Sound Exposure of Southern Resident Killer Whales

Rachael M. Griffin and David E. Bain

2006

ABSTRACT

The southern resident killer whale, *Orcinus spp.*, population is listed as Endangered. Underwater noise, resulting from human activity, is being recognized internationally as a serious form of environmental pollution. The purpose of this project was to determine the effects of vessel noise on the echolocation range of southern resident killer whales. Noise levels were sampled using a calibrated hydrophone and digital audio recorder during whale-watch activities. A total of 200 1-min samples of southern resident killer whale acoustic habitat were recorded during 2005. Range of received levels was 106 to 146 dB RMS // 1μPa. The potential annual decrease in foraging space due to increased noise levels ranged from 15% to 20%. This research project provides an important step in implementing future whale-watch guidelines. Reducing the fraction of time whales are exposed to increased ambient noise levels would increase effective foraging area. Managing noise emitted from commercial whale-watch vessels is an important step in the recovery of this endangered population.

INTRODUCTION

There are four distinct populations of killer whales in British Columbia. These include two populations of fish eaters (northern and southern Vancouver Island summer residents), a population of meat eaters (transients), and a fourth population that rarely come into coastal waters (offshores) (Ford & Ellis 1999). Resident killer whales live in stable social groups comprised of family units. Matrilineal groups are comprised of the oldest female and her descendents (Bigg *et al.* 1990, Ford 1991). Pods are the usual social group of killer whales and are made up of related matrilines (Ford 1991). The southern resident killer whale population contains three pods (J, K, and L). There are about 85 southern residents compared to over 200 northern residents. The southern resident killer whale population frequents the trans-boundary waters of the Salish Sea from May to October (Figure 1).

