Boats displace killer whales from a marine protected area

Andrew W. Trites [1], Wesley M. Hochachka [1,2], Sarah K. Carter [1]
Marke M. Wong & Rob Williams [3]

[1] *Marine Mammal Research Unit, Fisheries Centre, University of British Columbia, Room 247, AERL, 2202 Main Mall, Vancouver, B.C., Canada, V6T 1Z4*

Tel: 604 822-8181 Fax: 604 822-8180 E-mail: trites@zoology.ubc.ca

[2] *Present Address: Laboratory of Ornithology, Cornell University, 159 Sapsucker Woods Road, Ithaca, NY 18540, USA*

[3] *Raincoast Conservation Society, Pearse Island, Box 193 Alert Bay BC V0N 1A0 Canada; and Sea Mammal Research Unit, Gatty Marine Lab, University of St Andrews, St Andrews Fife KY16 8LB Scotland*

12 April 2007

Abstract

Movements of vessels and killer whales (*Orcinus orca*) were monitored during summer daylight hours from July to September (1991-94) to determine whether vessels affected killer whales in the Robson Bight - Michael Bigg Ecological Reserve, British Columbia. Killer whales were seen in all parts of the Reserve, but spent significantly more time near the rubbing beaches than anywhere else. Overall, killer whales partitioned their time in the Reserve among resting (12%), rubbing (25%) and other activities (63%). Vessels, primarily commercial fishing vessels, were observed entering the Reserve over 12,000 times during the 4-year study. They did not appear to have marked effects on the numbers of whales in the Reserve. However, vessels did appear to affect the movements of the whales in this near-shore habitat. Whales were more likely to move to another area of the Reserve or to leave the Reserve entirely when vessels were present than when they were absent, and were more sensitive to vessels near the rubbing beaches than anywhere else in the Reserve. Our findings suggest that boats can displace whales from areas that might be designated as critical habitat. However, the possible long-term consequences of such short-term effects are not known and require further study.

Introduction

There is growing concern about the possible effects of whale-watching on cetaceans (Williams et al. 2002ab, Constantine et al. 2004, Lusseau 2005). Since the early 1980s, increasing numbers of people have been boarding vessels to observe whales and dolphins in the wild. Species that are readily accessible by whale watchers include humpback whales, gray whales, killer whales, bottlenose dolphins and spinner dolphins. Whether or not whale-watching and other vessel activity (e.g., fishing, shipping, etc.) are having detrimental effects on cetacean populations is not yet known.

In British Columbia, there are two prime areas to view killer whales. One is Haro Strait at the southern end of Vancouver Island, and the other is Johnstone Strait on the northeastern coast of Vancouver Island (Fig. 1). Johnstone Strait has several distinctions. During summer, it is frequented by killer whales seeking salmon and the opportunity to rub their bodies on its pebble beaches (Nichol and Shackleton 1996). The abundance of salmon and the presence of killer whales also draw people to the area. Johnstone Strait is a busy section of the Inside Passage between Vancouver and southeast Alaska, and an important area for commercial and recreational salmon fishing. Johnstone Strait is also one of the best known places in the world to view killer whales in the wild, and is a major destination for many of the 25,000 people who visit northern Vancouver Island area each year (1993 census data – Duffus and Dearden 1993, Ford et al. 2000). In sharp contrast to the thousands of visitors that come to Johnstone Strait each summer, the resident killer whale population that ranges from Vancouver Island to southeast Alaska only numbers about 200 individuals (Ford et al. 2000). It is not known whether the whales that frequent Robson Bight can tolerate the current levels of fishing and shipping activity as well as the increasing demands of nature-based tourism.

Two forms of killer whales in British Columbia, *residents* and *transients*, are socially and morphometrically separated (Bigg et al. 1990, Ford et al. 2000). Residents eat predominately fish while transients prefer marine mammal prey (Ford et al. 1998). The transients travel in small, fluid groups typically consisting of a mother and two or three offspring (Baird and Whitehead 2000). They do not use the rubbing beaches of Robson Bight. Residents do use the beaches and tend to live in stable groups (pods or matrilines) composed of several related females and their offspring. There are separate northern and southern communities of resident killer whales in British Columbia and adjacent waters of Washington State. The northern residents range mostly from the mid-point of Vancouver Island, north to southeast Alaska. Some pods appear to prefer certain portions of their range over others. In general, the northern residents frequent western Johnstone Strait and Queen Charlotte Strait from June to October to intercept the migrating salmon (Nichol and Shackleton 1996). It is rare to have more than 50 of these whales present in one place at one time during the peak of whale activity. Killer whales can be individually identified by dorsal fin and saddle patch. Pods can also be identified by their unique underwater vocalizations (Ford 1989). In 1993, the approximate mid-point of our study, there were 16 northern resident pods consisting of 35 subpods and 200 whales (Ford et al. 2000).

