The Role of Salinity and Temperature in Killer Whale's (*Orcinus Orca*) Ability to Effectively Locate Salmon in the Salish Sea

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Abstract:

The Southern Resident Killer Whales (SRKW), a distinctive ecotype inhabiting the Salish Sea, eats predominantly Chinook Salmon Species. SRKW presence in the Salish Sea varies throughout the year, but is most constant during the summer and early fall months. This study investigates SRKW response to estuarine fluctuation in the Salish Sea, and Columbia estuaries. Data on the Fraser and Columbia Rivers were correlated with Fraser and Columbia Chinook return, and SRKW presence and absence in the Salish Sea. Measurements taken during the month of May found a strong influence of the Fraser River on the Salish Sea estuarine environment. SRKW, and Chinook movement in and out of the Salish Sea were found to have strong correlations with Fraser River Discharge.

Introduction

The Salish Sea, a large estuarine system located in northern Washington state and southern British Columbia, is the area in which the Southern Resident Killer Whales (SRKW) spend the majority of the year (NOAA recovery plan, Ford et al. 2000; Hauser 2006). There are two distinct ecotypes of Orca (*Orcinus Orca)* that can commonly be found in these coastal waters off Washington State and British Columbia: Transients and Residents (Ford and Ellis 2006).

Although physiologically these two ecotypes are virtually indistinguishable, they exhibit fundamental differences in diet, socialization, and behavior (Ford et al. 2000; Ford et al 1998). Transients travel in small pods, inhabit a large range, and eat—almost exclusively—marine mammals. Resident Killer Whales, on the other hand, travel in large pods made up of several matriarchal clans, inhabit a smaller range, and are fish eating (Ford et al. 2000). This central difference between these two ecotypes is attributed in part to behavioral traditions that are passed down through generations (Ford and Ellis 2006).

The SRKW have been observed feeding on 22 different fish species in the Salish Sea, but observations of SRKW foraging, as well as collected fecal samples, have led researches to believe that SRKW forage predominantly on Salmonid species, specifically Chinook (*Oncorhynchus Tshawytscha)* (Ford et al. 2000; Baird et al. 2003).

Prey choice in predators is usually determined by a combination of prey availability and energetic profitability, but in the case of SRKW this doesn't seem to be true. Chinook Salmon are among the least abundant salmon species in the Salish Sea ecosystem. However, Chinook salmon are the largest of the salmonids and have an extremely high lipid content (Ford and Ellis 2006). It's evident from the SRKW selective dietary choice that the nutritional paybacks of Chinook salmon outweigh the energy expended to find and catch Chinook.

Very little is known about the diet of the SRKW during the winter months, but the SRKW requirement for Chinook during the spring, summer, and fall months can be seen through their movements into—and around—the Salish Sea. The SRKW travel somewhat predictably throughout the Salish Sea, foraging in core areas that presumably have an abundance of food (Ford et al. 2000; Samuel et al 1985). It has been observed that the SRKW movements through the Salish Sea follow the patterns of Chinook salmon migration (Ford et al. 2000).

Salmon migration is often studied, but relatively little is known about movements through the water column on their migration back to their natal streams (Candy and Quinn 1999). Adult salmon leave the open ocean where they feed to make a final journey back to their natal streams where they complete their life cycle with reproduction (Quinn et al. [No date]). Chinook and Coho Salmon make comparatively slower migrations than other salmon species, spending a longer amount of time in estuarine waters (Godfrey et al. 1975; Major et al. 1978; Fisher and Pearcy 1978). During their migration salmon undergo three major biological transformations in diet, osmotic processes, and hormone production. These biological transformations occur as a direct result of environmental changes, such as salinity, temperature, and current (Truscott et al. 1986; Quinn 2005)

As a large estuary, the Salish Sea is an incredibly complex system. 19 large rivers feed into the Salish Sea creating a constant outflow of brackish water on the surface layer, whilst the lower layers contain water of lower-salinity coming in through the Strait of Juan de Fuca (Fig.1). The incredibly complex bathymetry carved out by glacial movement creates intense, somewhat unpredictable currents. (Khangaonkar et al. 2011; Pawlowicz et al. 2011; Banas et al. 2010).

