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

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Introduction

Residents, one of three killer whale ecotypes, inhabit the North Pacific region and specialize on Chinook salmon, while others specialize on marine mammals and sharks (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). Much 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). 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).

Bathymetry is very unique in the Salish Sea. Yet organisms, such as seals, find their way across bodies of water using strictly tidal currents and not the bathymetry (Ream, Sterling and Loughlin 2005). SRKW prey movement, such as Chinook salmon, seems to be tidally dependent; therefore so might SRKW (Felleman 1986). Salish Sea currents are extremely variable and slight changes are perceived by and effect marine mammals (Hindle, Rosen and Trites 2010). Looking at Washbourne's Tables and tidal models of the San Juan Islands it is obvious how varied currents can be throughout the day (Foreman *et al.* 1995). Past studies have shown how environmental factors, such as tides and currents, effect hunting strategies and navigation paths of various vertebrates such as seals and turtles (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 this assumption is accurate. More simply, it is yet to be known if SRKW take advantage of water tides and currents similar to the behavior of turtles and seals (Gaspar *et al*. 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, it is possible the conserved energy could be used for surface active behaviors (SABS) of killer whales. 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, 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 in killer whales and energy budgets, a series of studies have examined activity states with relation to energy budgets and effects that alter frequency of SABS (Noren 2011 and Noren *et al.* 2009).

In addition to currents, salinity may also play some role in the movement of SRKW. Fresh water is less dense and rests on top of water with higher salinity concentrations. Bathymetry mixes the water column and Haro Straight, having unique bathymetry (some of the deepest depths), is predicted to have unique haloclines and water columns. Salinity in the Strait of Georgia (likely similar dynamics in Haro Strait) influenced by the unique bathymetry (Pawlowicz 2010 and Khangaonkar *et al.* 2011), 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).

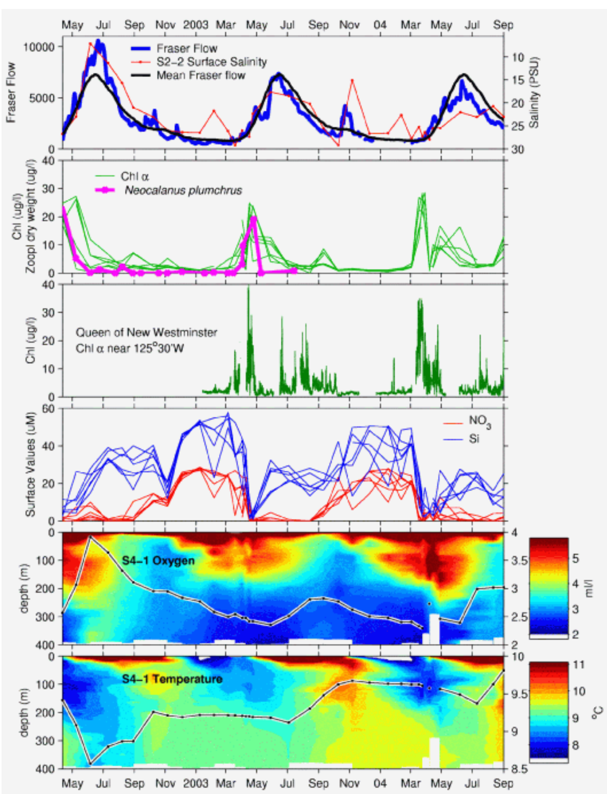


Figure 1: Graphs show how various factors change and affect properties in the Strait of Georgia, likely very likely similar in Haro Strait. The top graph shows how the Fraser River flow influences the salinity in the Haro Strait over the course of 3 years (Pawlowicz 2010).

This study aims to investigate if SRKW move with, against, or perpendicular to the currents of the water they are navigating through and if SABS are more frequent while moving with or against currents. SABS expend varied metabolic costs (Noren 2011 and Ream, Sterling and Loughlin 2005). The metabolic costs may have an effect on whale activity when moving with or against a current. SRKW live in a dynamic environment where physical factors, specifically current, salinity, and temperature, are constantly in flux, thus, it is likely they effect travel direction and energetics.

Methods

Data was collected on the west side of Stuart, Henry, and San Juan Island from a 13 meter biodiesel-electric sailing catamaran (Gato Verde) over the course of a 3 week time period.

Study Sites

From mid September to mid October data was collected at two primary sites designated by general location: north side and south side (Figure 2). The north side site was binned which included Kellett Bluff and Henry Island observations. Eagle Point and Salmon Bank were binned into the south side site. When opportunities presented themselves three secondary sites were visited: far north side, mid north side, and mid south side (Figure 2). Far north side site included Turn Point. The mid north side bin consisted of Orca Sound, Lime Kiln, and San Juan County Park. The mid south side site was binned, which included Hannah Heights, Pile Point, and False Bay. Open CPN (v 2.3.1, ©2000-2010) was used to obtain the specific location for each site where data was collected and observed. The primary sites were chosen due to the frequent SRKW sightings in combination with regional locations (N and S ends of Haro Strait). The far north side site was included because it is a frequent turn around point for SRKW. The mid north side and mid south side sites broke up the middle section of the west side where SRKW travel through and commonly observed. The mid south side has a shift in current and may provide insight to the relationship of current velocity and SRKW movement patterns.