Concerns about boat traffic on whales have triggered management responses that fall into two broad categories. One was the designation of an important part of the whales' range as a voluntary no-entry protected area. In 1982, the Robson Bight (Michael Bigg) Ecological Reserve was established in Johnstone Strait by BC Parks (British Columbia Ministry of Environment, Lands, and Parks) to protect the killer whales and the beaches that killer whales traditionally use to rub their bodies. The Reserve consists of 1,248 hectares of water and 505 ha of land, but only the land is protected from human intrusion. People may legally fish and sail in the Reserve at any time, but the seabed and shoreline are protected, making anchoring or landing in the Reserve illegal. A visitor management

program was conducted in 1987, 1989 and 1990 to direct recreational traffic (on a voluntary basis) away from the Ecological Reserve and to monitor its use by whales, visitors and researchers (Taylor 1988, Taylor and Parsons 1989). The program was expanded between 1991 and 1994 to develop an education and research program (Wong et al. 1993). By the beginning of our study, boundary violations among commercial whale-watchers had become exceedingly rare, while boundary compliance among commercial fisherman was equally rare (Wong and Williams 1998).

The other mitigation measure was the adoption of voluntary whale-watching guidelines. Boaters are asked to remain 100m from whales, to parallel slowly, and to approach whales from the side. In addition, boaters are asked not to 'leapfrog,' that is, to speed up and place one's boat in a whale's predicted path. The biological consequences of these guidelines have been tested experimentally. When approached by an experimental boat that followed whale-watching guidelines (Williams et al. 2002b) or violated them by leapfrogging the whale's path (Williams et al. 2002a), focal animals adopted paths that were less direct than during preceding, no-boat conditions. No research has been conducted as yet to assess the potential for repeated disturbance from boats to cause short-term habitat displacement.

The goal of our study was to monitor the summer movements of killer whales and vessels in an area of moderate vessel traffic to determine whether vessels affected the presence and behavior of killer whales. The following attempts to determine whether vessels had an effect on the habitat use of killer whales in a nearshore environment by monitoring the movements of whales and vessels within the Robson Bight – Michael Bigg Ecological Reserve. The 4-year study reveals what can only be considered short-term effects, and provides a valuable baseline database to eventually evaluate possible long-term effects.

Methods

Study Site

The Ecological Reserve was divided into four areas of different sizes (Zones 3-6) using a vessel equipped with a LORAN positioning device to determine the boundaries (Fig. 1). Whale watching data were not collected in Zones 1 and 2, which fell outside of the Reserve. Whale and vessel activities were monitored from a 50m cliff on West Cracroft Island across from the Ecological Reserve (Fig. 1). The distance between the cliff and the most distant part of the study area (Zone 6) was 5-6 km.

Data Collection

Observations were made from July 1 to August 31 during daylight hours. However, in some years, observations were made as early as June 28 and as late as September 6. In 1991, all observations were made between 0800h and 2000h, but times varied from day to day. In 1992, 1993 and 1994, observations alternated between 0800-1800h and 1000-2000h. Observations were not made during foul weather when the zones and whales could not be clearly seen.

Killer whales that entered the Ecological Reserve were visually identified from their dorsal fins and saddle patches. Identifications were verified with researchers and commercial whale watching operators on board vessels in Johnstone Strait. On occasion, pods were identified by their distinct calls (Ford 1989) using hydrophones. Observers noted the number of whales present in each Zone and identified them as members of a particular matriline. Designation of matrilines followed Ford *et al.* (2000). Times that groups entered and left each zone in the Reserve were recorded in all years, but activity of the group (rubbing, resting or other) was only recorded in 1992 and 1993. *Rubbing* was assumed to occur when the whales were in Zone 6 and within 50 m of shore (Briggs 1991). *Resting* was noted when the whales were grouped in a resting line (Ford 1989). Observers noted the total time spent rubbing or resting, and the time of occurrence. Activities such as travelling, foraging and socializing were grouped as *other* because they were not differentiated consistently in all years of the study.

