abundance and long-term trends in abundance, and productivity among others) for each CU were integrated to generate a final status assessment (DFO, 2013; Grant and Pestal, 2013). Until a new status assessment is completed in 2017, the current CUs statuses apply (Table 6). For the 24 Fraser River Sockeye Salmon CUs, 11 CUs have a Red or Red/Amber status, six have an Amber or Amber/Green status, and five have a Green status. Blended statuses (Red/Amber or Amber/Green) were identified when individual metrics showed inconsistent signals and consensus on a single status zone among workshop participants could not be obtained. The remaining two CUs are either data deficient or undetermined.

Table 6. Integrated status designations for the 24 Fraser River Sockeye Salmon Conservation Units ranked from poor (red) to healthy (green). Management Groups include Early Stuart (EStu), Early Summer (ES), Summer (S) and Late (L). Adapted from Grant and Pestal (2013).

Stock	Conservation Unit (Management Group)	Status
Early Stuart	Takla-Trembleur (EStu)	Red
Nadina	Nadina-Francois (ES)	Red
Taseko	Taseko (ES)	Red
Nahatlatch	Nahatlatch (ES)	Red
Bowron	Bowron (ES)	Red
Cultus	Cultus (L)	Red
Harrison/Widgeon	Widgeon-River	Red
Chilliwack	Chilliwack (ES)	Red/Amber
Stellako	Francois-Fraser (S)	Red/Amber
Quesnel	Quesnel (S)	Red/Amber
Late Stuart	Takla-Trembleur-Stuart (S)	Red/Amber
Fennel and Miscellaneous Early Summers	North Barriere (ES)	Amber
Gates	Anderson-Seton (ES)	Amber
Raft and Miscellaneous Early Summers	Kamloops (ES)	Amber
Weaver	Harrison U/S (L)	Amber
Pitt	Pitt (ES)	Amber/Green
Scotch, Seymour, Miscellaneous Early Summers	Shuswap (ES)	Amber/Green
Chilko	Chilko-S and Chilko (ES)	Green
Birkenhead	Lillooet-Harrison (L)	Green
Miscellaneous Lates	Harrison D/S (L)	Green
Late Shuswap	Shuswap Complex (L)	Green
Harrison	Harrison River	Green
Chilko	Chilko (ES)	Data Deficient
Seton	Seton (L)	Unknown

SUMMARY

Of the 24 Fraser River Sockeye Salmon conservation units (CUs), 22 are lake-type and two are river-type. These CUs are divided into four Management Groups: Early Stuart, Early Summer, Summer and Late. Summer and Late Management Groups contribute the majority of fish to the overall Fraser River Sockeye Salmon returns in any given year and the Late Management Group is the dominant group every four years (such as 2006, 2010, 2014…).

Biological status zones have been determined for each of the 24 CUs. The zones represent a CU's biological status and the extent of management intervention required. There are 11 CUs that have a Red or Red/Amber status, six with an Amber or Amber/Green status, and five are Green. The remaining two CUs are either data deficient or undetermined.

In general, lake-type Sockeye Salmon smolts exit the Fraser River between mid-April and late-May with a peak in early-May. Juvenile lake-type Fraser River Sockeye Salmon have been found in the Strait of Georgia as late as August and tend to exit the Strait of Georgia through the Discovery Islands. The amount of time an average juvenile lake-type Sockeye Salmon spends migrating through the Strait of Georgia has been estimated to between 20 and 59 days. In recent years, juvenile Fraser River Sockeye Salmon have been caught in the Discovery Islands from mid-May to mid-July, with peak catches early-to-mid June. The residence time of juvenile Fraser River Sockeye Salmon in the Discovery Islands is estimated to range between 5 to 14 days.

River-type Harrison River Sockeye Salmon smolts exit the Fraser River between early-June and late-July with a peak in mid-July. Juvenile Harrison River Sockeye Salmon migrate out of the Strait of Georgia in the late-autumn and early-winter through either the northern or southern route. There are no estimates of residence time of Harrison River Sockeye Salmon juveniles in the Discovery Islands.

Adult Sockeye Salmon return to the Fraser River via the northern route and southern route. The proportion that divert through Johnstone Strait in recent years has been 52%. In-season test fishery data shows that adult Sockeye Salmon are present in the Discovery Islands from at least mid-July to the beginning of September. Back calculations based on swimming speed and arrival time at Mission estimate that adult Sockeye Salmon could be in the Discovery Islands from late-June to early-October assuming no residence time in the Strait of Georgia. Based on these same estimates, Fraser River Sockeye Salmon could spend approximately three days swimming through the Discovery Islands.

REFERENCES CITED

Barraclough, W. E. and Phillips, A. C. 1978. Distribution of juvenile salmon in the southern Strait of Georgia during the period April – July 1966 – 1969. Fish Mar. Serv. Tech. Rep. 826. 47 p.