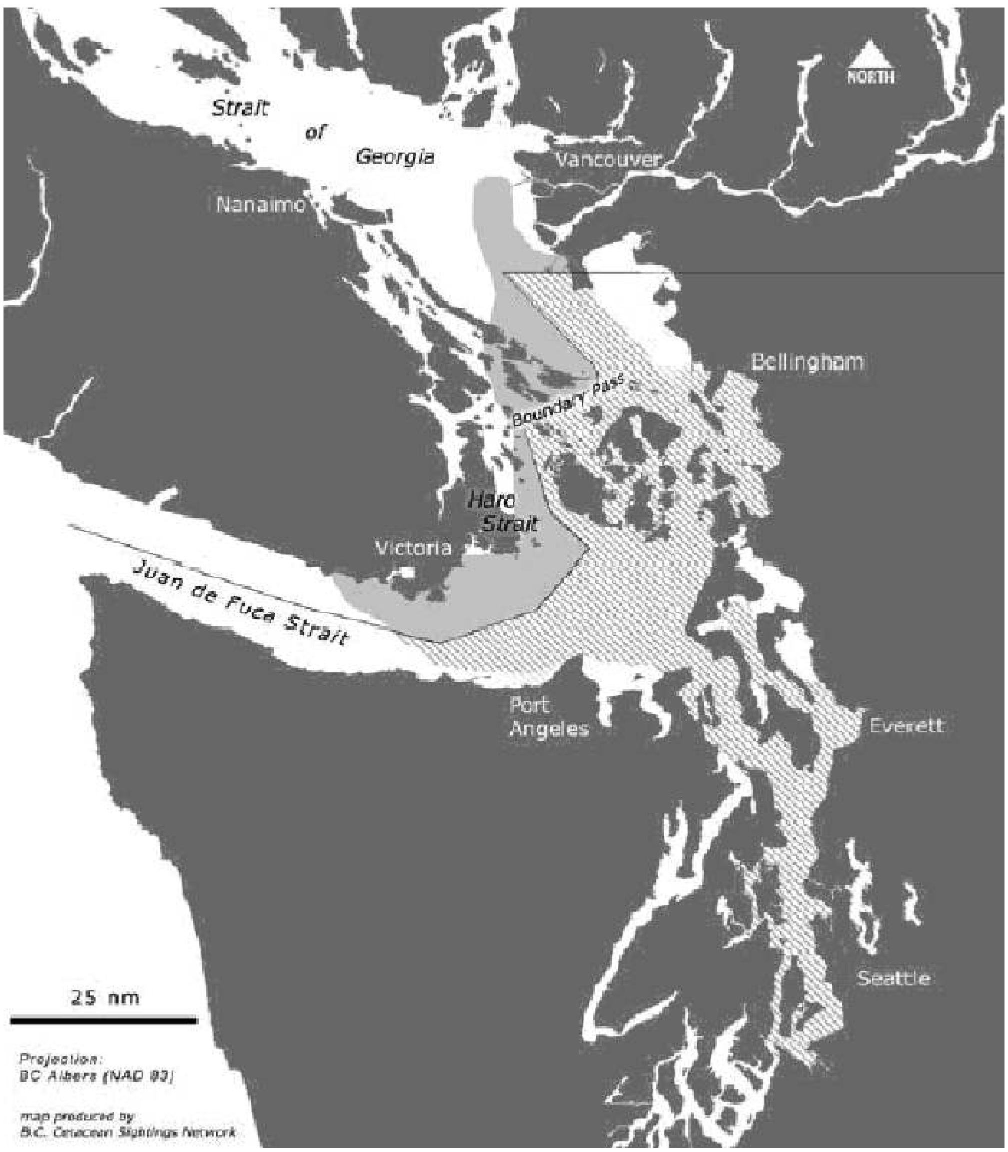


Figure 1. Critical habitat of endangered southern resident killer whale population (map modified from NRS 2005).

This area is proposed as southern resident killer whale critical habitat in the National Recovery Strategy of Canada (NRS 2005). In 2001, the Committee on the Status of Endangered Species in Canada (COSEWIC) placed this population on its Endangered species list. The southern resident killer whale population is small and declined by 17% between 1995 and 2001 (NRS 2005). Marine wildlife in this area is increasingly threatened by toxic contamination, loss of habitat, declining food supply, global climate change, and disturbance from a high volume of vessel traffic. Commercial and recreational whale watching in this region has experienced tremendous growth over the past decade (Osborne *et. al.* 2002, Foote *et. al.* 2004).

This habitat consists of the proposed Southern Georgia Strait National Marine Conservation Area (Figure 2), existing Southern Gulf Island National Park Reserve (Figure 3), and San Juan Island Marine Stewardship Area (Figure 4).

