An Early Marine Life History Strategy for Fraser River Sockeye Salmon

By

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THIS PAPER MAY BE CITED IN THE FOLLOWING MANNER:
Abstract
The Fraser River is one of the major producers of sockeye salmon. Most of the populations have fry that spend one year in a lake before migrating to the ocean. A small percentage spends two years in a lake, and a small percentage are sea type and migrate directly into the ocean in the year that they emerge from the gravel. Most smolts from the lake-type populations migrate into the Strait of Georgia in early May and by the end of June they are spread out form the Gulf Islands area in the Strait of Georgia to at least Hecate Strait, a linear distance of about 1,000 km. Most sea-type juveniles enter the Strait of Georgia in July and remain until about November. Although the sea-type population was only about 1.2 % of the production in the since 1952, it has been 5.0% in the last six years. We propose that sockeye salmon smolts from the Fraser River migrate and disperse over a vast area of the ocean in the critical early marine period, as well as using the Strait of Georgia over an extended period, to ensure that some juveniles always find favourable ocean conditions and abundant prey. This means that juvenile sockeye salmon from the Fraser River are spread out in time and space in the early marine period. It is important to recognize that there is an early marine life history strategy for Fraser River sockeye salmon and that the strategy is an adaptation to optimize the survival of the aggregate of populations over a period of hundreds to thousands of years of changing climate and ocean conditions.
Introduction

Major sockeye salmon producing areas are the Ozernaya and Kamchatka rivers in Russia, Bristol Bay in Alaska and the Fraser River in Canada. In recent years, the average return to the Bristol Bay area has been about 40 million fish. Beginning in the mid 1990s, the total return to the Fraser River declined from a high of about 23.6 million fish in 1993 to a historic low of 1.6 million fish in 2009. However, in 2010 there was an historic high total return of 28.4 million fish. The life history of sockeye salmon from the Fraser River has been extensively studied in fresh water, but there have been considerably fewer studies of the early marine period. Groot and Cooke (1987) looked at the possibility that the migration route of juvenile sockeye salmon after they left the Fraser River influenced the route followed by returning adults. Preikshot et al. (2012) estimated the average time that juvenile sockeye salmon from the Fraser River spent in the Strait of Georgia before they exited north through Johnstone Strait. In this report we look at the distribution pattern of juvenile sockeye salmon from the Fraser River in the early marine period and propose that the dispersion of juveniles over a large area in the early marine period is an adaptation to ensure that some juveniles always find favourable ocean conditions including abundant prey. It is understood that run timing and time of spawning are adaptations to help maximize the productivity of Fraser River sockeye salmon in fresh water but early and late ocean entry times and a spreading out of juveniles over a large area in the early marine period are life history strategies that are not generally recognized.

Methods

The surveys in the Strait of Georgia used a trawl that was fished at 15 m depths. The net opening was about 15 m and the head rope was set at the surface, 15m, 30 m, 45 m, 60 m, and deeper than 60 m. the trawl design and method of fishing are reported in Beamish et al. (2000) and Sweeting et al. (2003). The track lines were the same in all years (Figure 1). Fishing in the Gulf Islands (Figure 1) was not part of the standard survey, but extra trawl sets were conducted in late June and early July in 2008 and 2009. Each survey in the Strait of Georgia took about 8 to 10 days with an average of about 90 30-min sets. Virtually all juvenile sockeye salmon were captured in the top 30 m and only catches in this depth are reported in this paper. Catches are the number of fish in 30 min of fishing. The average catch is the number of individuals caught at a specific depth stratum, divided by the total amount of fishing time and expressed as the average
Most juvenile sockeye salmon were measured for fork length (to the nearest mm) and weights (to the nearest g) were taken when sea conditions permitted. Condition was calculated as weight (g) divided by the cube of length (mm), all times 100,000. The population composition of selected juvenile sockeye salmon catches was determined using microsatellite DNA according to the methods of Beacham et al. (2005).

Results
Preikshot et al. (2012) showed that the average freshwater migration of most juvenile sockeye salmon smolts from the Fraser River extended from about early April to the end of May with the average maximum number passing a counting area (Mission) on May 4 and leaving the river on May 5 (Figure 2). The end of the migration out of the river varied from May 14 to May 28, for six study years with a mean exit date of May 19.

