Assessing growth of juvenile salmon in the Strait of Georgia

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Abstract

In the summer of 2013 plasma samples were obtained from juvenile salmon captured during the annual DFO survey of the Strait of Georgia (SOG). These samples were used to assess levels of the hormone insulin-like growth factor 1 (IGF1), an index of growth rate for juvenile fish, including salmon. A grand total of 1171 plasma samples were collected in 2013. Patterns of IGF1 variation differed across regions, between species and between 2012 and 2013. No pink salmon were sampled in the SOG in 2013; as expected, and relatively few sockeye salmon were sampled. In contrast, robust numbers of coho, Chinook and chum salmon were collected. For Chinook salmon, highest IGF1 levels were found in the northern regions of the SOG, lowest levels were found in Puget Sound and Queen Charlotte Strait. Coho salmon IGF1 levels were relatively similar across sampling regions with the exceptions of lower levels found in Malaspina and Johnstone Straits. Chum salmon IGF1 levels were highest in Malaspina Strait and the lowest levels were found in Johnstone Strait and northern Puget Sound. Coho and Chinook salmon IGF1 levels found in the main basin of the SOG were significantly lower in 2013 than found in 2012. Chum salmon IGF1 levels in the main basin of the SOG were similar in 2012 and 2013.

Introduction

In the summer of 2013 plasma samples were obtained from juvenile salmon captured during the annual DFO survey of the Strait of Georgia (Beamish et al. 2008, 2010). In addition, samples were obtained from Johnstone Strait, Queen Charlotte Strait and Queen Charlotte Sound to the west and north of the SOG and from Puget Sound to the south in Washington. These samples were used to assess levels of the hormone insulin-like growth factor 1, an index of growth rate for juvenile fish, including salmon (Beckman 2011).

Early marine growth has been shown to relate to survival in a number of studies of juvenile salmon (sockeye salmon (*Oncorhynchus nerka*), Farley et al. 2011, chum salmon (*O. keta*), Healey 1982, Chinook salmon *O. tshawytscha*, Tomaro et al. 2012, and coho salmon (*O. kisutch*), Holtby et al. 1990). Samples collected in 2013 will provide species specific assessments of early ocean growth in the Strait of Georgia for juvenile Chinook, sockeye and coho salmon from the Fraser River and other rivers tributary to the Strait of Georgia. Comparison of these data to samples obtained from 2012 will provide information on differences in ocean rearing habitats between the years. Together these data will result in development of improved information for resource management, including better stock assessment, data acquisition and improved scientific understanding of factors limiting salmon production in marine environments.

This work represents a collaborative effort between DFO and NOAA Fisheries to better understand how the marine environment regulates salmon productivity and to develop an index of marine salmon survival for salmon stocks that rear in the Strait of Georgia and the greater Salish Sea.

Methods

<u>Survey</u>: Figure 1 shows the regional areas and specific trawl sites in which juvenile salmon were collected and plasma samples were obtained: Strait of Georgia (SOG), Queen Charlotte Strait/JohnstoneStrait (QCS/JS) and Puget Sound (PS). DFO survey techniques for the capture of salmon in the Strait of Georgia have been described in Beamish et al. (2008). Briefly, juvenile salmon were obtained from surface trawls conducted throughout the Strait of Georgia. Salmon were removed from the trawl, placed on crushed ice and bled within 45 minutes of the trawl coming on board using a heparinized syringe.

<u>Blood processing and hormone analysis</u>: Blood samples were kept on ice (up to 4 hours) prior to centrifugation. Plasma was removed from the centrifuged samples and frozen on board the ship, then transferred to Seattle (on dry ice) where they were placed in a –80^{o}C freezer until the samples are assayed by TRF-immune assay according to a modification of the methods of Small and Peterson (2005).

Results

A grand total of 1171 plasma samples were obtained from juvenile salmon in the summer of 2013 for analysis of the hormone IGF1. Samples were obtained from Queen Charlotte/Johnstone Strait (QCS/JS), the Strait of Georgia (SOG) and Puget Sound (PS). Samples were relatively evenly distributed between coho, Chinook, and chum salmon. No pink salmon were captured in the SOG and relatively few sockeye salmon were sampled. Most samples (758, 65%) were obtained from SOG, the focus of the PSC funded study (Tables 1 and 2).

Chinook salmon IGF1 values varied roughly between 50 and 75 ng/ml across the SOG, levels found in the Gulf Islands and Malaspina Strait were significantly less than found in other regions of the SOG. IGF1 levels in the Puget Sound and Johnstone Strait were the lowest found in the survey. IGF1 levels measured in Desolation Sound were the highest for Chinook salmon in 2013 (Table 3, Figure 2, 3 and 11). In general, IGF1 levels measured for Chinook salmon in 2013 were lower than measured in 2012 (Table 3, 4 and Figure 3). IGF1 levels measured in northern SOG, SOG, Malaspina Strait, the Fraser River Plume and the Gulf Islands were all lower in 2013 than 2012, suggesting a broad-scale difference in growth between the two years.

Coho salmon IGF1 values were broadly rather even across the SOG in 2013, averaging between 60 and 70 ng/ml. Lower levels were found in Malaspina Strait, within the SOG, and Johnstone Strait, connecting the SOG to Queen Charlotte Strait and the Pacific Ocean (Table 3, Figure 4, 5 and 11). Similarly to what was found with Chinook salmon, coho salmon IGF1 levels in 2013 were lower than found in 2012. Specifically, lower IGF1 levels were found in the Discovery Islands, Desolation Strait, the northern SOG, SOG, and Malaspina Strait in 2013 as compared to 2012 (Table 4 and Figure 5). In both years, the lowest IGF1 levels measured were found in Johnstone Strait.

Chum salmon IGF1 values varied little across the SOG in 2013, with only samples from Malaspina Strait significantly higher than found in other regions. Chum salmon IGF1 levels from fish sampled in the northern Puget Sound were the lowest measured in 2013; yet, only 8 fish were sampled (Table 3, Figure 6, 7, and 11). IGF1 levels of chum salmon in the SOG were broadly similar 2012 and 2013 (Table 4, Figure 7). IGF1 levels from 2013 were higher than measured in 2012 in Johnstone and Queen Charlotte Staits; however, IGF1 levels measured in Johnstone Strait were among the lowest measured in both years.

No pink salmon were sampled in the SOG in 2013. A few fish were sampled in Johnstone Strait, Queen Charlotte Strait and Queen Charlotte Sound and IGF1 levels in Johnstone Strait and Queen Charlotte Strait were low in both 2012 and 2013 (Table 3, Figure 8).

Sockeye salmon IGF1 values varied little over the SOG in 2013 (Table 1, 2 and 3; Figure 9, 11). Average IGF1 levels in 2013 were higher than found in 2012; yet, few fish were sampled and the difference between the years was solely generated by a significant increase in IGF1 levels in the northern SOG in 2013 (Figure 10).

Regional patterns in IGF1 level for Chinook, coho and chum salmon were broadly similar in 2012 and 2013 (Figure 11). Higher IGF1 levels were variously found among the Discovery Islands, Desolation Sound and the northern SOG in both years. Relatively lower IGF1 levels were found in the Puget Sound, Johnstone Strait and Queen Charlotte Strait in both years.

Spatial similarity in IGF1 variation was examined by assessing the correlations of IGF1 levels among different species when fish were collected in the same tow (Table 5). Similarly to 2012, little relation was found among coho, Chinook and chum salmon IGF1 levels, indicating substantial heterogeneity in relative growth rates at the level of a tow.

To date, juvenile coho salmon IGF1 has been measured in the Strait of Georgia in six different years: 1998 - 2001, 2012 and 2013. IGF1 levels measured in 2013 were similar to those measured in 1999; between the low levels found in 1998, 2000 and 2001 and the relatively high levels found in 2012. Some caution must be taken in interpreting these results. Samples from 1998 – 2001 were obtained from central and southern regions of the SOG and perhaps are not completely comparable to the full surveys generated in 2012 and 2013. The value of summer IGF1 levels for predicting summer growth, fall abundance and overall marine survival awaits the return of adult coho salmon from the 2012 and 2013 ocean entry years and the analysis of this data.