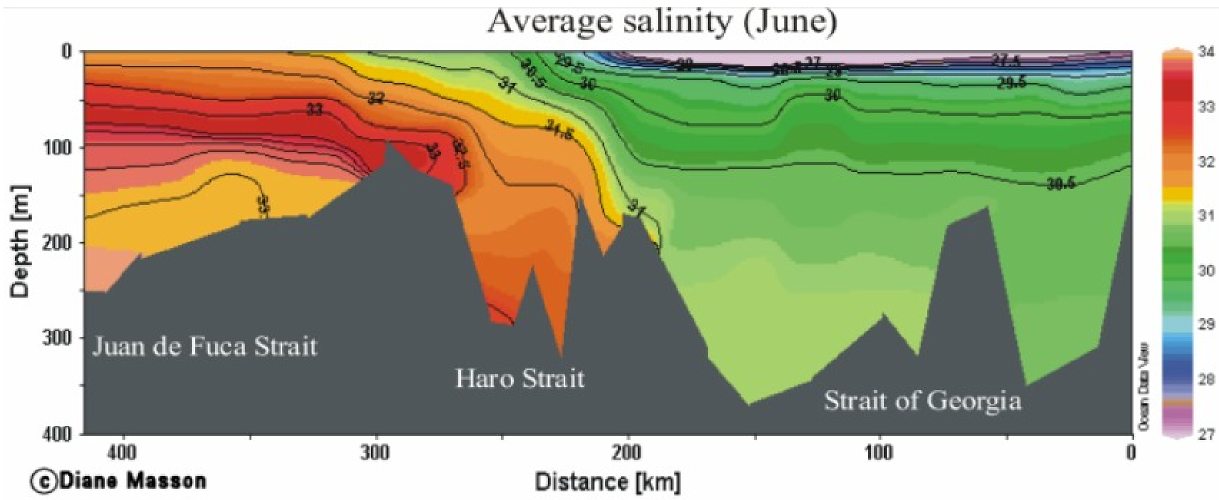


Fig.1
Tidally modulated mixing in Haro Strait, Juan de Fuca Strait, and Strait of Georgia during the month of June.

Estuarine systems play a key role as transition zones, full of environmental extremes, that are potentially used for orientation by the organisms living, or passing through, the ecosystem (Quinn et al.) Studies suggest that salinity and temperature changes in coastal waters play a crucial role in orienting Chinook salmon back to their natal streams, especially during the night (Quinn 2005). This study aims to answer if SRKW sensitive enough to the annual changes in the Salish Sea environment to use them as orientation cues to find Chinook salmon. It is therefore hypothesized that SRKW are able to track salmon runs in part due to their sensitivities to salinity and temperature. This cannot be directly observed, but can be inferred through the transitive relation theory. This study will aim at establishing a connection between the seasonal fluctuation in salinity and temperature in the Salish Sea estuary due to Fraser River flow, and fluctuations in the number of SRKW sightings in the Salish Sea.

Methods

CTD casts and plankton tows were taken off the Gato Verde, a 42ft research catamaran, from May 2nd 2012 to May 16th 2012. The CTD casts and plankton tows were conducted at 11 different waypoints (fig.2). Waypoints were chosen in important bathymetric and whale areas throughout the Salish Sea.

Fig.2
CTD and Plankton Waypoints

A: Salmon bank, B: Hein Bank, C: Eagle Point, D: False Bay & Pile Point, E: Lime Kiln, F: Kellet Bluff, G: Turn Point, H: West Bank, I: East Point

60m CTD casts were taken. Samples were taken every eight seconds on the way down and up. For this projects purposes only the down casts were used. Temperature and salinity down casts were averaged by day from 2-60m and from 2-20m.

A plankton net was dropped to a depth of 20m off the starboard side of the Gato Verde with a 10lb weight attached. The plankton samples were then put into vials, fixed, and put into the freezer aboard the Gato Verde. These samples were later put into 1mL slide sectioned off into μL squares. Pictures of five squares were taken from each sample using a microscope camera. The Five squares from each sample were counted using J image, and averaged by species, and again by total density.

Fraser Flow and Temperature data was collected from the HOPE station on the Fraser (Fig. 3). Fraser flow was measured in m^3/S, and temperature was measured in degrees Celsius. Temperature and flow data was used only from the days in April 2012 when CTD casts and plankton tows were taken.

The above variables were charted against time and each other in excel. A Pearsons Correlation Test was performed on the above data sets. This statistical test produced a P value for the correlations between the above variables, and determined if the correlations were negative or positive.

Archived Data

Archived Fraser Flow data was collected from the Fraser HOPE station (fig. 3) data was collected from the time period between April 1st and October 31st from 2006-2010. The collected data was binned into julian weeks. Coinciding julian weeks were then averaged together to create an average of all four years.

Fraser Chinook data was obtained from the Albion Test Fishery on the Fraser River. Density of Chinook returning to the Fraser River was recorded by the Albion in Catch per unit effort (CPUE). The Albion test fishery is located just East of Vancouver on the Fraser River, and uses gill nets to catch Fraser Chinook. Albion data was collected from the time period between April 1st and October 31st from 2006-2010. The collected data was binned into julian weeks. Coinciding julian weeks were then averaged together to create an average of all four years.

