Bottom-up Analysis of Lower Trophic Levels Within Foraging areas of the Southern Resident killer whales.

Kelsey Donahue
Beam Reach Marine Science and Sustainability School
Friday Harbor Labs
620 University Road
Friday Harbor, WA 98250

The Salish Sea is comprised[RK1] of a complex ecosystem of food webs that are influenced by both abiotic and biotic factors. These interactions can be illustrated by monitoring top down[RK2] verses bottom up affects on organisms. Southern Resident killer whales (SRKW's) serve as a vital model for analyzing both types of processes[RK3]. In 1995 their population declined until 2005 when they were listed as Endangered under the ESA (Hanson et al., 2010). Their declining numbers led to Recovery Plan[RK4] in 2008 which established 3 primary factors attributing to their decline; presence of vessels, toxins and prey availability. The presence of vessels and amount of toxins are both examples of top down affects on these marine mammals. Prey availability is a bottom up control of these killer whales and is currently a poorly understood topic in most coastal systems (Reum et al., 2011;Horne and Gauthier, 2004). In the late 1800s Southern Resident killer whales most common diet; Chinook Salmon (*Onchohynchus tshawytscha*), started declining in major river systems (NMFS, 2008). The decline of Chinook has a direct affect on whale populations because they [RK5]fluctuate in response to the abundance of Chinook runs (NMFS, 2008). In order to sustain long-term fish populations, studies have suggested that bottom up control of trophic interactions is [RK6]the principle mechanism that should be researched [RK7](Ware and Thomson, 2005;NMFS, 2008). A similar study examined coupled trophic interactions that influenced fish populations and found that physical factors played an important role in each relationship (Emmet and Sampson, 2007).

Understanding the ecological importance of the Southern Residents' prey could be the key to conserving these endangered species.

The diet of the Southern Resident killer whales is a topic that has a limited amount of information. There are no accessible records of maps [RK8]locating prey densities or spatial and temporal distributions of prey in correlation with their range (Horne and Gauthier, 2004). Therefore, past studies have calculated the diet of these whales based on opportunistic observations of predator-prey interactions, stomach contents of whale carcasses, and sampling prey fragments from the surface of the water after a foraging event (Ford and Ellis, 2006;Ford et al., 1998). It has been found from May to October, that salmon are the dominant food source (Ford et al., 1998). Chinook Salmon appear to be their preferred prey and coincidentally are the least common salmon species in the northeastern Pacific (NMFS, 2008;Ford and Ellis, 2006). The reason for this preference could be due their large size high lipid content (Ford et al., 1998). This energy efficient fish caused concerns when their native population started declining[RK9]. In response to this decline, fish hatcheries increased abundances of Chinook termed 'blackmouth', which have been steadily replacing wild Chinook populations (NMFS, 2008[RK10]). Blackmouth reside in the San Juan Islands year-round, allowing for an alternate [RK11]food source to the killer whales (Barsh et al., 2010). Other salmon prey species that are more abundant but not as targeted are Chum, Pink, Coho, and Sockeye salmon (NMFS, 2008). A study by Ford et al. (1998) found 4% of SRKW's prey items were non-salmonids and were labeled as either epibenthic or demersal species[RK12].

Since Chinook Salmon are predominantly targeted by Southern Residents, it is important to understand what controls Chinook populations. Seasonal variation in prey preference of Chinook Salmon most likely occur in response to fluctuating prey in coastal waters (Hunt et al., 1999). Healey (1991) found that the importance for Chinook feeding on Sand Lance (*Ammodytes hexapterus*) and Pacific Herring (*Clupea pallasii*)

populations increased from south to north along the Pacific coast (Hunt et al., 1991). A more recent study conducted by Barsh et al. (2010) in the San Juan Islands found that most of their diet consisted of Sand Lance, crab larvae, and insects. Even though there is seasonal variation in abundances of these prey, Barsh et al. (2010) found that juvenile Sand Lance were the Chinooks largest source of food in terms of biomass. In 2010, 83% of the wild Chinook analyzed in their research consumed Sand Lance. These small 15-20 cm long fish consume zooplankton during foraging activity and bury themselves in sand between these periods (Pearson et al., 1984). A non-for profit group called, 'Friends of the San Juans', recently documented Sand Lance abundance around the islands. Their map of Sand Lance distribution illustrates that these forage fish prefer sandy protected bays away from areas of major current flows.