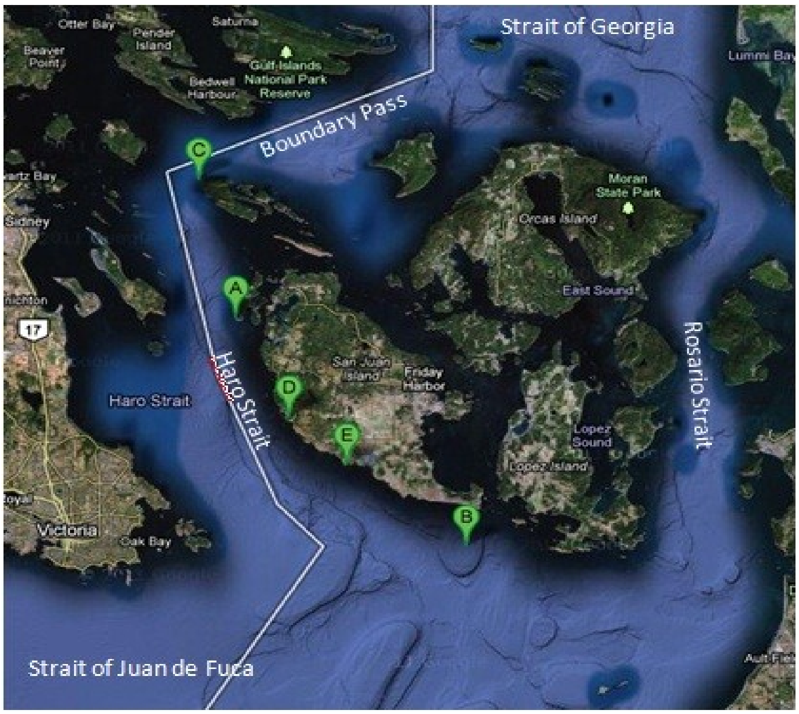


Figure 2: Map of the sites where data was collected. Primary sites are points A and B. Point A is north side site (Kellett Bluff and Henry Island. Point B is south side site (Eagle Point and Salmon Bank. Secondary sites are points C-E. Point C is far north point (Turn Point). Point D is mid north side (Orca Sound, Lime Kiln, and San Juan County Park. Point E is mid south side (Hannah Heights, Pile Point, and False Bay).

Archived Data

Archived current data from WWW Tide and Current Predictors (http://tbone.biol.sc.edu/tide/sites_uswest.html) database was gathered from 2000-2011 for a reference to compare newly gathered data from a 3 week period on the Gato Verde. Current data was collected for Salmon Bank, Pile Point, Lime Kiln, and Kellett Bluff prediction sites. Prediction sites were chosen based on minimal distance from study sight. Salmon Bank was an average of Cattle Point 1.2 miles and Cattle Point 2.8 miles sites. Pile Point data was obtained from the Discovery Island 3.3 miles site. Lime

Kiln current data was obtained from an average of Kellett Bluff and Discovery Island 3.3 miles sites. Kellett Bluff data was derived directly from Kellett Bluff site. The type of current (flood-water moving in, ebb-water moving out, and mix-water moving in and out) was gathered and compared to whale travel direction and location. Current was broken up into five classifications: strong flood (1.25->2.5), weak flood (<.25-1.25), mix-flood and ebb currents, weak ebb (<-.25- -1.25), and strong ebb (-1.25->-2.5).

Data on sightings around the area are kept in a database by the Whale Museum on San Juan Island, WA. This data was used as historical data for whale presence and direction of travel (Orca Master). A Global Positioning System (GPS) was used to obtain coordinates for observational locations were used to choose sights for archived data. When pod identification for a given record was labeled as “orca” it was uncertain if the whales were southern residents or transients and therefore the entire record was discarded. Coordinates were chosen based on relevance to study sites and given a location name. Location and coordinates consisted of inner Salmon Bank (48.4454, -123.035), outer Salmon Bank (48.4062, -123.031), Pile Point (48.4629, -123.109), Lime Kiln (48.5065, -123.179), Kellett Bluff 1 (48.5602, -123.217), and Kellett Bluff 2 (48.6089, -123.24). The two Salmon Bank locations were pooled together for Salmon Bank sightings and the two Kellett Bluff locations were pooled together for Kellett Bluff sightings. Pile Point and Lime Kiln coordinates only had one GPS location used for sightings records.

Whale travel direction was reported in the archives as N, S, E, and W with variations of each (ie. NNE or NE). If travel direction was not recorded, recorded data could not be used, hence the record was discarded. Direction that contained multiple compass directions (NNE) was given a simplified direction of the first noted direction (ie. NNE=N). Direction was transformed into degree with N=0^{o} and S=180^{o}. Current degree was subtracted from whale degree and assigned a category of with, against, or perpendicular depending on the difference in degrees. Each Movement with the current was defined as travel $0^{o}\pm45^{o}$ from the direction of current. Movement against the current was defined as travel $180^{o}\pm45^{o}$ away from the direction of the current. Movement perpendicular to the current encompassed travel $\pm90^{o}$ from the direction of the current.