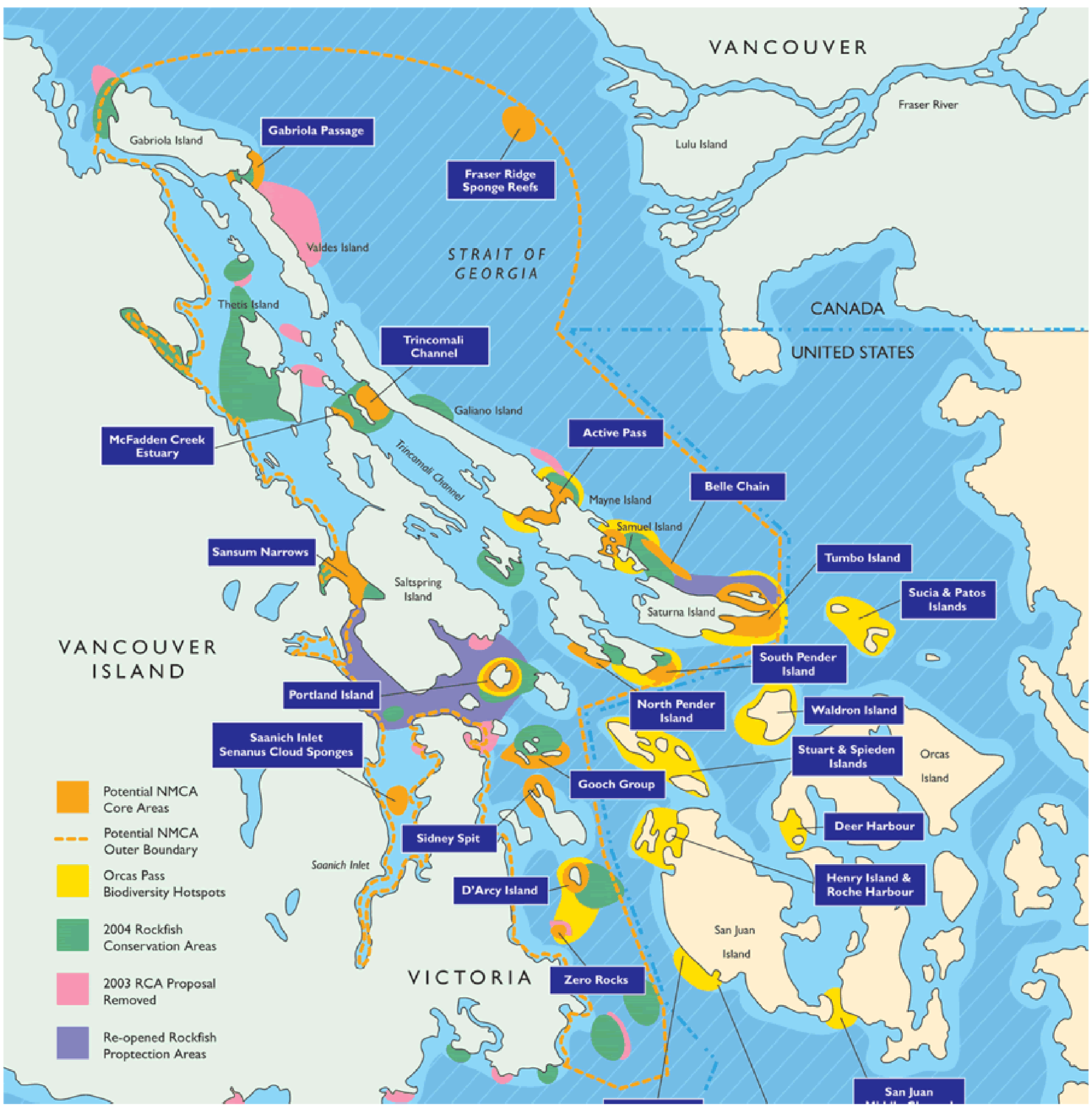


Figure 2. Zoning considerations for the Southern Strait of Georgia National Marine Conservation Area (http://www.cpawsbc.org/marine/sites/ssg_map.php)

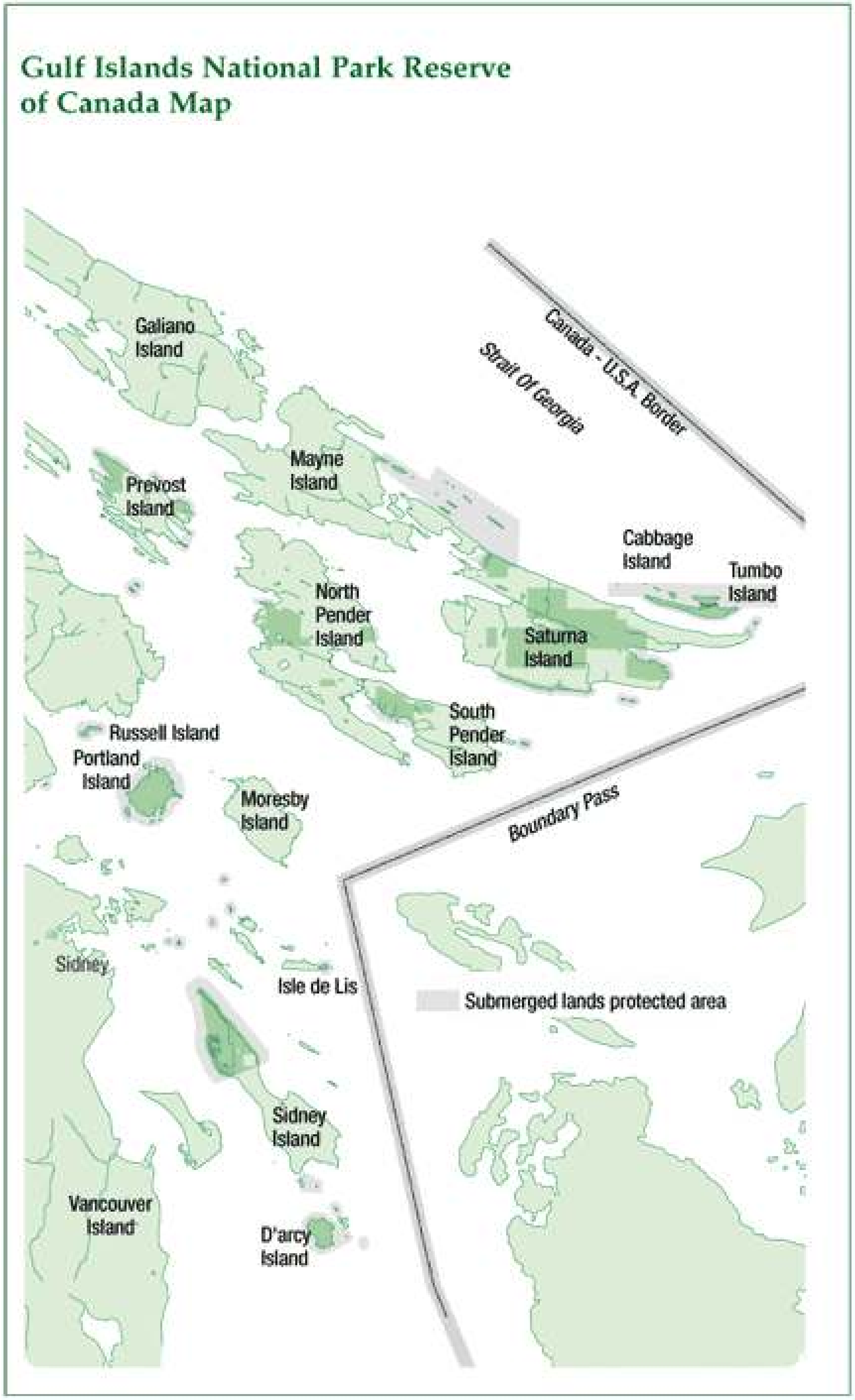


Figure 3. Southern Gulf Island National Park Reserve (http://www.pc.gc.ca/voyage-travel/pv-vp/itm12-/page13_e.asp)