Chinook densities are not only found to fluctuate with forage fish populations but also with biomass of zooplankton. A study of the ecosystem off the coast of Washington and southern British Columbia found a linear relationship between fish yield and zooplankton (Ware and Thomson, 2005). Zooplankton are heterotrophic plankton that cycle carbon and other elements in the ocean (Roemmich and McGowan, 2006). They maintain a patchy distribution within the water column and have been found to aggregate in areas where phytoplankton is available (Johannessen and Macdonald, 2009;Roemmich and McGowan, 2006). Phytoplankton are photosynthetic organisms in the upper euphotic zone that rely on nutrients for growth (Takashi et al., 1977). These nutrients are supplied to the phytoplankton by environmental factors such as river run-off, currents and tides. These physical forces create upwelling and mixing of particles within the water column allowing nutrients to reach the surface (Takahashi, 1997). What determines how nutrients are distributed within the marine ecosystem of the San Juans depends on current interaction with the topography of the ocean floor (Zamon, 2002). In areas consisting of deep canyons and steep walls, there is a high-energy zone with fast currents running along the bottom. Haro Straits' deep topography

demonstrates this high energy by continually mixing suspended particles at mid depth (Johannessen et al., 2006). The general coastal area of Washington and British Columbia coast are found to have high levels of nutrients because there is annual upwelling coming from the fluctuation in freshwater discharge of the Fraser and Columbia River systems (Yin et al., 1997;Ware and Thomson, 2005). High levels of nutrients and phytoplankton have been consistently referred to areas of high primary productivity (Ware and Thomson, 2005). Primary productivity is controlled by photosynthetic activity of the pigment Chlorophyll a within phytoplankton (Takahashi et al., 1997). Therefore, our project will measure phytoplankton biomass in order to define primary productivity levels. Land-based nutrients are another source influencing photosynthetic activity. Nutrients from land supply nitrogen to the marine ecosystem stimulating primary production in certain areas around the San Juan Islands (McCutchen, 2011[RK13]). A satellite-imaging program, Sea-viewing Wide Field-of-view Sensor (SeaWIFs), is used to map out areas of high chlorophyll a concentration or high primary productivity. A high biomass of chlorophyll a can be seen in the most recent SeaWIFs images of the Pacific coastal regions (SeaWIFs, 2002). Detailed SeaWIFs images of the San Juans are unavailable, however correlations can be made based on past trends of chlorophyll a concentrations along the Pacific coast. These trends depict a correlation between influx of freshwater from a river or land source and areas of high primary productivity[RK14].

It is apparent that physical factors play an important role in distribution and abundance of lower trophic levels. Bathymetry, temperature, salinity, nutrients, turbidity, tides, and currents all contribute to primary production, which in turn affects forage fish and salmon populations. Figure 1. Summarizes the linear relationship between all of these factors along with primary literature that has established these interactions. This project focuses on a region where the Southern Resident killer whales have displayed foraging behavior on a yearly basis. Our general goal is to analyze

bottom up control of the Southern Residents in this region and to link areas of foraging activity with high levels of primary productivity.

A study in 2009 observed when the Southern Residents were engaged in feeding activity and organized observations into areas of varied feeding probabilities. Their map is displayed in Figure 2 and was used as a base for our range of study (Ashe et al, 2010). Specifically we will measure the environmental variables and densities lower trophic levels within Salmon Bank. This area is lies within the Southern Resident foraging area and is known to yield high fish densities. *We hypothesize that there will be a strong linear relationship between primary production and fish densities within Salmon Bank*.[RK15] Physical factors will also be measured to establish the dynamics behind the marine ecosystem within this region.

The importance of this research project is to investigate a possible reason the Southern Resident killer whales are experiencing a decline. If bottom up affects have a greater affect on their population compared to top down affects that are currently a greater focus, then this could be valuable information for future research to expand on. NOAA fisheries will also have a greater amount of data about distributions of salmon in the Spring season, which could influence future forage area conservation for the whales. Foraging behavior is crucial to analyze because this activity is correlated with the location of prey (Gende and Sigler, 2006). A study on the foraging behavior of seals in relation to prey found that feeding was associated with oceanic 'hot spots' or areas of high primary productivity (Gende and Sigler, 2006). Our project aims to analyze these components around Salmon Bank and compare our results to other areas of high primary productivity and fish densities within and outside of the observed forage zone to test the significance of our conclusions. Another result will be a better understanding of environmental processes within the southern region of the San Juans. Recent concerns of increased temperatures have immediate effects on these processes that

directly affect marine organisms. Therefore, our data will also contribute to updating the status of the San Juan Islands marine environment.

