**Correlating Southern Resident Orca Sightings with Pacific Salmon Densities: A Three Part Analysis**

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**Abstract**

The Southern Resident Killer Whales (SRKWs) inhabit the Salish seas of Northern Washington, USA and Southern British Columbia, Canada, during the summer and fall months. These whales have been listed as endangered, and feed very selectively on threatened Chinook salmon which migrate through the area on their way back to their native streams. This study investigates the correlation between Orca sightings and Chinook salmon abundance in the Salish Sea region on three different scales. For a broad scale analysis, an archive sightings database was used to obtain Orca sightings data in the San Juan Islands, WA, which was correlated with Chinook catch data obtained for the Fraser River from the Department of Fisheries and Oceans. Data was used from April to October of 2006 to 2010. Number of “whale days” from the sightings database was regressed against catch per unit effort (CPUE) of Chinook, binned by week. For seasonal scale analysis, echosounder data from the August 2008 was analyzed to determine densities of large target fish at Lime Kiln State Park, San Juan Island, WA. The depth in the water, and the backscatter frequency, were analyzed to determine which could be counted as salmon. These salmon densities were compared for three day when there were multiple whale sightings recorded specifically at Lime Kiln State Park. For a fine scale analysis, field data was collected over a twenty day period through the end of September and beginning of October, 2011. On each “whale day”, foraging behaviour was noted and timed to obtain percent of time foraging. Fish finder images were collected each day and analyzed for presence and absence of large targets considered to be salmon. Trolling at depths where large targets were seen was performed in order to confirm the presence of salmon species. The percent time the Orcas were observed foraging was regressed against the percent of large target images. Results show that number of Orca sightings per week positively correspond with CPUE of Chinook salmon in the Fraser River, and the amount of time foraging was observed also positively corresponds with estimated salmon numbers. This reinforces the idea that SRKWs are highly dependent on their salmon prey, and this dependence is reflected in the time spent, and movements within, the Salish Seas region.

**Introduction**

In the Salish Sea region of northern Washington and southern British Columbia, lives an ecotype of killer whale (*Orincus orca*) called residents. These southern resident killer whales (SRKW) live in matrilineal groups and have a “home range” in which they live. During the early summer to fall months, they reside mainly in the Salish Sea region, while in the winter months they are known to travel south to the California coast (Ford et al. 2000). Studies have found that resident killer whales in the Salish Seas have a very strong preference to feeding on salmon species, with only rare examples, derived from prey samples or fecal samples, of them eating other marine species (Hanson et al. 2010). In recent years it has been shown that they particularly, and almost exclusively, hunt Chinook salmon (*Oncorhynchus tshawytscha*). Ford et al. (1998) determined from observational data over many years, and through examining stomach contents of stranded whales, that over two-thirds of the fish the southern resident orcas consumed could be identified as Chinook salmon. Chinook tend to be much larger than other salmon and have the highest fat content, which may play a large role in the whales’ preference (Ford et al. 1998). The main exception to this is when they (HOW MUCH TIME) will prey on available Chum salmon (*Oncorhynchus keta)* (Ford and Ellis, 2006).

Since the southern resident killer whales very specifically hunt the Chinook salmon, it has been the focus of many studies for over 30 years. Spring, Summer, and Fall salmon runs occur in the Salish Seas, most notably for the Columbia and Fraser rivers (Trudel et al. 2009), which corresponds with when the SRKWs are most often sighted in the area. Chinook abundance has been shown to directly correspond with killer whale mortality, emphasizing the dependence the SRKWs have on the bottom-up relationship with the salmon (Ford et al. 2009). It has also been shown that PCB toxin bioaccumulation is occurring from the whales eating Chinook with high PCB concentrations (more noticeably Chinook from the south) (Cullon et al. 2009), which is potentially a major problem due to this dependence.

