J. CETACEAN RES. MANAGE.

Feeding Hotspots and Whalewatching "Not-spots": Using Killer Whale Behavior to Prioritize Vessel Exclusion Zones

E. ASHE[A] AND R. WILLIAMS[B]

a Raincoast Conservation Society, School of Biology, University of St Andrews, St Andrews KY16 8LB Scotland UK. Email: ea84@st-andrews.ac.uk
b. Raincoast Conservation Society, Pearse Island Box 193 Alert Bay BC V0N 1A0 Canada and Sea Mammal Research Unit, Gatty Marine Laboratory, University of St Andrews, St Andrews KY16 8LB Scotland UK

ABSTRACT

Among other factors, vessel traffic has been implicated in the decline of the Endangered "southern resident" killer whales in the northeast Pacific. Notwithstanding recreational and industrial traffic, commercial whalewatching alone comprises more boats than there are killer whales to be watched. Requiem or refuge reserves present an obvious impact mitigation option, but they run the risk of tokenism if arbitrarily placed. Recent studies reported that resident killer whales were most vulnerable to vessel disturbance while feeding; therefore targeting foraging hotspots for protection should confer greater conservation benefit to whales than protecting their habitat generically. We present new results from two analyses of killer whale habitat use, using classification trees and spatial models, from data collected during May-September 2006 in the inshore waters near San Juan Island, Washington State (USA) and adjacent Canadian waters. The spatial resolution of our prediction grid was influenced by interviews with on-the-water boater education coordinators, which yielded a practical grid cell size within which boats could feasibly be excluded with existing financial resources and reasonable boater compliance. Our results showed that fairly minor adjustments to the boundaries of existing no-go zones would encompass greater portions of killer whale feeding areas. A recurring theme in the use of MPAs to protect cetaceans is the need to identify areas that are large enough to be biologically meaningful while being small enough to allow real management of human activities within those boundaries. Our approach, identifying areas that whales use primarily for activities in which they are particularly sensitive to anthropogenic disturbance, balances pragmatism and conservation benefit by identifying small, but important areas to prioritize for protection.

INTRODUCTION

Killer whales are susceptible to increased ambient noise levels (Bain and Dahlheim 1994, Erbe 2002, Foote *et al.* 2004). When acoustic harassment devices were introduced to a peripheral part of the range of northern resident killer whales, they abandoned the area for a period of years (Morton and Symonds 2002), and affected matrilines have yet to re-colonize the area (A.M. Morton, pers. comm.) Southern resident killer whales are followed by a source of disturbance where changing their residency pattern would separate the population from a primary food source. Therefore, we must create situations in which killer whales can avoid disturbance and carry out activities essential to population survival and recovery such as mating and foraging. One way to mitigate some of these effects might be to identify areas of demonstrated importance to the whales, and to close them to boats altogether (Lusseau and Higham 2004).

Prey availability (Allendorf *et al.* 1997) and vessel traffic (Williams *et al.* 2002a,b) have been implicated as factors in the population decline of the fish-eating 'southern resident' population of killer whales (Baird, 2001, Krahn 2004).
The decline to just 80 animals in 2001 prompted an 'Endangered' status listing under the U.S. and Washington State Endangered Species Act and the Canadian Species At Risk Act. While these factors are often researched independently, we examined these together, as recent research provides evidence that the synergistic relationship of reduced

prey base and pervasive vessel traffic is evident in killer whale behavioral changes. Williams, Lusseau and Hammond (2006) report that northern resident killer whales were more likely to abandon feeding activities in the presence of vessels than in the absence of vessels. A study of southern resident population revealed a similar trend in which abandonment of feeding behavior was strongly linked to vessel presence. (Bain, Lusseau, Williams and Smith, 2006).

In addition to the physical disturbance of boats (Williams 2002a, 2002b, Williams and Ashe, in press), killer whales are susceptible to increased ambient noise (Bain and Dahlheim 1994, Erbe 2002, Foote 2004). The ambient noise to which killer whales are often exposed has the potential for engine noise to mask echolocation clicks(Bain and Dahlheim) suggests that available prey to killer whales may go undetected. Thus, reduced prey availability due to habitat loss, coupled with reduced prey acquisition by whales due to masking, may disrupt normal foraging behavior and reduce foraging efficiency. Reduction in foraging efficiency in a prey-limited population can carry costs to individual and potentially population-level fitness.

Excluding anthropogenic activity from all habitat used by southern resident killer whales is not a reasonable option. In order, to mitigate effects vessel on feeding activity, the most important components of the animals' habitat must be prioritized. For a mobile marine predator like killer whales, this may mean identifying hotspots critical to foraging and breeding. In the case of fish-eating killer whales, we believe, the priority should be given to protecting feeding hotspots.

Not only is it important to understand where animals are feeding for the sake of conserving important feeding areas, but vessel interaction studies (Williams *et al*. 2006) also suggest that this behaviour state may actually be impacted by vessels. As such, identifying and protecting areas where killer whales are more likely to feed serves two purposes, namely preserving areas that important for prey resources and also mitigating potential impacts that may reduce feeding opportunities. Therefore, we sought to identify whether preferred feeding locations exist in the summer range.

One approach to mapping preferred feeding habitat for killer whales is to map where preferred prey are found. Although resident killer whales are known to consume a variety of fish, salmon is considered the preferred prey of both the northern and southern resident communities(Ford *et al.* 1998, Ford and Ellis 2005). A number of studies over the years have noted that occurrence and habitat use correlated with salmon migration (Heimlich-Boran 1986, Felleman *et al.* 1991, Nichol and Shackleton 1996). A recent study has reported higher than expected rates of mortality of killer whales during the period of decline were highly correlated with changes in abundance of chinook salmon (Ford *et al.* 2005). However, the prey location is not necessarily indicative of locations of strategic, successful or reliable prey capture. Examples of static feeding areas include the attack channels of Patagonia and the sub-Antarctic Crozet Islands, where killer whales actually hunt seals from the beach(Lopez and Lopez 1985, Guinet and Bouvier 1995). In these cases, particular habitat features may facilitate capture of their highly mobile prey.

However, killer whale feeding activity and prey capture events are not always as conspicuous as intentional stranding feeding events. Baird and Hanson (2004) note that not all successful prey capture events observed occurred while killer whales were engaged in what looked like foraging behavior. However, a number of studies in have noted that killer whales do consume prey during an activity state typified by fast, non-directional swimming (Felleman *et al.* (1991), Hoelzel(1993), Ford *et al.* (1998) and Ford and Ellis (2006). There is a strong correlation between the behavior we measure at the surface and what the animals are doing underwater.

Statistical advances in spatio-temporal modeling allow more rigorous analysis of habitat use than was previously available in earlier habitat-use studies on this population (Felleman 1986, Heimlich-Boran, 1986, Hoelzel 1993). One model for how to identify and mitigate impacts of boat-based tourism that targets cetaceans is found in New Zealand, where a number of dolphin-watching tours focus on bottlenose dolphins. There, Lusseau (2003) measured behavioral responses of bottlenose dolphins to boats in Doubtful Sound, New Zealand, and discovered that the animals were most vulnerable to disturbance when resting or socializing. Lusseau and Higham (2004) then mapped how dolphins used their habitat and outlined a conservation plan to protect preferred resting habitat.