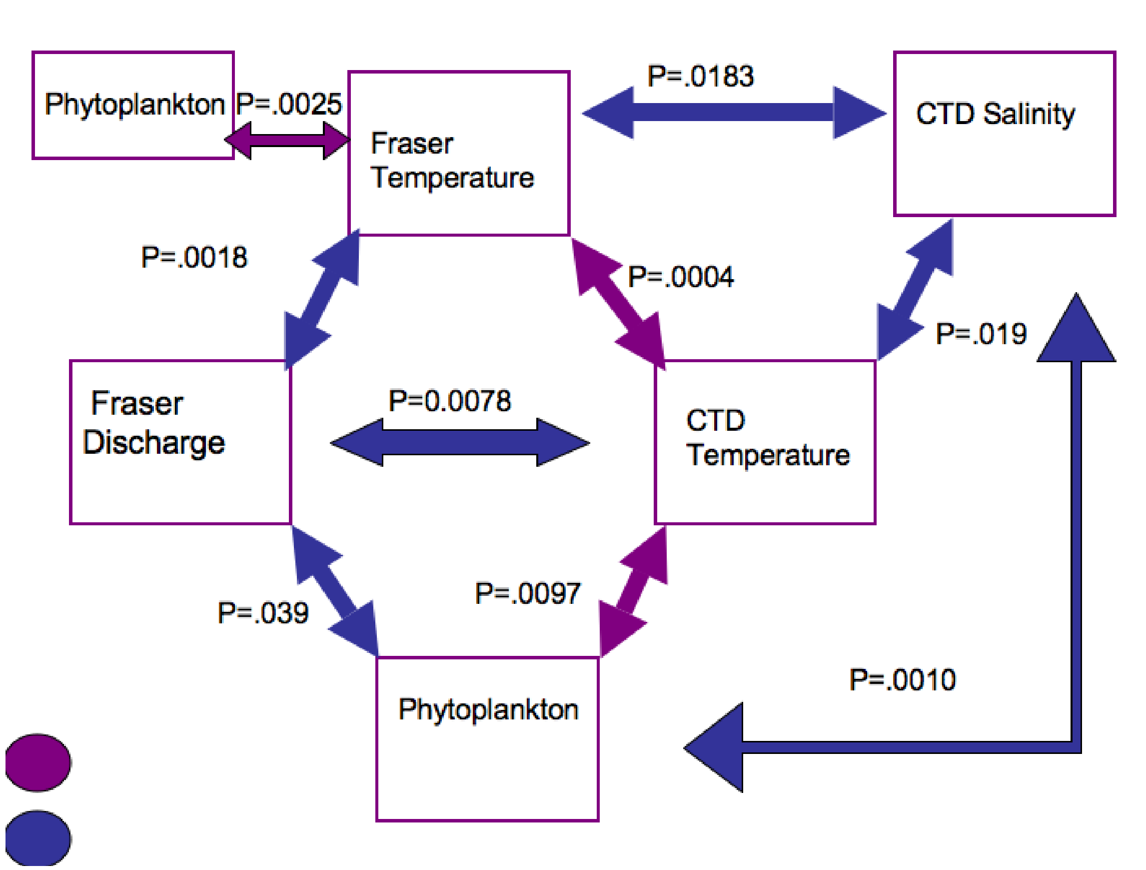
Orca sighting data was obtained from the Orcamaster database, provided by the Whale museum located in Friday Harbor, WA. Orcamaster data was analyzed in a method adapted from Charla Basran's project. Orcamaster sighting data collected between April 1st and October 31st 2006-2010. Whale sightings were expressed as whale days, which were defined as the presence of the SRKW in the Salish Sea. Each julian week was given a number from 0-7 reflecting the number of whale days that week. Coinciding julian weeks were then averaged together to create an average of all four years, and a continuous data set of whale presence and absence in the Salish Sea.

Archived data was also collected from the Columbia River. Because the Columbia River is dammed no flow data was used. Columbia temperature and Chinook data was gathered from a USGS station at the Dells (fig.4) Temperature data was collected in degrees Celsius. Columbia Chinook data was recorded in actual density passing the Dells USGS station. Both temperature and Chinook data were collected from the time period between April 1st and October 31st from 2006-2010. The collected data was binned into Julian weeks. Coinciding julian weeks were then averaged together to create an average of all four years.

The Orcamaster database was used to create a four year average of whale absence from the Salish Sea. Whale absence was expressed as days of absence, which were defined as the absence of the SRKW in the Salish Sea. Each julian week was given a number from 0-7 reflecting the number of days of absence that week. Coinciding julian weeks were then averaged together to create an average of all four years, and a continuous data set of whale absence.

Results

The measurements taken in the spring 2012 expressed a high level of Fraser River influence on the fluctuations of the Salish Sea environment. Strong negative and positive correlations were found between Fraser, CTD , and Phytoplankton data. Fraser Discharge was found to have a negative correlation with CTD temperature (Pearson Correlation P= 0.0018 R= -0.94)(Fig. 4). Fraser discharge had a negative correlation with phytoplankton density (Pearsons Correlation P=0.039 R= -0.78) Tests didn't show any significant correlation between Fraser Discharge and CTD salinity, but interestingly there was a confident negative correlation between Fraser Temperature and CTD salinity (Pearsons P= 0.0183 R -0.084). Fraser temperature and CTD temperature were found to have a significant positive correlation with one another. Fraser temperature, and CTD temperature were both found to have significant positive correlations with each other (Pearsons P=0.0025 R=.93, P=0.0097 R=.88). CTD salinity and temperature were found to have a significant negative correlation (Pearsons P= .019 R=-0.83) CTD salinity had a negative correlation with phytoplankton density (Pearsons P=.001 R=-0.95).



Pearsons test correlations between 2012 Fraser, CTD, and phytoplankton data. Arrows show all significant correlations. Blue arrows show negative correlations and the purple arrows show positive correlations.

The averaged Albion CPUE hit its peak from late August to early September, julian weeks 21-23, with an average slightly above 2. When CPUE was lagged 10 weeks to match up with the peak in Fraser flow they both hit their peak between julian weeks 10 and 12. Before lagging CPUE by ten weeks the Pearsons test showed no significant correlation between Fraser flow and CPUE with a P value of .1847. When the 10-week lag was applied there developed a significant correlation between Fraser flow and CPUE with a P value of .000 (Fig.5).