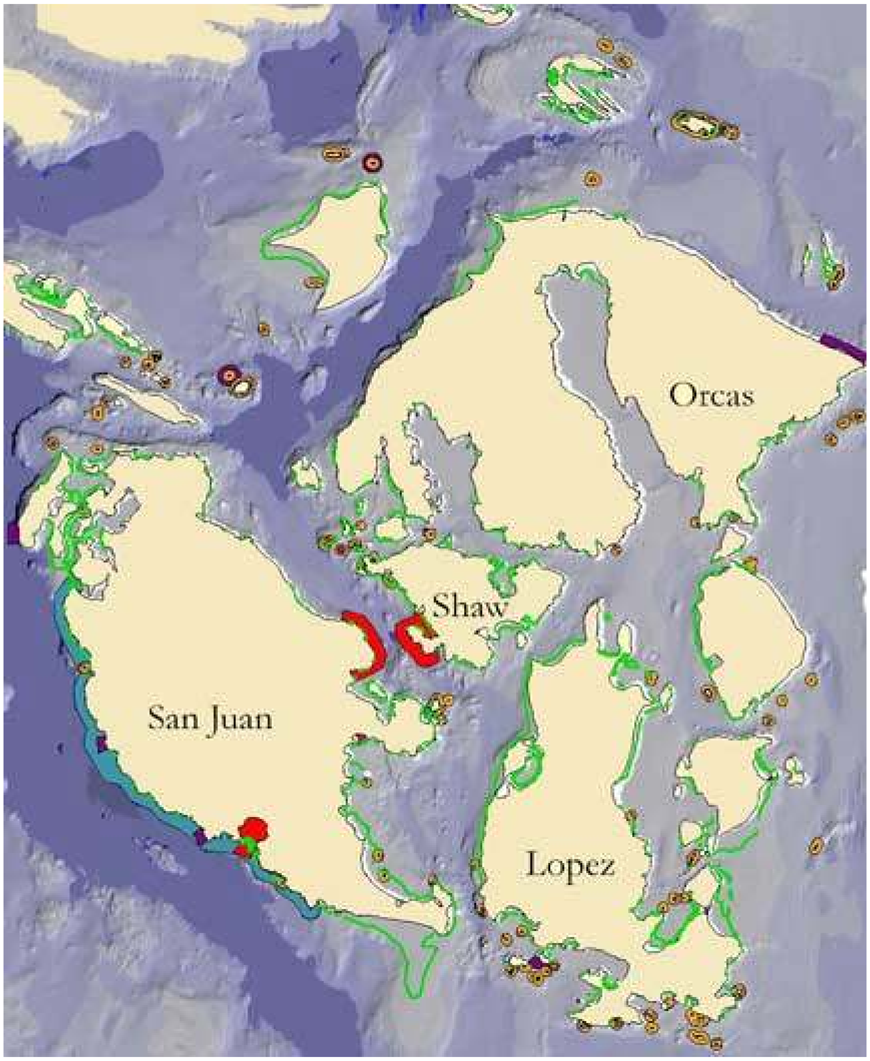
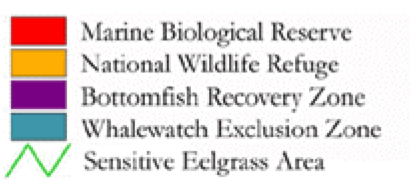


Figure 4. San Juan Island Marine Stewardship Area
(http://sjcmrc.org/programs/stewardship_MPAs.htm)



National Marine Conservation Areas (NMCA) are types of marine protected areas managed by Parks Canada for the sustainable use of recreation, education, and research. These areas are established under the Canada National Marine Conservation Areas Act and are implemented to preserve the structure and function of unique ecosystems. The NMCA program was designed to represent Canada's biodiversity, encourage monitoring, and protect depleted species. These areas include both the water column and submerged lands, and can include adjacent lands. They include at least one zone allowing ecologically sustainable use of marine resources and at least one zone that fully protects special features or sensitive core ecosystems elements. The Southern Strait of Georgia is among the most productive of all marine ecosystems in the world. Upwelling causes mixing of fresh and oceanic water, resulting in a nutrient rich and highly productive marine environment. Scientists, fisherman, and community members have identified marine biodiversity hotspots in this area. These zones include important areas for the protection of the southern resident killer whale population. The Southern Gulf Island National Park Reserve offers the opportunity for the public to learn and experience these spectacular coastal ecosystems. San Juan County Marine Stewardship Area protects unique and valuable marine resources while allowing sustainable use.