We believe that this provides a powerful model for how to identify the kind of habitat to protect in order to confer greatest conservation advantage to southern resident killer whales. Our approach used two main themes. First, we identified priority habitat to protect by mapping how animals used our study area. Secondly, we interviewed on-the-water environmental educators about the amount of habitat that can be practically closed to boaters.

We interviewed managers and stakeholders about the size of an area that they could effectively close to boats. That estimate was used as an average cell size for a grid to overlay on the southern resident killer whale range. Next, we investigated how the animals use that available habitat for different activities and behaviors, and applied a similar framework to identify the most efficient and biologically relevant reserve placement which in this case is feeding areas. The results of this analysis provides a series of four habitat use and suitability maps for each of four behavioral categories from which the most appropriate sites for feeding area protection can be chosen.

METHODS

Field data collection of whale behavior and positional data

Data were collected from a 7.92 meter power boat from May to August 2006 in the inshore waters around San Juan Island, Washington State (USA) and adjacent Canadian waters. The data collection platform was primarily dedicated to conducting a killer whale energetics study. Whales were searched for by boat and reports of killer whale presence and location was monitored using a local real-time paging system that reports marine mammal sightings. The pager system primarily relays information to commercial whalewatching operators about the location of any killer whales in the area.

When killer whales were encountered, a focal group of animals was chosen at random to follow. An overarching goal for the field season was to obtain representative sample of all matrilines and individuals in the population, so there is no reason to assume bias in the focal group selection process. During a focal group follow, the boat operator maintained a working distance of at least 100m from the whales in accordance with local wildlife viewing guidelines in order to minimize the potential for vessel disturbance (Williams et al, 2002a).

Behavioral activity state for a focal group was recorded every ten minutes using scan-sampling (Altmann, 1974). Scan sample information and geographic position of the whales were recorded onto with a Palm Handspring Visor PDA fitted with a Magellan GPS companion receiver. The Palm was programmed with customized CyberTracker software (www.**cybertracker**.co.za).

During each ten-minute scan sample, focal group behavior was recorded as one of four activity states categories: travel/forage, feed, rest or socialize. These activity states were defined so that they were consistent with previous studies on impacts of vessel traffic on the behavior of northern resident killer whales (Williams *et al.* 2002a, 2002b, Williams *et al.*, 2006). As a result, they may not correspond directly with activity state definitions used in other studies (Ford *et al.* 2000, 2005, Baird and Hanson 2004). The issue of comparability with other studies is addressed below. To eliminate inter-observer variability, activity state was consistently scored by one individual (EA) throughout the entire study period.

There is growing concern about the subjective nature of these behavioral categories introducing observer-effects. Lack of consistency makes it difficult to compare across studies and over time. Ha *et al.* 2004 attempted to facilitate consistency in recording resident killer whale behavior, but changing methods and definitions makes difficult to compare across years. As above, we collected data so that they could be used for their intended purpose, namely to map where animals were engaged in the activity state that Williams *et al.* 2006 identified as the activity state in which whales were most likely to respond to vessel traffic; an activity state that those authors called “feeding.” However, we recognized that the value of our data would be greater if they were also, comparable with other studies on southern resident killer whales. Therefore, we also collected finer-scale behavioral data including directionality, speed, etc. should future analyses of larger datasets be desirable or needed for management. However, the finer-scale behavioral data were not used in subsequent analyses for this study.

Notwithstanding the discussion above about the need for objectivity in scoring what the animals were doing, our primary focus was on mapping animal location. To that end, CyberTracker was programmed to record the position of the boat every minute. In order to estimate the position of the whale, we measured the compass bearing and estimated distance between the focal group and our vessel. The visual estimates of range to the animal were periodically checked with a laser-range finder (Bushnell Yardage Pro 1000). The range and bearing were used to calculate the position of the whale as an offset from the boat's position using the GeoFunc add-in for Excel (courtesy Dr. Jeff Laake, National Marine Mammal Laboratory, Seattle, WA), then mapped in ArcView GIS 3.2.

Interviews with local experts to define "manageable units"

The spatial scale at which to define an exclusion zone and prediction grid was based on interviews with on-the-water boater education coordinators and the boundaries of the study area. The goal of these interviews was to identify the size of an area that could be kept reasonably clear of recreational and whalewatching vessels with typical levels of annual funding for zodiac crews and land-based spotters, good signage and reasonable boater compliance. This output was used to generate a practical grid cell size across which animal behavior and habitat use could be predicted, such that managers could assess how much habitat could be protected under a variety of funding and vessel-management scenarios. The resulting grid, hereafter called the prediction grid, was overlaid on a digital map of the study area with the use of Manifold System and ArcView GIS 3.2 software.

Analysis of whale data to map killer whale habitat use

Two analysis methods were used to assess whether the likelihood of whales' being observed feeding is related to latitude or longitude – a tree-based model and a generalized additive model (GAM). The classification tree can be thought of as an exploratory analysis tool, and the GAM is an objective way of quantifying how the whale behavior varied spatially.

The goal of a classification tree is to identify covariates that correctly classify the response variable (whale behavior in this case) into increasingly homogeneous subgroups. In this case, ranges of latitude and longitude are considered in which the observations tend to be homogeneous with respect to the response value, whale behavior. A classification tree was fitted to the entire dataset in R using the "tree" package. The package uses a process called recursive partitioning, a statistically robust and objective method to split the data into two subsets, each of which contains observations that tend to be composed of either feeding or non-feeding whales. Each subset is then considered for further splitting, such that the data are split into progressively more homogeneous subsets – homogeneity is evaluated using a standardized statistical parameter – ending in a "terminal node" that show the classification rules. Of course, continued indefinitely, this process would result in as many splitting rules as there are observations. Instead, cross validation is used to determine an appropriate end point. This is generally done by randomly sub-setting the data into training and testing sets, and by choosing a model that performs well at classifying both datasets. After model fitting in R, the values of the terminal nodes were exported to a GIS package to plot the ranges of locations in which whales tended to be observed feeding.

The second analytical technique used was a GAM. Package mgcv in R was used to model the probability of whales' behavior being classified as either feeding or not-feeding as functions of latitude and longitude. GAMs are a sophisticated, non-linear extension of regression models that allow the response variable to take on a wide range of forms. With GAMs, the explanatory variables need not be linear, but instead are replaced by smoothing functions. After fitting a GAM to the data, the selected model was used to predict the probability of whales feeding at every point in our prediction grid, based on the latitude and longitude of each grid cell.

RESULTS

Sample size of behavioral data

A total of 764 observations were recorded between May 15 and August 2, 2006. Data were collected from all three killer whale pods (J, K, L). The relative proportions of killer whale behaviors observed during the study is displayed as a behavioral budget in Table 2.

Classification Tree results

The selected model had four terminal nodes, and successfully predicted the activity state (feeding versus not-feeding) of 83% of the observations. Whales tended to be feeding in a latitudinal band between 48.4476ºN and 48.4894ºN (Figure 4). There was also evidence for a high-probability feeding area east of 123.05ºW (Figure 4).