Ten types of vessels were observed: kayaks, sail boats, power boats, ocean liners, commercial fish boats, commercial whale watching boats, government patrol boats, research boats, tugs and others (*e.g.* float planes). Commercial fishing vessels consisted of seiners, gillnetters, and trollers with inboard diesel engines. Recreational power boats were typically shorter and faster than commercial fishing vessels, and had both inboard and outboard engines. Observers recorded the type of vessel present, and the time it moved from one zone to another. Stationary vessels were not recorded. Thus the number of vessels within any given zone could be estimated for any given time of day (*vessel visits*).

Numbers of fishing vessels and the amounts of salmon landed in Johnstone Strait (DFO Statistical Area 12) were obtained from Fisheries and Oceans Canada (Paul Ryall, pers. comm. Pacific Biological Station, Nanaimo, British Columbia).

Data Analysis

Data for days missed because of inclement weather were treated as missing values. We also combined data from recreational power and sail vessels because numbers of sail vessels were few and most were powered by inboard engines while in the narrow Strait.

To analyze the amount of time that whales were present, we used *group hours* (the number of whales in the group times the number of hours present). Since killer whales typically travel in social groups (Heimlich-Boran 1986), this is an accurate summary statistic for examining either the amount of time that whales were present, or the amount of time that they were engaged in specific activities. Groups contained entire pods and subpods of whales, combinations of subpods, or a fraction of a single subpod.

We examined daily, seasonal, and inter-annual variation in activity of vessels and whales independently before considering whether vessels had an influence on whale activity (the interaction). Differences in daily, seasonal and annual activity of whales and vessels were statistically tested using analysis of covariance. We also tested for inter-annual variation in resting and rubbing activities.

We began each analysis by including all potentially important variables to

determine the probability that each affected the activities of whales and boats. We then repeated the analyses, including only those variables that were potentially statistically significant in the initial ANCOVA ($P<0.15$). If the selected coefficients again proved significant ($P<0.05$), they were included in the equations predicting average variation in activity as a function of the statistically significant factors.

Vessels - We used a seasonal and a diurnal ANCOVA model to test whether the number of times that vessels entered zones in the Ecological Reserve was affected by *hour, day, year* or *zone*. The seasonal model included the variables *year, zone, day* and day^2 (in case the relationship between day and vessel activity was nonlinear). We also added the interactions *zone*day* and $zone*day^2$ because vessels may not have used all zones of the Reserve equally over the summer months. The diurnal model included *year, zone, hour* and $hour^2$ (in case of nonlinear changes in activity through the day). In addition, we considered the interaction between *hour* and *zone*, and between $hour^2$ and *zone* to verify whether vessels selectively entered the different zones at different times of the day. Finally we included the effects of *day* and day^2 to control for any within-season variation.

Whales - As for vessels, we used two basic ANCOVA models to test whether the number of whales and the amount of time they spent in the Reserve (*group hours*) were related to *hour, day, year* or *zone*. Factors included in the seasonal models were *zone, year, day*, and day^2, as well as the interactions *zone*day* and $zone*day^2$. The diurnal models considered *zone, year, day*, day^2, *hour* and $hour^2$, plus the interactions *zone*hour* and $zone*hour^2$.

Vessel - Whale Interactions - The possible effect of boats on numbers of whales in the Reserve was tested using weighted regressions (to account for the observed decreasing variance in number of whales with rise in vessel visits). We analyzed data from each zone separately to control for possible differences among zones, and considered two categories of whale use (number of whales, and *group hours*) and three categories of vessel types (recreational vessels, commercial fishing vessels, and total vessels). We employed Bonferroni corrections for each set of four analyses (*i.e.* for Zones 3-6), and only considered results to be statistically significant if they occurred with a probability of less than 0.0125 as opposed to $P<0.05$ (because the likelihood of obtaining a statistically significant result increases with the number of statistical tests conducted, even when no biological basis exists for finding differences).