Discussion

This second survey of summer growth rates of juvenile salmon in the Strait of Georgia re-enforces some of the findings from 2012 and offers some new insights. It is evident that spatial variation in juvenile salmon growth rate during the summer exists, with some patterns consistent across years and species. Growth rates of different species of juvenile salmon are not necessarily spatially or temporally consistent. Finally, inter-annual variation in juvenile salmon growth rate occurs. In this report we will give limited consideration to Pink salmon, that were essentially absent in the SOG in the summer of 2013 or Sockeye salmon, that were in limited abundance during the survey (late June and July).

Care must be taken when assessing the results presented. Different statistical analyses have been used in different figures and tables and these analyses may not be directly comparable. The data is still being assessed and the “best” statistical approach has not yet been determined. Analysis of Variance (ANOVA) has been used to test spatial differences between regions within a year and temporal differences within a region between years (Figures 2 – 10). These might be considered the most robust statistical differentiation of differences between regions, yet these comparisons do not generate a simple characterization of regional spatial differentiation. In Figure 11 and Table 3 we generated an overall mean across all regions for each species in a given year and then determined whether the IGF1 level for a given region differed by more than 0.5 sd from that overall mean. This might be considered an assessment of the relative regional differences in IGF1 for a given year for a given species. This assessment is sensitive to relative variation between regions and is influenced by the number of regions samples were obtained in. Nonetheless, there is moderate agreement between the two approaches and both yield some interesting insights.

In 2013 there was little difference in growth rates of coho, Chinook or chum salmon within the “main basin” of the SOG (NSOG, SOG, SSOG), suggesting that there is a common yearly signal across this region for these species. Within “fringe regions” of the Strait of Georgia there was some differentiation, with higher IGF1 levels for coho and Chinook salmon found in the Discovery Islands, Desolation Sound and the Fraser River Plume; lower IGF1 levels were found for chum salmon in the Fraser River Plume and for coho salmon in Malaspina Strait. The biological significance of these findings are not readily apparent but the patterns demonstrates both spatial variability in growth rate between regions and a dichotomy in the response of different juvenile salmon species to regional variation in oceanography.

Comparison of IGF1 levels from juvenile salmon collected outside the Strait of Georgia demonstrate some consistent patterns across years and speices. IGF1 levels in Johnstone Strait were consistently low, across both species and years. These findings are consistent with the suggestions of McKinnell et al. (in press) that biological productivity in the Johnstone Strait region is low due to the high degree of tidal mixing through Seymour Narrows. IGF1 levels of Chinook salmon collected in the Puget Sound were also relatively low in both years. To date, analysis of the Chinook salmon IGF1 data has lumped all data together (juvenile Chinook salmon in their 1st summer of ocean residence). This approach ignores life history differences within and between populations (sub-yearling or yearling ocean entry) and may obscure differences between populations. Specific analysis by genetic stock and region may reveal different patterns among juvenile Chinook salmon growth rates.

There were clear differences in IGF1 levels of coho and Chinook salmon sampled in 2012 and 2013, with higher levels found in 2012. The differences in IGF1 level between 2013 and 2012 was apparent in multiple samples from a broad stretch of regions across the central and northern SOG for both species and extended into the Fraser River Plume and Gulf Islands for Chinook salmon. These data are consistent with a potentially reduced food consumption rate in 2013 for both species as compared to 2012. However, IGF1 levels measured in both 2012 and 2013 are greater than found in 1998, 2000 and 2001; suggesting overall feeding rates in 2012 and 2013 were higher than found a decade earlier.

Chum salmon IGF1 levels were generally similar in 2012 and 2013, in contrast to the patterns found for coho and Chinook salmon. It has been well established that the feeding habits of juvenile chum salmon differ from those of juvenile coho and Chinook salmon, with chum salmon selecting copepods and gelatinous zooplankton with coho and Chinook salmon selecting larger crustacean zooplankton and larval and juvenile fish (Brodeur et al. 2007). Thus, the differences found between species between regional patterns of IGF1 level may reflect differing patterns of production and abundance for different species of zooplankton and juvenile fish within the Strait of Georgia.

If juvenile salmon growth is related to subsequent survival, as has been found in other studies (Farley et al. 2011, Healey 1982, Holtby et al. 1990, Tomaro et al. 2012), these data suggest that relative survival coho and Chinook salmon will be greater in the Strait of Georgia in 2012 relative to 2013. However, we can't make any definitive conclusions about differences in regional survival without knowledge of the relative mixing of different stocks within the SOG and the relative abundance of coho and pink salmon juveniles in different regions.

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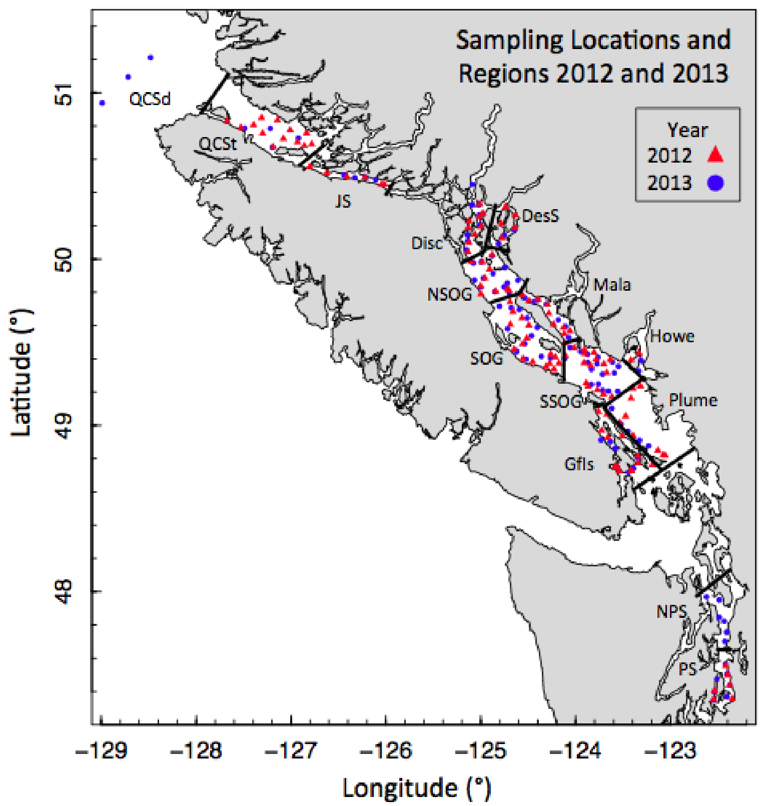

Figure 1. A map of the regions in which IGF1 values were measured from juvenile salmon in 2012 and 2013, including the Strait of Georgia (SOG), Johnstone Strait (JS), Queen Charlotte Strait (QCSt), Queen Charlotte Sound (QCSd) and Puget Sound (PS). Locations within the Strait of Georgia region were sub-divided into the following geographic regions: Discovery Islands (Disc), Desolation Sound (DesS), Northern Strait of Geogia (NSOG), Strait of Georgia (SOG), Malaspina Strait (Mala), Southern Strait of Georgia (SSOG), Gulf Islands (GfIs), Howe Sound (Howe) and Fraser River Plume (Plume). Individual tow locations where samples from juvenile salmon were obtained are marked with a red triangle (2012) or a blue circle (2013).

