Energetic cost of behaviour in *Ornicus orca*: a non-invasive acoustic study.

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Research proposal

The Salish sea ecosystem supports a great plethora of marine obligates, including Cetaceans, which have evolved highly adapted physiology and behaviour to utilize this environment and the challenges it presents. The killer whale (*Ornicus orca*), is the largest cetacean in the Delphinidae family. There are three distinct ecotypes of *O. orca* in this area: offshores, transients, and residents (Holt 2008). Each ecotype is distinct in terms of typical behaviour, ecology, vocalisations and social structure. The Southern Resident population consists of three pods J, K and L, which interact with each other. From 1995 to 2001 the population size of the Southern Resident community had decreased from a high 98 individuals to a low of 79 animals, which is a reduction of 20% of the entire population in only 6 years (Bain 2002). While we do not fully understand the reason for this decline, several contributing factors have been reported, such as prey availability through decrease in Salmon stocks, exposure to toxic chemicals, as well as the increase in commercial and private vessels mostly for whale watching over the last 10 years (Bain 2002).

Whale watching is sighted as a factor due to studies that have documented the impact of vessel traffic on different whale ecotypes. Studies have concluded that the animals change their behaviour in the presence of boats (Kriete 2002). In the Northern Resident killer whales it was shown that the whales swim significantly faster, increasing the angle between successive dives or choosing less direct paths in their swimming direction in order to avoid boats when vessels were in the vicinity (Williams et al 2002, Kriete ?). Trites and Bain (2000) estimated theoretically that the male killer whales added an extra 13% in traveling distance when followed by boats. Boats have also been linked to a loss in feeding opportunities and this could result in a substantial (18%) estimated decrease in energy intake. Whales may also adopt less predictable paths of movement (Williams et al 2002, Holt 2008, Goold and Fish 1998) and endure compromised immune system levels due to stress and energy expenditure (Simmons and Dolman 2000). Although behavioral impacts have been demonstrated in this population, few direct measurements of energetic costs have been conducted, which makes it harder to estimate longer term population level impacts.

The impacts of energetic stress affect the sexes differently due to variation of metabolic efficiency and size variation. In *O. orcas*, males are approximately 10 meters in length whereas females range from 6-8 meters (Baird 2006). As body size increases, the surface area to volume ratio decreases and thus the surface exchange of heat is proportionally lower. This results in a lower heat loss rate and thus greater metabolic efficiency. When traveling in mixed groups all activities will carry an energetic cost and will possibly affect group cohesion and survival success.

The emphasis of acoustic studies on killer whales have been on pulsed calls or whistle vocalisations and their relation to social organization, genealogy, and behaviour (Ford 1991, Deecke et al. 2010). These are all acoustic signals, however very little work has been done on acoustic cues, especially in marine mammals. Acoustic cues are sounds produced as a result of physiological or locomotive needs, and are not produced to provide a benefit to either the sender or receiver (Wood review 2010). In *O. orcas*, and other marine mammals, the obligation to breathe at the surface, provides a measurable cue from the blow as they exhale. Not only can these cues be measured, but they can also provide information about the biology of the individual and the species, particularly their energetics. Energetics are important as it affects fitness and ultimately survival. Survival is largely a function of the amount of energy expended while in motion and the amount of energy gained through food consumed. While gravity is the primary force behind the energetic cost of locomotion in terrestrial mammals (Cavagna et al 1997, Taylor et al 1980), in marine mammals it is a combination of hydrostatic pressure, body drag, effort and buoyancy (Williams 2001). Reliable measurements of energetic cost in marine mammals are difficult to obtain in nature, however this previously unutilized area of acoustic cues could help to shed light on the energetics. Engergetic in this study will be taken to mean the volume of air exchanged in a period of time. This is a good measure as it represents effort, without requiring interference with the animals being studied.

With the conservation of the Southern Residents in mind, the following questions are posed: does blow amplitude, and thus air volume exchanged and energy used, vary with behavioural state? Are longer dives more energetically costly? To test these questions the Sound Exposure Level (SEL) at the source of a blow (air exhalation) will be measured by analysing the received level and estimating sound attenuation from the source to give source volume. SEL is a measurement of the energy of a sound, which is calculated by integrating the squared instantaneous sound pressure over a stated time interval (Richardson et al 1995). In this study, in order to use the measurement for energetic profiling, the volume of air exhaled needs to be implied. SEL will allow for blows of different amplitude and duration to hold the same value because they would involve the same amount of air exchanged. The assumption made is that the higher the SEL value the higher the volume of air exchanged (a method for calculating this is still pending). A single SEL value can be assigned to a short, high amplitude blow and a long, low amplitude blow. Both will allow for the same amount of air to be exchanged. This assumption could be tested also. Do shorter blows have higher amplitude and vice versa? Distance from the animal blowing to the microphone will also affect the amplitude of the recorded blow. Therefore, the spreading loss will be included in calculations of SEL to control for distance effects.