We examined the effects of vessels on the activity of whales in the Reserve by estimating the probability that whales would leave a zone within a given amount of time when vessels were present or absent. We chose an arbitrary 15 minute time block believing that it was short enough to observe any immediate effect of vessels on the whales, yet long enough that the effect did not have to be instantaneous. We also recognized that factors other than entry of vessels could affect the probability of whales going from one zone to another. Thus our analysis simultaneously included the number of *vessel visits* within the 15 minute period, as well as *zone, year, day*, day^2, *hour*, $hour^2$, number of whales in the zone, and the amount of time that groups of whales had already been in the zone (*group*

hours). Numbers of whales was included as a variable because the response of whales to vessels could depend on the number of whales present. Likewise, the time that whales have already been in a zone may affect their propensity to leave. Finally, *hour* and *day* were included because the effect of vessels entering could vary with time and season.

The data were divided into 15-minute blocks, with periods starting on the hour and at 15-minute intervals thereafter. We did not explore other intervals or start times because dividing the data set many different ways and applying multiple analyses could result in spurious findings. Whales could make one of two choices within each 15-minute period; they could either "leave" or "not leave". Given the dichotomy of choices, we applied logistic regression to estimate the probability that groups of whales would leave a zone when vessels entered.

Results

Vessel Activity

The number of times that vessels moved from one zone to another was highly variable (Fig. 2, range: 1 to 128 crossings per day, mean: 17.3 crossings per day – all vessel types combined and all zones summed within a day). Most of the vessels moving within the Ecological Reserve were commercial fish boats (Table 1, 76-87% of the total). Recreational power and sailing vessels represented only 9-17% of all vessel visits (Table 1). Note that commercial whale watch boats (referred to as commercial charter vessels in Table 1) rarely entered the Reserve, and in no year did their presence inside the Reserve account for 1% of all vessel visits.

Intra-Seasonal Variation - Considerable variation was noted in the number of times vessels moved across zone boundaries in the Ecological Reserve (Fig. 2). In general, few vessels entered the Reserve until the last week of July when commercial fishing activity increased. Significant peaks in visits by commercial vessels were noted in early August and again at the end of August. In contrast, visits by recreational vessels peaked during the last week of July. The frequency of commercial and recreational vessels entering the Reserve rose from east to west (*i.e.* lowest in Zone 6 - the rubbing beaches, and highest in Zone 3; Fig. 3). However, no relationship was found between the movements of recreational vessels and commercial fishing vessels within the Reserve.

Frequency of visits to the Reserve by commercial and recreational vessels differed among years, zones and time of month ($P<0.05$ for the ANCOVA *year, zone, day* and day^2 terms), but there was no systematic increase or decrease in vessel visits over the four years of study. Plotting the average number of times per day that vessels crossed zone boundaries by week (*i.e. vessel visits* in Zone 3 + *vessel visits* in Zone 4 + ...) shows the underlying seasonal rise in vessel activity in the Ecological Reserve as a whole (Fig. 4a).

The high variability in vessel activity among years, particularly during the month of August, may reflect differences in the size of salmon runs sought by the commercial vessels. Total level of activity by commercial fishing vessels within the Ecological Reserve was positively correlated with overall numbers of commercial boats fishing throughout

Johnstone Strait (r^2 =0.61, $F_{1,34}$ =52.86, P<0.001; Fig. 2). This suggests that much of the variation in vessel activity within the Ecological Reserve was driven by the schedule of short-term fishing openings.

Diurnal Variation - Vessel movements within the Reserve ranged from 0 to 20 visits per hour, with a mean of 2.01, and were higher for commercial fishing vessels than for recreational vessels. The small number of visits by recreational vessels tended to peak slightly at 1200 h and dropped off through the rest of the day while commercial vessel activity was highest in the early morning and late afternoon - early evening (P < 0.05 for the ANCOVA *hour* and *hour* ^{2} terms). No diurnal movement patterns were detected, however, when commercial, recreational and other vessel types were pooled together.

As with seasonal changes in vessel activity, relatively few vessels entered zones in the Ecological Reserve at any given hour, but variability from hour to hour was extremely high and could not be explained by daily differences in average vessel activity.

Whale Activity

Eleven of the 16 northern resident pods were seen in the Ecological Reserve at least once during the four years of study (Table 2). Of these, five pods (A1, A4, A5, C1 and I11) used the Reserve more frequently than others, with the A1 pod being the most consistently sighted (*i.e.* they were present on 39-82% of the days observed). Number of times that pods and subpods were seen varied from year to year (Tables 2 and 3). On some occasions, subpods arrived together with other members of their pod, while at other times they came alone. Subpods were seen an average of 193 times each year (1991-93) over an annual average of 66 days of observation (Table 3 - weighted mean). In 1994, however, they were only seen 100 times.