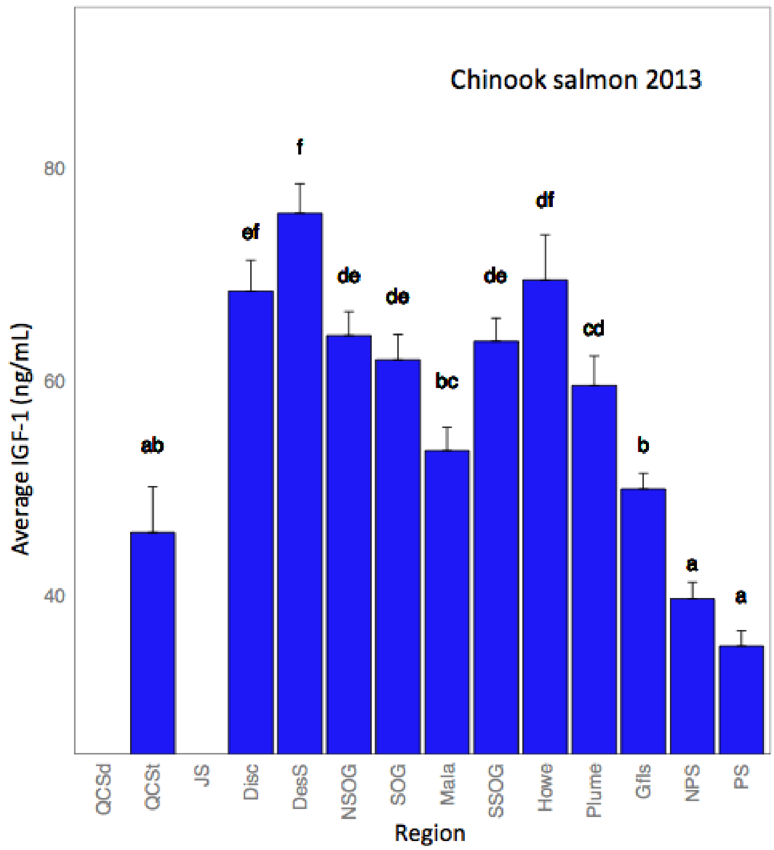

Figure 2. Mean IGF1 values (+ se) of juvenile Chinook salmon collected from the Strait of Georgia (SOG), Johnstone Strait (JS), Queen Charlotte Strait (QCSt), Queen Charlotte Sound (QCSd) and Puget Sound (PS) in 2013. Means for each region were generated by taking the mean of IGF1 levels measured from each trawl set within each region. Significant differences between regions are indicated by differing letters above the column for each region ($p < 0.05$). Locations within the Strait of Georgia region were sub-divided into the following geographic regions: Discovery Islands (Disc), Desolation Sound (DesS), Northern Strait of Geogia (NSOG), Strait of Georgia (SOG), Malaspina Strait (Mala), Southern Strait of Georgia (SSOG), Gulf Islands (GfIs), Howe Sound (Howe) and Fraser River Plume (Plume).

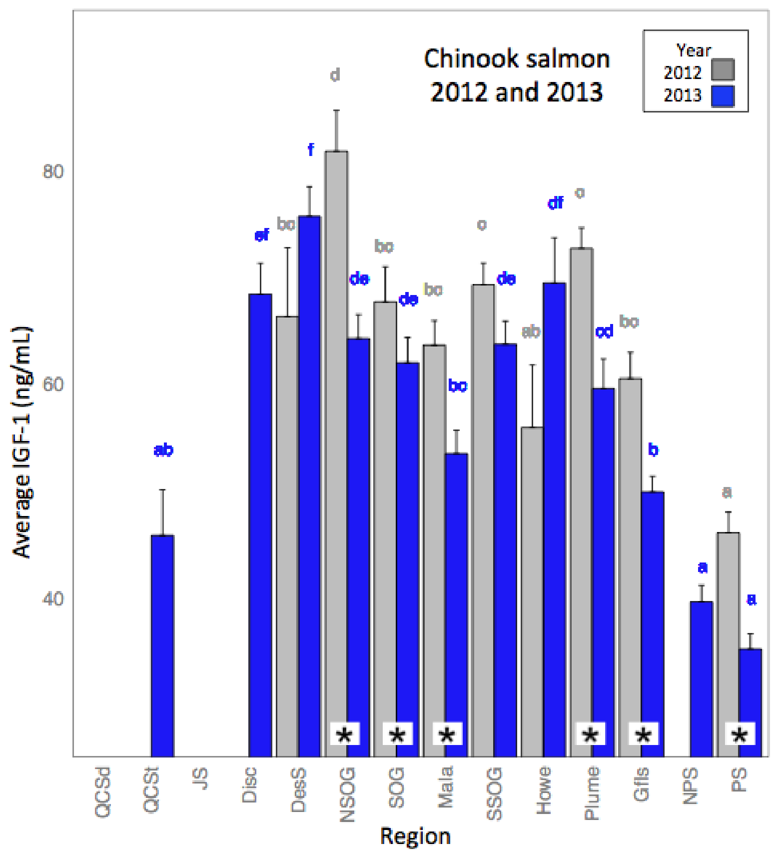

Figure 3. Mean IGF1 values (+ se) of juvenile Chinook salmon collected from the Strait of Georgia (SOG), Johnstone Strait (JS), Queen Charlotte Strait (QCSt), Queen Charlotte Sound (QCSd) and Puget Sound (PS) in 2012 (gray) and 2013 (blue). Means for each region were generated by taking the mean of IGF1 levels measured from each trawl set within each region in each year. Significant differences between regions within a year are indicated by differing letters above each column ($p < 0.05$). Significant differences within a region between years in indicated by an asterisk (*, $p < 0.05$). Locations within the Strait of Georgia region were sub-divided into the following geographic regions: Discovery Islands (Disc), Desolation Sound (DesS), Northern Strait of Geogia (NSOG), Strait of Georgia (SOG), Malaspina Strait (Mala), Southern Strait of Georgia (SSOG), Gulf Islands (GfIs), Howe Sound (Howe) and Fraser River Plume (Plume).

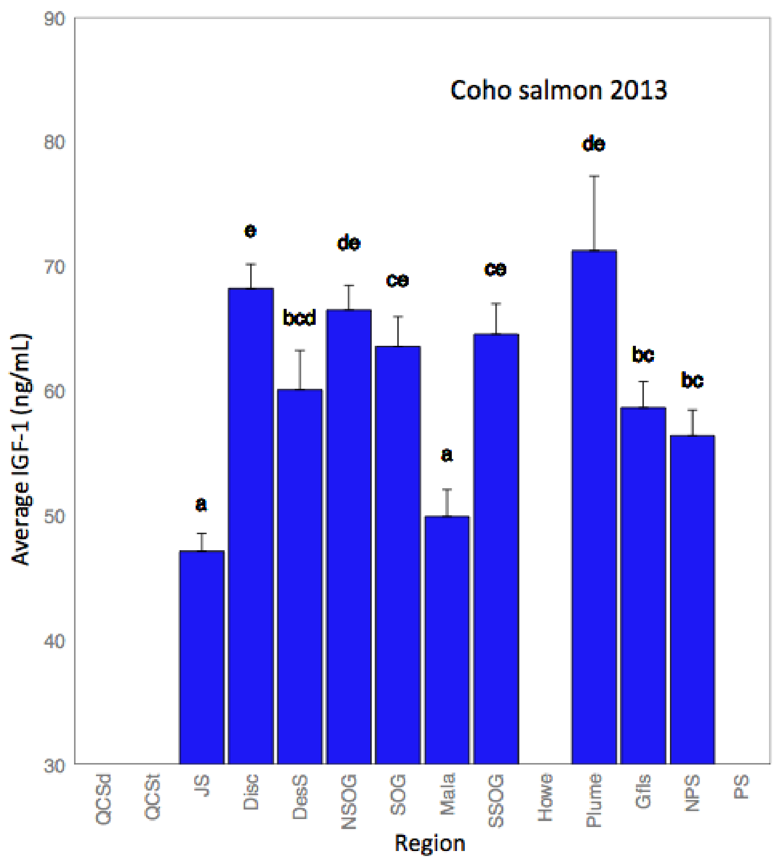

Figure 4. Mean IGF1 values (+ se) of juvenile coho salmon collected from the Strait of Georgia (SOG), Johnstone Strait (JS), Queen Charlotte Strait (QCSt), Queen Charlotte Sound (QCSd) and Puget Sound (PS) in 2013. Means for each region were generated by taking the mean of IGF1 levels measured from each trawl set within each region. Significant differences between regions are indicated by differing letters above the column for each region ($p < 0.05$). Locations within the Strait of Georgia region were sub-divided into the following geographic regions: Discovery Islands (Disc), Desolation Sound (DesS), Northern Strait of Geogia (NSOG), Strait of Georgia (SOG), Malaspina Strait (Mala), Southern Strait of Georgia (SSOG), Gulf Islands (GfIs), Howe Sound (Howe) and Fraser River Plume (Plume).