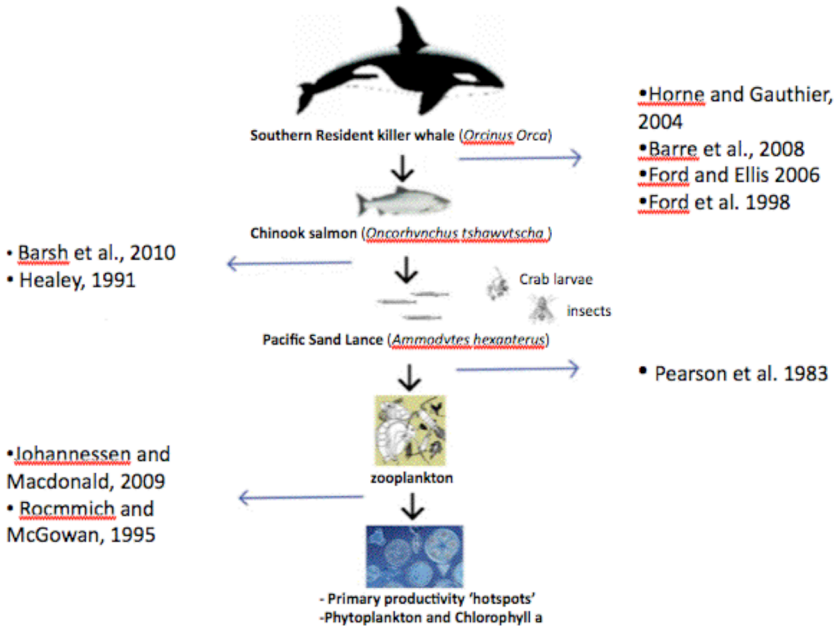

Figure 1. A trophic model illustrating the linear relationship between the Southern Resident killer whales, Chinook Salmon, Sand Lances, zooplankton, phytoplankton and primary productivity 'hotspots'.

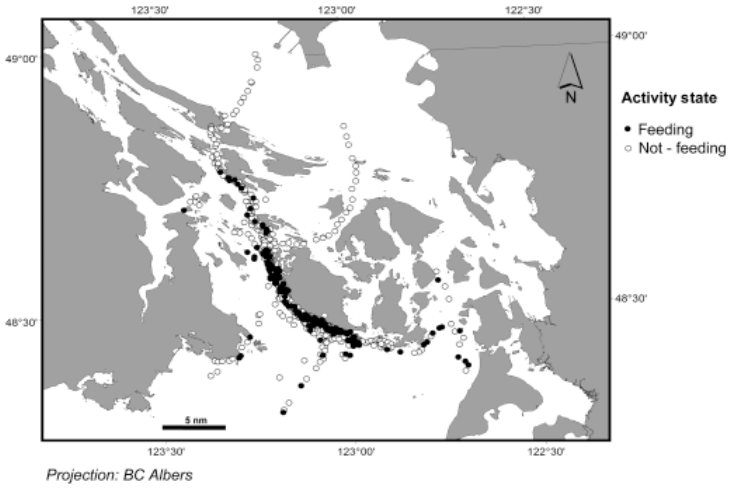

Figure 2. Map of feeding and no-feeding behavior locations of Southern Resident killer whales out of 764 observations. Highest feeding activity is found along the western coast of San Juan Island.

Methods:

Salmon Bank will be the primary zone of sampling and will be found by using Global Positioning System (GPS) coordinates calculated before departure. All other measurements will be located in opportunistic areas the research catamaran; the Gato Verde encounters based on weather conditions and observations of the SRKW's. Each sampling zone will be organized into 3 near shore and 3 offshore transects. Near shore will be define as an area approximately 1 mile from the shoreline and offshore sections will be between 5-10 miles away from the near shore sampling sight. Two plankton nets will be towed down each transect and timed for 5 minutes one direction, then 5 minutes in the approximate opposite direction. A 15 μm and 150 μm plankton net will capture both phytoplankton and zooplankton that will be recorded by cell counts per milliliter then averaged among 3 transects. GPS will record where the net starts, turns around and is lifted from the water. Amount of cell counts calculated per transect will be based on samples of phytoplankton and zooplankton from 1 sample bottle/net/transect which is equal to approximately 11, 10 square counts observed under the microscope per area. In order to measure the speed of the currents, a Marsh McBirney flow meter will be attached to the net to quantitatively count that speed of sifting particles through the nets. Each transect will have 3 points where the temperature, salinity, nutrients, turbidity, tides and currents will be measured. At initial start of transect, point of approximate and 10 minutes along the transect, temperature, salinity will be measured by using a CTD at depths 0-5, 5-10 and 10-20 meters. Niskin bottles attached to the CTD will measure the chlorophyll a, and nutrients (nitrate and phosphate) numbers at each of these depths. A transmissometer will also be attached to the CTD at each of these depths to record the amount of light scattered by suspended particles. Once environmental variables are measured, a fish finder running along each transect will be recorded on video then quantified fish densities per section will be categorized by abundance every 5 minutes along transect lines. Every site will be re-

measured every 3 days from April 17 through May 30. Plots of densities will graph time against abundance and cell counts and physical factors will be averaged across the 3 transects per near shore and offshore sites.