The amount of time spent resting, rubbing or engaged in other activities depended upon which zone of the Ecological Reserve the whales were in (Table 4). In general, killer whales spent an average of 15% of their time resting in Zones 3, 4 and 5; and 85% of their time engaged in other activities. In contrast, whales spent 67% of their time rubbing in Zone 6, but only 6% resting and 27% engaged in other activities. Within the Reserve as a whole, however, whales spent an average of 12% of their time resting, 25% rubbing, and 63% engaged in other activities (Zones 3-6).

How the whales use the Ecological Reserve might change from year to year if pods behave differently from one another. Unfortunately we were unable to compare the activities of individual pods given the available data, and therefore assumed that no significant differences existed among the activities of pods within a season or from year to year.

Intra-Seasonal Variation - Numbers of whales and the amount of time that groups of whales spent in the Reserve (*group hours*) varied considerably between June 29 and September 5 (Fig. 5). In general, both numbers of whales and *group hours* rose through the month of July, peaking in early to mid August, and declining gradually thereafter (Fig. 5).

Inter-annual variability in the number of whales present and the amount of time they

spent within the Reserve was also considerable ($P<0.01$ for the *year* term). Most striking was the drop in numbers of pods sighted in 1994 (Tables 2 and 3), when most whales left at the end of July and did not return for the remainder of that summer (Fig. 4b). Killer whales travelled in all parts of the reserve with equal frequency (Fig. 6a), but spent significantly more time in Zone 6 (at the rubbing beaches) than anywhere else in the Reserve (Fig. 6b).

Amounts of time that groups of whales spent resting and rubbing did not vary systematically through the season ($P>0.10$ for the *day* and day^2 terms), but did vary by year ($P<0.01$ for *year*). There was also a slight effect of time of day ($P=0.10$ for the *hour* term). Group hours of rubbing increased linearly throughout the day (0800-1800 h) from 0 to 1 h in 1992 and from 0.4 to 1.4 h in 1993.

Diurnal Variation - As with numbers of whales counted throughout the season, the numbers counted throughout the day varied considerably (range 0 to 51 per hour) with a general increase in numbers in all zones from morning to evening. Time spent in Zone 6 (the rubbing beaches) was significantly longer than anywhere else in the Reserve and increased from morning to evening ($P<0.01$ for *zone*). In contrast, time spent each day in the other three Zones was low and relatively constant. As with previous analyses, however, changes in average movements of whales were far smaller than the range of variation seen within any single hour of the day.

Whale - Boat Interactions

Attempts to ascertain the effects of boats on whales can be confounded by the inherent daily and seasonal changes in their numbers and activities. However, systematic variations in numbers and activities over the season are unlikely to affect analyses of interaction between vessels and whales. This is because average changes in the numbers and activities of whales and vessels were far smaller than the range of variation seen within a given hour or day.

Effect of Boats on Numbers of Whales - There were many days when whales or boats were not in the Reserve at the same time, as well as many days when they were present together (Fig. 7). However, there is little evidence that activities of vessels were related to either numbers of whales or time whales spent within the reserve (Fig. 7). Variation in boat activity did not appear to be associated with variation in numbers of whales using the Ecological Reserve. Only 1 of the 12 regressions of whale numbers against vessel visits was statistically significant (12 = 4 zones x 3 categories of vessels – commercial, recreational and total). This suggests a decrease of 0.12 whales each time vessels entered Zone 5. Similarly only 1 of the 12 regressions of vessel activity against *group hours* was statistically significant. In Zone 5, whale activity was reduced by 0.01 *group hours* for each additional commercial fishing vessel that entered the zone. Thus the magnitudes of the statistically significant effects of additional boats on whale numbers and *group hours* were small and probably of no biological importance.