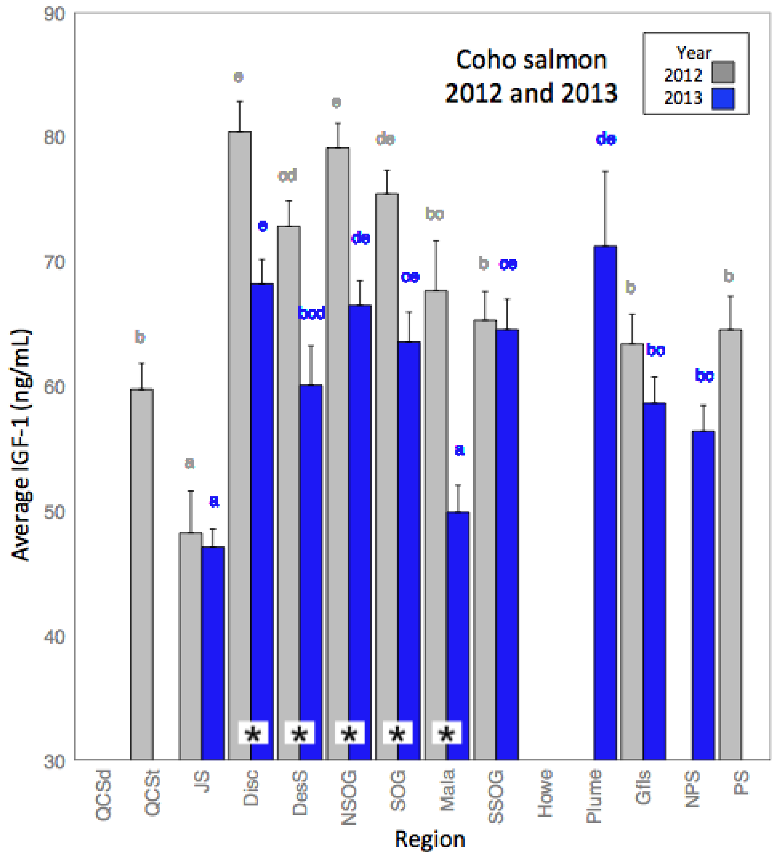

Figure 5. Mean IGF1 values (+ se) of juvenile coho salmon collected from the Strait of Georgia (SOG), Johnstone Strait (JS), Queen Charlotte Strait (QCSt), Queen Charlotte Sound (QCSd) and Puget Sound (PS) in 2012 (gray) and 2013 (blue). Means for each region were generated by taking the mean of IGF1 levels measured from each trawl set within each region in each year. Significant differences between regions within a year are indicated by differing letters above each column ($p < 0.05$). Significant differences within a region between years in indicated by an asterisk (*, $p < 0.05$). Locations within the Strait of Georgia region were sub-divided into the following geographic regions: Discovery Islands (Disc), Desolation Sound (DesS), Northern Strait of Geogia (NSOG), Strait of Georgia (SOG), Malaspina Strait (Mala), Southern Strait of Georgia (SSOG), Gulf Islands (GfIs), Howe Sound (Howe) and Fraser River Plume (Plume).

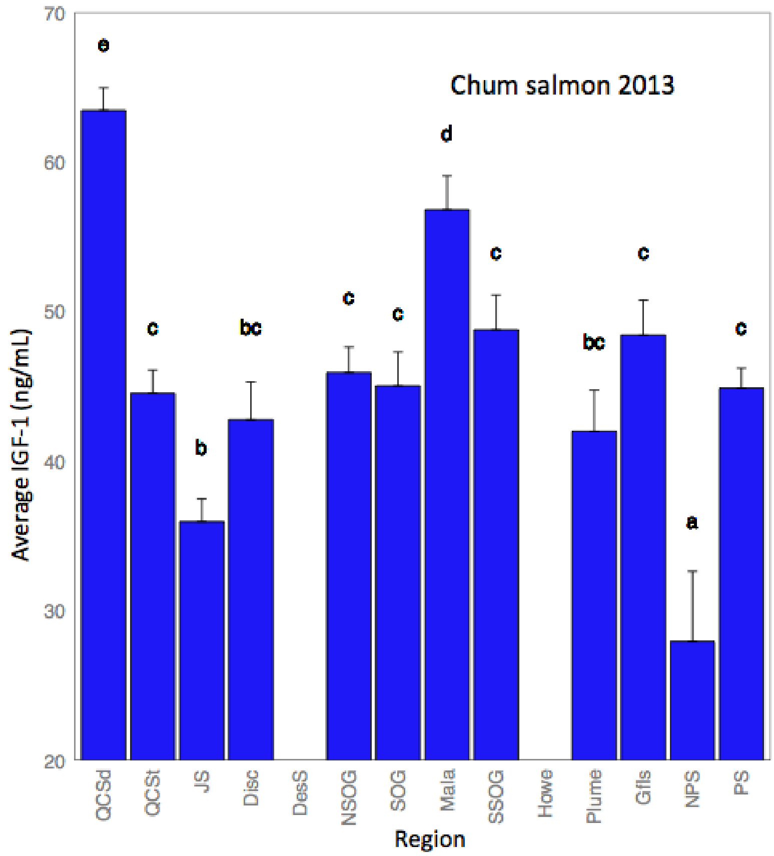

Figure 6. Mean IGF1 values (+ se) of juvenile chum salmon collected from the Strait of Georgia (SOG), Johnstone Strait (JS), Queen Charlotte Strait (QCSt), Queen Charlotte Sound (QCSd) and Puget Sound (PS) in 2013. Means for each region were generated by taking the mean of IGF1 levels measured from each trawl set within each region. Significant differences between regions are indicated by differing letters above the column for each region ($p < 0.05$). Locations within the Strait of Georgia region were sub-divided into the following geographic regions: Discovery Islands (Disc), Desolation Sound (DesS), Northern Strait of Geogia (NSOG), Strait of Georgia (SOG), Malaspina Strait (Mala), Southern Strait of Georgia (SSOG), Gulf Islands (GfIs), Howe Sound (Howe) and Fraser River Plume (Plume).