This unique predator-prey relationship is even more interesting due to the fact that Chinook salmon in the study area are declining and have been listed as threatened and endangered (Myers et al. 1998), as have the SRKWs themselves. The National Oceanic and Atmospheric Association (NOAA) listed different evolutionary significant units (ESUs) of Chinook in the Salish Seas as either endangered or threatened in 1999, including Columbia River and Puget Sound runs. The SRKWs were later listed as endangered as well, in 2005 (NOAA, 2011 ).

Previous studies conducted on the Northern resident killer whales, looked at the correlation between the killer whale sightings and salmon numbers to infer about seasonal movement of the killer whale pods (Nichol and Shackleton, 1996). Other studies focused on where feeding behaviour is most likely to occur. Ashe et al. (2009) found that during the summer months, SRKWs were most likely to display foraging behaviour on the south-west coast of San Juan Island. This suggests that fish density may be highest in this area, and this region will be of particular interest in the current study.

Chinook salmon are often found at depths of 50m or more, and have been known to dive down to depths of up to 300m (Candy and Thomas, 1999). These depths correspond well with the bathymetry of Haro Strait (on the west side of San Juan Island), which has depths of over 200m in many places.

Echosounder and fish finder data has previously been used to conduct fish analyses during killer whale encounters in the San Juan Islands. Horne and Gauthier (2004) used an echosounder to view images of biomass in the water. They were able to characterize fish in the water during SRKW foraging events by size of the targets in the images and by depth at which the targets were found. They also trolled for salmon from the boat in order to positively identify salmon species presence.

In this study, similar methods to those used by Nichol and Shackleton (1996) and Horne and Gauthier (2004) are used to look at correlations between SRKWs and their salmon prey while they are residing in the Salish Seas in the summer and fall months. Since the killer whales’ survival is strongly linked to their salmon prey, it is hypothesized that number of whale sightings in the Haro Strait and Fraser River areas will positively correlate with salmon densities at the time of sightings. Furthermore, it is also hypothesized that the time the whales spend exhibiting foraging behaviour while observing them in the field will correlate positively with presence of large fish targets (considered to be salmon) in fish finder images taken while observing the whales from a boat. This study will look at three different examples of this correlation: a large scale example using the archive whale sighting data and salmon catch per unit effort numbers for the Fraser river, a localized example using surface sightings records and Biosonics echosounder data specifically localized at Lime Kiln State Park, WA, and a finer scale example using observations of whale foraging behaviour and fish finder image data collected out in the field over a 20 day period.

**Methods**

All data collected and analyzed was for the southern resident killer whales and salmon species in the Salish Seas off of Northern Washington, USA and Southern British Columbia, Canada. The methods used in this paper are an adaptation of the methods used by Nichol and Shackleton (1996) in their study of the Northern resident killer whales, and Horne and Gauthier (2004) in their study of killer whale prey presence.

Archive Data Analysis

Archive data of salmon densities was obtained from the Department of Fisheries and Oceans from the Albion test fishery on the Fraser River. This data is recorded as daily catch per unit effort (CPUE) of fish density, and was binned into weekly averages. A total of twenty-nine weeks in April - October from 2006-2010 were used for the first part of the analysis. Whale sightings data was obtained from the Orca Master database through the Whale Museum in Friday Harbor, WA, and was queried using SQLShare (Fourdeuce, inc. 2005-2009). The number of “whale days” (days in which the orcas were sighted) were summed and then averaged for each of the study weeks. A Pearson correlation test was run on the average number of whale days per week and the average weekly salmon CPUE to test for a correlation between the two, using Systat statistical software (Systat version 13 © Systat inc. 2008). The r-value from the correlation test was then looked up in a critical-value table to determine whether the correlation was significant (α = 0.05).