Recovery plans for the endangered southern resident killer whale population includes investigation into their acoustic habitat. Vessel noise has been identified as a possible factor in the decline of this population (Federal Register 2004, Krahn *et. al.* 2004, Bain *et. al*. 2002). Vessel traffic is known to increase the energy expenditure of killer whales (Williams *et. al.* 2002ab). Similar behavioural responses to vessel traffic have been observed in bottlenose dolphins, *Tursiops truncaus* (Nowacek *et. al.* 2001).

Killer whale vocalization consists of whistles, pulsed calls, and echolocation clicks. Whistles are tones used for close-range communication (Thomsen *et al*. 2001) and are predominantly between 6 to 12 kHz (Richardson *et al*. 1995). Calls are used to maintain group cohesion and integrity (Ford *et. al*. 2000), fundamental frequencies range from 300Hz to 6 kHz, and have source levels of 160dB (Richardson *et. al*. 1995, Miller 2002). Echolocation is the active detection and ranging of prey and the marine environment. Killer whales generate broad-frequency clicks and listen for the reflected echoes (Berta and Sumich 1994). Center frequencies of clicks range from 45 to 80kHz and source levels are 195 to 224dB // 1μPa (Awbrey *et. al.* 1982, Au *et. al*. 2004).

Vessels produce underwater noise within the hearing range of killer whales. Engines operating at high RPM produce higher intensity sounds and are distributed over a higher frequency range than vessels traveling at low RPM. Frequency range and source levels for small boats are 0.86kHz to 8.0 kHz and 141dB to 161dB respectively (Williams *et. al*. 2002a). Outboard motors operating at high speeds including frequencies above 20kHz and create source levels around 165 to 175dB (Bain 2002b). Large commercial ships produce frequencies from 100 Hz to 8.0 kHz and source levels of 180dB to 188dB (Galli *et. al.* 2003).

There are several considerations in terms of sound interfering with killer whale ability to hear biologically meaningful signals. These include masking of emitted sounds and damage to hearing. The later could be temporary (Temporary Threshold Shifts, TTS) or permanent (Permanent Threshold Shifts, PTS). Permanent threshold shifts occur at higher exposure levels than the onset of TTS. In urban zones, masking effects would be most significant on killer whale hearing (Bain 2002b). Noise can mask killer whale vocalizations (Szymanski *et. al.* 1998, 1999, Bain and Dahlheim 1994). Auditory masking resulting from sound exposure may have long-term biological significance on the fitness of killer whales. Masking occurs with the greatest of magnitude directly in front of the killer whales (Bain and Dahlheim 1994). The extent of noise interference with signal detection depends on the loudness of received levels. The volume of space actively searched by echolocation decreases with increases in noise levels. Active foraging space is the area over which echolocation can function. An increase in noise decreases the amount of echolocation pulse transmission loss tolerated by the whales. A decrease in echolocation range reduces their maximum prey detection range. The sonar equation allows quantitative determination of the decrease in echolocation transmission distance due to increased noise levels (Bain 2002b).

DT – maximum echolocation detection threshold
SL – echolocation source levels (independent of noise)
TL – transmission loss of click (TL = 20 log R); R = transmission distance (Au 1993)
TS – target strength (independent of noise)
NR – received noise level
NR_o – minimum ambient level
ΔR – ratio of detection ranges for an echolocation click in presence and absence of noise

$$DT = SL - 2TL + TS - NR \quad \Rightarrow \quad \mathbf{\Delta R = 10^{[-0.025\,(NR-NRo)]}}$$

Change in foraging efficiency depends on foraging tactics (Bain 2002a). The foraging method used by killer whales to locate prey determines the total reduction in active space searched. These strategies can be broken down into four separate models (Bain 2002b). Fixed Location Model, occurs when the whales know the location of prey. Linear Search Model, happens when the whales and fish are on the same path. If the whales travel faster than the fish their foraging capability will be unchanged due to noise levels or the effect could be linearly proportional to echolocation range. Planar Model, prey are in a two-dimensional fixed location. For example, fish at a certain depths, along a rock wall, or near the bottom of the ocean. There are two ways the whales can hunt for prey in the Planar Model. First, when whales swim through the same plane as the prey the effect on active space is linear. Second, when the whales swim perpendicular to the plane of prey the effect is proportional to the square of the range. Volumetric Model, prey could be anywhere in the water column. The main food for resident killer whales is chinook salmon (*Oncorhynchus tshawytschu*) making up over 60% of their diet (Ford *et. al.* 1998). Chinook salmon are distributed in such a way that would require volumetric searches (Bain 2002b). Linear, planar, and volumetric foraging tactics would be affected by increases in noise levels.