Descriptive GAM results

The selected model had modest explanatory power (less than 10% of the variability). It was of the form:

Probability of Feeding vs Not-Feeding ~ (Longitude, Latitude)

using the binomial family and a logit link function. The parameter coefficients are found in Table 3. The intercept term was highly significant. The two-dimensional smooth function of latitude and longitude showed a very complex relationship with the whale behavior, as indicated by the estimated 14 degrees of freedom afforded to the relationship by mgcv.

GAM prediction

The selected GAM was used to predict the probability of whales feeding in each of the 5550 grid cells. Note that these predictions were made based solely on latitude and longitude. They reflect only the probability that animals, given their presence in that cell, would be feeding there. In other words, they do not reflect the probability that animals would ever be seen there in the first place. This is an important distinction, because much of the prediction grid represents locations that were never visited, or that were visited but in which whales were never observed. However, the prediction is shown in Figure 6. The predicted probability of feeding ranged from 0 (that is, very unlikely to be feeding) to 0.95 (that is, very likely to be feeding).

Priority area for protection: the intersection/overlap of the preferred habitat and a manageable size results

We have tried to integrate the information we have obtained from three sources: the interviews with on-the-water environmental educators about the size of an area from which boats could be excluded practically; the results from the classification tree to identify boundaries between which whales tended to be feeding; and the results from the GAM to identify locations where the probability of feeding taking place was higher than the average. The overlap of these three pieces of information gives us a high-priority area from which boats could be excluded. First, we show this high-priority area in relation to the predicted probability of whales feeding throughout the study area, ,excluding the darkest area on the map in the southeast where whales were very rarely observed (Figure 7). Secondly, we show the highest-priority exclusion zone in relation to the location of the data, that is, where whales were observed in our study. Thirdly, we show the highest and second-highest priority exclusion zones(Figure 8).

DISCUSSION

Our study met its primary objectives, namely to map where southern resident killer whales were feeding in summer 2006, and to identify an area that could be closed to boats based on the whales' habitat use. We achieved our primary objectives in a short pilot study, in a cost-effective manner, and outline an objective way to identify priority areas for conservation. It remains to be seen whether our highest-priority exclusion is one that killer whales use consistently for feeding – additional datasets should be examined to see if whales used that area in other seasons or other years. Based on data from the commercial whalewatching operator sightings network(1996-2001), Hauser 2006 found that the southern resident killer whales use their summer habitat non-randomly and suggests the westside of San Juan Island as a summer core area. We have identified an area objectively that whales used more for feeding than one would predict from chance alone. In addition to a high probability feeding area, the proposed exclusion zone, was independently observed to have experienced the highest average number of vessels in the presence of southern residents in 2005(Koski 2005).

Relatively small protected areas can afford mobile predators refuge from tourism traffic for a relatively small cost to managers and tour operators. Identification of important feeding areas and habitat requirements in those areas can provide a framework for managers to designate spatially explicit protected areas in the southern resident range. Designation of a marine refuge temporal zoning or limited use area could mitigate both physical and acoustic anthropogenic disturbance in portions of their seasonal range. This is an objective approach to design, placement, and enforcement of a protected area that is currently not widely used (Hoyt 2005). Often, no-go areas are placed in areas that are convenient for humans; to address aesthetic concerns of waterfront property owners, to encourage shore-based whalewatching rather than focusing on the habitat needs of the whales themselves. While we recognize the potential for an influence on behavior from observing killer whales from a boat, a boat was deemed the most appropriate methodology in this case to maximize spatial coverage. Additional whale-oriented vessels were commonly present during focal follows. Average numbers boats following a group of whales range from 14-28.5(Erbe 2002) and the whales occasionally are accompanied by as many as 120 vessels at once (Koski 2005). Vessel presence in the case of the "southern resident" population represents an average day time condition from May-September and were therefore not included as covariates in this study.

What we propose should be regarded as a reassessment of existing and enforced guidelines and exclusion zones. Assuming that the National Marine Fisheries Service is formally addressing the large scale issues of prey availability, contaminants, exposure to navy sonar (NMFS, 2006) through Critical Habitat designation, this study seeks to identify one small patch of water as a refuge free from boat traffic and noise.

Robson Bight-Michael Bigg Ecological Reserve in Johnstone Strait, British Columbia represents a successful example of protecting important killer whale habitat from boat traffic with a high-level of boater compliance (Ashe and Williams, 2003).

Presumably, whales could forage anywhere that fish are present but the results of our study suggest that certain areas may be more strategic for fish capture than others. As it is impossible to consider excluding anthropogenic activity from all habitat, used by southern resident killer whales, the most important components of animals' habitat must be prioritized. For a mobile marine predator, this may mean identifying hotspots critical to foraging and breeding (Harwood 2001, Hooker and Gerber 2004). In our case, we can only describe where the animals were feeding on average during the time of the study. Therefore, we cannot be certain that the preferred feeding habitat identified here is fixed or ephemeral. However, evidence suggests that marine predator and prey aggregate in productive hotspots (Worm *et al*., 2003). In addition, recent analyses by Hauser(2006) suggest that variability of southern resident killer whale general habitat use, decreases and becomes more predictable over longer time scales. In terms of the variability of feeding areas, more data collected over several years are required to plan spatially explicit protected areas for cetaceans given the uncertain temporal component of site fidelity (Wilson *et al.*, 2004). It is hoped that our study outlines a method by which such a small, stable feeding hotspot could be identified for the southern resident killer whale and protected.

Acknowledgements
We thank Robin Baird, Sandy Chancey, Shannon Davis, Fred Felleman, Brad Hanson, Jeff Hogan, Erich Hoyt, Kari Koski, Ivan Reiff, Doug Sandilands, Meike Scheidat, Jodi Smith. Thank you to Ari Friedlaender, David Lusseau, Monique Mackenzie, Rene Swift , for statistical advice. For field assistance we thank Jacqueline Daly, Deborah Giles, Dawn Noren and Dara Reiter. Thank you to Brady Olsen for oceanographic consulting and equipment. Thank you to Dawn Noren for her thoughtful and helpful comments on an earlier version. Thank you to the developers from Cybertracker and the R core development team. This work was permitted in the USA by the ESA permit #781-1824-00 and in Canada by Marine Mammal 2006-07 and SARA-33 permits.

REFERENCES

Altmann, J., 1974. Observational study of behaviour: sampling methods. Behaviour 49, 227–267.

Ashe, E. and Williams, R., 2003. Voluntary Compliance with the boundaries of a killer whale sanctuary. In Abstracts of the 14th Biennial Conference on the Biology of Marine Mammals, Greensboro, NC.

Allendorf, F.W., Bayles, D., Bottom, D.L., Currens, K.P., Frissell,C.A., Hankin, D., Lichatowich, J.A., Nehlsen, W., Trotter, P.C.,Williams, T.H., 1997. Prioritizing Pacific salmon stocks for conservation. Conservation Biology **11**:140–152.

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

Bain, D.E., Smith, J.C Williams, R., and Lusseau, D., 2006. Effects of vessels on behavior of southern resident killer whales (Orcinus spp.). NMFS Contract Report No. AB133F03SE0950 and AB133F04CN0040. 61 pp.

Baird, R.W., 2001. Status of Killer Whales, Orcinus orca, in Canada.Canadian Field-Naturalist 115, 676–701.