J_week	CPUE_AVG_Week	#_Whale_Days_perweek	AVG_Discharge_Week
1	0.080357143	1.571428	1107
2	0.07962963	1	1448
3	0.057142857	1.42857	2043
4	0.060833333	2	2686
5	0.055714286	2.14285	3036
6	0.050857143	3	3562
7	0.071142857	4	4246
8	0.040571429	4	6129
9	0.051428571	4.14285	6557
10	0.096285714	4.85714	7227
11	0.225428571	4.42857	7153
12	0.3975	4.857142	6553
13	0.78452381	5	5921
14	0.886666667	4.85714	5454
15	0.648333333	4.857142	5150
16	0.904047619	4.85714	4567
17	0.915714286	4.85714	4092
18	1.000714286	4.7142	3724
19	1.190555556	4.5714	3267
20	1.64775	4.42857	2898
21	2.197435897	4.2857	2613
22	2.233157895	4.42857	2425
23	2.143181818	4	2209
24	1.695555556	4.14285	2050
25	1.041666667	4	1777
26	0.765555556	4.28571	1652
27	1.28125	3.57142	1831
28	0.611666667	3.42857	1610
29	0.17625	3.14285	1468
30	0.056	3.28571	1453

Fig. 5 Fraser CPUE, Discharge, and Whale days averaged by julian week. Data averaged from April to October 2006-2010.

Whale days and Fraser River flow have a very tight correlation between julian weeks 1-12. From julian week 13 to week 31 the correlation between whale days and Fraser River flow becomes less strong (Fig. 6). The overall correlation was significant with a P value of .0009. A similar trend can be seen with Columbia Chinook and whale absence from the Salish Sea. Before Columbia Chinook density was lagged four weeks when correlated with SRKW absence from the Salish Sea there was no significant correlation found (Pearsons P value .5231 R= -0.12). After lagged four weeks the Pearsons Correlation test found a significant correlation with a P value of .0015. From julian weeks 1-13 the correlation between whale absence from the Salish Sea and follows a much closer trend than weeks 14-31 (Fig.7).

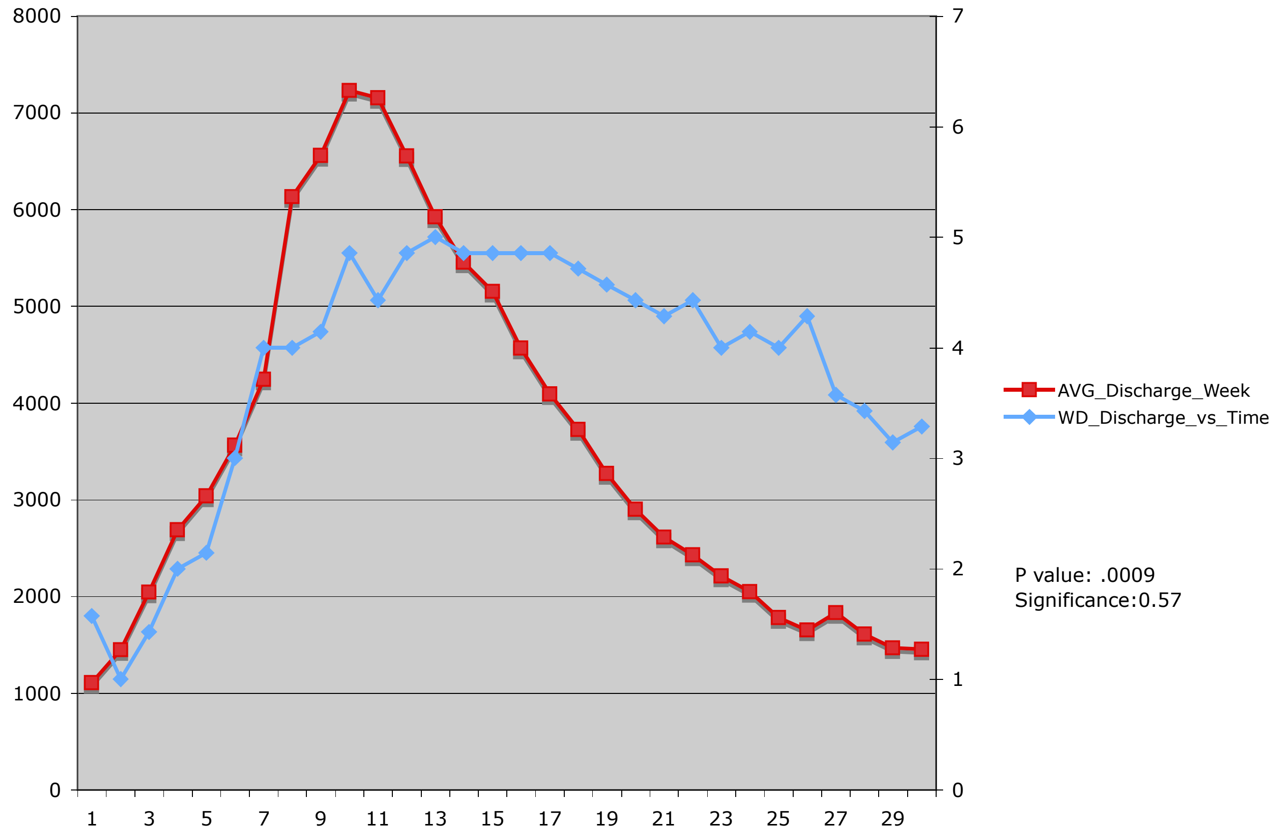


Fig. 6
Fraser River discharge and whale day. Sorted and averaged by julian week from April to October 2006-2010