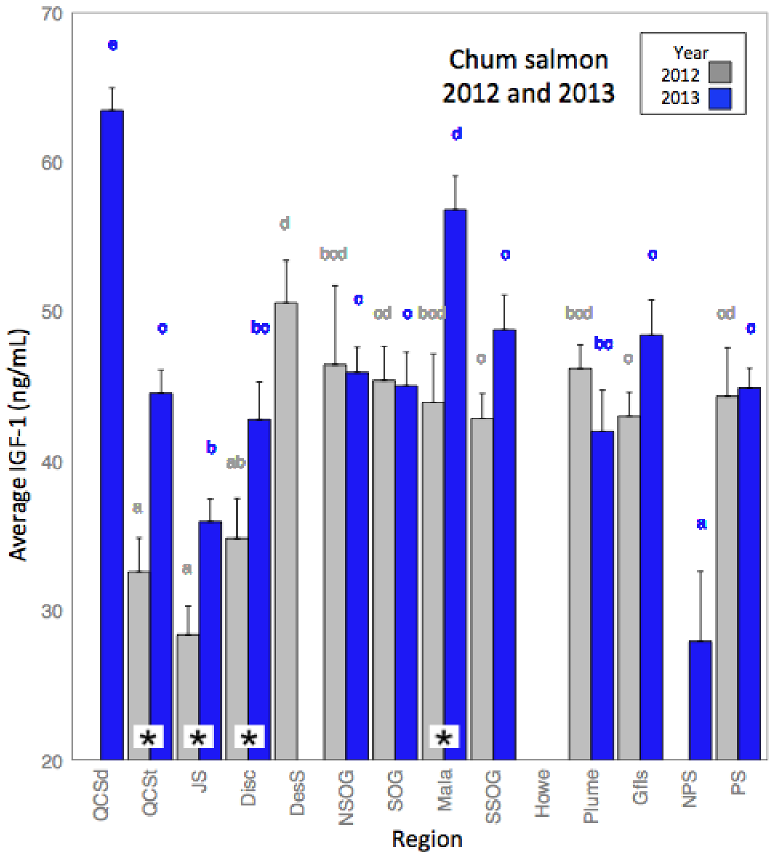

Figure 7. Mean IGF1 values (+ se) of juvenile chum salmon collected from the Strait of Georgia (SOG), Johnstone Strait (JS), Queen Charlotte Strait (QCSt), Queen Charlotte Sound (QCSd) and Puget Sound (PS) in 2012 (gray) and 2013 (blue). Means for each region were generated by taking the mean of IGF1 levels measured from each trawl set within each region in each year. Significant differences between regions within a year are indicated by differing letters above each column ($p < 0.05$). Significant differences within a region between years in indicated by an asterisk (*, $p < 0.05$). Locations within the Strait of Georgia region were sub-divided into the following geographic regions: Discovery Islands (Disc), Desolation Sound (DesS), Northern Strait of Geogia (NSOG), Strait of Georgia (SOG), Malaspina Strait (Mala), Southern Strait of Georgia (SSOG), Gulf Islands (GfIs), Howe Sound (Howe) and Fraser River Plume (Plume).

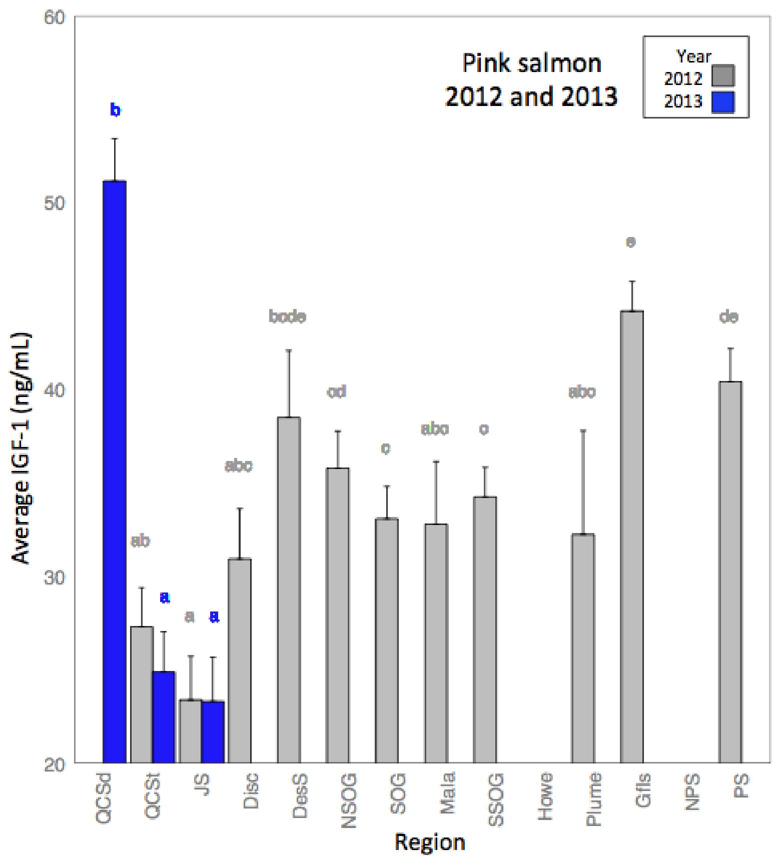

Figure 8. Mean IGF1 values (+ se) of juvenile pink salmon collected from the Strait of Georgia (SOG), Johnstone Strait (JS), Queen Charlotte Strait (QCSt), Queen Charlotte Sound (QCSd) and Puget Sound (PS) in 2012 (gray) and 2013 (blue). Note – no pink salmon were collected within the Strait of Georgia in 2013. Means for each region were generated by taking the mean of IGF1 levels measured from each trawl set within each region in each year. Significant differences between regions within a year are indicated by differing letters above each column ($p < 0.05$). Significant differences within a region between years in indicated by an asterisk (*, $p < 0.05$). Locations within the Strait of Georgia region were sub-divided into the following geographic regions: Discovery Islands (Disc), Desolation Sound (DesS), Northern Strait of Geogia (NSOG), Strait of Georgia (SOG), Malaspina Strait (Mala), Southern Strait of Georgia (SSOG), Gulf Islands (GfIs), Howe Sound (Howe) and Fraser River Plume (Plume).

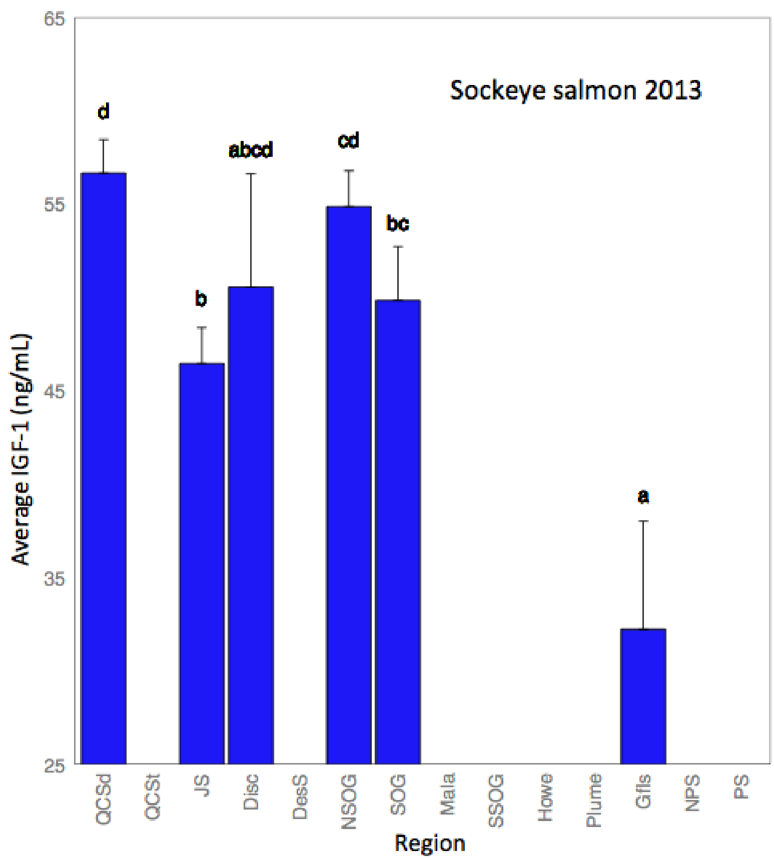

Figure 9. Mean IGF1 values (+ se) of juvenile sockeye salmon collected from the Strait of Georgia (SOG), Johnstone Strait (JS), Queen Charlotte Strait (QCSt), Queen Charlotte Sound (QCSd) and Puget Sound (PS) in 2012 (gray) and 2013 (blue). Means for each region were generated by taking the mean of IGF1 levels measured from each trawl set within each region in each year. Significant differences between regions are indicated by differing letters above the column for each region ($p < 0.05$). Significant differences within a region between years in indicated by an asterisk (*, $p < 0.05$). Locations within the Strait of Georgia region were sub-divided into the following geographic regions: Discovery Islands (Disc), Desolation Sound (DesS), Northern Strait of Geogia (NSOG), Strait of Georgia (SOG), Malaspina Strait (Mala), Southern Strait of Georgia (SSOG), Gulf Islands (GfIs), Howe Sound (Howe) and Fraser River Plume (Plume).