Objectives of this project were to identify received sound levels and to determine potential impacts on southern resident prey detection range. Studies have measured ambient noise and source levels from commercial whale-watch vessels (Bain 2002a, Erbe 2002, Galli *et. al.* 2003). This project is the first to measure received noise levels. Data collected facilitated calculation of reduction in energy acquisition resulting from vessel noise. Energy cost of noise level exposure assisted the estimation of total effect whale watching has on resident killer whales. This information is important for developing whale-watch guidelines and to promote the continuation of a vital economic community while ensuring the recovery of the endangered southern resident killer whale population.

METHODS

The study was conducted in southern resident killer whale habitat from Saturna to Lopez Islands during July to October 2005. The hydrophone was lowered to 10m depth and recordings were made with engines off in the presence of both whales and boats. Standardized notes were taken on sea-state, location, killer whale behaviour, and vessel traffic for each sixty-second sample. Samples were made with a Brüel & Kjær 8105 hydrophone, Brüel & Kjær 2635 amplifier, and Marantz PMD660 portable digital recorder. The B&K hydrophone is spherical, omnidirectioanl, and has a voltage sensitivity of -205 dB // 1V/Pa. Frequency range of the transducer is 0.1 Hz to 100 kHz. The B&K amplifier is equipped with a push button activated test oscillator, which applies a calibrated sinusoidal signal to the input. Samples were made directly into wav files onto a flash card with 16-bit resolution and 44.1kHz sampling frequency. Files were analyzed with OVAL (Orca Vocalization and Localization) acoustic software. The computer program was used to calculate loudness level (root-mean square, RMS) of sample waveforms. Recordings were made during whale-watch activity and therefore recordings were above sea state and other natural noise level factors. Measurements were analyzed to determine distribution of noise exposure experienced by the southern resident killer whales. Reduction in energy acquisition was calculated resulting from vessel noise. Whale-watching vessels have been reported to be with the whales for approximately 90% of daylight hours and accompanied 25% of the time during a six month whale-watch season (Bain 2002b). Reduction in carrying capacity is approximately 3% due to avoidance behaviour. Carrying capacity (K) is the number of animals a population can support in a given area (Berta and Sumich 1999).

RESULTS

A total of 200 noise level samples were recorded. The minimum value of received levels was 106 dB RMS // 1μPa. Median and maximum values were 128 and 146 dB RMS // 1μPa respectively (Figure 7).