The above technique will allow the following hypotheses to be tested;

1) Foraging, fast travel and play will be more energetically costly than resting, slow travel and milling.
2) As dive length increases so will the energetic effort to perform that dive, and thus blow amplitude will increase.
3) SEL is an appropriate measurement for this study. Shorter blows will have a higher amplitude (measured as Sound Pressure Levels in dB re 20µPa) than longer blows.

Methods

Data collection:

Acoustic measurements and surface behaviour observations of the Southern Resident ecotype will be done in the Greater Puget Sound region. Data acquisition will occur over a 5 five-week period, from mid-September to late-October 2010. Data analysis will be continuous throughout this period as well as for one week upon return to land. Data acquisition will be from the fore deck of the Gato Verde, a 42' long sailing catamaran. During all study periods the Be Whale Wise guidelines will be followed and The State Law observed, to limit observer error due to interference.

When the whales are within 200m of the boat the study period is initiated. At the start of each study period a GPS way point will be taken, in order to allow for cross reference to identification photos. If the focal animal is not identified at the time of surface recording, we will photograph each focal animal and verbally document which time frame on the camera matches the blow series recorded. We will later use the Center for Whale Research ID Guide, 2009 edition to identify individuals from the photographs (Ellifrit et al 2009).

All acoustic recordings will be taken using an Earth Works QTC40 omni directional microphone with a flat frequency response from 4Hz to 40KHz recording to a Marantz professional solid state recorder PMD660 (PCM-44.1K recording wave files to a 1.0GB compact flash dish). The microphone will be mounted with a parabolic dish to aid directionality and boost the signal to noise ratio of the recordings. When recording; time, distance, sex, behaviour state and orientation to the boat will be audibly noted on the recording. Time will be read from a watch sychronised to the GPS and cameras used. Distance will be determined using a Newcon Optik x9; LRM 2000PRC laser range finder. Sex will be determined from visual observations (based on dorsal fin shape characteristic of different sexes), and the decision finalized based on identification photo analysis, in order to limit error due to juvenile males looking similar to females.

Five behaviours will be used: foraging, milling, resting, traveling and playing. I will be using the following definitions:

Foraging	Traveling	Resting	Milling	Play
Erratic high speed swimming, lunging, rapid circling and chasing fish at the surface. Includes feeding or searching for food. It Is the most common activity. The pod is usually spread out with small subpods that are generally swimming together. There are usually 2-3 short dives made, followed by a loner diver (1-3 minutes). Foraging is thought to compromise 65% of the Southern Resident behavior.	Traveling is defined as when a group of whales is consistently swimming in a specific direction. Usually there is a tight formation, and there cannot be ay signs of feeding or searching for food. They usually travel faster than when they forage, and they often surface and dive simultaneously. They are usually Very vocal while traveling.	This behavior is very easily recognized because the whales swim slowly, in a tightly knit group, usually abreast. While swimming abreast, the offspring usually surround their mother. They are very quiet and make longer dives. Resting is thought to make up 13% of southern resident behavior.	Repeated, non-linear orientation; nondirectional; any distance, slow or medium speed.	Many different physical interactions, displays, and percussive events. Socializing behavior includes sexual interactions, kelping, aerial displays (breaching, tail slapping, spyhopping, etc.) This is thought to account for 15% of the Southern Resident's time.

Figure 1. Behaviour categories adapted from NOAA 2004, Ford et al 2000, Barrett-Lennard et al 2004.

Orientation to boat will be determined using a clock face template, with 12o'clock at the bow and time continuing clockwise around the boat to 6o'clock at the stern (See appendix figure 1 for diagram). Orientation will be important for identification and cross referencing behaviours with hand written data.

The recordings will be continuous over 6-10 blows for a individual selected based on the following criteria; within focal range of microphone, surfacing alone (i.e. out of sync with group if there are many individuals) and performing one behaviour during the whole recording. All juveniles will be excluded from this study as their metabolic rate is affected by growth and thus their energetic cost is not comparable to adults. A new recording is started for each new individual or behaviour.