Baird, R.W. and Hanson, M.B. 2004. Diet studies of “southern resident” killer whales: prey sampling and behavioral cues of predation. Report to NOAA, Order No. AB133F-03-SE-1070, 12 pp.

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.

Felleman, F.L. 1986. Feeding ecology of the killer whale, *Orcinus orca*. M.S. thesis. University of Washington, Seattle, WA.

Felleman, F.L., Heimlich-Boran, J.R., Osborne, R.W., 1991. The feeding ecology of killer whales (Orcinus orca) in the Pacific Northwest. In: Pryor, K., Norris, K.S. (Eds.), Dolphin Societies: Discoveries and Puzzles. University of California Press, Berkeley, pp. 113–147.

Foote, A.D., Osborne, R.W., Hoezel, A.R., 2004. Whale-call response to masking boat noise. Nature 428, 910.

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

Ford, J.K.B., Ellis, G.M., Balcomb, K.C., 2000. Killer Whales: The Natural History and Genealogy of Orcinus orca in British Columbia and Washington State, 2nd ed. University of British Columbia Press, Vancouver.

Ford, J.K.B., Ellis, G.M., Barrett-Lennard, L.G., Morton, A.B., Palm, R.S., Balcomb, 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.

Guinet, C. and J. Bouvier. 1995. Development of intentional stranding hunting techniques in killer whale(*Orcinus orca*) calves at Crozet Archipelago. Canadian Journal of Zoology **73**:27-33

Hauser, D.D.W. 2006. Summer space use of Southern Resident killer whales (*Orcinus orca*) within Washington and British Columbia inshore waters. M.S. thesis. University of Washington, Seattle, WA.

Ha, J. C. 2004. Southern resident killer whale behavior workshop final report. NMFS NWFSC. 5 pp.

Harwood, J. 2001. Marine mammals and their environment in the twenty-first century. Journal of Mammalogy **82**: 630-40.

Heimlich-Boran J. 1986. Fishery correlations with the occurrence of killer whales in greater Puget Sound. In: Kirkevold BC, Lockard JS (eds) Behavioral Biology of Killer Whales. Alan R. Liss, Inc., New York, p 113-131

Hoelzel, A.R., 1993. Foraging behavior and social group dynamics in Puget Sound killer whales. Animal Behavior **45**: 581-591.

Hooker, S.K., and Gerber, L.R., 2004. Marine reserves as a tool for ecosystem-based management: the potential importance of megafauna. Bioscience **54**: 27-39

Hoyt, E., 2005. Marine Protected Areas for Whales, Dolphins and Porpoises. Earthscan, London, 516pp.

Koski, K. 2006. 2004-2005 Final Program Report: Soundwatch Public Outreach/Boater Education Project. The Whale Museum, Friday Harbor, Washington.

Krahn, M. M., M. J. Ford, W. F. Perrin, P. R. Wade, R. P. Angliss, M. B. Hanson, B. L. Taylor, G. M. Ylitalo, M. E. Dahlheim, J. E. Stein, and R. S. Waples, 2004. 2004 status review of southern resident killer whales (*Orcinus orca*) under the Endangered Species Act. NOAA Technical Memorandum NMFS-NWFSC-62, U.S. Department of Commerce, Seattle, Washington.

Lopez J.C. and Lopez D., 1985. Killer whales (*Orcinus orca*) of Patagonia, and their behavior of intentional stranding while hunting nearshore. Journal of Mammalogy **66**:181-183

Lusseau, D. 2003. Effects of tour boats on the behavior of bottlenose dolphins: Using Markov chains to model anthropogenic impacts. Conservation Biology **17**: 1785-1793.

Lusseau, D. and Higham, J.E.S., 2004. Managing the impacts of dolphin-based tourism through the definition of critical habitats: the case of bottlenose dolphins (*Tursiops* spp.) in Doubtful Sound, New Zealand. Tourism Management **25**: 657-667.

Lusseau, D., Williams, R., Wilson, B., Grellier, K., Barton, T.R., Hammond, P.S. and Thompson, P.M., 2004. Parallel influence of climate on the behavior of Pacific killer whales and Atlantic bottlenose dolphins Ecology Letters **7**: 1068-1076.

Morton, A.B., Symonds, H.K., 2002. Displacement of Orcinus orca (L.) by high amplitude sound in British Columbia, Canada. ICES Journal of Marine Science **59**: 71–80.

National Marine Fisheries Service., 2006. Proposed Recovery Plan for Southern Resident Killer Whales (*Orcinus orca*). National Marine Fisheries Service, Northwest Region, Seattle, Washington. 219 pp.

Nichol, L.M., Shackleton, D.M., 1996. Seasonal movements and foraging behaviour of northern resident killer whales (*Orcinus orca*) in relation to the inshore distribution of salmon(*Oncorhynchus spp.)* in British Columbia. Canadian Journal of Zoology **74**: 983–991.

Williams, R. and Ashe, E., 2007. Killer whale evasive tactics vary with boat number. Journal of Zoology, London. 0:00-00

Williams, Rob, Trites, A.W., and Bain, D.E., 2002a. Behavioural responses of killer whales to whale-watching traffic: opportunistic observations and experimental approaches. Journal of Zoology, London **256**: 255-270.

Williams, R., Bain, D.E., Ford, J.K.B., Trites, A.W., 2002b. Behavioural responses of male killer whales to a ‘leapfrogging’ vessel. Journal of Cetacean Research and Management **4**(3): 305-310.

Williams, R., Lusseau, D. and Hammond, P.S., 2006. Estimating relative energetic costs of human disturbance to killer whales (*Orcinus orca*). Biological Conservation **133**(3): 301-311.

Wilson, B., Reid, R.J., Grellier, K. and Thompson, P., 2004. Considering the temporal when managing the spatial: a population range expansion impacts protected areas-based management for bottlenose dolphins. Animal Conservation **7**: 331-338.

Worm, B., Lotze, H.K. and Meyers, R.A., 2003. Predator diversity hotspots in the blue ocean. Proceedings of the National Academy of Sciences, U.S.A., **100**:9884-8.

Table 1: Definitions used for field-classification of coarse activity state of focal groups

Definition	Probable function
Whales were swimming at slow speed with predictable sequences of several short (30s) dives followed by a 3-5 minute long dive. This activity state was characterized by the absence of surface-active behavior (e.g., breaching or tail-slapping).	Rest
Whales surfaced and dove independently but all whales in the group were heading in the same general direction. The dive sequences of individuals showed regular patterns of several short dives followed by a long one, and whales swam at moderate speeds.	Travel /Forage
Individuals were spread out; individuals were surfacing and diving independently in irregular sequences of long and short dives; and individuals displayed fast, non-directional surfacings in the form of frequent directional changes.	Feed
Animals surfaced in tight groups with individuals engaged in tactile behavior; whales showed irregular surfacing and diving sequences and swim speeds; irregular direction of movement; and high rates of surface-active behavior.	Socialize

Table 2: Southern resident killer whale activity budget as observed during study period.