A second archive data analysis was performed with Biosonics echosounder data and Dr. Bob Otis’ sightings database from the Lime Kiln State Park lighthouse WA, from August of 2008. Echosounder image data from the lighthouse was analysed using Visual Analyzer software (……) to determine the presence, count, and depth of large target fish (considered to be salmon). Targets were counted as salmon if they produced a backscatter frequency of -25 to -15 dB based on work done by……. Small schools of fish within the same target strength range were given a count of 5 fish based on the approximate size of a single salmon target. Three days, August 8th, 10th, and 14th, were chosen for analysis based on the fact that all three of these days had more than one whale sighting at the Lime Kiln with a time interval with no whales sighted in between. Fish targets per minute were calculated for each of four categories for each day: one hour pre-whale sightings, during whale sightings, between whale sightings, and one hour post-whale sightings. The average number of fish per minute for the pre-whale sightings and post-whale sightings were compared to the average for during whale sightings using a Wilcox test in R statistical software (…) to test for a significant difference (α = 0.05).

Field Study Analysis

Observational data collection was carried out on board the sailing biodiesel/electric catamaran, Gato Verde, over a twenty day period. Total time spent observing the whales each day was recorded, as well as amount of time foraging behaviour was observed. Foraging behaviour is difficult to define, but whales were considered to be foraging when they were alternating between milling and travelling, and lunging or chasing events could be inferred when prey was present, as per the NOAA behavioural definitions determined in a conference in 2004. Using a GP-1650 WF fish finder and a ………….., salmon presence and absence was determined during foraging and non-foraging whale observations, using the backscatter images. Images from the fish finder were analyzed to determine presence, and depth of large target fish (considered to be salmon). Trolling with salmon fishing gear was also performed on the boat at depths where large fish finder targets were being detected to support the salmon data being collected from the fish finder images. The percent of time the whales spent foraging was calculated for each whale day and was correlated with the percent of fish finder images displaying large target fish during that time using a Pearson correlation test. The percent of fish finder images were also compared between foraging and non-foraging whale observation using a Wilcoxon test.

Results

The average number of whale days per week in April to October of 2006-2010 peaked at seven days per week in late July and early August. The peak catch per unit effort of Chinook salmon was 2.22, occurring in early September. There was a significant positive correlation between the average number of whale days per week in the Salish Seas area and the average catch per unit effort of Chinook salmon in the Fraser River (Figure 1.) (Pearson correlation, r = .492, p<0.05). The same analysis was performed using Chum salmon catch per unit effort data for comparison and there was no significant relationship (Figure 2.) (Pearson correlation, r= , p<0.05).

Figure 1. The average number of whale days per week over 29 weeks from April to October of 2006 to 2010 (blue) and the average catch per unit effort (CPUE) of Chinook salmon at the Albion test fishery on the lower Fraser river over the same 29 weeks (red). The two have a positive significant correlation (Pearson correlation, r = .492, p<0.05).

Figure 1. The average number of whale days per week over 29 weeks from April to October of 2006 to 2010 (blue) and the average catch per unit effort (CPUE) of Chum salmon at the Albion test fishery on the lower Fraser river over the same 29 weeks (red). The two do not have a significant correlation (Pearson correlation, r = , p>0.05).

The average amount of time the orcas were observed foraging per day was 30.76%. There was a significant positive correlation between the percent time the orcas were observed foraging per day and the percent of fish finder images displaying large targets during foraging times (Figure 3.) (Pearson correlation, r = .751, p<0.05). There was however, no significant difference between the percent of images displaying large targets during non-foraging versus foraging times (Wilcoxon test, p = .619).

Discussion

As hypothesised, the number of whale days per week in the Salish Seas had a significant positive correlation with the CPUE of Chinook salmon in the Fraser River. Salmon stocks migrating through the Salish Seas are slow migrators compared to other stocks, with yearlings moving approximately 2.3-5.4km/day (Trudel et al. 2009). This slow migration could be a possible attribute to the Salish Seas being home to SRKWs for over half of the year since there is prey for a long period of time. There is a time lag between the peak killer whale sightings per week and the peak CPUE of Chinook in the Fraser River. This is likely due to the distance between the west side of San Juan Island (where the majority of the killer whale sightings in the database occur from late Spring to early Fall) and the Albion test fishery which is located on the lower Fraser River.

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