Examining the Temporal Correlation of Southern Resident Killer Whale (*Orcinus orca*) "West-side Shuffle" with Fraser Chinook Salmon (*Oncorhynchus tshawytscha*) Upriver Migration

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Introduction

Southern Resident killer whales (*Orcinus orca*), henceforth referred to as SRKW, are a population of killer whales native to the Pacific coast of North America. This distinct population segment of killer whales has been listed under Endangered Species Act by National Oceanic and Atmospheric Administration (NOAA) in November 2005, and has remained so as of today (NOAA 2011). Extensive studies by Ford and Ellis (2006) and Hanson et al. (2010) have shown that SRKW selectively prey on Chinook salmon (*Oncorhynchus tshawytscha*), particularly of the Fraser river stock. Fraser river Chinook salmon (FCS) is a sensitive stock that is being managed and protected under Canada's Policy for Conservation of Wild Pacific Salmon by the Canadian Department of Fisheries and Oceans (DFO 2011). Given that this is a situation where an endangered apex predator selectively preys on a sensitive species, the importance of continuing to study SRKW and FCS cannot be forsworn.

Ford and Ellis (2006) suggested that SRKW's preference for Chinook salmon is most likely due to the salmon's relatively large size, high energy content and perennial presence in SRKW's coastal range. SRKW is the apex predator of the Pacific Ocean. In the attempt to examine the link between SRKW survival and prey abundance, Ford et al. (2010) discovered that SRKW survival rates are strongly correlated with availability of Chinook salmon. They have hence hypothesized that SRKW are dependent on Chinook salmon as their primary food source . They have also suggested that SRKW's specialization in Chinook salmon is a form of "fixed behavioural tradition" that has been inherited from generation to generation by learning. In a more recent study, Hanson et al. (2010) discovered, by examining kill remains and genetic material in SRKW feces, that during the summer months, around 80% of the Chinook prey originated from the Fraser River, in particular the Upper Fraser.

During the summer months of June, July and August each year, SRKW are known by local whale watchers to travel back and forth Haro Strait, along the west coast of San Juan Island. Alternatively, they may also travel around the San Juan Island through Rosario Strait and return to Haro Strait. During this time, SRKW are also frequently observed to be foraging. This behaviour is colloquially known as the "west-side shuffle" (Jones 2011).

FCS return to their natal stream to spawn between April and September, with one subpopulation – the Harrison River Chinook returning during September to November. FCS has been categorized by the DFO into three seasonal runs. The spring run migrates through lower Fraser River before July 15; the summer run does so between July 15 and September 1; while the fall run enter the lower Fraser after September 1 (DFO 1999). This information suggests that the timing of SRKW west-side shuffle seems to coincide with upriver migration of adult FCS.

The west-side shuffle seems to be a yearly pattern for SRKW, yet none can predict the timing of the beginning and end of this shuffling pattern. Similarly, although the general timing of FCS runs are known, none can predict the occurrence of runs in a finer scale. In light of the suggestion by Ford et al. (2010) that SRKW's specialization in FCS is a learnt and fixed behavioral tradition, it would be interesting to find out by what reference point the SRKW begin their west-side shuffle. Previous studies by Ashe et al. (2010) and Basran (2011) have established an general annual trend to suggest that this reference point is likely the upriver migration of FCS. Nonetheless, finer temporal analysis by day has not been done.

For my upcoming research, I propose a method of data analysis that will quantify the SRKW "west-side shuffle" temporally and determine the beginning and end of this movement pattern. I will examine how this pattern relates to FCS upriver migration by juxtaposing the timing of west-side shuffle with catch per unit effort of FCS 50km upstream of Fraser River. I will analyze these two variables for each year from 2006 to 2010 to find out if there is a subtle annual shift in the timing of these phenomena. I hypothesize that if the "west-side shuffle" of Southern Resident Killer Whales is a foraging pattern related to upriver migration of adult Fraser Chinook salmon, the timing of west-side shuffle should correlate with the timing of Fraser Chinook salmon upriver migration with a consistent lag.

Previous Studies

Ashe et al. (2010) mapped SRKW sightings between May to August 2006 in the Salish Sea area using the geographic information system (GIS) and for each sighting, it was determined by observation if the killer whales were foraging or feeding. They discovered that SRKW were more likely to be foraging or feeding along the south-west coast of San Juan Island than at other adjacent locations.