Data Analysis:

Data files will be analysed using a MacBook Pro laptop computer running both Windows 7 and Mac OS X (version 10.5.8) software. Wav files will be analysed using the Audacity 1.3 Beta software. Each blow will be listened to, and viewed in both waveform and spectrogram. A spectrogram will be computed for both the blow being analysed and the background noise before the blow (not after due to a dramatic increase in background noise because of camera clicks and movement around the boat). This will then be exported into an excel file for conversion into SEL using the formula:

$$dB_{SEL} = 10\log \frac{SEL_{ENERGY}}{SEL_{O}}$$

In order to use the data collected, the microphone must be calibrated. This will be done using a speaker playing a consistent sound at a known distance from the microphone. A sound level meter will be situated next to the microphone and the two readings will be compared for calibration calculations. The dish, which surrounds the microphone, will have an impact on the gain of the recordings. The calibration should be done for the microphone only and the microphone with dish.

The acoustic attenuation also needs to be analysed, as this will be used to calculate source level of each blow. This will be done using a pre-recorded sound played from a speaker at a set dB level different distances away from the microphone. The dB will also be altered but distance kept the same. This will be repeated under a range of different weather conditions (temperature and wind speed), which will be measured using a Kestrel 2000 for accuracy.

All behaviours reported audibly during recording will be compared to the written behaviour data sheet taken at the same time. Time is matched by using the same watch for both the written and the recorded data. If they don’t agree the observation made during recordings on the sound file will be taken as correct.

Individual ID’s will also be added into a spreadsheet and only these blow recordings will be used (as age and size can effect metabolism as mentioned above, and will be used in a calculation of cost of transport as detailed bellow). Variation in saddle-patch colouration and dorsal fin characteristics will be used to identify individuals. Comparisons will be made with the Center for Whale Research ID Guide, 2009 edition of southern resident killer whales. Individuals will be identified and correlated with a particular time and orientation.

Once this has been collated the data needs to be statistically analysed. Hypothesis 1, behaviour alters SEL_{dB}, will be analysed using an ANOVA. Hypothesis 2, dive length vs SEL_{dB}, will be analysed using a correlation or regression. Hypothesis 3, Blow amplitude (in dB re 20 micropa) vs duration, will be analysed using a regression.

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Appendix

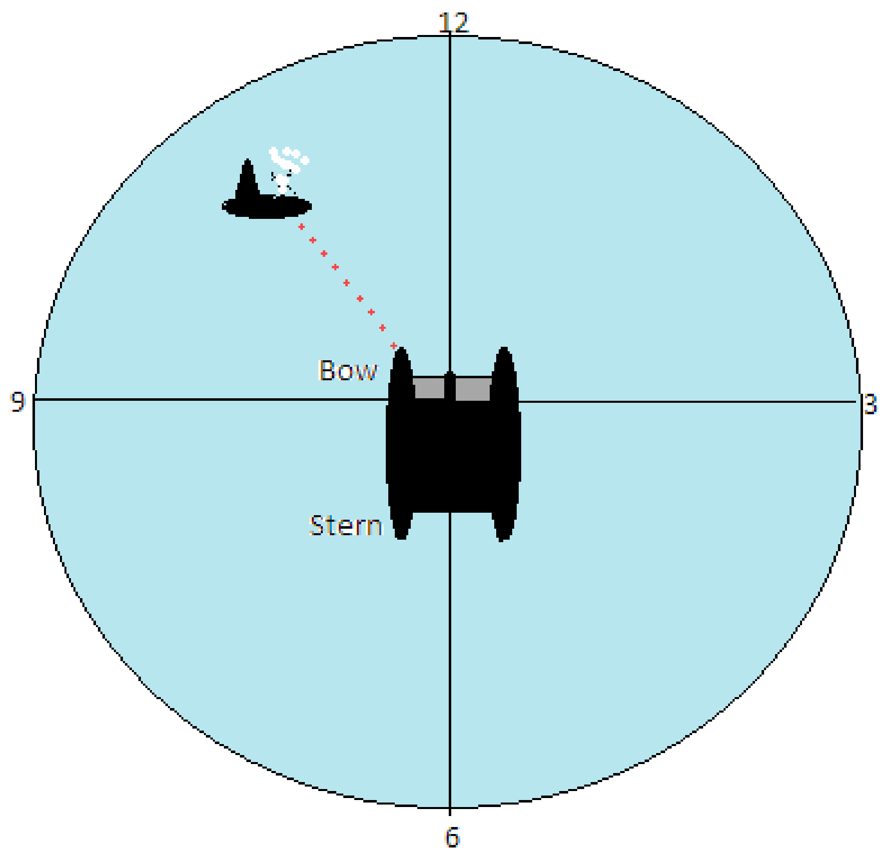

Figure 1, Clock orientation of whales to the Gato Verde during behaviour observations.