Activity State	**Total Observations In Each Activity State**	**Percentage of Total Observed Activities**
Rest	63	8.2%
Socialize	28	3.7%
Travel/Forage	485	63.5%
Feed	188	24.6%

Table 3. Parametric coefficients of the selected GAM (The smooth spline relationship between location and probability of feeding is shown in Figure 5):

	Estimate	std. err.	t ratio	Pr(>|t|)
(Intercept)	-1.2796	0.104	-12.3	< 2.22e-16

Approximate significance of smooth terms:

	edf	chi.sq	p-value
s(Longitude,Latitude)	14.19	50.504	5.7386e-06

R-sq.(adj) = 0.07 Deviance explained = 8.57%

UBRE score = -0.042564 Scale est. = 1 n = 764

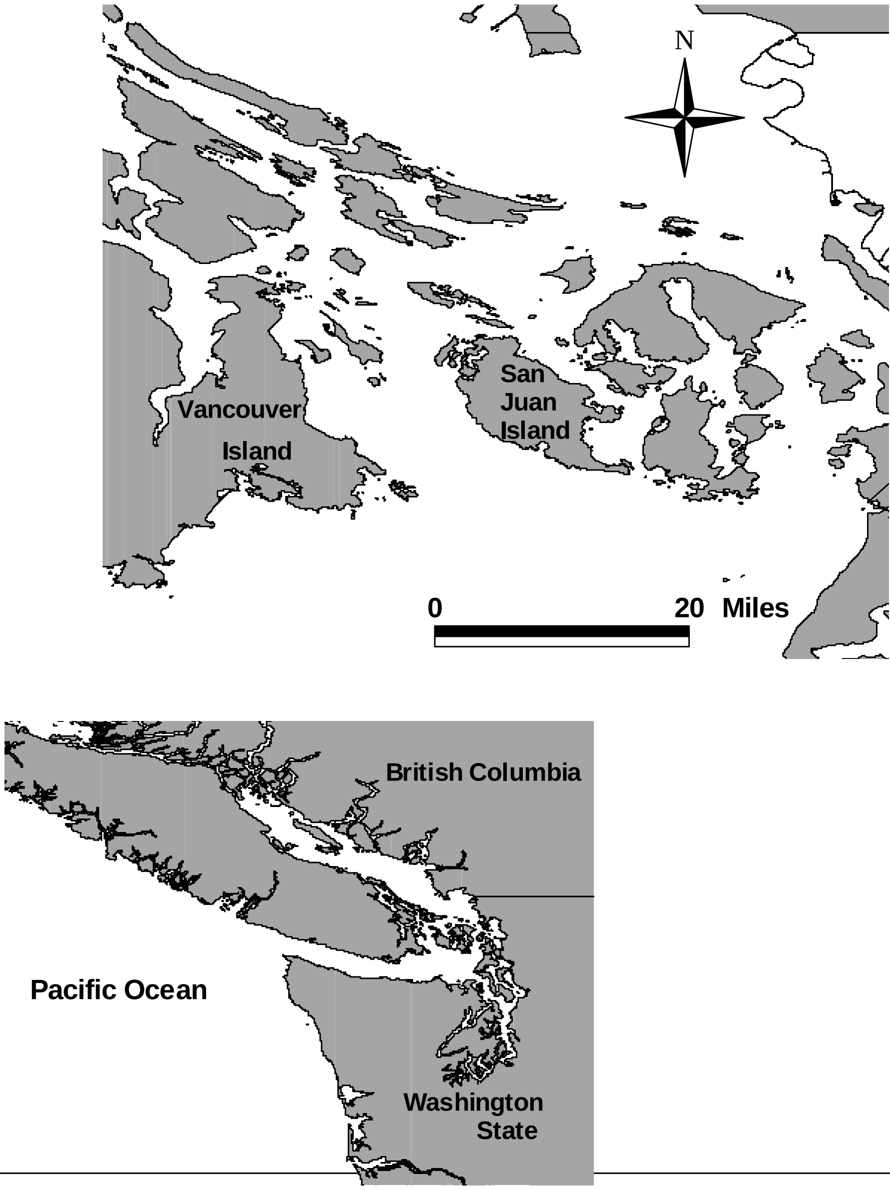

Figure 1. Map of the study area

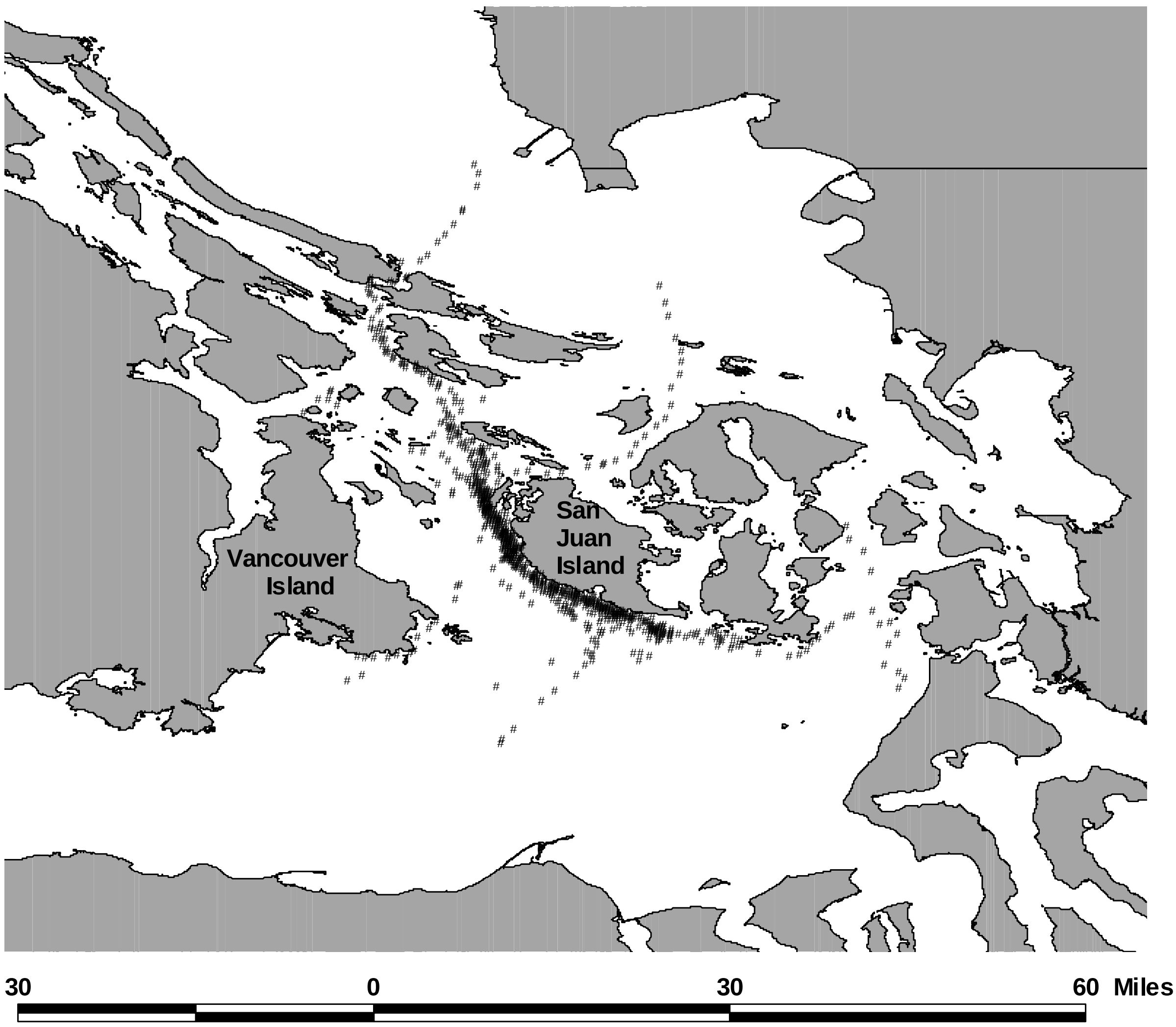

Figure 2: Map of locations for all activity states.