Catches of juvenile sockeye salmon in the trawl survey were used by Preikshot et al. (2012) to estimate that, on average, the juvenile sockeye salmon from the Fraser River left the Strait of Georgia by July 12. Catches up to and including July 12 for 8 years of surveys from 1998 to 2009 (Figure 3) showed that juvenile sockeye salmon were distributed throughout the Strait of Georgia in late June and early July. In 2008 and 2009, trawl sets conducted within the Gulf Islands (Figure 1) showed that juvenile sockeye salmon were commonly found among the islands (Table 1). In late June 2008, the CPUE in the Gulf Islands area was greater than in the Strait of Georgia.

The average length of sockeye salmon in these surveys ranged from 86 mm in 1998 to 133 mm in 2001 (Figure 4). The population composition as indicated by DNA showed that the populations within the Gulf Islands were similar to the populations within the Strait of Georgia (Figure 5). Furthermore, the expected composition of the populations as determined from the forecast assessments was also similar to the observed composition in the Strait of Georgia and in the Gulf Islands in 2008 and 2009 (Figure 6). In 2008 and 2009, the Lower Adams River and Chilko River populations respectively were dominant in the DNA sample as was expected from the forecasts.
In the September trawl surveys from 1998 to 2009, the catches of juvenile sockeye salmon exceeded the catches in July in some years (Figure 7). Catches occurred throughout the Strait of Georgia but were concentrated in the south (Figure 8) including the Gulf Islands. The population composition of these fish was virtually all from the Harrison River (Figure 9). These Harrison River sockeye salmon were the dominant sockeye salmon in Howe Sound in July (Figure 10) after mid July and dominated the catches in the Gulf Islands through to November (Figure 11). The Harrison River sockeye salmon were much smaller than the other populations in July (Figure 12). The average length of these juvenile sockeye salmon in September varies (Figure 13), but in general, was larger than the average length of the juvenile sockeye salmon in the Strait of Georgia in July (Figure 4).

Thomson et al. (2012) compared average catches of juvenile sockeye salmon from the Fraser River in the Strait of Georgia, Queen Charlotte Sound and Hecate Strait (Table 2). Comparisons were for surveys in late June and early July. In 2007 and 2008, catches in Queen Charlotte Sound were larger than in the Strait of Georgia, but in 2009, the catches were larger in the Strait of Georgia. Catches in Hecate Strait were surprisingly constant and higher than the Strait of Georgia in 2007, but lower in 2008 and 2009.

The total return of the Harrison River population varied over the period from 1952 to the present, with the highest returns in recent years, including the record high return of approximately 1.4 million fish in 2010 (Figure 14).

**Discussion**

Juvenile sockeye salmon in their first ocean year are in the Strait of Georgia from about late April through to some time after November. The lake-type juveniles that spend at least one year in fresh water are virtually gone by mid July. These life history types are replaced by sea-type sockeye salmon from the Harrison River that go to sea quickly without spending a least one winter in fresh water after hatching. In July these sea-type fish are readily distinguished by their small size. Birtwell et al. (1987) reported that these juveniles from the Harrison River were most abundant in the lower Fraser in late June to early July with smaller numbers remaining in the river through to October. Our catches indicate that the sea-type sockeye salmon move from the
river into Howe Sound and can be abundant there in June and July. After mid July the juvenile sea-type sockeye salmon begin to be very abundant in the Strait of Georgia. They are in the Strait of Georgia through to November when they most likely move offshore as they are rarely found in the Strait of Georgia in the winter (R. Beamish, personal communication). Thus, there are juvenile sockeye salmon from the Fraser River in the Strait of Georgia from about late April to at least mid November, a period of 7 months. Preikshot et al. (2012) estimated that the average residence time of the lake-type sockeye salmon in the Strait of Georgia was about 43 to 54 days. The average residence time of the sea-type, juvenile Harrison River sockeye salmon was not estimated but it appears to be from about mid July to mid October or even mid November, which is about 90 to 120 days.

Initially, the lake-type juveniles occupy the Strait of Georgia and this life history type on average over the past 59 years represented about 99% of all Fraser River sockeye salmon. Thomson et al. (2012) showed that at the end of June, juvenile sockeye salmon from the Fraser River were distributed as far north as Queen Charlotte Sound and Hecate Strait (Table 2), a linear distance of about 1,000 km. Thus, at the end of June, juvenile lake-type sockeye salmon, including major populations, such as Chilko Lake and Lower Adams River, are distributed over a vast area of coastal British Columbia.

Thomson et al. (2012) showed that the larger fish were farther north which would be expected if they were feeding for a longer period than fish farther south. There is some evidence that some of these large fish are also older sockeye salmon smolts that spend more than one year in a lake may move faster out of the Strait of Georgia. (C. Neville, personal communication; Preikshot et al. 2012). However, these larger, and presumably of a freshwater age of two years, were only 2.3% of a sample of 282 juveniles sampled from purse seines in late May 2011 (Preikshot et al. 2012) and 2.9% of the 681 juveniles sampled from purse seines in late May 2012 (C. Neville, personal communication).