References:

Ashe, E., D.P., Noren, and R. Williams. 2010. Animal behaviour and marine protected areas: incorporating behavioural data into the selection of marine protected areas for an endangered killer whale population. Animal Conservation 13: 196-203

Barsh, Russel. "What Juvenile Salmon eat in the WRIA2 nearshore". 2011 KWIAHT (Center for the historical ecology of the Salish Sea). University of Washington's Friday Harbor Laboratories. 5 April 2011.

Dekshenieks, M. M., P.L., Donaghay, J.M., Sullivan, J.E.B. Rines, T. R. Osborn, and M.S. Twardowski. 2001. Temporal and spatial occurrence of thin phytoplankton layers in relation to physical processes. Marine Ecology Progress Series 223:61-71

Emmet, R.L., and D.B., Sampson. 2007. The relationships between predatory fish, forage fishes, and juvenile salmonid marine survival off the Columbia River: a simple trophic model analysis. CalCOFI Rep. 48:92-105

Ford, J.K.B., and G.M., Ellis. 2006. Selective foraging by fish-eating killer whales *Orcinus orca* in British Columbia. Marine Ecology Progress Series 316: 185-199

Ford, J.K.B, G.M., Ellis, L.G., Barrett-Lennard, A.B., Morton, R.S., Palmon, and K.C., Balcom III. 1998. Dietary specialization in two sympatric populations of killer whales (*Orcinus orca*) in coastal British Columbia and adjacent waters. Can. J. Zool. 76: 1456-1471

Gende, S.M., and M.F., Sigler. 2006. Persistence of forage fish 'hotspots' and its association with foraging Steller sea lions (*Eumetopias jubatus*) in southeast Alaska. Deep-Sea Research II 53: 432-441

Hanson, M.B., R.W., Baird, J.K.B., Ford, J., Hempelmann-Halos, D.M., Van Doornik, J.R., Candy, C.K., Emmons, G.S., Schorr, B., Gisborne, K.L., Ayres, S.K., Wasser, K.C., Balcomb, K., Balcomb-Bartok, J.G., Sneva, and M.J., Ford. 2010. Species and stock identification of prey consumed by endangered southern resident killer whales in their summer range. Endangered Species Research 11: 69-82

Horne, J. K., and S. Gauthier. 2004. Potential prey of killer whales in Puget Sound: A Pilot Study. Northwest Fisheries Science Center. Seattle, Washington 42

Hunt, S. L., T. J. Mulligan, K. Komori. 1999. Ocean feeding habits of Chinook salmon, *Oncorhynchus tshyawytshca*, off northern California. Fish. Bull 97:717-721

Johannessen, S.C., D., Masson, and R.W., Macdonald. 2006. Distribution and cycling of suspended particles inferred from transmissivity in the Strait of Georgia, Haro Strait and Juan de Fuca Strait. Atmospheric-Ocean 44: 17-27

Johannessen, S.C., and R.W., Macdonald. 2009. Effects of local and global change on an inland sea: the Strait of Georgia, British Columbia, Canada. Climate Research 40: 1-21

National Marine Fisheries Service (NMFS). 2008. Recovery Plan for Southern Resident Killer Whales (Orcinus orca). National Academies Press, Washington, D.C.□10

Pearson, W.H., D.L., Woodruff, and P.C., Sugarman. 1984. The burrowing behavior of Sand Lance, *Ammodytes hexapterus*: Effects of oil-contaminated sediment. Marine Environmental Research 11:17-32

Reum, J.C.P., T.E. Essington, C.M., Greene, C.A., Rice, and K.L., Fresh. 2011. Multiscales influence of climate on estuarine populations of forage fish: the role of coastal upwelling, freshwater flow and temperature. Marine Ecology Progress Series 425: 203-215

Roemmich, D., and J., McGown. 2006. Climatic warming and the decline of zooplankton in the California current. Science, New Series 267: 1324-1326

Takahashi, M., D.L., Seibert, and W.H., Thomas. 1997. Occasional blooms of phytoplankton during summer in Saanich Inlet, B.C., Canada. Deep-Sea Research 24: 775-780

Therriault, T.W., D.E., Hay, and J .F., Schweigert. 2009. Biological overview and trends in pelagic forage fish abundance in the Salish Sea (Strait of Georgia, British Columbia). Marine Ornithology 37:3-8

Ware, D.M., and R.E., Thomson. 2005. Bottom-up ecosystem trophic dynamics determine fish production in the Northeast Pacific. Science 308: 1280-1284

Yin, K., P.J., Harrison, and R.J., Beamish. 1997. Effects of a fluctuation in Fraser River discharge on primary production in the central Strait of Georgia, British Columbia, Canada. Can. J. Fish. Aquat. Sci. 54: 1015-1024

Zamon, J.E. 2002. Tidal changes in copepod abundance and maintenance of summer *Coscinodiscus* bloom in the southern San Juan Channel, San Juan Islands, USA. Marine Ecology Progress Series 226: 193-210