Further investigation with archived data was done on Kellett Bluff due to the distinctive pattern difference in the collected data (figure 4). Similar patterns in current direction and whale travel direction for far north, mid north, mid south, and south study sites resulted in only one location being chosen to analyze archived data (figure 4). Pile Point, mid south study site, was analyzed because it was among the site which demonstrated standard pattern compared to Kellett Bluff, north study site. Only months of September and October were closely examined because field data was collected at the end and beginning of those months. Archived data was cross examined with collected data for Kellett Buff to distinguish pattern differences overtime between current direction and whale travel direction. Data management was carried out using SQLShare (eScience ©2011) and statistical testing was carried out using R (v 2.13.2 ©2011).

Field Collected Data

Measurements of temperature, salinity, and surface current velocity were taken at designated study sites during ebb, flood, and slack tides as opportunity allowed.

Current velocity was obtained through daily predictions from Multi-Tide (v 11.0.5). Daily predictions were averaged if the location where data was collected was between current predicting stations. Predicted current velocity was compared to Washbourne's Table predictions to determine how accurate predictions were. The type of current (strong or weak flood, ebb, or mix) was noted when SRKW were first seen and if it changed while with SRKW. YSI probe was used to measure surface temperature and salinity when time was limited and the Conductivity, Temperature, and Depth (CTD) sensor was not logical. Using a CTD depth, salinity, and temperature of the water at a precise location was measured. The CTD was hooked up to a crane and 4 people helped lower it into the water. Only data collected on the down-cast of CTD is used because up-cast data would be brought back through previously 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 if measurements from both were measured in the same day (table 1). CTD salinity and temperature measurements were averaged per cast per day then compared to YSI salinity and temperature measurements. As seen in table 1 CTD and YSI measurements are relatively similar when measurements were taken around the same location on the same days. Thus, data collected with either instrument, CTD or YSI, can be used.

Date	Location	Instrument Used	Salinity (ppm)	Temp (^{o}C)
9/20/2011	Salmon Bank	YSI	29.4	11.4
9/20/2011	Kellett Bluff	CTD	30.29279	10.15402
9/21/2011	Kellett Bluff	CTD	30.44803	10.13427
9/21/2011	San Juan County Park	YSI	29.5	10.8
9/22/2011	Lime Kiln	YSI	29.8	10.5
9/22/2011	SW of Salmon Bank	CTD	30.81036	9.972313
9/23/2011	SW of Salmon Bank	CTD	30.88504	10.01237
9/24/2011	Kellett Bluff	CTD	30.59367	9.936503
9/27/2011	Kellett Bluff	CTD	30.75479	9.582711
9/27/2011	False Bay	YSI	30.9	9.7
9/27/2011	False Bay	YSI	30.9	9.8
9/27/2011	Orca Sound	YSI	30.5	10.2
9/27/2011	Kellett Bluff	CTD	30.98528	9.64334
9/28/2011	Hannah Heights	YSI	31.2	9.7
9/28/2011	Kellett Bluff	YSI	30.9	9.9
10/3/2011	Kellett Bluff	CTD	30.35065	9.816338
10/3/2011	Kellett Bluff	CTD	30.63214	9.742815
10/4/2011	Turn Point	CTD	30.11564	9.888296
10/5/2011	Turn Point	CTD	29.7160	10.0153

			4	2
10/5/2011	Kellett Bluff	CTD	30.3853 4	9.85694 1
10/6/2011	Kellett Bluff	CTD	30.4931 9	9.79076 1
10/6/2011	Outter Salmon Bank	CTD	31.0159 5	9.84628 4
10/7/2011	SW Salmon Bank	CTD	30.4824	10.0046 4
10/7/2011	Kellett Bluff	CTD	30.5706 5	9.82745 4
10/8/2011	N of Orca Sound	YSI	30.3	10.1
10/9/2011	Kellett Bluff	CTD	30.1905 2	9.82271 6
10/10/201 1	Kellett Bluff	CTD	30.1317 5	9.90804 9
10/12/201 1	Kellett Bluff	CTD	30.3563 9	9.82383 2
10/12/201 1	SW Salmon Bank	CTD	30.7769 8	9.82865 4

Table 1: Shows the similarities between CTD and YSI measurements of salinity and temperature. Days where data was collected around the same area are similar regardless which instrument was used. Therefore, days where only one instrument was used provided accurate data.

Haloclines and thermoclines (HTC) were recorded when analyzing CTD casts by day and compared to SABS. Δ salinity and Δ temperature was taken from each cast per day in the top 30m of the water column and the full 60m. Δ salinity and Δ temperature was taken for the top 30m because SRKW spend most of their time within that portion of the water column (Baird *et al. 2003*). Data from the top 30m was then compared to SABS and similarly done with 60m. Various depths of HTC were defined as mixed, standard stratification, above average stratification, and high stratification. Mixed stratification included casts with no HTC, standard stratification consisted of 1 HTC, above average stratification contained 2 HTC, and high stratification had 3 HTC. Depth at which HTC occurred was compared to total amount of SABS by date.