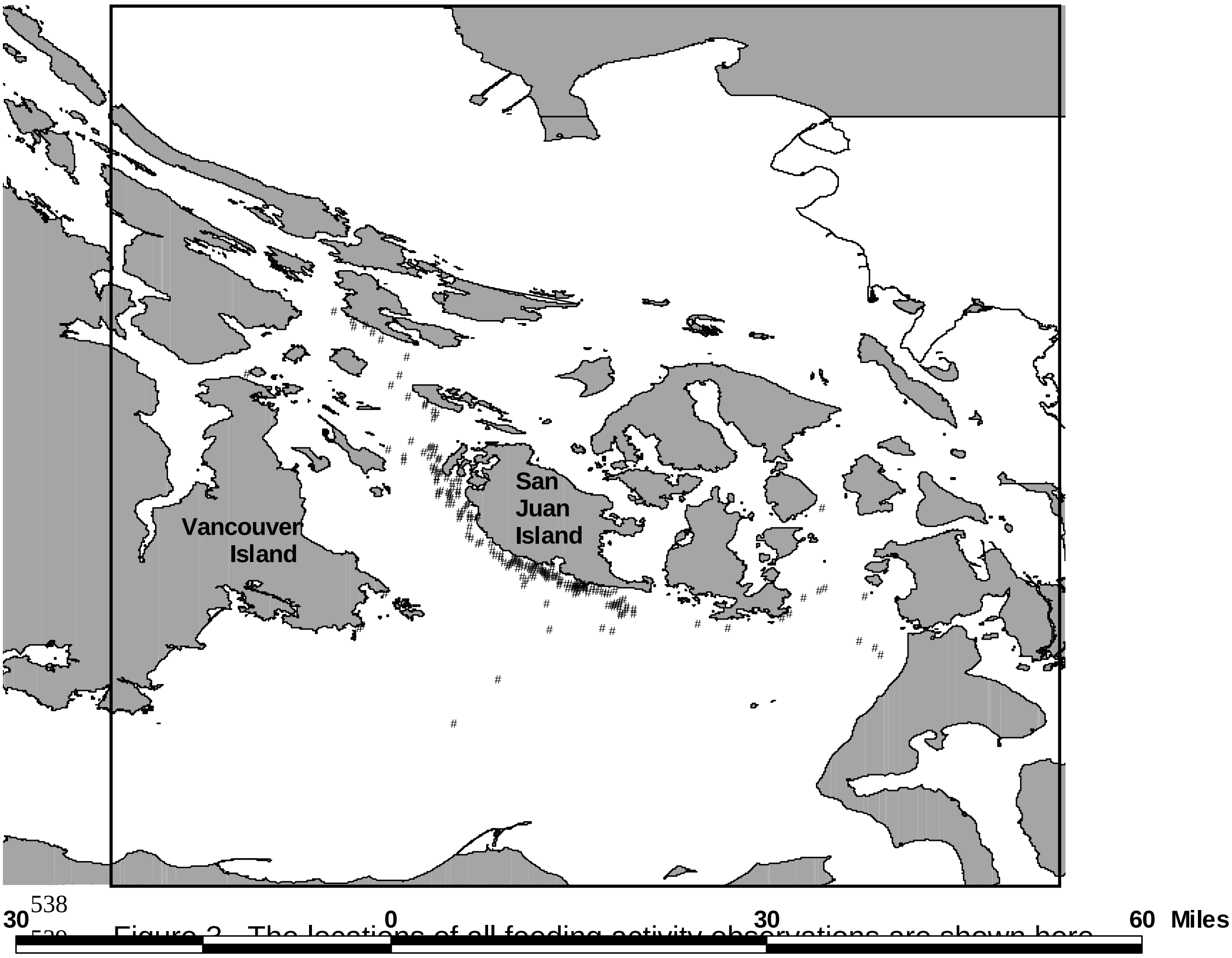

Figure 2. The locations of all feeding activity observations are shown here.

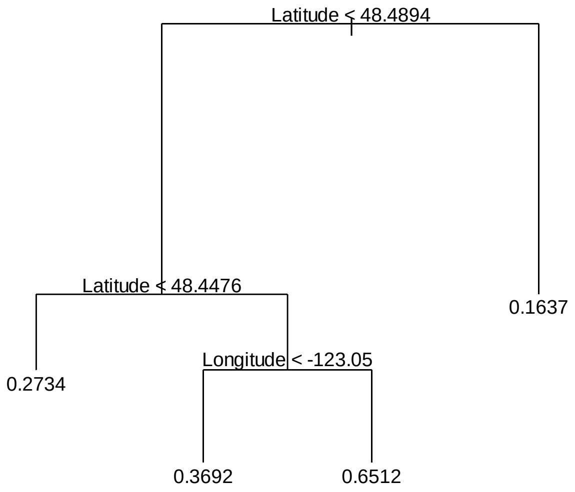

Figure 4. The selected classification tree. The text at a branch identifies nodes, that is, rules for splitting or sub-setting the data. The numbers at the terminal nodes refer to the proportion of observations in that subset that were of feeding animals.