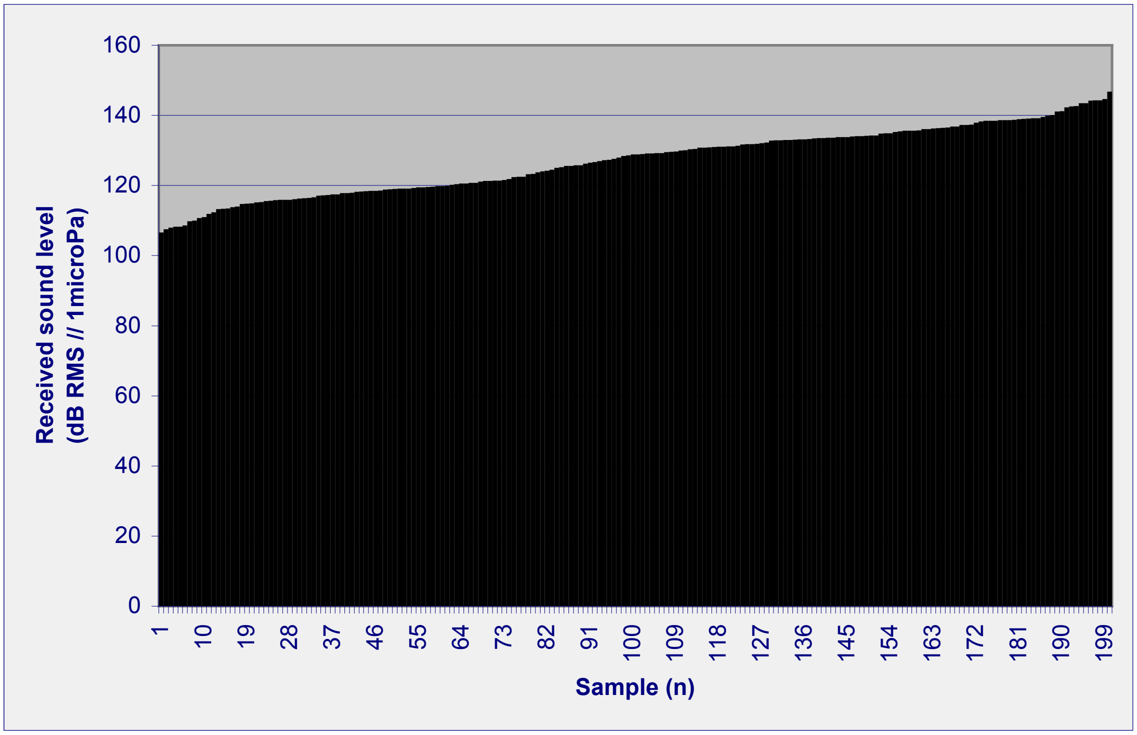


Figure 7. Received sound level (dB RMS // 1μPa) recorded per sample.

The total reduction in echolocation range was determined from potential decrease in transmission distance of echolocation clicks. Table 1 shows the noise level effects on southern resident killer whale echolocation ability for linear, planar, and volumetric search tactics was a 64%, 83%, and 90% reduction in active foraging space. The potential annual vessel effect on resident killer whale foraging behaviour was 15% for linear, 19% for planar, and 20% for volumetric search models.

Table I. Potential vessel impacts on resident killer whale behaviour.

Foraging Model	Ave reduction active space (%)	Annual foraging effect (%)
Linear	64	15
Planar	83	19
Volumetric	90	20

DISCUSSION

The southern resident killer whale population is threatened with extinction. This project sampled the acoustic environment of southern resident killer whale habitat. The objective of this research was to determine the received noise levels and to what affect it has on southern resident population growth. The minimum received sound level was 106 dB RMS // 1µPa. This is near reported levels for the area (95 dB RMS // 1µPa, Galli *et. al.* 2003 and 108 dB RMS // 1µPa, Bain 2002a). The median and maximum received levels were 128 dB and 146 dB RMS // 1µPa. Noise levels increased from minimum ambient level by 40 dB RMS // 1µPa resulting in an estimated 64% to 90% decrease in active foraging space. This in combination with decrease in energy costs due to avoidance behaviour equates to 19% to 26% in total potential reduction in southern resident carrying capacity due to vessel behaviour. Acoustic management is an important factor in the establishment of protected areas. Actively managing the acoustic environment is essential for the protection of this endangered population of whales. This could be accomplished by 1) decreasing the number of boats below the number of matrilines so not all whales are watched all the time, or having boats close together to accomplish the same affect, 2) decreasing noise from vessels by reducing noise produced (propulsion types, operating speeds) and increasing distance between vessels and whales, 3) limiting the time vessels spend with whales through seasonal closures, time of day limitations, and/or area closures. Closing quiet areas to commercial whale watching could increase foraging space up to 80% while the whales are in the protected areas. Determining actual received noise levels increases value of results. An average 20dB increase in ambient levels may affect killer whale ability to find food. Further research is necessary to make strong conclusions on the effects of vessel noise on killer whale foraging efficiency. Information is needed to determine foraging tactics per area. Circle scanning sonar would determine location of prey relative to path of the whales. Future investigations involve sampling areas when no boats are present to determine the complete range of received noise levels.

REFERENCES

Au, W. W. L., Ford, J. K. B., Horne, J. K., Newman Allman, K. A. (2004) Echolocation signals of free-ranging killer whales (*Orcinus orca*) and modeling of foraging for chinook salmon *(Oncorhynchus tshawytschu). Journal of the Acoustical Society of America*. 115: 901-909.

Au, W. W. L. (1993) The sonar of dolphins. Springer-Verlag, New York.

Awbrey, F. T., Thomas, J. A., Evans, W. E., Leatherwood, S. (1982) Ross Sea killer whale vocalizations: preliminary description and comparison with those of some northern hemisphere killer whales. *Report of the International Whaling Commission*. 32:667-670.

Bain, D. E. (2002a) Acoustical properties of pingers and the San Juan Island commercial gillnet fishery. *NMFS Contract Report No. 40ABNF701651*.

Bain, D. E. (2002b) A Model Linking Energetic Effects of Whale Watching to Killer Whale

(*Orcinus orca*) Population Dynamics. Friday Harbor Laboratories, University of Washington.

Bain, D. E., Dahlheim, M. E. (1994) Effects of masking noise on detection thresholds of killer whales. In (T. R. Loughlin, ed.) Marine Mammals and the Exxon Valdez. Academic Press, N.Y. 243-256.