Effect of Boats on Activities of Whales - Even though vessel activity did not appear to affect the numbers of whales using the Ecological Reserve, there appeared to be a subtle

effect of vessels on the movement of whales. Logistic regressions showed that whales were more likely to leave a zone of the Reserve when vessels entered it than if the vessels stayed out, and that the probability of a whale leaving rose as the number of vessels entering the zone increased (Fig. 8). The regressions also showed that the probability of whales spontaneously leaving a zone in the absence of vessels, increased as the day progressed, and that the whales were more likely to leave Zone 6 (the rubbing beaches) than any other zone of the Ecological Reserve (probabilities of whales leaving Zone 6 within the next 15 minutes ranged from 82-90% compared to 56-71% in Zones 3-5).

Effects of vessels on whale activity were more pronounced in the morning than later in the day (Fig. 8). For example, at 0800 h, whales in Zones 3-5 had a 56% probability of leaving the zone within the next 15 minutes when no boats were present. When one boat entered, the probability of whales leaving rose to 60%. With five boats it rose to 70%. By 20:00h, however, numbers of vessels appear to have little or no effect on the likelihood of whales leaving a zone.

Discussion

Our primary goal was to determine if vessels affected killer whales in the Ecological Reserve. To that end, we found that vessels negatively affected the movement of whales, but could not discern any effect on numbers of whales using the Reserve. However, the potential for vessel traffic to cause even short-term displacement from important habitat may have management and conservation implications in Canada under the Species at Risk Act.

Numbers of whales and the movements of whales and vessels within the Ecological Reserve varied systematically among years, days, and hour of day. Both showed a general increase in activity as the summer progressed that may reflect the abundance of salmon in the Reserve. Seasonal movements of resident killer whales into the inside Pacific coastal waters have been related to the inshore distribution and abundance of salmon in Juan de Fuca Strait (Heimlich-Boran 1986, 1988) and Johnstone Strait (Guinet 1990, Nichol and Shackleton 1996). This suggests that the concomitant rise and fall in seasonal numbers of vessels and whales entering the Ecological Reserve (Figs. 3 and 5) reflected the local abundance of salmon that both were seeking. We explored this possibility but did not find any significant correlations between whales (numbers and *group hours* of activity in Zones 3-6) and the amounts of salmon caught (pink, chum, sockeye, chinook and total salmon reported from gillnet and troll combined catches in DFO Statistical Area 12 of Johnstone Strait). This may mean that killer whale use of the Reserve was independent of the abundance of salmon or, more likely, that catch statistics were not a good index of salmon abundance in the Reserve. Subsequent attempts to model relationships between killer whales and prey availability have found significant inter-annual variation in chinook salmon availability and the grouping behaviour of killer whales in Johnstone Strait in summer using summary statistics from DFO test fisheries, which may be a more reliable indicator of relative abundance than commercial catch data (Lusseau *et al*. 2004).

The seasonal presence and activities of whales and vessels were consistent in all

years except 1994, when the whales left the Reserve and Johnstone Strait much earlier than normal (Fig. 4). It must be kept in mind, however, that all of the general patterns described were surrounded by such high variability that neither boat nor whale activity can be accurately predicted for a given date or time.

The total time that groups of whales spent within the Ecological Reserve (all zones combined) was not correlated with daily levels of vessel activity (Fig. 7). However, when we considered whale activity on a much finer scale, we found that the probability of whales leaving a zone increased slightly with increasing numbers of boats entering that zone, and that this effect was more pronounced in the morning than later in the day (Fig. 8). The lack of a major effect of vessels on the day-to-day use of the Ecological Reserve by killer whales, coupled with the presence of a finer scale effect, suggests that (1) vessel activity does not have marked effects on the presence of whales in the Ecological Reserve, but that (2) the activities of whales within the Ecological Reserve are affected. In particular, it appears that whales are more likely to move when vessels are present than when they are absent. They are also more likely to leave the rubbing beach area than any other place in the Reserve.

It has been previously suggested that killer whales are more sensitive to human disturbance in Zone 6 than in any other zone (Briggs 1993). However, killer whales could also have a higher probability of leaving Zone 6 because of its relatively small size (Fig. 1) and the apparent propensity for some individuals to increase their swimming speed in the presence of boats (Kruse 1991, Williams 1999). Increases in swimming speed appears to be a common response of many species of cetaceans to disturbance by vessels (e.g., humpback whales – Baker and Herman 1982, Scheidat et al. 2004) (; bowhead whales – Richardson et al. 1985, Weinrich et al. 1992; and fin whales – Notarbartolo di Sciara et al. 1996, Jahoda et al. 2003).