Surface Active Behaviors (SABS)

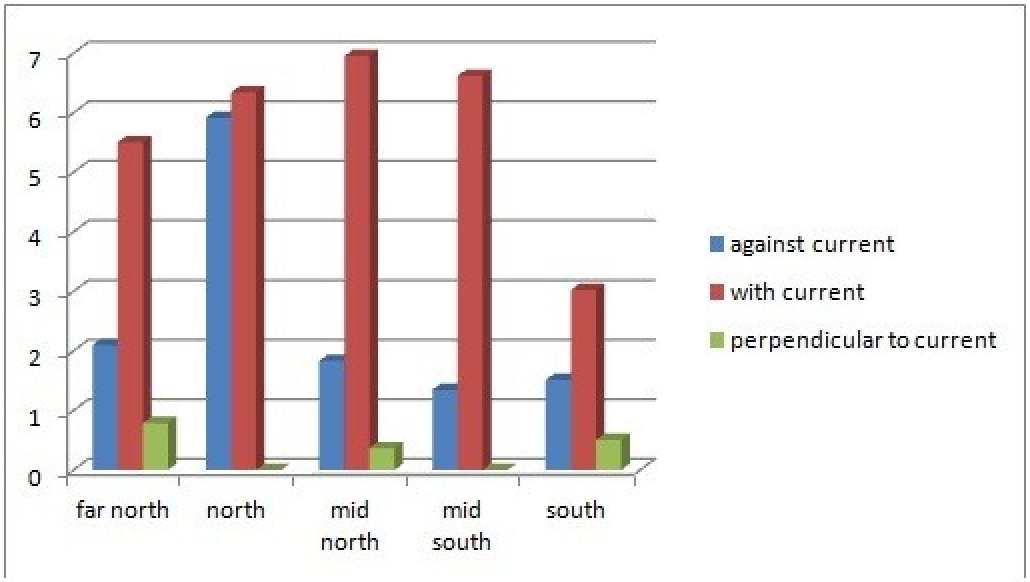
Data was collected and recoded when killer whales were encountered. Direction of movement (N, S, E, and W) of SRKW and whether movement was with, against, or perpendicular to the current was recorded. Current data from prediction sites were gathered at the end of each day that corresponded with time and location of whale encounter to acquire current velocity and direction. Type and time of behavior was recorded separately to later quantify the rate at which each behavior was being displayed. Behaviors were defined as breaching, spy hopping, fluke slap, reverse fluke slap, peck slap, cartwheel, and porpoising. If foraging was observed it was noted and traveling direction disregarded. Foraging is characterized as a sudden change in speed and direction. If foraging was not noted it may have skewed the results. This would show multiple direction changes when, in reality, only foraging occurred.

Results

Whale Travel-collected data

SRKW spend most of their time, about 70.4%, traveling (Noren 2011). Of the three weeks spent observing SRKW it was found 22% of the time they were traveling against the current, 70% of the time they were traveling with the current, and 6% of the time they were traveling perpendicular to the current. Whale travel direction was compared to current direction (flood vs. ebb) by day and location (figure 3). Wilcoxon tests were run in R; however, there was not a statistical relationship between current direction and whale travel direction. When comparing whale travel direction going with the current $p=0.402$ and when going against the current $p=0.6905$. Testing the relationship between ebb currents and whale travel direction with and against the current $p=0.1425$. Analyzing flood currents and whale travel direction with and against the current p=0.8413. Sample size for daily parameters was n=12 and for flood and ebb parameters n=24. With minimal (n=3) and specific days consisting foraging, whale movement perpendicular to current direction was cross examined with foraging data. Foraging data collected within the same time period (fall 2011) was adopted from Hayley Dorrance and Charla Basran. Conversely, no correlation was found to exist.

A.