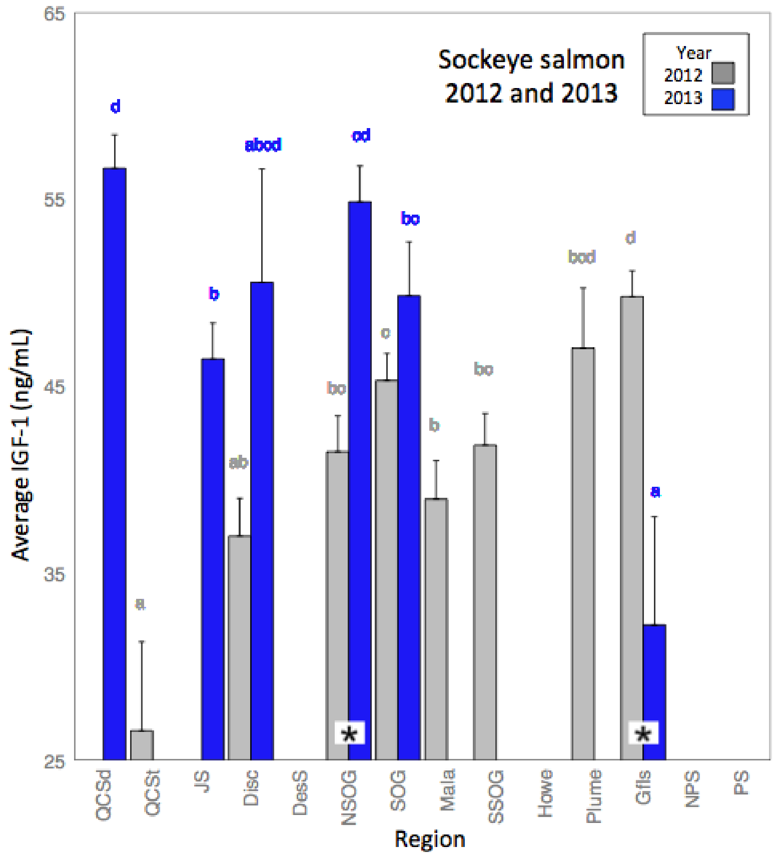

Figure 10. Mean IGF1 values (+ se) of juvenile sockeye salmon collected from the Strait of Georgia (SOG), Johnstone Strait (JS), Queen Charlotte Strait (QCSt), Queen Charlotte Sound (QCSd) and Puget Sound (PS) in 2012 (gray) and 2013 (blue). Means for each region were generated by taking the mean of IGF1 levels measured from each trawl set within each region in each year. Significant differences between regions within a year are indicated by differing letters above each column ($p < 0.05$). Significant differences within a region between years in indicated by an asterisk (*, $p < 0.05$). Locations within the Strait of Georgia region were sub-divided into the following geographic regions: Discovery Islands (Disc), Desolation Sound (DesS), Northern Strait of Geogia (NSOG), Strait of Georgia (SOG), Malaspina Strait (Mala), Southern Strait of Georgia (SSOG), Gulf Islands (GfIs), Howe Sound (Howe) and Fraser River Plume (Plume).

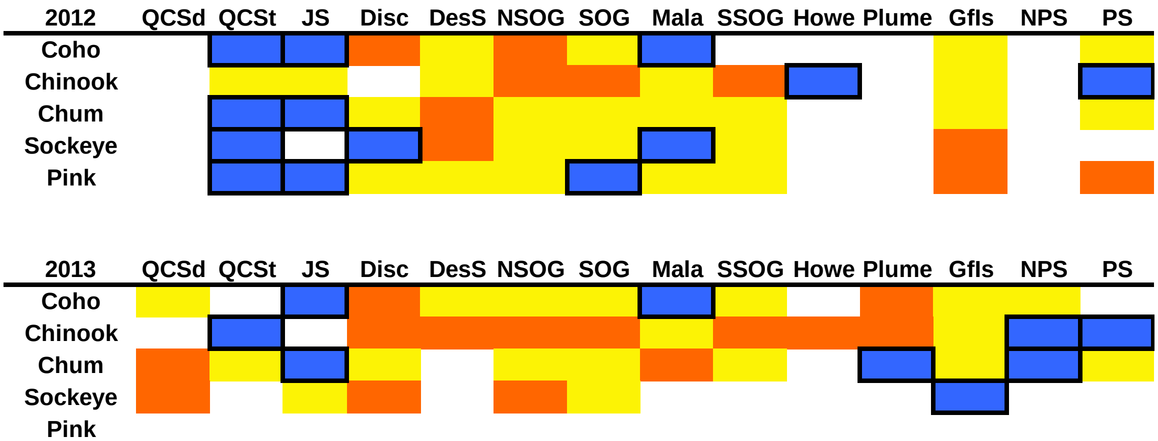

Figure 11. A stoplight chart depicting spatial differences in growth of juvenile salmon (as assessed by plasma IGF1 levels) among regions. Region means more than 0.5 sd higher than the grand mean (all regions) are high-lighted in orange, station means more than 0.5 sd lower than the grand mean (all stations) are high-lighted in blue. Regions are arrayed from Northwest (Queen Charlotte Strait) to Southeast (Puget Sound) across the Strait of Georgia. Areas of no color indicate insufficient data.

Table 1. Date and location of trawls conducted to collect juvenile salmon in 2013. Number of plasma samples obtained from each species at each site is indicated.

							# of samples				
Month	Day	Year	Region	Set #	Lat	Long	Chinook	coho	chum	pink	sockeye
6	26	2013	Plume	1	48.877	-123.232	4	3			
6	26	2013	Plume	2	48.910	-123.327	2	1	7		
6	26	2013	Plume	3	48.964	-123.449	8				
6	26	2013	Plume	4	49.007	-123.521	6	1	1		
6	26	2013	Plume	6	49.102	-123.619	4	6			
6	27	2013	HoweSnd	11	49.326	-123.334	4				
6	27	2013	HoweSnd	12	49.389	-123.311	4				
6	27	2013	SSOG	15	49.204	-123.558	1				
6	27	2013	SSOG	16	49.205	-123.655	9	2			
6	27	2013	SSOG	17	49.210	-123.716		6	3		
6	27	2013	SSOG	18	49.245	-123.835		9			
6	28	2013	SSOG	19	49.248	-123.760	5	3			
6	28	2013	SSOG	20	49.307	-123.716	2				
6	28	2013	SSOG	22	49.315	-123.592	1	1			
6	28	2013	SSOG	23	49.354	-123.549	2				
6	28	2013	SSOG	24	49.380	-123.613	2				
6	29	2013	Malaspina	25	49.528	-124.076	5	4			
6	29	2013	Malaspina	26	49.594	-124.105	7	5			
6	29	2013	Malaspina	27	49.634	-124.184	4	5	4		
6	29	2013	Malaspina	29	49.728	-124.309	5	3			
6	29	2013	Malaspina	30	49.753	-124.405		6	7		
6	29	2013	Malaspina	31	49.742	-124.447	6	2			
6	29	2013	Malaspina	32	49.768	-124.540			8		
6	29	2013	Malaspina	34	49.872	-124.610	4				
6	30	2013	SOG	35	49.449	-124.626	4	5	2		4
6	30	2013	SOG	36	49.491	-124.536	5	4			
6	30	2013	SOG	37	49.539	-124.466	6	7			
6	30	2013	SOG	38	49.589	-124.405		3	5		2
6	30	2013	SOG	39	49.645	-124.510		3			
6	30	2013	SOG	40	49.696	-124.595	5		8		
6	30	2013	SOG	41	49.707	-124.679	6				
6	30	2013	SOG	43	49.580	-124.718		5	5		5
7	1	2013	NSOG	45	49.833	-124.756	4	3	6		7
7	1	2013	NSOG	46	49.804	-124.853	2	7	4		
7	1	2013	NSOG	48	49.831	-125.005		6	6		
7	1	2013	NSOG	49	49.873	-125.068	2	3			
7	1	2013	NSOG	50	49.885	-124.971	4	3			
7	1	2013	NSOG	51	49.913	-124.872	3	8	5		5

Table 1. continued.