E. Ashe, D. P. Noren and R. Williams

Animal behaviour and marine protected areas

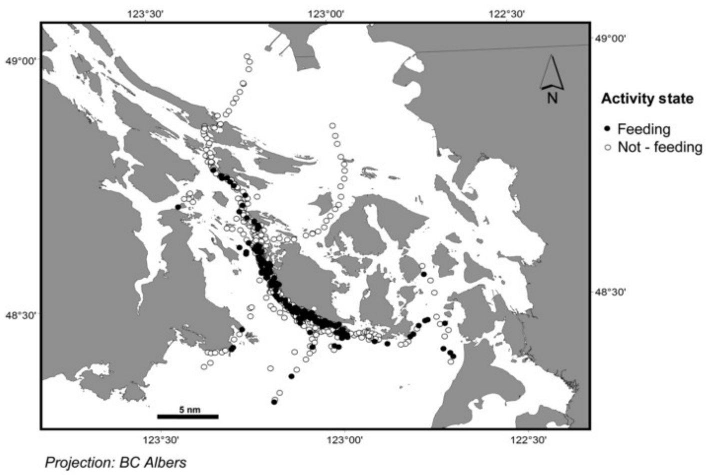
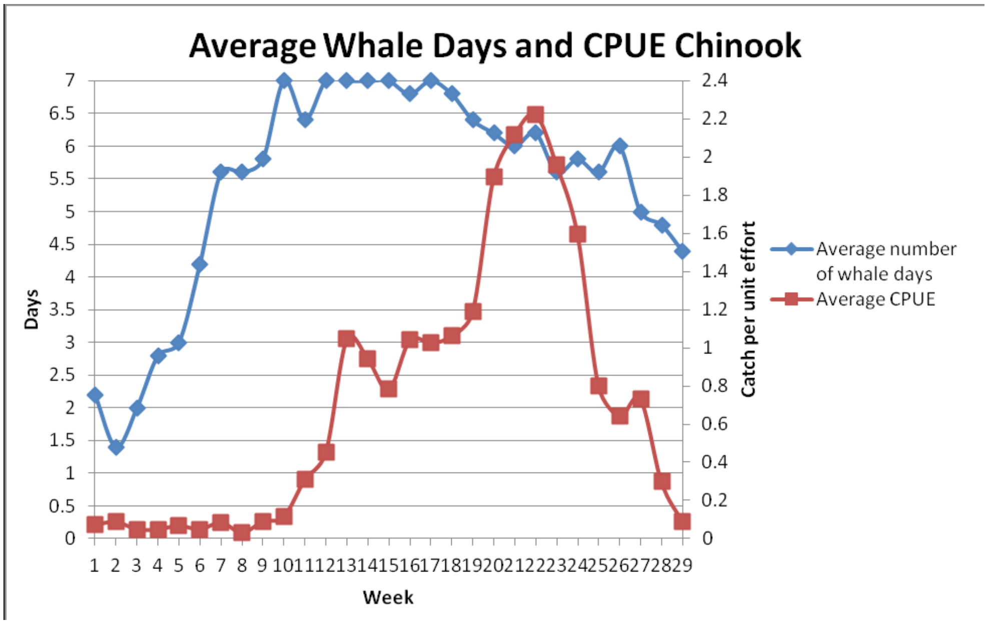


Figure 2 Map of locations for all feeding (closed circles) and non-feeding (open circles) activity observations ($n = 764$) in the study area.

©Ashe et al. 2010

Charla Basran, a Beam Reach student from 2011, inferred from Ashe's study that Chinook density may be relatively high in the south-west coast of San Juan Island. She discovered that the number of whale days (days where killer whale sightings occur) per week in the Salish Sea had a significant positive correlation with the FCS density which was inferred from catch per unit effort of FCS at Albion test fishery.

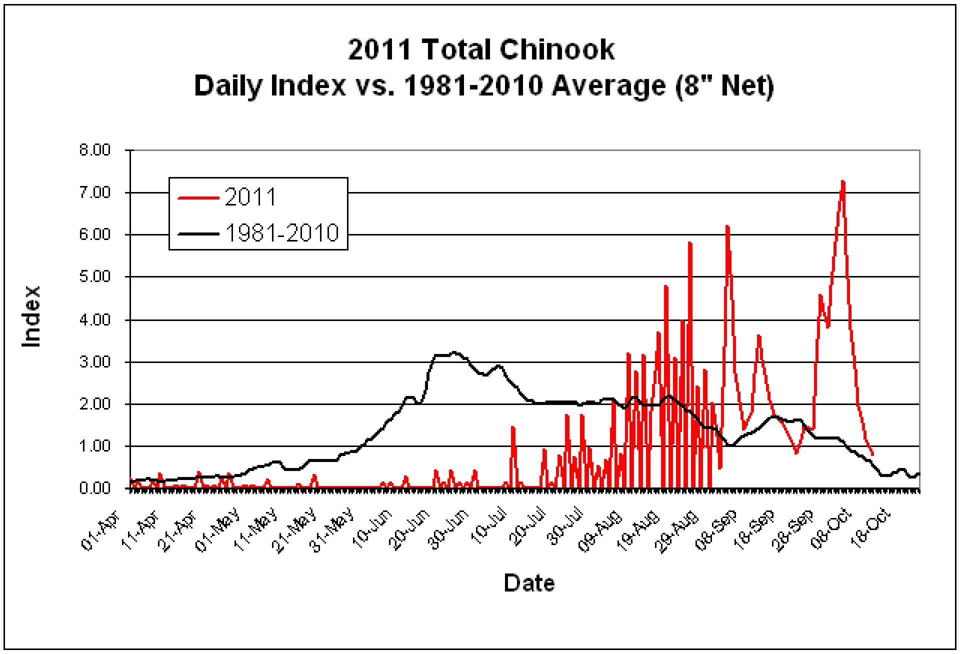


© Basran 2011

Basran averaged "whale days" at San Juan Islands per week from 2006 to 2010, superimposing temporally numerical data from each year to obtain a general trend. She then applied a similar method to obtain a time series of weekly catch per unit effort of FCS from 2006 to 2010, at Albion Test Fishery at Albion, BC, Canada, a test fishery 50km upstream of Fraser River. Basran discovered a lag of approximately one to two weeks between the peak in number of killer whale sightings per week, often occurring in late July or August, and the peak of CPUE of FCS, often occurring in early September.