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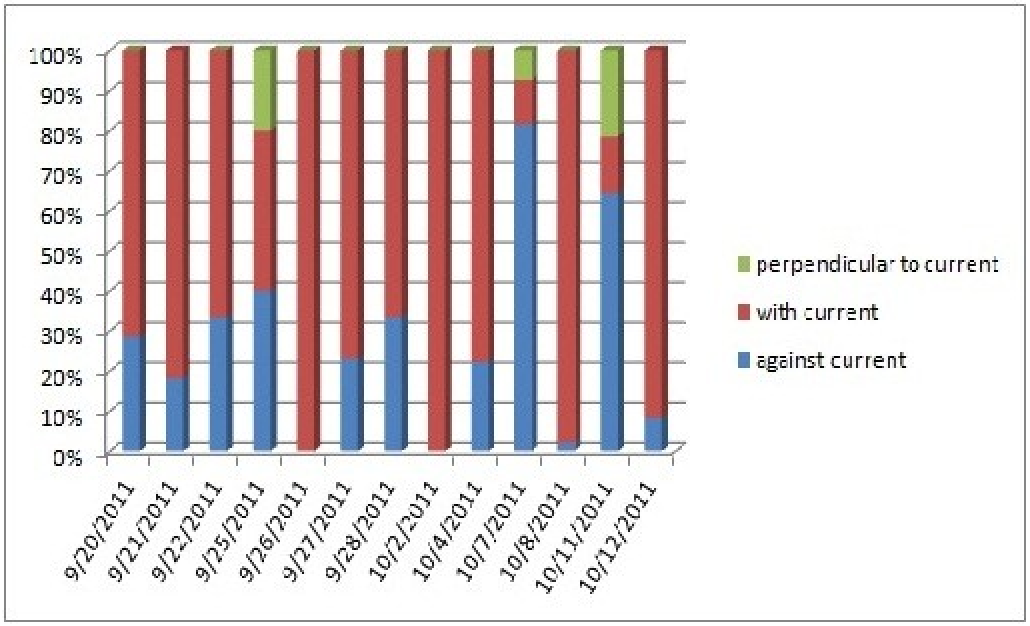
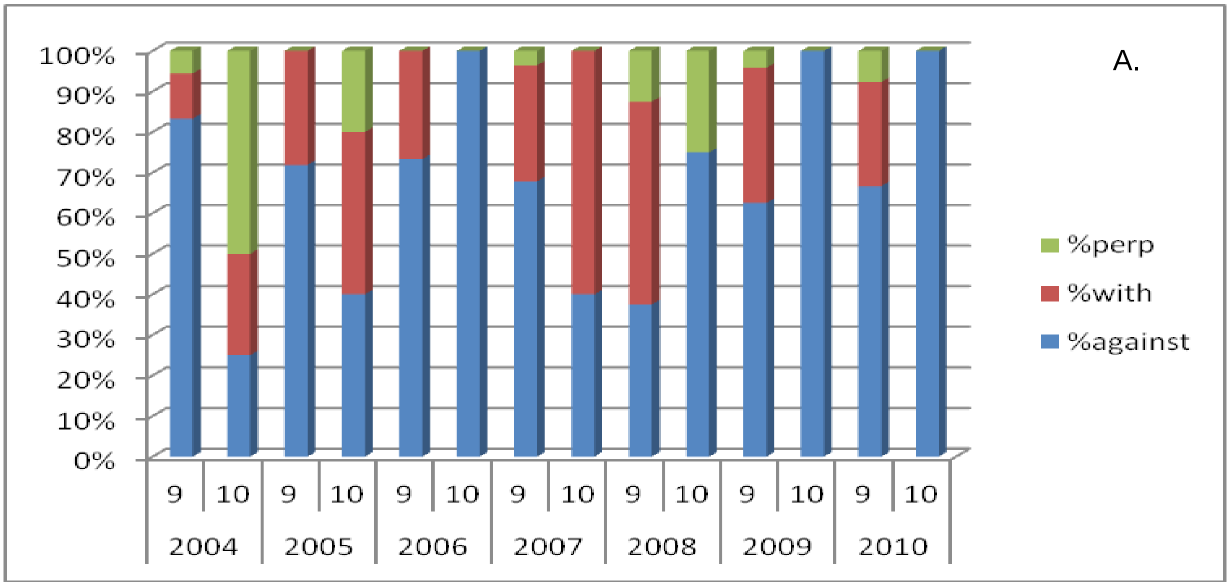


***Figure 3*:** Relationship between current direction (flood or ebb) and whale travel direction (with, against, or perpendicular). Graph A shows current direction and whale direction by location and graph B shows direction by date.

Majority of the study sites show a standard pattern of whales traveling concurrent to the current; although the north site shows the greatest variance.

Whale travel-archived data

Ten years of archived data was examined for Pile Point. Whale sightings and current data from archives were examined using SQL Share and R. Before the year 2004 whale sightings were not recording during the months of September and October, therefore only the years 2004-2010 of data were analyzed further. Data was analyzed in a general sense as well as by flood and ebb. Flood and ebb data was then compared to whale travel direction. Archived data did not have 7 consecutive years available with sightings in September and October; however, for comparison purposes years were still used. 2006 and 2010 years had only September sightings recorded. At Pile Point it was found SRKW invest majority of their time navigating against the currents of Haro Strait (figure 4).



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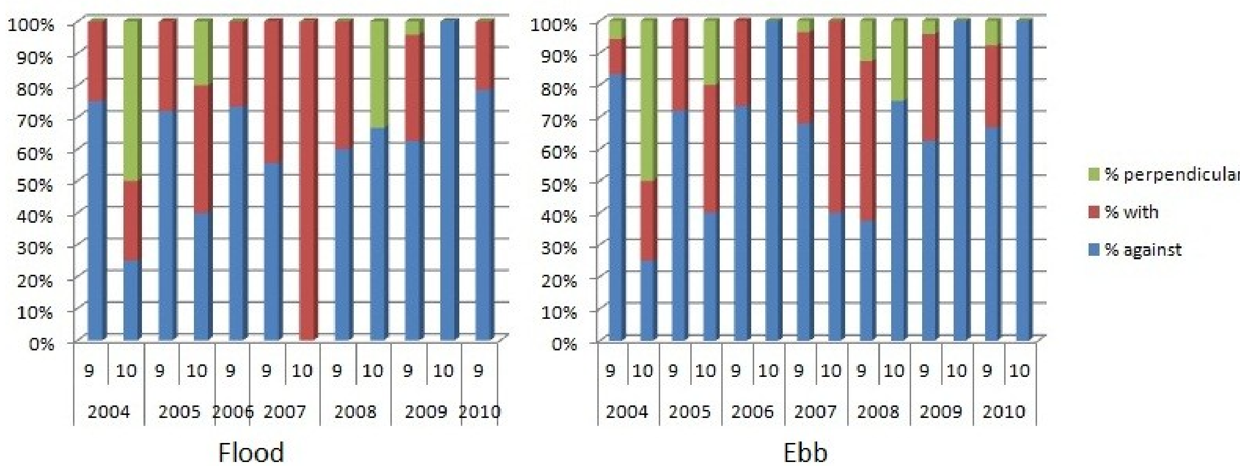

***Figure 4*:** Whale direction compared to current direction at Pile Point from 2004-2010. Graph A illustrates the general whale: current summary while B shows the relationship during a flood and C during an ebb.