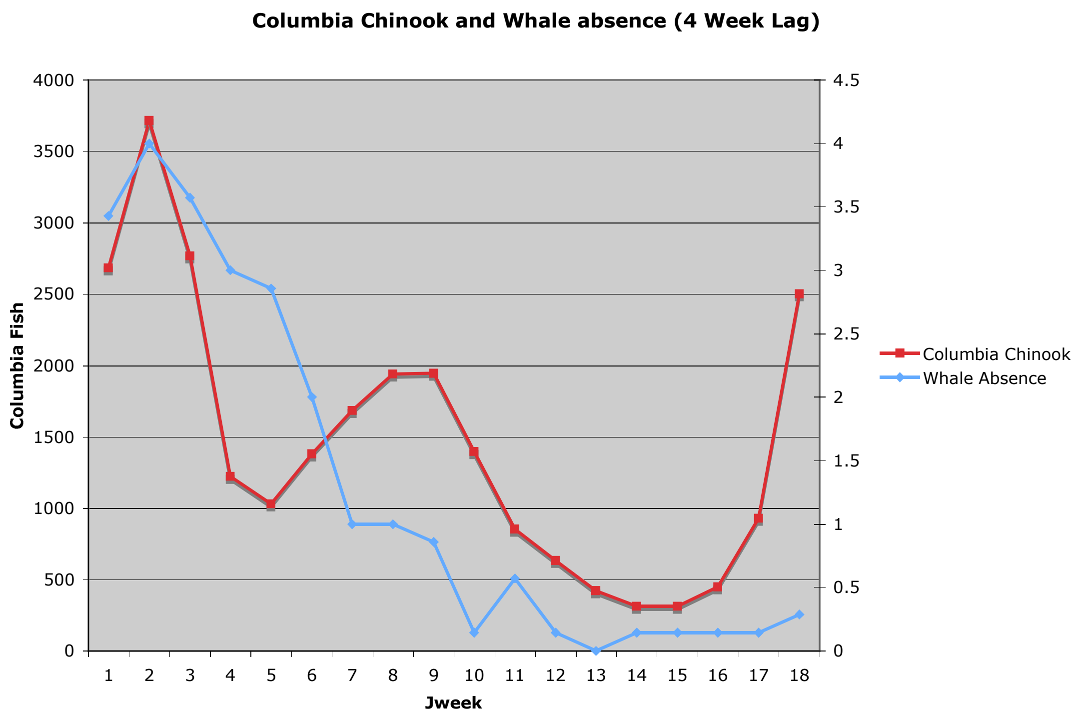


Fig. 7 Columbia Chinook and Whale absence data with a lag of four weeks. Averaged and sorted by julian week, and

Discussion

As hypothesized, there were strong correlations found between SRKW presence and absence in estuarine environments and temporal and seasonal fluctuations. Confident correlations between both SRKW presence and absence and Chinook presence and absence from the Columbia and Salish Sea estuaries were evident in the data collected.

When 2012 CTD, Fraser River, and phytoplankton data was analyzed the influences of the Fraser River could be seen through salinity, temperature, and phytoplankton fluctuations in the top 20m of water (fig. 8). The found correlations provided evidence that during the period studied as Fraser Flow decreased the Fraser Temperature increased dramatically. This decrease in Fraser Flow could be due to a lack of snow pack, or the melting of snow during the later summer months. The increase of Fraser temperature, and decrease in Fraser flow led to a substantial increase within the whole water column, but the influences could most markedly be seen in the top 20m of the water column. Interestingly the data collected on Salish Sea salinity exhibited no significant correlation with Fraser River Flow, but did express a significant correlation between salinity and Fraser River Temperature. This discrepancy may be due to an averaging out of the halocline when the top 20m of the water profile were averaged. Phytoplankton density measurements provided a good indicator of the influences of Fraser Flow in the Salish Sea ecosystem. Phytoplankton densities significantly increased as the Fraser River flow decreased and Fraser River temperature increased. The measured phytoplankton bloom had a strong correlation with increasing Salish Sea temperature, and decreasing Salish Sea Salinity, but the bloom was probably driven by an increase in solar radiation.

