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

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Introduction

Residents are one of three killer whale ecotypes that specialize on Chinook salmon inhabiting the North Pacific region (Ford, Ellis and Balcomb 2000; Ford and Ellis 2006; Hauser *et al.* 2007 and Marsh 2008). Southern Resident Killer Whales (SRKW) were listed as endangered under the endangered species act (ESA) in November 2005 (NMFS 2005). A significant amount of scientific effort has been put into studying SRKW behavior, ecology, and environmental relationships to better understand their relationship with their surroundings (Ford and Ellis 2006; Zamon et al. 2007 and Felleman 1986). Significant amounts of information is known about summer behaviors, distribution patterns, and environmental relationships compared to in winter months (Hauser *et al.* 2007; Zamon *et al.* 2007 and Ford and Ellis 2006), when this study was conducted. SRKW are known to spend much of their time around the southern Vancouver Island and Washington state area, specifically Haro Strait (Hauser *et al.* 2007), feeding primarily on Chinook (*Oncorhynchus tshawytscha*) and Chum (*Oncorhynchus keta*) salmon (Baird et al. 2003 and Ford and Ellis 2006). Past studies have shown how environmental factors such as tides and currents effect hunting strategies and navigation paths of various marine mammals and reptiles such as turtles and seals (Hindle, Rosen and Trites 2010; Ream, Sterling and Loughlin 2005 and

Gaspar et al. 2006). Although it has been widely accepted SRKW follow Chinook salmon (Ford and Ellis 2006; Felleman 1986 and Baird *et al.* 2003) there has yet to be a study demonstrating the assumption is accurate. More simply, it is yet to be known if SRKW take advantage of water tides and currents similar to behavior of turtles and seals (Gaspar *et el*. 2006).

Tides and currents are used by multiple marine mammals for assistance in hunting, migration, or reducing energy expenditures (Ream, Sterling and Loughlin 2005 and Gaspar *et al.* 2006). While moving with the tide and current marine mammals conserve additional energy they would naturally expend while swimming against them (Ream, Sterling and Loughlin 2005). Therefore, the conserved energy could be used for surface active behaviors (SABS). SABS can occur during many activity states (foraging, traveling etc.) of SRKW and can be influenced by outside factors such as tidal factors, prey abundance that provides energy for SABS, and boat presence (Ream, Sterling and Loughlin 2005; Noren *et al.* 2009; Benson and Trites 2002). Although studies have not specifically looked at frequency of SABS and energy budgets, they have examined activity states with relation to energy budgets (Noren 2011) and effects that alter frequency of SABS (Noren *et al.* 2009).

In addition to currents, salinity may also play some role in the movement of SRKW. Salinity in the Haro Strait, influenced by the unique bathymetry (Pawlowicz 2010), decreases with increased Fraser River input (Figure 1). Although little is known about salinity effects, attention and research has been increasingly targeted on relationships with salinity and the environment (Sutherland *et al.* 2011; Khangaonkar 2011 and

Pawlowicz 2010). Research on SRKW has yet to include salinity as an environmental factor.

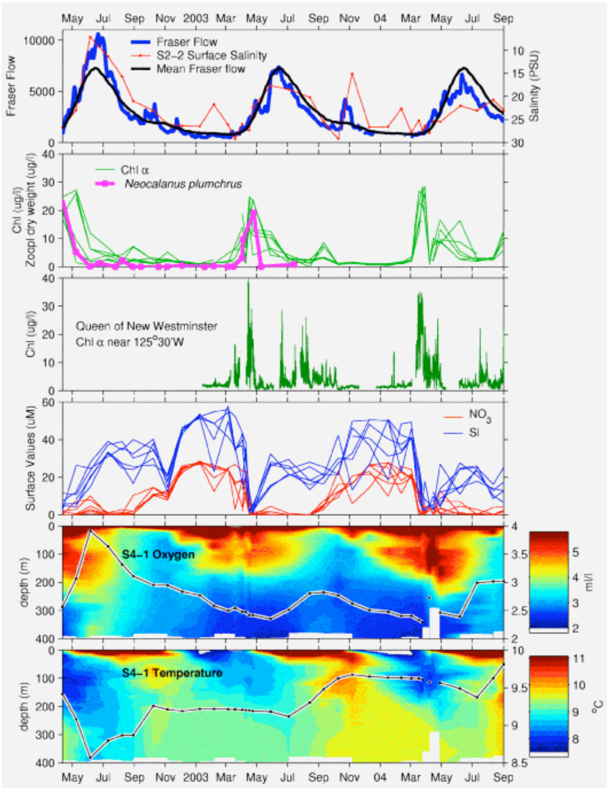

Figure 1: Graphs show how various factors change and affect properties in the Haro Strait. The top graph shows how the Fraser River flow influences the salinity in the Haro Strait over the course of 3 years (Pawlowicz 2010).