							# of samples				
Month	Day	Year	Region	Set #	Lat	Long	Chinook	coho	chum	pink	sockeye
7	1	2013	NSOG	53	49.983	-124.995	9				1
7	1	2013	NSOG	54	49.976	-125.079			7		7
7	1	2013	NSOG	55	49.996	-125.105	4		7		4
7	2	2013	DiscIs	56	50.055	-125.152	8	7			4
7	2	2013	DiscIs	57	50.109	-125.137	5		1		1
7	2	2013	DiscIs	58	50.147	-125.143		5	9		
7	2	2013	DiscIs	59	50.205	-125.007	6				
7	2	2013	DiscIs	60	50.265	-125.017	4	3	8		
7	2	2013	DiscIs	61	50.324	-125.095		5	5		
7	2	2013	DiscIs	62	50.448	-125.089	2				
7	2	2013	DiscIs	63	50.325	-125.021	5	5	3		
7	3	2013	DesSnd	64	50.177	-124.650	6	5			
7	3	2013	DesSnd	65	50.143	-124.754	7				
7	3	2013	DesSnd	66	50.092	-124.813	7	6			
7	3	2013	NSOG	67	50.020	-124.881	7	3	8		
7	3	2013	NSOG	68	49.949	-124.747	5	4	2		
7	3	2013	NSOG	69	49.855	-124.721		5	7		2
7	3	2013	NSOG	70	49.793	-124.701		5			
7	3	2013	SOG	72	49.716	-124.804					1
7	4	2013	SOG	73	49.442	-124.623	5	5	8		3
7	4	2013	SOG	74	49.397	-124.522	7	5			
7	4	2013	SOG	76	49.414	-124.363		5	1		1
7	4	2013	SOG	77	49.404	-124.267	11				
7	4	2013	SSOG	80	49.401	-124.115		9	2		
7	4	2013	SSOG	81	49.467	-124.058	6				
7	5	2013	GlfIs	82	48.807	-123.350	6	5	9		1
7	5	2013	GlfIs	83	48.741	-123.392	6	5			
7	5	2013	GlfIs	84	48.717	-123.445	3	5			
7	5	2013	GlfIs	85	48.861	-123.585	9	5	6		2
7	5	2013	GlfIs	86	48.903	-123.634	4	3			
7	5	2013	GlfIs	87	48.912	-123.734			7		3
7	5	2013	GlfIs	88	48.745	-123.559	5	5	9		
7	6	2013	SSOG	89	49.443	-123.948	4	6			
7	6	2013	SSOG	90	49.427	-123.876	6				
7	6	2013	SSOG	91	49.377	-123.874	3	6	3		
7	6	2013	SSOG	92	49.370	-123.777	6				
7	6	2013	SSOG	93	49.409	-123.765	8				
7	6	2013	SSOG	94	49.337	-123.834	5	6			

Table 1 continued.

							# of samples				
Month	Day	Year	Region	Set #	Lat	Long	Chinook	coho	chum	pink	sockeye
7	9	2013	PS	109	47.564	-122.424	10		10		
7	9	2013	PS	110	47.504	-122.404	7		12		
7	9	2013	PS	111	47.438	-122.375	10		8		
7	9	2013	PS	113	47.368	-122.408	10		3		
7	9	2013	PS	114	47.347	-122.545	8		10		
7	9	2013	PS	115	47.398	-122.538	9				
7	9	2013	PS	117	47.475	-122.513			10		
7	9	2013	NPS	119	47.701	-122.428	10	5	4		
7	10	2013	NPS	120	47.756	-122.410	8	10			
7	10	2013	NPS	121	47.822	-122.435	10	9			
7	10	2013	NPS	122	47.845	-122.490	10	8			
7	10	2013	NPS	123	47.951	-122.488	10	7	4		
7	10	2013	NPS	124	47.969	-122.622	10				
7	18	2013	QCSnd	288	50.938	-128.990			15	6	5
7	18	2013	QCSnd	294	51.095	-128.717			2		
7	18	2013	QCSnd	300	51.211	-128.480		9	14		14
7	19	2013	QCST	303	50.786	-127.490	1		11		
7	19	2013	QCST	309	50.785	-127.219	1		12	9	
7	19	2013	QCST	315	50.672	-127.197	2		5		
7	19	2013	QCST	321	50.727	-126.923	1		3		
7	19	2013	JS	330	50.504	-126.442			6		2
7	20	2013	JS	333	50.489	-126.329		16	24		8
7	20	2013	JS	336	50.490	-126.215		9			
7	20	2013	JS	339	50.476	-126.108		4	13	9	
			totals				412	314	339	24	82

Table 2. Total number of IGF1 samples collected from juvenile salmon by region in the summer of 2012 and 2013.

2012

	Salmon Species					
Region	Chinook	coho	chum	pink	sockeye	Total
Strait of Georgia	243	172	137	165	215	932
Puget Sound	43	21	19	30	0	113
JS-QCSd	0	23	57	53	5	138
Totals	286	216	213	248	220	1183

2013

Region	Chinook	coho	chum	pink	sockeye	Total
Strait of Georgia	295	237	173	0	53	758
Puget Sound	112	39	61	0	0	212
JS-QCSd	5	38	105	24	29	201
Totals	412	314	339	24	82	1171

Table 3. Mean IGF1 level by station and species. Station means more than 0.5 sd higher than the grand mean (all stations) are high-lighted in orange, station means more than 0.5 sd lower than the grand mean (all stations) are high-lighted in green.

Month	Day	Year	Region	Set #	Lat	Long	Chinook	coho	chum	pink	sockeye
6	26	2013	Plume	1	48.877	-123.232	60.9	100.3			
6	26	2013	Plume	2	48.910	-123.327	77.6	60.5	44.2		
6	26	2013	Plume	3	48.964	-123.449	59.6				
6	26	2013	Plume	4	49.007	-123.521	65.4	55.1	26.6		
6	26	2013	Plume	6	49.102	-123.619	40.2	61.2			
6	27	2013	HoweSnd	11	49.326	-123.334	68.6				
6	27	2013	HoweSnd	12	49.389	-123.311	70.3				
6	27	2013	SSOG	15	49.204	-123.558	92.1				
6	27	2013	SSOG	16	49.205	-123.655	71.3	51.1			
6	27	2013	SSOG	17	49.210	-123.716		75.7	47.6		
6	27	2013	SSOG	18	49.245	-123.835		68.0			
6	28	2013	SSOG	19	49.248	-123.760	68.7	48.5			
6	28	2013	SSOG	20	49.307	-123.716	76.9				
6	28	2013	SSOG	22	49.315	-123.592	59.0	85.7			
6	28	2013	SSOG	23	49.354	-123.549	72.0				
6	28	2013	SSOG	24	49.380	-123.613	65.4				
6	29	2013	Malaspina	25	49.528	-124.076	49.1	44.7			
6	29	2013	Malaspina	26	49.594	-124.105	55.2	51.4			
6	29	2013	Malaspina	27	49.634	-124.184	47.3	43.5	52.7		
6	29	2013	Malaspina	29	49.728	-124.309	57.0	42.0			
6	29	2013	Malaspina	30	49.753	-124.405		60.6	53.9		
6	29	2013	Malaspina	31	49.742	-124.447	56.3	52.5			
6	29	2013	Malaspina	32	49.768	-124.540			61.4		
6	29	2013	Malaspina	34	49.872	-124.610	53.1				
6	30	2013	SOG	35	49.449	-124.626	62.7	62.0	36.6		48.0
6	30	2013	SOG	36	49.491	-124.536	67.3	79.6			
6	30	2013	SOG	37	49.539	-124.466	73.6	58.0			
6	30	2013	SOG	38	49.589	-124.405		55.0	40.1		47.7
6	30	2013	SOG	39	49.645	-124.510		57.9			
6	30	2013	SOG	40	49.696	-124.595	49.3		52.3		
6	30	2013	SOG	41	49.707	-124.679	64.4				
6	30	2013	SOG	43	49.580	-124.718		79.8	31.1		54.4
7	1	2013	NSOG	45	49.833	-124.756	69.7	59.6	46.2		55.9
7	1	2013	NSOG	46	49.804	-124.853	66.3	70.7	39.9		
7	1	2013	NSOG	48	49.831	-125.005		57.4	44.6		
7	1	2013	NSOG	49	49.873	-125.068	61.9	61.7			
7	1	2013	NSOG	50	49.885	-124.971	66.8	69.4			
7	1	2013	NSOG	51	49.913	-124.872	55.9	75.8	50.5		59.8
7	1	2013	NSOG	53	49.983	-124.995	71.0				62.9