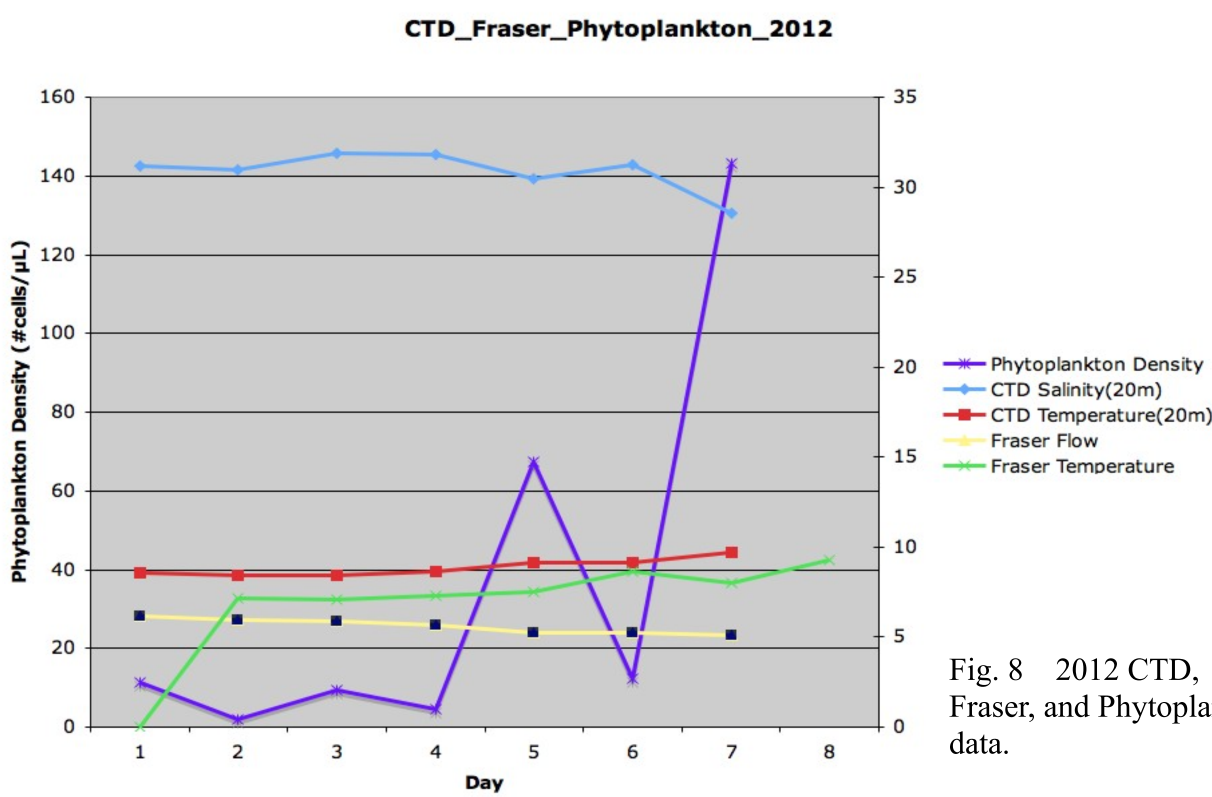
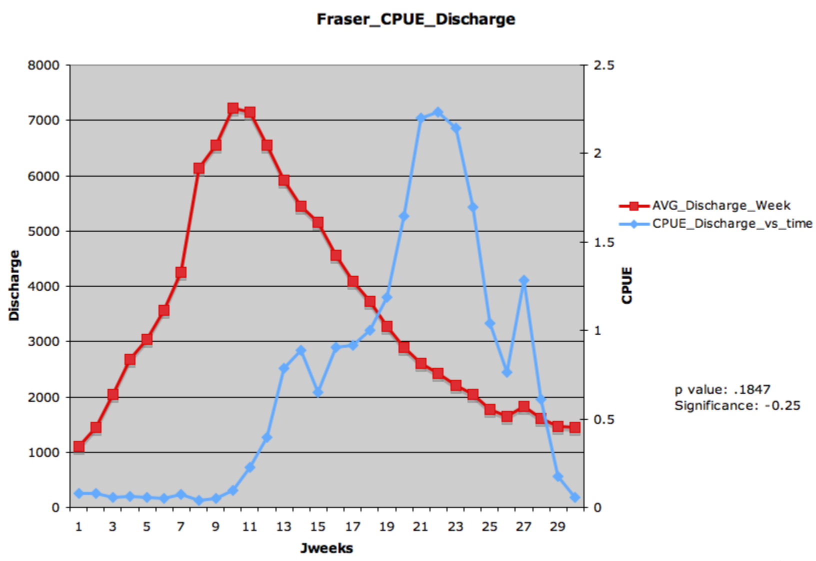


Fig. 8 2012 CTD, Fraser, and Phytoplankton data.

Studies show that hydrological features, such as salinity and temperature gradients greatly influence the distribution and density of cetacean prey (Bearzi et al.). When first plotted this hydrological influence could not be seen between Fraser Flow and Fraser Chinook return (CPUE). After a lag of 10 weeks was applied to the returning densities of Fraser Chinook a significant correlation was found. This lag 'effect' can be explained by the path particles discharged from the Fraser River, and the rout of the Fraser Chinook through the Salish Sea (Fig.9). From the time of discharge from the mouth of the Fraser River it takes surface particles around 14 days to reach the open ocean via the Strait of Juan de Fuca (Flowweaver). Unlike most other salmon species Chinook slowly migrate through estuarine systems taking several weeks to migrate up to their natal stream (Quinn et al.) A previous Beam Reach student, Charla Basran, calculated in her project that it took Fraser Chinook around 14 days to migrate to the Albion test fishery from the San Juan Islands. During this slow migration it is thought that Chinook use salinity and temperature fluctuations in the water column, especially at night, to navigate towards their natal streams.



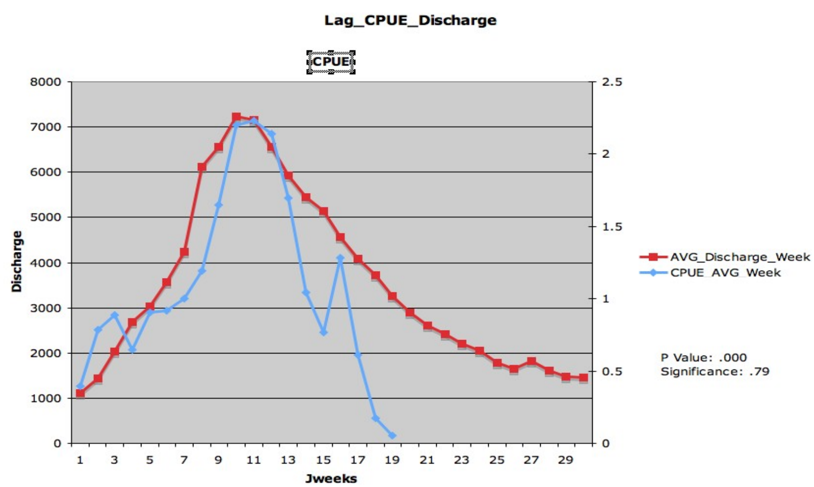


Fig. 9 Fraser Flow and CPUE before 10-week lag and after 10 week lag. Before the 10 week lag there doesn't appear to be a significant correlation between Fraser discharge and CPUE. After the 10 week lag was applied there was a confident correlation between Fraser discharge and CPUE.