Surface Active Behaviors

SABS were analyzed as SABS per hour per day of observation where whales were observed on 13 days. SABS and current were analyzed by day (n=13) and by site as well as current type (n=10). As predicted, SABS frequency increased when whales traveled equivalent to current flow direction; however, there is not enough statistical evidence to say there is a relationship (figure 5). P=0.6857 for flood and ebb SABS against the current and p=1 for flood and ebb SABS with the current.

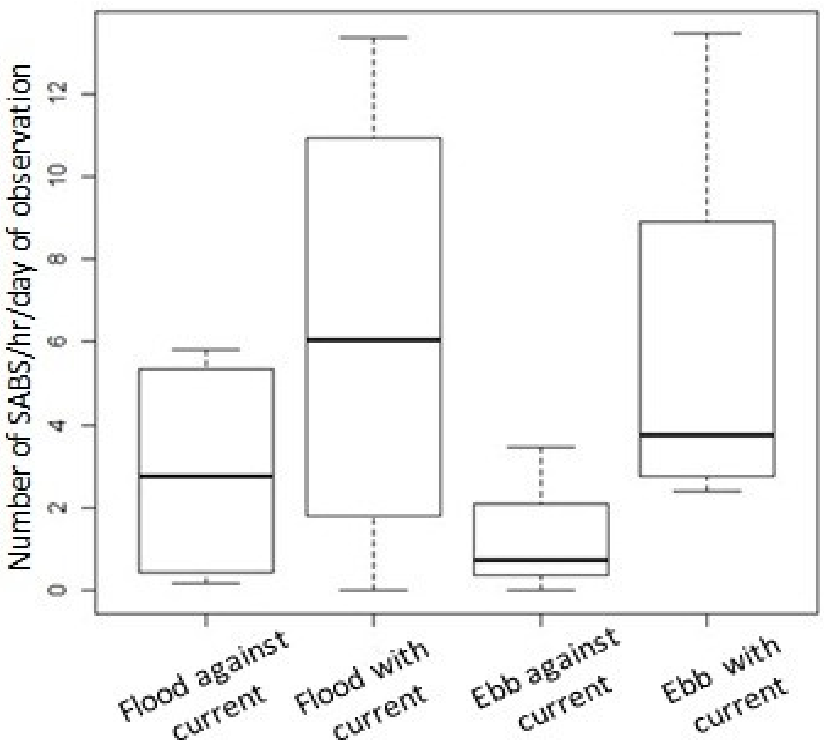

Figure 5: Comparing amount of SABS to current (flood vs. ebb) and whale travel direction (with or against).

To look more in depth at physical factors that may affect the energetics of a killer whale, water profiles were taken. Halocline and thermocline depths were examined with the amount of observed SABS per hour per day. However, there were only five data points due to the lack of coinciding whale observation days to days where CTD casts were taken (r^2=0.436). Three data points were taken at Kellett Bluff and two were taken Salmon Bank and Turn Point. Stratification was very heavily weighted in the standard stratification category (n=4). The outlying point is a well mixed stratification day (n=1) and had the most amount of SABS observed.

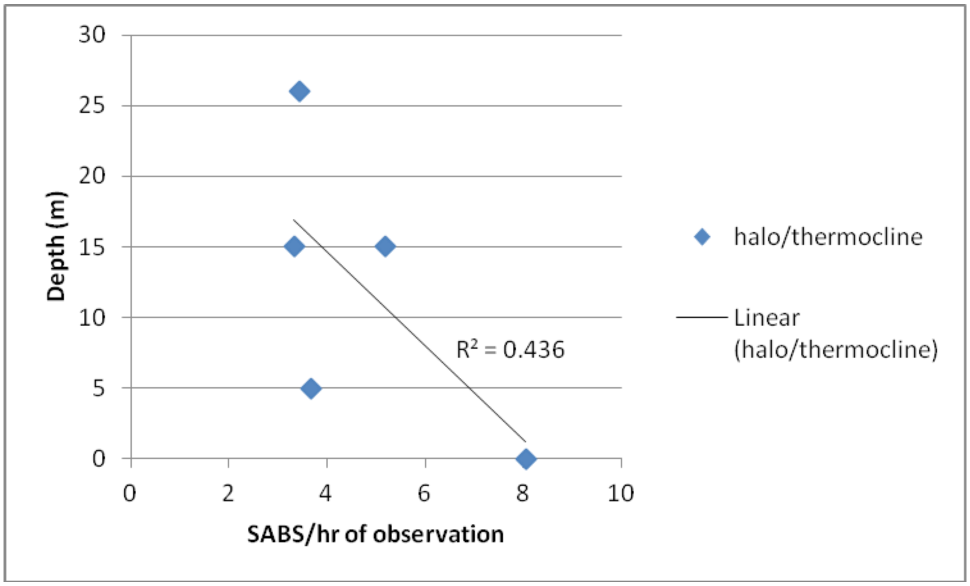

Figure 5: Number of SABS/hr of observation against halocline and thermocline depth (m).