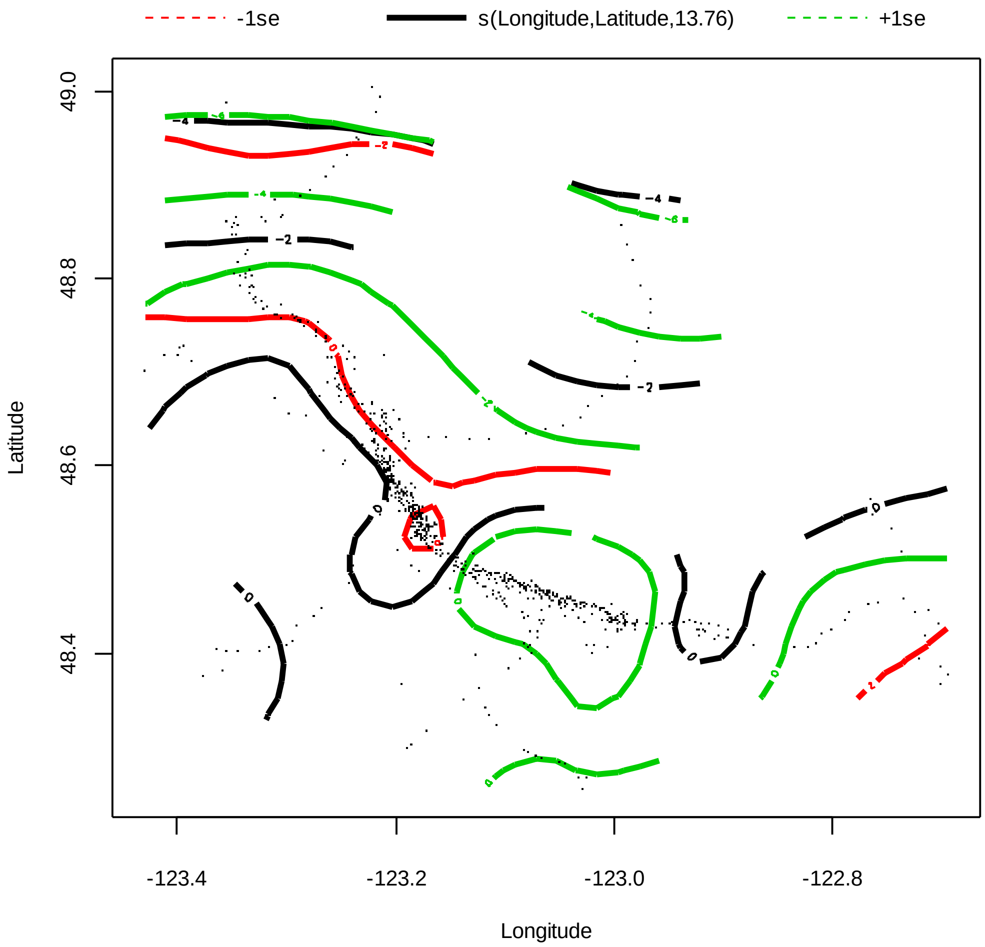

Figure 5. The smoothed relationship between location and whale behavior. The largest, center circle near the bottom represents an area in which there is a high probability of feeding. The smaller circle above and to the left represents an area in which feeding is highly unlikely to be observed. The circle of high probability feeding encompasses much of the southwestern end of San Juan Island, WA.

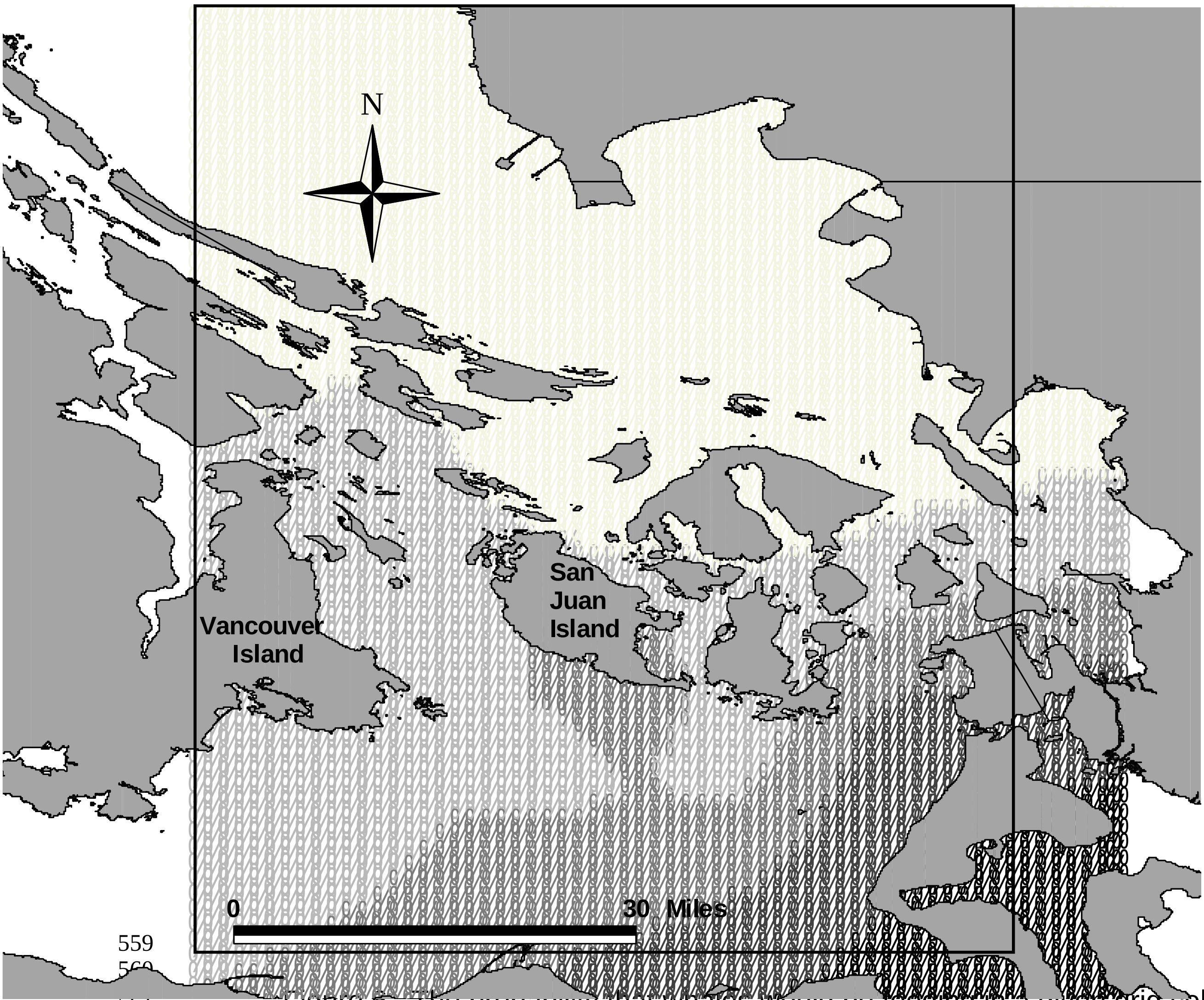

Figure 6. The probability that whales would be feeding in a given grid cell; the darker the colour, the higher the probability that whales would be feeding in that cell. The region to the north and west represent places where feeding activity was predicted to be highly unlikely, as designated by white areas. The second lightest gray colour represents places where the probability of feeding was similar to that predicted from chance alone. The next darker colour (the dark grey area to the south of San Juan Island) represents places with a higher-than-average probability of feeding taking place. The darkest grey colour represents a very high probability of feeding taking place, but it should be noted that very little search effort and very few observations of whale behavior were recorded in that part of the study area and represents an extrapolation.