This study aims to answer if SRKW move with the tides and currents of the water they are navigating through and if SABS are more frequent while moving with or against tides and currents. Various SABS expend varied metabolic costs and energy requirements may be taken into account before participating in an activity (Noren 2011 and Ream, Sterling and Loughlin 2005). Therefore, physical factors, specifically tidal components and salinity, will play a major role in SRKW movement and SABS causing them to naturally move with the tides while noting salinity gradients and engaging in more SABS when navigating in the direction of tidal factors.

Methods

Data was collected from a 13 meter biodiesel-electric sailing catamaran (Gato Verde) over the course of a 3 week time period.

Data Collection Sites

From mid September to mid October data was collected at five primary sites designated by using a Global Positioning System (GPS): Salmon Bank, Eagle Point, Middle Bank, Pile Point, and Lime Kiln (Figure 2). When opportunities presented themselves four secondary sites were designated around the Strait of Georgia: Kellett Bluff, Turn Point, East Point, and West Bank (Figure 2). Locations outside of the primary and secondary sample sites were based on daily locations and opportune encounters with Southern Resident Killer Whales (SRKW). A GPS was used to obtain the specific location for each site where data was collected and observed. The five primary sites were chosen due to the frequent SRKW sightings in combination with regional location. The four secondary sites were visited if time and weather permitted. Data sites were desired on the North, West and South sides of the Salish Sea. There were three sites located on the South end of the Salish Sea: Salmon Bank, Middle Bank, and Eagle Point. Salmon Bank was chosen due to the shift in current to the NW and the SE. Salmon Bank is a key site to analyze and discover if current velocity has a relationship with SRKW choice of migration direction. Middle Bank is where the Strait of Juan de Fuca meets with the Haro Strait and SRKW pass this point to migrate out to the open ocean. Eagle Point is a common area for SRKW foraging and therefore a highly desired location. West side sites consist of Pile Point and Lime Kiln. SRKW must migrate through this region when moving up or down Haro Strait, which is a common sight for observations, therefore these destinations were selected.

Sites near the Strait of Georgia, secondary sites, were decided on due to the location on the North side of the Salish Sea. Currents in the Strait of Georgia regions split direction and velocity to the Southwest (Boundary Pass) and to the Southeast (just above Rosario Strait). Currents may have a strong influence on the desired direction SRKW decide to navigate and having currents split into different directions may shed some light.

Figure 2: Map of the sites where data was collected. Primary sites are points A-E. Point A is Salmon Bank. Point B is Middle Bank. Point C is Eagle Point. Point D is Pile Point. Point E is Lime Kiln. Secondary data collection sites are points F-I. Point F is Kellett Bluff. Point G is Turn Point. Point H is West Bank. Point I is East Point.

Archived Data

Archived data from NOAA's Tides and Currents and saltwatertides database was gathered from 2008-2011 for a reference to compare newly gathered data from a 3 week period on the Gato Verde. Tidal highs and lows were gathered and corresponded with whale sightings and location. Information on sightings around the area is kept in a database held within the Whale Museum on San Juan Island, WA. Tidal height and current velocity was then correlated with whale sightings and location using SQLShare

(Figure 3). Salinity and water temperature was then compared to whale sightings and location, again using SQLShare (Figure 3).