Snap shots of the water column at various locations were taken using a CTD. From the CTD casts Δ salinity and Δ temperature was extracted. To compare Δ salinity and Δ temperature to SABS, observations had to coincide with CTD casts (n=5, figure 6). Because SRKW spend majority of their time within the top 30m of the water column Δ salinity and Δ temperature was calculated at 30m and 60m (Baird *et al.* 2003). 60m was used because it was twice the depth of typical SRKW depth and possibly a depth entered when participating in certain SABS. Δ salinity and Δ temperature do not have an effect on SABS per hour of observation at 30m or 60m (patterns are the same). The far outlying data points may sway the results; however, with a small sample size it is hard to reach a confident conclusion.

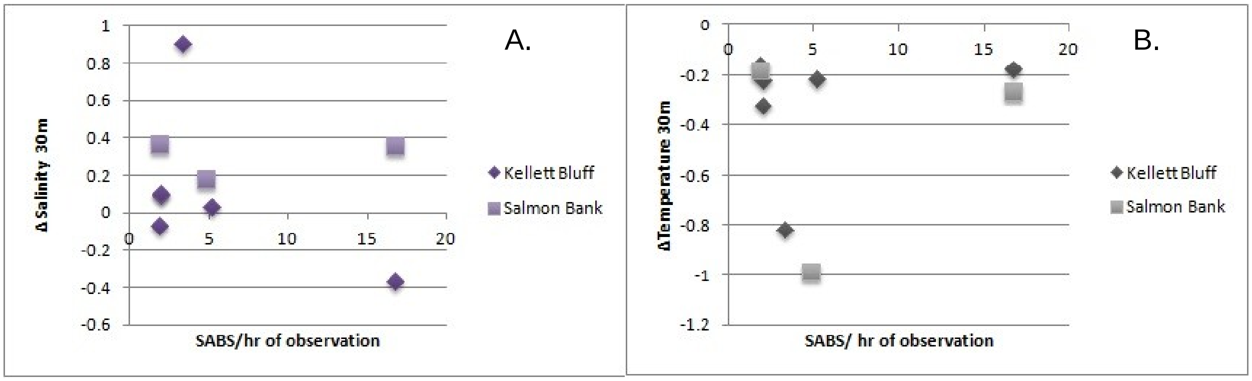

Figure 6: Graph A shows the relationship between SABS/hr of observation and the Δ salinity within the top 30m of the water column at Kellett Bluff and Salmon Bank. B. Δ temperature within the top 30m of the water column compared to SABS at Kellett Bluff and Salmon Bank. Δ salinity and Δ temperature within the top 60m of the water column showed the same patters as depth of 30m.

Discussion

This study contains bias of data collection days only taking place when whales were sighted and between the hours of 9:30 and 16:20 between the days of September 19 – October 13, 2011.

Current direction vs. whale travel direction

The common theory behind whale travel has been linked to the current direction; however, being such a common hypothesis it has been overlooked to test the theory. It was found whales prefer to travel in the direction of the current; however, it was not a statistically significant finding. Noren found depending on the sex of the whale there are varying metabolic costs (2011). A model study found Stellar sea lion swimming efficiency increased when traveling with the current compared to against the current (Hindle, Rosen and Trites 2010). Thus, whale gender, possibly individual whales, and current intensity should be incorporated into future studies.

SRKW showed varied short and long term trends. Short term included collected field data over three weeks whereas the long term consisted of collected archived data over seven years. Short term trends showed whales traveling with the current more than against or perpendicular to the current. Long term trends showed whales traveling most frequently against the current compared to with or perpendicular to the current. These trends may be based on the overall travel metabolic costs for a SRKW. Felleman came to similar results (1986). It seemed whales were aware of currents and current change times; therefore, had change of directions or milling around slack tides (Felleman 1986). Continual analysis of the collected data by monitoring the time change in currents may reveal results similar to Felleman's. Specifically, changes 2 hours before and after currents would be the object of these analyses (Felleman 1986). Seasonal comparisons could also be analyzed as well as behavior differences between flood and ebb. It was found whales traveled north more often in Haro Strait compared to Rosario Strait when they frequently traveled south (Felleman 1986). Data could be collected in each location to investigate if bathymetry differences in these regions effects travel direction.