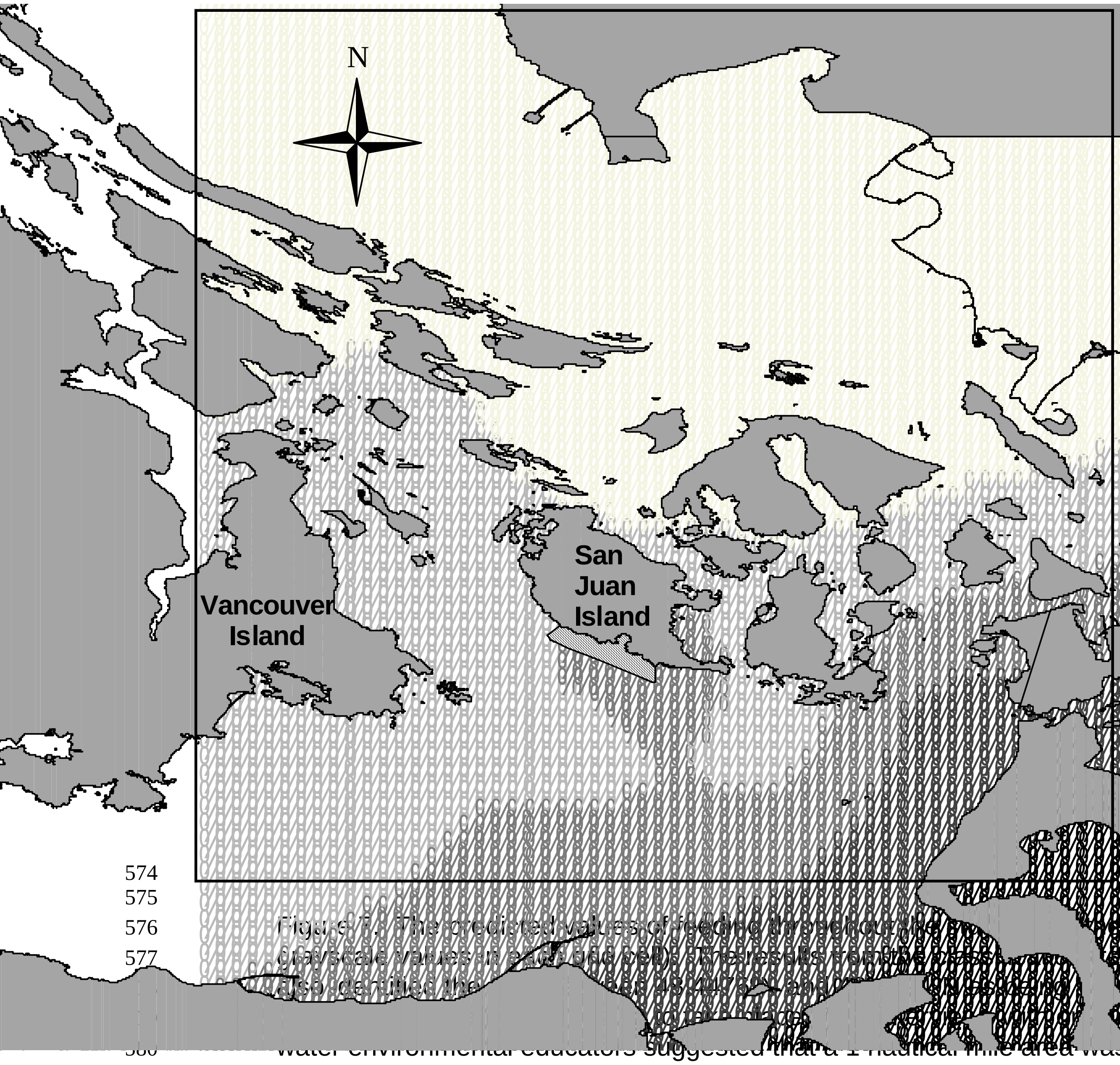

Figure 7. The predicted values of feeding throughout the [illegible] (grayscale values in each grid cell). The results from the class[illegible] we also identified the [illegible] between 48.447[illegible] and [illegible] interesting [illegible] to [illegible] place [illegible] whale-water environmental educators suggested that a 1 nautical mile area was considered manageable. As a result, we identified the region up to 1 mile off the southwestern shore of San Juan Island as a high-priority feeding area to protect as potential exclusion zone.

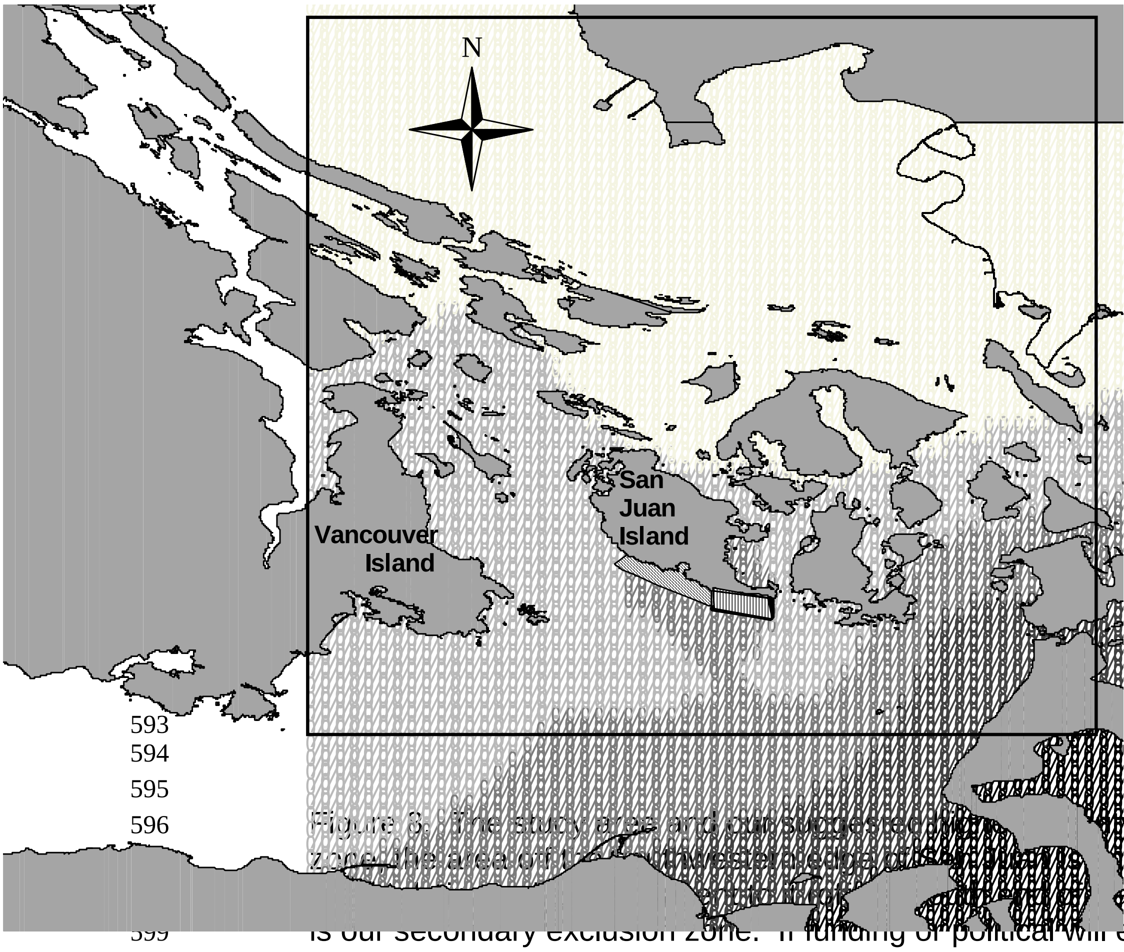

Figure 8. The study area and our suggested hig[illegible]y exclusion zone, the area off the southwestern edge of San Juan Is[illegible]d. The [illegible]ent to it (off [illegible] end of [illegible]an Juan Island) is our secondary exclusion zone. If funding or political will existed to protect a larger area, then both could be protected.