Table 3. continued

Month	Day	Year	Region	Set #	Lat	Long	Chinook	coho	chum	pink	sockeye
7	1	2013	NSOG	54	49.976	-125.079			47.7		51.0
7	1	2013	NSOG	55	49.996	-125.105	78.0		50.9		50.8
7	2	2013	DiscIs	56	50.055	-125.152	77.1	69.2			48.6
7	2	2013	DiscIs	57	50.109	-125.137	63.8		48.7		58.6
7	2	2013	DiscIs	58	50.147	-125.143		73.8	46.3		
7	2	2013	DiscIs	59	50.205	-125.007	65.3				
7	2	2013	DiscIs	60	50.265	-125.017	52.3	63.1	33.5		
7	2	2013	DiscIs	61	50.324	-125.095		62.2	42.4		
7	2	2013	DiscIs	62	50.448	-125.089	62.1				
7	2	2013	DiscIs	63	50.325	-125.021	78.0	70.5	55.5		
7	3	2013	DesSnd	64	50.177	-124.650	73.1	63.5			
7	3	2013	DesSnd	65	50.143	-124.754	77.3				
7	3	2013	DesSnd	66	50.092	-124.813	76.2	57.3			
7	3	2013	NSOG	67	50.020	-124.881	54.6	65.4	37.5		
7	3	2013	NSOG	68	49.949	-124.747	53.1	62.8	33.4		
7	3	2013	NSOG	69	49.855	-124.721		67.4	53.5		56.4
7	3	2013	NSOG	70	49.793	-124.701		64.5			
7	3	2013	SOG	72	49.716	-124.804					48.5
7	4	2013	SOG	73	49.442	-124.623	44.3	60.0	51.1		48.2
7	4	2013	SOG	74	49.397	-124.522	72.0	60.9			
7	4	2013	SOG	76	49.414	-124.363		58.9	49.4		45.0
7	4	2013	SOG	77	49.404	-124.267	58.9				
7	4	2013	SSOG	80	49.401	-124.115		76.2	45.3		
7	4	2013	SSOG	81	49.467	-124.058	57.2				
7	5	2013	GIfIs	82	48.807	-123.350	51.5	60.0	41.4		23.3
7	5	2013	GIfIs	83	48.741	-123.392	53.0	58.5			
7	5	2013	GIfIs	84	48.717	-123.445	52.3	60.4			
7	5	2013	GIfIs	85	48.861	-123.585	47.2	51.2	60.5		44.0
7	5	2013	GIfIs	86	48.903	-123.634	51.6	53.4			
7	5	2013	GIfIs	87	48.912	-123.734			53.1		27.4
7	5	2013	GIfIs	88	48.745	-123.559	46.0	66.2	43.7		
7	6	2013	SSOG	89	49.443	-123.948	67.0	51.3			
7	6	2013	SSOG	90	49.427	-123.876	71.8				
7	6	2013	SSOG	91	49.377	-123.874	51.9	57.7	52.3		
7	6	2013	SSOG	92	49.370	-123.777	44.8				
7	6	2013	SSOG	93	49.409	-123.765	55.8				
7	6	2013	SSOG	94	49.337	-123.834	68.5	59.7			

Table 3. continued

Month	Day	Year	Region	Set #	Lat	Long	Chinook	coho	chum	pink	sockeye
7	9	2013	PS	109	47.564	-122.424	32.1		43.7		
7	9	2013	PS	110	47.504	-122.404	35.5		39.8		
7	9	2013	PS	111	47.438	-122.375	37.1		46.3		
7	9	2013	PS	113	47.368	-122.408	40.2		52.2		
7	9	2013	PS	114	47.347	-122.545	33.6		49.7		
7	9	2013	PS	115	47.398	-122.538	32.0				
7	9	2013	PS	117	47.475	-122.513			43.9		
7	9	2013	NPS	119	47.701	-122.428	40.9	64.6	24.4		
7	10	2013	NPS	120	47.756	-122.410	43.2	53.6			
7	10	2013	NPS	121	47.822	-122.435	41.1	60.9			
7	10	2013	NPS	122	47.845	-122.490	43.6	50.5			
7	10	2013	NPS	123	47.951	-122.488	34.5	55.6	31.5		
7	10	2013	NPS	124	47.969	-122.622	34.9				
7	18	2013	QCSnd	288	50.938	-128.990			59.6	51.2	54.7
7	18	2013	QCSnd	294	51.095	-128.717			71.6		
7	18	2013	QCSnd	300	51.211	-128.480		52.2	66.4		57.4
7	19	2013	QCST	303	50.786	-127.490	42.3		49.1		
7	19	2013	QCST	309	50.785	-127.219	36.8		43.6	24.9	
7	19	2013	QCST	315	50.672	-127.197	43.8		43.5		
7	19	2013	QCST	321	50.727	-126.923	62.2		33.1		
7	19	2013	JS	330	50.504	-126.442			43.2		43.2
7	20	2013	JS	333	50.489	-126.329		46.2	34.4		47.3
7	20	2013	JS	336	50.490	-126.215		42.9			
7	20	2013	JS	339	50.476	-126.108		48.7	35.4	23.3	
					grand mean		57.5	60.9	45.7	33.1	49.2
					sd		13.8	10.8	9.7	15.6	9.6

low	< grand mean - 0.5 sd
high	> grand mean + 0.5 sd

Table 4. Mean IGF1 level of juvenile salmon sampled in the main basin of the Strait of Georgia 2012 and 2013 (NSOG, SOG, SSOG). Means were generated from the average IGF1 value from each site.

2012

	Coho	Chinook	Chum	Pink	Sockeye
mean	76.2	72.2	43.1	33.7	42.7
sd	14.3	13.0	3.2	7.2	7.1
cv (%)	19	18	7	21	17
# sites sampled	20	29	19	12	25
total fish sampled	90	142	88	51	105

2013

	Coho	Chinook	Chum	Pink	Sockeye
mean	64.3	64.3	45.0		52.4
sd	9.4	10.3	6.9		5.5
cv (%)	15	16	15		10
# sites sampled	28	31	18		12
total fish sampled	137	149	89		42

Table 5. Correlations between mean IGF1 level of juvenile salmon species pairs collected from the same tow 2012 and 2013.

	# tows	r	p
2012			
Coho vs Chinook	12	0.39	0.22
Coho vs Sockeye	7	0.32	0.51
Coho vs Pink	14	-0.16	0.59
Coho vs Chum	21	0.01	0.95
Chinook vs Sockeye	10	-0.23	0.54
Chinook vs Pink	15	0.11	0.71
Chinook vs Chum	20	0.27	0.26
Sockeye vs Pink	16	0.54	0.03
Sockeye vs Chum	19	0.36	0.13
Pink vs Chum	35	0.48	<0.01
2013			
Coho vs Chinook	25	0.07	0.22
Coho vs Sockeye	6	0.16	0.44
Coho vs Pink			
Coho vs Chum	18	0.04	0.42
Chinook vs Sockeye			
Chinook vs Pink			
Chinook vs Chum	16	0.05	0.42
Sockeye vs Pink			
Sockeye vs Chum	8	0.23	0.23
Pink vs Chum			

Table 6. Mean IGF1 levels of juvenile coho salmon collected in the main basin of the Strait of Georgia in 1998-2001, 2012 and 2013.

Year[1]	mean July IGF1[2]	sd	n	Sept Len[3]	Sept CPUE[3]	% Survival[3] (ocean entry to Sept)
1998	45	12	91	243	38.4	13.6
1999	59.1	14	167	229	55.2	24.4
2000	48	2.5	89	248	32.5	10.7
2001	52	7.9	287	255	46.6	15.7
2012	76.2	14	90			
2013	64.3	9.4	137			

[1]2012 and 2013 values obtained in this study
[2]Beckman et al. unpublished
[3]Beamish et al. 2008