We propose that sockeye salmon smolts from the Fraser River both migrate and disperse as part of a strategy to place juveniles in a wide variety of habitats in the early marine period. Ultimately, these juveniles find their way to a winter feeding area, probably in the Gulf of Alaska, but in the critical marine period they are spatially widely dispersed from the Gulf Islands.
to Hecate Strait and probably even farther north. In addition, the aggregate of populations contains a late ocean entry, sea-type juvenile that utilizes the same Strait of Georgia habitat but at a later time in the year when most of the earlier competitors have left or died.

It is worth remembering that sockeye salmon probably spawn in fresh water because it is a safe refuge in which fry can survive without the protection of parents. The large number of populations with different genetic traits that have developed within the Fraser River drainage since the last glaciers retreated roughly 14,000 years ago are, in part, an adaptation to survive in the ocean – a far more hostile environment than fresh water. Our study shows that the aggregate of all sockeye salmon populations disperse their young over a vast area of the ocean in the critical early marine period as well as using the Strait of Georgia over an extended period. This strategy would minimize the effect of regional variations in prey production and ocean conditions on the survival of the aggregate of all populations. Even in exceptional situations as occurred in the spring of 2007 when most of the earlier or lake-type juveniles did not survive (Beamish et al. 2012, Thomson et al. 2012), the late ocean entry, sea-type smolts from the Harrison River population experienced much better survival than the earlier ocean entrants. The message in this paper is that it is important to understand how the aggregate of sockeye salmon smolts use the ocean in the early marine period, particularly because the evolved strategy is an adaptation for survival over hundreds to thousands of years of changing climate and ocean conditions.

Acknowledgements
Lana Fitzpatrick assisted with the preparation of this manuscript.
References


Table 1. Juvenile sockeye salmon catches in the trawl surveys in the Gulf Islands in June and July 2008 and 2009. Catches in the Strait of Georgia are included for comparison.

<table>
<thead>
<tr>
<th>Year</th>
<th>Date</th>
<th>June 24-26, 2008</th>
<th>June 27-July 6, 2008</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Location</td>
<td>Catch</td>
<td>CPUE</td>
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<tr>
<td>2008</td>
<td>Gulf Islands</td>
<td>672</td>
<td>59.3</td>
</tr>
<tr>
<td></td>
<td>Strait of Georgia</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean fork length (mm)</td>
<td>111</td>
<td>106</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(7.3)</td>
<td>(11.0)</td>
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<tr>
<td></td>
<td>Number measured for length</td>
<td>401</td>
<td>1,239</td>
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</table>

<table>
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<th>2009</th>
<th>Date</th>
<th>June 24-26, 2009</th>
<th>June 26-July 7, 2009</th>
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<tr>
<td></td>
<td>Location</td>
<td>Catch</td>
<td>CPUE</td>
</tr>
<tr>
<td></td>
<td>Gulf Islands</td>
<td>131</td>
<td>15.7</td>
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<tr>
<td></td>
<td>Strait of Georgia</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Mean fork length (mm)</td>
<td>108</td>
<td>116</td>
</tr>
<tr>
<td></td>
<td>(SD)</td>
<td>(9.2)</td>
<td>(10.3)</td>
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<tr>
<td></td>
<td>Number measured for length</td>
<td>131</td>
<td>1,183</td>
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</tbody>
</table>

Table 2. Average catch of juvenile sockeye salmon from the Fraser River in the top 15 m (numbers / 30-min set). From Thomson et al. (2012).