Beacham, T. D., Beamish, R. J., Candy, J. R., Wallace, C., Tucker, S., Moss, J. H. and Trudel, M. 2014a. Stock-specific migration pathways of juvenile sockeye salmon in British Columbia waters and in the Gulf of Alaska. Trans. Am. Fish. Soc. 143(6): 1386-1403.

Beacham, T. D., Beamish, R. J., Candy, J. R., Wallace, C., Tucker, S., Moss, J. H. and Trudel, M. 2014b. Stock-specific size of juvenile sockeye salmon in British Columbia waters and the Gulf of Alaska. Trans. Am. Fish. Soc. 143(4): 876-889.

Beamish, R. J., Lange, K. L., Neville, C. M., Sweeting, R., Beacham, T. D. and Preikshot, D. 2010. Late ocean entry of sea-type sockeye salmon form the Harrison river in the Fraser river drainage results in improved productivity. North Pacific Anadromous Fish Commission Documents. 1283. 30 p.

Beamish, R. J., McCaughran, D., King, J. R., Sweeting, R. M. and McFarlane, G. A. 2000. Estimating the Abundance of Juvenile Coho Salmon in the Strait of Georgia by Means of Surface Trawls. N. Am. J. Fish. Manage 20: 369-375.

Beamish, R. J., Neville, C. M., Sweeting, R. M., Beacham, T. D., Wade, J. and Li, L. 2016. Early ocean life history of Harrison River sockeye salmon and their contribution to the biodiversity of sockeye salmon in the Fraser River, British Columbia, Canada. Trans. Am. Fish. Soc. 145(2): 348-362.

Beamish, R. J., Trudel, M. and Sweeting, R. M. 2007. Canadian coastal and high seas juvenile pacific salmon studies. NPAFC Technical Report. 7: 4 p.

Brodeur, R. D., Daly, E. A., Sturdevant, M. V., Miller, T. W., Moss, J. H., Thiess, M. E., Trudel, M., Weitkamp, L. A., Armstrong, J. and Norton, E. C. 2007. Regional comparisons of juvenile salmon feeding in coastal marine waters off the West Coast of North America. Am. Fish. Soc. Symp. 57: 183-103.

Brown, T. J., Kask, B. A., McAllister, C. D., Macdonald, J. S. and Levings, C. D. 1984. Salmonid catch-data from Campbell River and Discovery Passage, 1984. Can. Data Rep. Fish. Aquat. Sci. 497. iii + 79.

Burgner, R. L. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). *In* Pacific Salmon Life Histories. Groot, C. and Margolis, L. (eds.). University of British Columbia Press, Vancouver, Canada. 1: pp 1-118.

Chandler, P. C., Foreman, M. G. G., Ouellet, M., Mimeault, C. and Wade, J. 2017. Oceanographic and environmental conditions in the Discovery Islands, British Columbia. DFO Can. Sec. Res. Doc. 2017/071. viii + 51 p.

Christensen, V. and Trites, A. W. 2011. Predation on Fraser River sockeye salmon. Cohen Commission Tech. Rept. 8: 129 p.

Clark, T. D., Furey, N. B., Rechisky, E. L., Gale, M. K., Jeffries, K. M., Porter, A. D., Casselman, M. T., Lotto, A. G., Patterson, D. A., Cooke, S. J., Farrell, A. P., Welch, D. W. and Hinch, S. G. 2016. Tracking wild sockeye salmon smolts to the ocean reveals distinct regions of nocturnal movement and high mortality. J. Ecol. Appl. 26(4): 959-978.

Cohen, B. I. 2012. Recommendations, summary, process. The uncertain future of Fraser River sockeye. Vol. 3. Minister of Public Works and Government Services Canada, Publishing and Depository Services, Ottawa, ON. 211 p.

DFO. 2005. Canada's policy for conservation of wild Pacific salmon. Fisheries and Oceans Canada. 49 p.

DFO. 2013. Integrated biological status of Fraser River sockeye salmon (*Oncorhynchus nerka*) under the Wild Salmon Policy. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/056. 13 p.

DFO. 2014. Supplement to the pre-season return forecasts for Fraser River Sockeye salmon in 2014. DFO Can. Sci. Advis. Sec. Sci. Resp. 2014/041. 57 p.

DFO. 2015. Supplement to the pre-season return forecasts for Fraser River Sockeye salmon in 2015. DFO Can. Sci. Advis. Sec. Sci. Resp. 2015/028. 49 p.

DFO. 2016. Pre-season run size forecasts for Fraser River sockeye (*Oncorhynchus nerka*) salmon in 2016. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/021.