Chinook return on the Columbia did not appear to be especially correlated to the temperature fluctuation of the Columbia. There are several variables that may be the predominant causes behind a lack of correlation (Fig.10). The first factor that could affect this correlation is the damming of the Columbia River. Dams create a situation in which Columbia discharge is regulated and not attuned to the natural cycles contributing estuarine fluctuations. Like the Fraser River the Columbia River is fed through glacial melt in Canada. The water that travels from the glacial source through the Columbia River has a longer amount of time to warm up as it travels to the ocean, thus making seasonal temperature fluctuations much milder (Fig.11). The Columbia River estuary does not empty into an inland sea, like the Fraser estuary, but rather into an open ocean, allowing it's freshwater to disperse much more quickly.

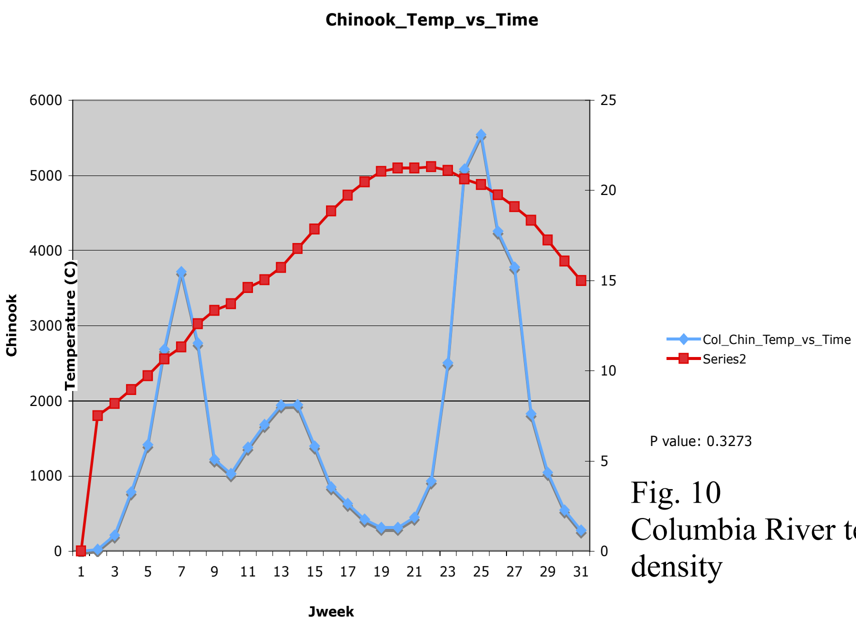


Fig. 10
Columbia River temperature and Chinook density

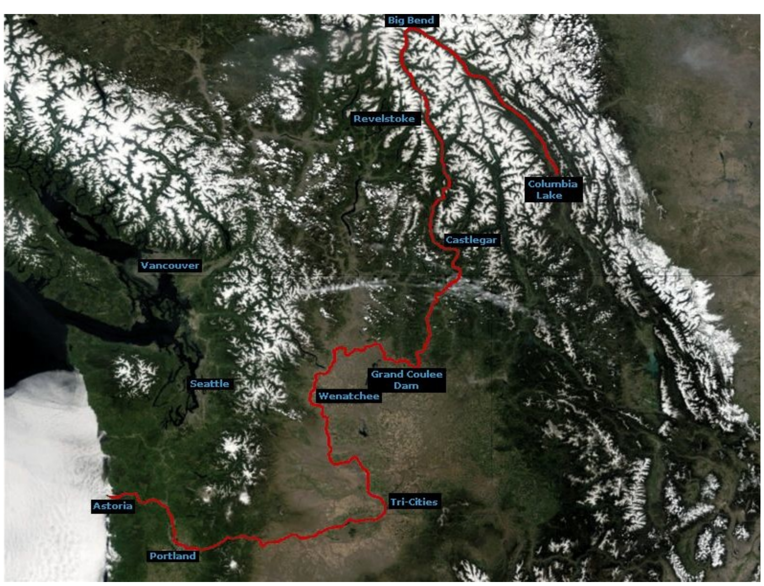
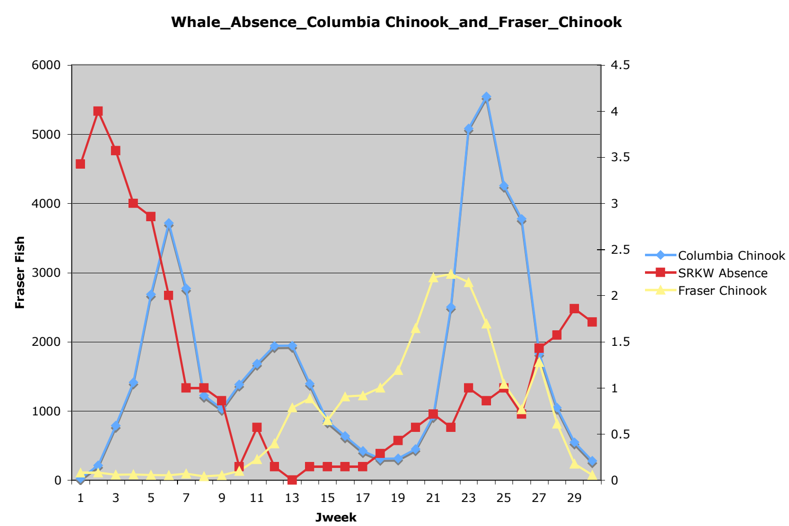