CPUE as Quantitative Indication of FCS Upriver Migration

My primary source of FCS count data will remain to be CPUE of FCS at Albion Test Fishery. I will plot CPUE by day to obtain a time series similar to one below:



© Albion Test Fishery 2011

The Albion Test Fishery deploys their fishing vessel twice a day to coincide with the daily high tide (ATF 2010). During flood tide, ocean currents travel from south to north from Haro Strait to Fraser River. Tidal currents can influence salmon movement. Candy and Quinn (1999) have discovered that adult Chinook salmon from British Columbia coastal waters tend to move with tidal currents and would mill around in areas of mixing water. From this information I infer that flood tide facilitates upriver migration of adult FCS from Salish Sea through Haro Strait, and that CPUE can be representative of FCS upriver migration. Therefore I will use the CPUE as a quantitative indication of FCS upriver migration. Furthermore, one could infer that adult FCS travel through the west coast of San Juan Island shortly before they enter Fraser River. Therefore, the presence of FCS at Haro Strait will precede an increase in CPUE.

The average swim speed of an adult Chinook Salmon ranges from 0.7 to 2.7 km/h (Candy and Quinn 1999) The distance between San Juan Island and Albion is about 150km , which would take a FCS at least 3-4 days to travel if swimming continuously. With reference to Basran's (2011) finding, one could expect a time lag up to 14 days between FCS presence off the west coast of San Juan Island and Albion.

Quantifying West-side Shuffle

As a baseline of reference, I define the west-side shuffle as a locomotive pattern. A Pacific killer whale can swim up to 13 km/h, and travel up to 96-161km of ocean in a day (Gordon and Flaherty 1995). The west coast of San Juan Island is approximately 30km. Depending on how far up north SRKW travel for each shuffle, one "shuffle" is roughly 60-120km. To travel San Juan Islands in a loop through Haro Strait and Rosario Strait, the distance is about 150km. A shuffle or loop should take a killer whale at least 24-36 hours.

From this information, I infer that during the west-side shuffle, the same group or individual SRKW would be observed again in at most 4 days.

Data Analysis

Archived temporal and spatial records of SRKW sightings from 2006-2010 will be obtained from the Orca Master database of the Whale Museum in Friday Harbor, WA. Sightings will be queried using SQLShare (Fourdeuce, inc. 2005-2009). Number of sightings will be plotted as a time series for each month of the year. To determine the beginning of west-side shuffle, I will examine the number of days without sightings in between days with sightings. If the abovementioned number of days is above four days, one could infer that the killer whales have made an exit and not a shuffle or loop. The beginning of west-side shuffle should see a consistent occurrence of sightings. No-sighting days during west-side shuffle should be less than or equal to four. The points in time where west-side shuffle begins and ends will thus be determined.

The above data will be juxtaposed with the time series of CPUE. The points in time where west-side shuffle begins and ends will be juxtaposed with the CPUE of FCS during the same time. The rate of increase or decrease of CPUE of these points in time will be determined each year and compared across all years.

Secondly, the maximum number of sightings for each year, and the maximum CPUE for each year will be determined. Time lag will be counted between these two events for each year and compared across all years.

Field Data Collection

From May 1 to May 23 2012, SRKW sightings while on board a research vessel will be tracked using a SPOT GPS tracking device to determine the direction of travel of SRKW. This will be done while referring to ATF CPUE data continuously. The beginning time of west-side shuffle will be determined and compared to CPUE similar to above method, with addition of directional data.

Further Discussion

There is a possibility that the FCS upriver migration can happen concurrently with downstream migration of FCS fry and smolts, which are known to begin to migrate to sea in spring (Turner 2009; Quinn 2005). Due to variable spawning grounds of different populations of FCS, the timing of juvenile entry into saltwater is highly variable as well (DFO 2011).

Trudel et al. (2009) discovered that juvenile FCS appeared to remain within the Strait of Georgia, which is north of Fraser River and has a lower salinity than Haro strait, during their first year. After their first year at sea, these juveniles migrate south out of Strait of Georgia through Juan de Fuca Strait. Older Chinook could often be found south of their natal stream.

It remains clear that SRKW at Haro Strait would primarily be foraging for adult FCS en route to upriver migration. However, Albion Test Fishery has not quantified the proportion of juveniles and adults in their daily catch. A portion of downriver-migrating juveniles may exist in the fish count which should be taken into consideration. Nonetheless, given the fact that the catch occurs during flood tide and the timing of juvenile downriver migration is highly variable across the months, I maintain that CPUE at ATF can be used as a quantitative indication of FCS upriver migration.

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