Farley, E. V., Murphy, J. M., Adkison, M. and Eisner, L. 2007. Juvenile sockeye salmon distribution, size, condition and diet during years with warm and cool spring sea temperatures along the eastern Bering Sea shelf. J. Fish Biol. 71: 1145–1158.

Folkes, M., Thompson, R. and Hourston, R. 2017. Evaluating models to forecast Fraser sockeye return timing and diversion rate. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/021. vi + 220 p.

Foreman, M. G. G., Chandler, P. C., Stucchi, D. J., Garver, K. A., Guo, M., Morrison, J. and Tuele, D. 2015. The ability of hydrodynamic models to inform decisions on the siting and management of aquaculture facilities in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/005. vii + 49 p.

Freshwater, C., Trudel, M., Beacham, T. D., Godbout, L., Neville, C.-E. M., Tucker, S. and Juanes, F. 2016a. Disentangling individual- and population-scale processes within a latitudinal size gradient in sockeye salmon. Can. J. Fish. Aquat. Sci. 73(8): 1190-1201.

Freshwater, C., Trudel, M., Beacham, T. D., Godbout, L., Neville, C.-E. M., Tucker, S. and Juanes, F. 2016b. Divergent migratory behaviours associated with body size and ocean entry phenology in juvenile sockeye salmon. Can. J. Fish. Aquat. Sci. 73: 1-10.

Grant, S. C. H., Macdonald, B. L., Cone, T. E., Holt, C. A., Cass, A. J., Porszt, E. J., Hume, J. M. B. and Pon, L. B. 2011. Evaluation of uncertainty in Fraser Sockeye (*Oncorhynchus nerka*) Wild Salmon Policy status using abundance and trends in abundance metrics. DFO. Can. Sci. Advis. Sec. Res. Doc. viii + 183 p.

Grant, S. C. H., Michielsens, C. G. J., Porszt, E. J. and Cass, A. 2010. Pre-season run size forecasts for Fraser River Sockeye salmon (*Oncorhynchys nerka*) in 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/042. 125 p.

Grant, S. C. H. and Pestal, G. 2013. Integrated biological status assessments under the Wild Salmon Policy using standardized metrics and expert judgement: Fraser River Sockeye salmon (*Oncorhynchus nerka*) case studies. Can. Sci. Advis. Sec. Res. Doc. 2012/106. v + 132 p.

Groot, C. and Cooke, K. 1987. Are the migrations of juvenile and adult Fraser River sockeye salmon (O*ncorhynchus nerka)* in near-shore waters related? Can. Sp. Publ. Fish. Aquat. Sci. 96: 53-60.

Healey, M. C. 1976. Herring in the diets of pacific salmon in Georgia Strait. Fisheries Research Board of Canada Manuscript Report Series No. 1382. 38 p.

Healey, M. C. 1978. The distribution, abundance and feeding habits of juvenile pacific salmon in Georgia Strait British Columbia. Fisheries and Marine Service Technical Report No. 788. 49 p.

Healey, M. C. 1980. The ecology of juvenile salmon in Georgia Strait, British Columbia. *In* Salmonid ecosystems of the North Pacific. Himsworth, D. C. (ed.). Oregon State University Press and Oregon State University Sea Grant College Program., Corvallis. pp 203-229.

Healey, M. C. 1991. Diets and feeding rates of juvenile Pink, Chum, and Sockeye salmon in Hecate Strait, British Columbia. Trans. Am. Fish. Soc. 120(3): 303-318.

Holtby, L. B. and Ciruna, K. A. 2007. Conservation units for pacific salmon under the Wild Salmon Policy. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/070. vi + 350 p.

Johnson, B. 2016. Development and evaluation of a new method for assessing migration timing of juvenile Fraser River sockeye salmon in their early marine phase. University of Northern British Columbia. 33 p. Undergraduate Thesis.

Killick, S. R. and Clemens, W. A. 1963. The age, sex ratio and size of Fraser River sockeye salmon, 1915 to 1960. Bulletin / International Pacific Salmon Fisheries Commission. Vol. 14. New Westminister, B. C. 146 p.

Lapointe, M., Folkes, M. and Hourston, R. 2015. Fraser River Sockeye diversion rate; 2014 the highest on record. *In* State of the physical, biological and selected fishery resources of the Pacific Canadian marine ecosystems in 2014. Chandler, P. C., King, S. A. and Perry, R. I. (eds.). Can. Tech. Rep. Fish. Aquat. Sci. 3131: pp 48-53.

Levings, C. D. and Kotyk, M. 1983. Results of two boat trawling for juvenile salmonids in Discovery Passage and nearby channels, northern Strait of Georgia. Can. Man. Rep. Fish. and Aquat. Sci. No. 1730. 55 p.