Bain, D. E., Anderson, W., Felleman, F., Harris, M., Higgins, P. (2002) Orca Recovery Conference Report. Earth Island Institute. www.earthisland.org/immp/orca/orcreportfinal.pdf

Bigg, M. A., Olesiuk, P. F., Ellis, G. M., Ford, J. K. B., Balcomb, K. C. (1990) Social organization and genealogy of resident killer whales (*Orcinus orca*) in the coastal waters of British Columbia and Washington State. *Report of the International Whaling Commission Special Issue No. 12.*

Berta, A., Sumich, J. L. (1999) Marine Mammals: Evolutionary Biology. Academic Press, London.

Erbe, C. (2002) Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. *Marine Mammal Science*, 18: 394 - 418.

Federal Register (2004) Endangered and threatened wildlife and plants: proposed threatened status for Southern Resident Killer Whales. 69: 76673-76682.

Foote, A. D., Osborne, R. W., Hoelzel, A. R. (2004) Whale-call response to masking boat noise. *Nature*. 428:910.

Ford, J. K. B. (1991) Vocal Traditions Among Resident Killer Whales *Orcinus orca* in Coastal Waters of BC, Canada. *Canadian Journal of Zoology*. 69: 1454-1483.

Ford, J. K. B. and Ellis, G. M. (1999) Transients. UBC Press, Vancouver, BC.

Ford, J. K. B., Ellis, G. M., Balcomb, K. C. (2000) Killer Whales. UBC Press, Vancouver, BC.

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

Galli, L., Hurlbutt, B., Jewett, W., Morton, W., Schuster, S., Van Hilsen, Z. (2003) Boat Source-Level Noise in Haro Strait: Relevance to Orca Whales. Orca Vocalization and Localization (OVAL). http://www.coloradocollege.edu/dept/ev/Research/Faculty/OVALItems/FinalRptWeb/finalAll.html

Krahn, M. M., Ford, M. J., Perrin, W. F., Wade, P. R., Angliss, R. P., Hanson, M. B., Taylor, B. L., Ylitalo, G. M., Dahlheim, M. E., Stein, J. E., Waples, R. S. (2004) Status review of southern resident killer whales (*Orcinus orca*) under the Endangered Species Act. *U.S. Dept. Commer., NOAA Tech. Memo*. NMFSNWFSC-62.

Miller, P. J. O. (2002) Mixed-directionality of killer whale stereotyped calls: a direction of movement cue? *Behavioral Ecology and Sociobiology*. 52:262-270.

NRS (2005) Canadian Southern Resident killer whale National Recovery Strategy. http://www-comm.pac.dfo-mpo.gc.ca/pages/consultations/marinemammals/RKWrecoverystrategy_e.htm

Norwacek, S. M., Wells, R. S., Solow, A. R (2001) Short-term effects of boat traffic on bottlenose dolphins, *Tursiops truncates*, in Sarasota Bay, Florida. *Marine Mammal Science*. 17: 673-688.

Osborne, R., Koski, K., Otis, R. (2002) Trends in whale watching traffic around southern resident killer whales. The Whale Museum, Friday Harbor, Washington.

Richardson, W. J., Greene, C. R., Malme, C. I., Thomson, D. H. (1995) Marine mammals and noise. Academic Press, San Diego.

Szymanski, M. D., Supin, A. Ya., Bain, D. E., Henry, K. R. (1998) Killer whale (*Orcinus orca*) auditory evoked potentials to rhythmic clicks in killer whales. *Marine Mammal Science*. 14: 676-691.

Szymanski, M. D., Bain, D. E., Kiehl, K., Henry, K. R., Pennington, S., Wong, S. (1999) Killer whale (*Orcinus orca*) hearing: auditory brainstem response and behavioural audiograms. *Journal of the Acoustical Society of America*. 106: 1134-1141.

Thomsen, F., Franck, D., Ford, J. K. B. (2001) Characteristics of Whistles from the Acoustic Repertoire of Resident Killer Whales (*Orcinus orca*) off Vancouver Island, British Columbia. *Journal of the Acoustical Society of America*. 109: 1240-1246.

Williams, R., Bain, D. E., Ford, J. K. B., Trites, A. W. (2002a) Behavioural responses of male killer whales to a 'leapfrogging' vessel. *Journal of Cetacean Resource Management*. 4: 305 - 310.

Williams, R., Trites, A. W., Bain, D. E. (2002b) Behavioural responses of killer whales (*Orcinus orca*) to whale-watching boats: opportunistic observations and experimental approaches. *Journal of Zoology*, London. 256: 255 - 270.