Archived data was only used from 2004-2010 because September and October months were necessary for comparison to field data. Collected data was recorded from the last two weeks of September and the first two weeks of October, therefore, both September and October were necessary to investigate if patterns were similar in past years. Archived data showed opposite results compared to field data. However, this may be due to alternative recording methods. Direction of travel may have been misdiagnosed when sightings were reported because sightings may be reported by anyone, even untrained observers. If additional data was to be collected for the spring season using the same methods, a seasonal correlation could be conducted on field and archived data. Seasonal relationships could be examined to see if they produce similar findings. If relationships change data should be analyzed for another year to see if there is a pattern or if a relationship between real time and archived data has changed. If the relationship exists and has shifted, alternative factors such as prey density and currents should be monitored in real time and compared to archived data.

Previous studies have shown marine mammals do not necessarily use bathymetry landmarks to travel but use the tidal currents (Ream, Sterling and Loughlin 2005). Future studies may want to look further into the currents. This can be done by examining current intensity as well as time before and after a current direction change compared to whale travel direction. Current intensity may play a role and although current intensity was recorded it was not a factor due to time restraints.

Current and whale travel direction vs. SABS

Trends clearly show a higher frequency of SABS when traveling in the same direction of the current; however, with additional data statistical tests may show a deeper relationship. In addition, a study on Stellar sea lions found a change in swimming patterns when going with vs. against currents (Hindle, Rosen, and Trites 2010). Although dive durations were not recorded in this study, SABS were thought to change based on energy expenditure and therefore based on effort swimming with compared to against currents. It appears there are more SABS on a flood compared to an ebb.

Noren shows varied metabolic costs for different daily activities including foraging and traveling (2011). Further studies could be conducted on the frequency of SABS compared to foraging efforts as well as metabolic costs. As stated before, when exploring currents and whale travel direction, location, season and current type should be considered. Although multiple locations were included various straits and passes were not. Haro Strait has a very unique bathymetry and with close similarity to the Strait of Georgia data collected from both sites could be compared in future studies (Pawlowicz 2010).

Halocline and thermocline vs. SABS

There is a lack of literature on the relationship between cline and SABS. Due to small sample size (n=5) it is hard to distinguish if there may be a trend or significant relationship with more data. Results show there is no relationship between cline and SABS. Bathymetry may play a role in SABS thus, more data is necessary for a more confident analysis. Haro Strait is frequently used by SRKW; however, other bodies of water were not taken into account as previously stated (Hauser *et al.* 2007 and Baird *et al.* 2003). The fall season brings extreme variability to the San Juan Islands, which generates additional questions about seasonal variability. Locality, Haro Strait compared to Rosario Strait, raises even more questions. Future studies could ensure CTD casts are done as close to whale sightings as possible to increase sample size. Data would need to be collected during spring and fall to incorporate seasonal variability. Locality would require whales observed in both Haro Strait and Rosario Strait. Rosario Strait is less visited by SRKW may result in less data by location; however, the comparison between locations is possible.

Δ salinity and Δ temperature vs. SABS

There was one outlying point for Δ salinity vs. SABS as well as Δ temperature vs SABS which could contribute to the lack of statistical significance. The data points include mostly standard stratification and one mixed. Data was matched with whale observation days and therefore many days discarded. Sample size was n=9, n=3 at Salmon Bank and n=6 at Kellett Bluff, and thus additional data is necessary for a more confident conclusion. Due to the fact a whale is a relatively large marine mammal and the Salish Sea has extremely variable water columns, changes in salinity and temperature may be unnoticed by a SRKW. Although, fall has a broader range of water column stratification when comparing fall to spring. Seasonal comparisons of Δ salinity and Δ temperature would be beneficial before conclusions are reached suggesting variability in salinity and temperature has no affect on SABS.

Conclusions

In conclusion, this study shows relationships between four different aspects of physical factors and SRKW movement or behavior. These aspects include: current direction and whale travel direction, current and whale travel direction vs SABS, halocline and thermocline vs SABS, and Δ salinity and Δ temperature vs SABS (figures 3-6). While it cannot be said with certainty there are strong relationships, there were trends observed between current direction and whale travel direction and current direction and SABS. The current direction and whale travel direction short term correlation showed a stronger relationship with the current rather than against the current. The short term correlation consisted of a three week collection of field data whereas the long term correlation consisted of seven years worth of archived data. The long term correlation showed a stronger relationship against the current rather than with the current. It is uncertain why field and archived data do not show similar patterns between current direction and whale travel direction. Therefore, additional data is necessary to find a pattern or shift in pattern between current direction and whale travel direction. Current intensity may also have an effect on whale travel direction and should therefore be added to future studies. The current direction vs SABS trend suggests a higher frequency of SABS when SRKW travel with the current. Again, additional data would provide more insight and with further statistical tests the strength of the relationship could be identified. This study was the first to establish a relationship, although extremely subtle, between halocline and thermocline vs SABS as well as Δ salinity and Δ temperature vs SABS. Seasonal and location comparisons may reveal potential trends or even relationships between physical factors, such as current, salinity, and temperature, and whale travel direction and energetics.

Future studies should use this study as insight to potential relationships between physical factors and whale travel direction and energy expenditures. Further data is needed on each analysis to investigate potential seasonal and location patterns. Data could be collected from Haro Strait and Rosario Strait due to frequent passage by SRKW. Physical factors, such as salinity, temperature, and currents, should be considered for additional analysis to whale travel direction and SABS. Continual analysis would reveal relationships among the different parameters examined in this study.

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