Madison, D. M., Horrall, R. M., Hasler, A. D. and Stasko, A. B. 1972. Migratory movements of adult sockeye salmon (*Oncorhynchus nerka*) in coastal British Columbia as revealed by ultrasonic tracking. J. Fish. Res. Bd. Can. 29(7): 1025-1033.

Morris, J. F. T. and Healey, M. C. 1988. Hecate Strait juvenile salmon survey: 1987. Canadian Data Report of Fisheries and Aquatic Sciences No. 701. 23 p.

Neville, C. M., Johnson, S. C., Beacham, T. D., Whitehouse, T., Tadey, J. and Trudel, M. 2016. Initial estimates from an integrated study examining the residence period and migration timing of juvenile sockeye salmon from the Fraser River through coastal waters of British Columbia. NPAFC Bull. 6: 45-60.

Neville, C. M., Trudel, M., Beamish, R. J. and Johnson, S. C. 2013. The early marine distribution of juvenile sockeye salmon produced from the extreme low return in 2009 and the entreme high return in 2010. North Pacific Anadromous Fish Commission 9: 65-68.

Pacific Salmon Commission. 2009. Conference on early migration and premature mortality in Fraser River late-run sockeye salmon: Proceedings. *In* Hinch, S. G. and Gardner, J. (eds.). Forest Sciences Centre, UBC. Oct. Pacific Fisheries Resource Conservation Council. pp 114.

Pacific Salmon Commission. 2016. Test fishing.

Pestal, G., Huang, A.-M., Cass, A. J. and the FRSSI Working Group. 2012. Updated methods for assessing harvest rules for Fraser River sockeye salmon (*Oncorhynchus nerka*). DFO Can. Sci. Advis. Sec. Res. Doc. 2011/133. viii + 175 p.

Peterman, R. M., Marinone, S. G., Thomson, K. A., Jardine, I. D., Crittenden, R. N., Leblond, P. H. and Walters, C. J. 1994. Simulation of juvenile sockeye salmon (*Oncorhynchus nerka*) migrations in the Strait of Georgia, British Columbia. Fish. Oceanogr. 3(4): 221-235.

Preikshot, D., Beamish, R. J., Sweeting, R. M., Neville, C. M. and Beacham, T. D. 2012. The residence time of juvenile Fraser River sockeye salmon in the Strait of Georgia. Mar. Coast. Fish. 4(1): 438-449.

Quinn, T. P. 1987. Estimated swimming speeds of migrating adult sockeye salmon. Can. J. Zool. 66: 2160-2163.

Schmidt, R. V., Healey, M. C., Jordan, F. P. and Hungar, R. M. 1978. Data record: Juvenile salmon and other fish species captured by 50-fathom purse seines in nearshore areas near Nanaimo, 1975. Canadian Data Report of Fisheries and Aquatic Sciences No. 119. 136 p.

Schmidt, R. V., Healey, M. C., Jordan, F. P. and Hunger, R. M. 1979a. Data record: Juvenile salmon and other fish species captured by 50-fathom purse seines in nearshore areas near Nanaimo, 1976. Canadian Data Report of Fisheries and Aquatic Sciences No. 168. 80 p.

Schmidt, R. V., Healey, M. C., Jordan, F. P. and Hunger, R. M. 1979b. Data record: Juvenile salmon and other fish species captured by 120-fathom purse seines in nearshore areas near Nanaimo, 1976-1977. Canadian Data Report of Fisheries and Aquatic Sciences No. 176. 139 p.

Shaw, W., McFarlane, G. A. and Beamish, R. J. 1983. An examination of the biology and distribution of Pacific hake, Walleye pollock, and Spiny dogfish in the Strait of Georgia. R/V G.B. REDD, May 25-June 18, 1976. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1697. 240 p.

Tucker, S., Trudel, M., Welch, D. W., Candy, J. R., Morris, J. F. T., Thiess, M. E., Wallace, C., Teel, D. J., Crawford, W., Farley, E. V. and Beacham, T. D. 2009. Seasonal stock-specific migrations of juvenile sockeye salmon along the west coast of North America: implications for growth. Trans. Am. Fish. Soc. 138(6): 1458-1480.

Walter, E. E., Scandol, J. P. and Healey, M. C. 1997. A reappraisal of the ocean migration patters on Fraser River sockeye salmon (*Oncorhynchus nerka*) by individual-based modelling. Can. J. Fish. Aquat. Sci. 54: 847-858.

Welch, D. W., Melnychuk, M. C., Rechisky, E. R., Porter, A. D., Jacobs, M. C., Ladouceur, A., McKinley, R. S. and Jackson, G. D. 2009. Freshwater and marine migration and survival of endangered Cultus Lake sockeye salmon (*Oncorhynchus nerka*) smolts using POST, a large-scale acoustic telemetry array. Can. J. Fish. Aquat. Sci. 66(5): 736-750.