<table>
<thead>
<tr>
<th>Year</th>
<th>Strait of Georgia</th>
<th>Queen Charlotte Sound</th>
<th>Hecate Strait</th>
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<tbody>
<tr>
<td>2007</td>
<td>1.9</td>
<td>20.2</td>
<td>14.0</td>
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<tr>
<td>2008</td>
<td>34.0</td>
<td>97.2</td>
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<tr>
<td>2009</td>
<td>33.9</td>
<td>22.1</td>
<td>13.4</td>
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</table>
Figure 1. Standard track lines (red) for trawl surveys in the Strait of Georgia. Sets were evenly spaced along the track lines. The standard survey did not include the Gulf Islands.
Figure 2. Average numbers of juvenile sockeye salmon smolts counted at the Mission site (Data from Fisheries & Oceans Canada and the Pacific Salmon Commission; analysis (7-day running average) and figure provided by Daniel Selbie and David Peterson). Mission is 60 km from the mouth of the Fraser River. It takes about one day for the smolts that pass Mission to enter the ocean (Preikshot et al. 2012).
Figure 3. Sockeye salmon catches (in 30 min) in the July trawl surveys for A) 2009, B) 2008, C) 2007, D) 2004, E) 2002, F) 2001, G) 1999 and H) 1998. The survey area is shown in light blue. Zero catches are not shown to facilitate comparison among years. The survey was identical to the track lines in Figure 1 in all years, with sets made in the same approximate location. The number of sets with 0 catch is identified.
(Continued). Sockeye salmon catches (in 30 min) in the July trawl surveys for A) 2009, B) 2008, C) 2007, D) 2004, E) 2002, F) 2001, G) 1999 and H) 1998. The survey area is shown in light blue. Zero catches are not shown to facilitate comparison among years. The survey was identical to the track lines in Figure 1 in all years, with sets made in the same approximate location. The number of sets with 0 catch is identified.
Figure 4. Lengths (mm) of juvenile sockeye salmon captured up to and including July 12 in surveys in the Strait of Georgia, 1998-2009. The average length for each survey is shown.
Figure 5. DNA composition of sockeye salmon captured in A) the Strait of Georgia trawl survey from June 27-July 16, 2008, B) the Gulf Islands purse seine survey from June 20-27, 2008, C) the Strait of Georgia trawl survey from June 26-July 7, 2009, and D) the Gulf Islands purse seine survey from June 1-5, 2009.
Figure 6. DNA composition of juvenile sockeye salmon captured in A) the Strait of Georgia July 2008 survey, B) the Gulf Islands survey from June 20-27, 2008, C) the expected proportions of the aggregate of specific run timings based on the stock assessment forecast for returns in 2010, showing that the samples in the survey are representative of the expected population composition, D) the Strait of Georgia July 2009 survey, E) the Gulf Islands survey from June 1-6, 2009, F) the expected proportions of the aggregate of specific run timings based on the 2011 stock assessment forecast showing that the samples in the survey are representative of the expected population composition. The populations are shown as aggregates of populations that are used in the management of sockeye salmon.
Figure 7. A) Average catch of sockeye salmon in the trawl survey in July in the Strait of Georgia, 1998-2010. Some of the variation in CPUE relates to cyclic dominance of the various populations. There was no survey in 2003. B) Average catch of sockeye salmon in the trawl survey in September in the Strait of Georgia, 1998-2009. The number of sets is shown for each year.
Figure 8. Sockeye salmon catches (in 30 minutes) in September trawl surveys for A) 2009, B) 2008, C) 2007, D) 2006. The survey area is shown in light blue. Zero catches are not shown to facilitate the comparison among years. The survey was identical in to the track lines in Figure 1 in all years, with sets made in the same approximate location. The number of sets with 0 catch is identified.
Figure 8 (Continued). Sockeye salmon catches (in 30 minutes) in September trawl surveys for E) 2005, F) 2004, G) 2003 and H) 2002. The survey area is shown in light blue. Zero catches are not shown to facilitate the comparison among years. The survey was identical to the track lines in Figure 1 in all years, with sets made in the same approximate location. The number of sets with 0 catch is identified.
Figure 8 (Continued). Sockeye salmon catches (in 30 minutes) in September trawl surveys for I) 2001, J) 2000, K) 1999 and L) 1998. The survey area is shown in light blue. Zero catches are not shown to facilitate the comparison among years. The survey was identical to the track lines in Figure 1, with sets made in the same approximate location. The number of sets with 0 catch is identified.
Figure 9. Population composition of juvenile sockeye salmon captured in the Strait of Georgia trawl survey as indicated by the DNA analysis in A) September 13-24, 2008, B) November 17-21, 2008 and C) September 16-25, 2009.

Figure 10. DNA composition of juvenile sockeye salmon captured in Howe Sound in A) July 21, 2008 and B) July 5, 2009, showing the dominance of Harrison River sockeye salmon in this area.
Figure 11. Population composition from the results of the DNA analysis of juvenile sockeye salmon captured in the Gulf Islands from November 17-19, 2008.

Figure 12. Lengths of juvenile sockeye salmon from the July survey in 2008. (A) Strait of Georgia (solid red diamonds) and Howe Sound (open diamonds).
Figure 13. Lengths (mm) of juvenile sockeye salmon captured in the September trawl surveys in the Strait of Georgia, 1998-2009. The average length for each survey is shown.
Figure 14. The total run of Harrison River sockeye salmon from 1952 to 2010.