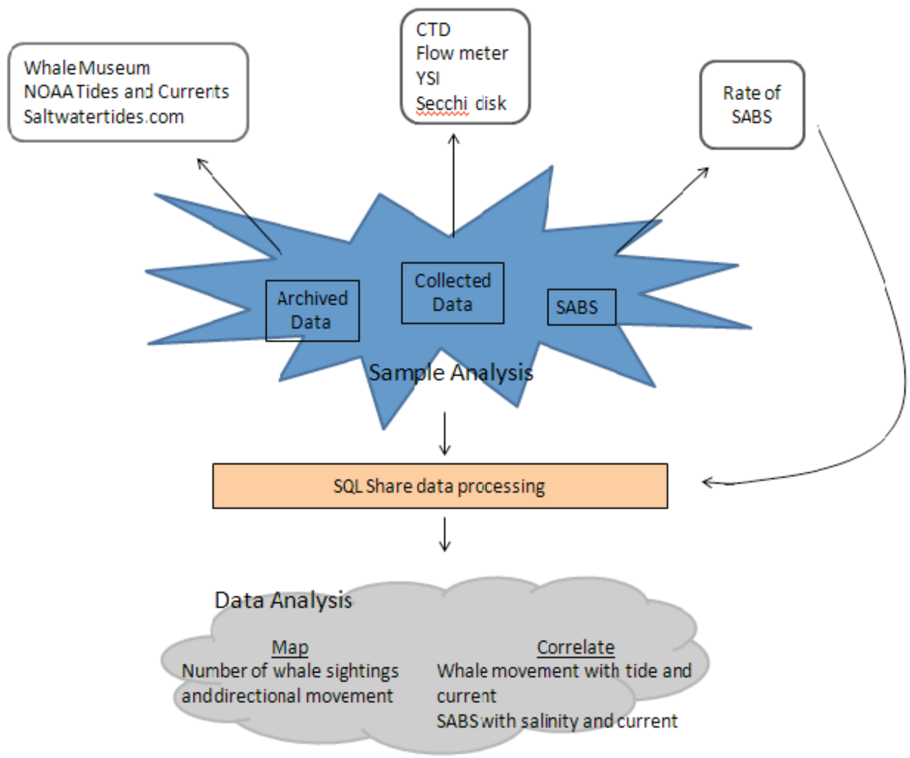

Figure 3: Diagram showing the relationship between sample analysis, data processing and data analysis

Collected Data

For sustainability purposes the Gato Verde stayed by southern sites for a few days so multiple tidal cycles could be monitored and recorded. Similarly, the Gato Verde docked near the northern sites for a few days consecutively. Measurements of temperature, salinity, wind speed, tidal height and current velocity were taken as close to a high and low tide as opportunity allowed. YSI probe was used when time was limited and the Conductivity, Temperature, and Depth (CTD) sensor was not logical. Lowering the YSI probe into the water for 5-15 minutes at 10 meters the temperature and salinity was measured. Using a CTD density, salinity, visibility, and temperature of the water at a precise location was measured and the data recorded directly to a computer after about 20 minutes time. The CTD was hooked up to a crane where 3 people helped to lower it in the water. Only data collected when lowering the CTD is used because it would be brought back through disturbed water. A transmissometer attached to the CTD measures particles suspended in the water, flurometer measures chlorophyll a florescence, and pressure strain gauge measures depth (Sea-Bird 2011).

Data was cross checked from the CTD and YSI to ensure information accuracy. A secchi disk was lowered into the water at each location to measure the visibility (Figure 3). Using the Washburn tables current was estimated and compared to the measured current. After stopping, an orange, an object that sits close to the water to minimize wind effects, was timed how long it took to float 13m (full length of the Gato Verde) to calculate current velocity (d=13m).

V=distance/time

To measure the current at certain depths (5-10, 10-20 and 20-30 meters) a General Oceanics torpedo flow meter was used. The flow meter was attached to the top of the CTD, thus, every time the CTD was cast current was measured at the equivalent depth (Figure 3). When CTD casts were not possible, due to time constraints, a weight was attached to the bottom of the flow meter and lowered to the desired depth for 15 minutes.

Surface Active Behaviors (SABS)

Data was collected and recoded when killer whales were encountered. Pod identification direction of movement (N, S, E, and W) and whether movement was with or against the current was recorded. Type and time of behavior was recorded separately to later quantify the rate at which each behavior was being displayed (Figure 3). Behaviors were defined as breaching, spy hopping, tail slap, peck slap, cartwheel, and porpoising. If foraging was observed it was noted and direction disregarded. Foraging is characterized as a sudden change in speed and direction, which may skew my results showing multiple direction changes when, in reality, it was foraging behavior.

Data Analysis

Using SQLShare queries were made to look at date, direction, location (latitude and longitude) and time of whale sighting.

Raw CTD data was plot in figures and graphs

Correlate whale movement with tide and current data along with whale SABS with salinity concentrations.

Map number of whale sightings (whale hot spots) vs whale directional movement.

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