Fig. 11 path of Columbia River

Strong positive correlations were found between whale presence and absence in the Salish Sea, and Chinook presence and absence in the Salish Sea. A rapid increase of CPUE around julian week nine coincided with an increase of Whale presence in the Salish Sea four weeks earlier around julian week five. This lag suggests that the Fraser Chinook are in the Salish Sea at least four weeks prior to arriving at the Albion Test Fishery on the Fraser River. This increase in Whale days also coincided with a decrease in Columbia River Chinook around julian week five. This suggests that in the late spring SRKW are foraging predominantly on Columbia Chinook until early June when the Fraser River Chinook begin to return (fig.12).



A closer association between Chinook, and SRKW presence and absence from the Salish Sea, and flow during the beginning of the summer indicates a significant response to salinity and temperature fluctuations by the SRKW when foraging between the Columbia and Fraser River stocks of salmon. As the summer progresses, and the Fraser River Chinook stocks peak, SRKW presence in the Salish Sea becomes nearly constant, making it less necessary for the SRKW to make use of fluctuations from the Fraser River to sense Chinook presence in the Salish Sea. This does not denote the discontinuation of SRKW use of environmental fluctuations to find prey, it is probable that SRKW use salinity and temperature fluctuations within the different areas of the Salish Sea to locate prey.

Conclusion

Although strong correlations were found between SRKW movement in and out of the Salish Sea, and Columbia and Fraser River influence, future research is needed to determine how SRKW react to fluctuations within the Salish Sea. Typically J, K, and L pods all return to the Salish Sea at different times during the late spring and early summer, it would be interesting to look into how the different pods react to salinity and temperature changes throughout the year.

CITATIONS:

Baird, R.W., Hanson M.B., Ashe EE, Heithaus M.R., Marshall GJ., Studies of Foraging in “Southern Resident” Killer Whales During July 2002: Dive Depths, Bursts in Speed, and the Use of a “Crittercam” System for Examining Sub-surface Behavior, National Geographic.

Candy, J.R., Quinn, T.P., 1999, Behaviour of adult Chinook salmon (Oncorhynchus tshawytscha) in British Columbia Coastal Waters Determine from Ultrasonic Telemetry, Canadian Journal of Zoology. 77: 1161-1169

Fisher, J.P., and Pearcy W.C., 1987, Movements of Coho, *Oncorhynchus kisutch*, and Chinook, *O. tshawytscha,* Salmon Tagged at Sea Off Oregon, Washington, and Vancouver Island During the Summers of 1982-85, Fish Bull, 85:819-826

Ford J, Ellis G., Selective Foraging by Fish-eating Killer Whales Orcinus Orca in British Columbia, Marine Ecology Progress Series, 316 (2006): 185-199.

Ford J.K.B., Ellis G.M., Balcomb K.C., 2000: Killer whales: the natural history and genealogy of Orcinus orca in British Columbia and Washington State, UBC Press, Vancouver.

Ford, J.K.B., Ellis G.M., Barrett-Lennard L.G., Morton A.B., Palm R.S., Balcomb K.C., 1998: Dietary specialization in two sympatric populations of killer whales (Orcinus orca) in coastal British Columbia and adjacent waters, Can. J. Zool. 76: 1456-1471

Godfrey H.K., Henry A., and Machidori S., 1975., Distribution and Abundance of Coho Salmon in Offshore Waters of the North Pacific Ocean, Int. North Pac. Fish. Comm. Bull. No. 31

Hauser D.D.W., Longdon M.G., Holmes E.E., VanBlaricom G.R., Osborne R.W., Summer Distribution Patterns of Southern Resident Killer Whales Orcinus orca: Core Areas and Spatial Segregation of Social Groups. Marine Ecology Progress Series. 351(2007): 301-310.

Major, R.L., Ito J.,,Ito S., and Godfrey H., 1978: Distribution and origin of Chinook salmon (*Oncorhynchus tshawytscha*) in offshore waters of the North Pacific Ocean.Int. North Pac. Fish. Comm. Bull. No. 38

Khangaonkar T., Yang A., Kim T., and Roberts M., 2011: Tidally Averaged

Circulation in Puget Sound Sub-basins: Comparison of Historical Data, Analytical Model, and Numerical Model., 93: 305-319.

NOAA's National Marine Fisheries Service (2011). http://www.nwr.noaa.gov

Quinn T.P., Olson A., Vertical and horizontal movements of adult Chinook Salmon *Oncorhynchus tshawytscha* in the Columbia River estuary.

Quinn T.P., The Behavior and Ecology of Pacific Salmon and Trout. University of Washington, 2005: 53-61p.

Samuel M.D., Pierce D.J., Garton E.O., (1985) "Identifying areas of concentrated use within the home range." J Anim Ecol 54: 711-719

Sharon B., "Movement and Surface Active Behavior of Killer Whale (*Orcinus orca)* in Response to Tidal Height, Current Velocity, and Salinity."2011

Truscott, B., Idler D.R., So Y.P., and Walsh J.M., 1986, Maturation steroids and Gonadotropin in upstream migratory sockeye salmon, Gen. Comp. Endocrino. 62: 99-110