Commercial fishing accounted for most of the whale-boat interactions, and is currently allowed in all areas of the Ecological Reserve because of traditional and cultural rights. Given the large number of vessels that are active in Johnstone Strait, consideration might be given to restricting all human activity in Robson Bight, particularly near the rubbing beaches. Our results showed that killer whales favored use of the rubbing beaches in Zone 6 and were more sensitive to human disturbance here than anywhere else in the Reserve. The creation of Reserves that restrict the presence of vessels may be a means of ensuring that short-term effects on killer whales and other species of cetaceans never escalate into long-term impacts.

Although our analyses indicate that vessels affected whale activities, we do not know what the biological consequences of the effects are, or their exact cause. However, the nature of the behavioural response is worth examining in greater detail. By increasing the likelihood that whales would leave a given zone of the Reserve, increasing numbers of boats essentially displaced whales temporarily from portions of their range. Habitat displacement has been demonstrated at a much finer scale for this population — the tendency for whales to adopt circuitous swim paths when approached for 20 minutes by an

experimental boat can be thought of as micro-scale displacement (Williams et al. 2002a, Williams et al. 2002b). Northern residents were displaced also at a much larger spatial and temporal scale when acoustic harassment devices were introduced for several years to open-net Atlantic salmon farms in the nearby Broughton Archipelago (Morton and Symonds 2002). The long-term sustainability of the whale-watching industry, in addition to conservation of killer whale populations, will depend on reducing the probability that whales will be displaced from their core areas. This is an important consideration in designating and protecting critical habit of killer whale populations that are deemed to be at risk.

Inconsistent data recording precluded us from answering many of the questions that we wished to pose about killer whales and boats in Johnstone Strait. Some unanswered questions include: (1) Did whales leave a zone only when directly approached by vessels, and if so was there some critical distance beyond which whales were unaffected? (2) Were some pods of whales more sensitive to disturbance than others? (3) When whales left a zone of the Ecological Reserve following entry by vessels, what direction did they travel relative to the vessel or vessels in question? (4) Were animals equally vulnerable to disturbance in all initial activity states? (5) Is the magnitude of the effects of vessels on whales biologically significant? Such questions need to be answered to draw firmer conclusions about the impact of vessel activity on whales in the Ecological Reserve.

Our results showed a subtle effect of vessels on the time whales spent in the Robson Bight - Michael Bigg Ecological Reserve, but no effect on their numbers. Only with additional research can the possible long-term effects of vessels on whales be ascertained.

Acknowledgements

Funding for this study was provided by BC Parks. We are grateful to the many field assistants who provided invaluable logistical support for the warden program, and spent hundreds of hours sitting on the cliff scanning the Ecological Reserve for whales and vessels. We would particularly like to thank S.Bambini, K. Bennet, S. Bennet, T. Bird, B. Brachvogel, M. Bratty, D. Briggs, L. Carnahan, B. Casher, D. Chardonnens, F. Chardonnens-Peeterbroek, C. Cornish, G. D'Alquen, W. Easton, P. Edgar, L. Elliott, E. Ellis, M. Falconer, A. Fikart, J. Fullerton, C. Fussel, S. Godwin, C. Gordon, E. Gregr, R. Hardisty, M. Hanneman, L. Higgs, E. Hildebrand, J. Hume, D. Hunter, V. Komori, D. Lister, L. Lowe, S. McBride, L. McIntosh, S. Macy, C. Mahoney, L. Marshall, S. Molyneaux, L. Nash, L. Nichol, J. Pinsoneult, L. Press, C. Ramey, J. Roop, M. Scheidat, T. Schroder, H. Sit, J. Smith, T. Tanaka, R. Taylor, R. Thomas, J. Vanderleelie, K. Williston, and S. Wischniowski.

We would also like to acknowledge the support and assistance of the local whale watching community. J. Borrowman and B. Mackay provided invaluable logistical support, local knowledge of the marine area and whale activity. P. Spong, H. Symonds and their co-workers at OrcaLab assisted in locating and identifying pods. We also wish to thank Mountain Equipment Coop, PFC Foods and Telegraph Cove Resorts Ltd. for graciously providing valuable field equipment and/or facilities. R. Simmons (BC Parks)

and E. Gregr (BION Research Inc) provided valuable insights into the available database, and P. Ryall (DFO) provided information on commercial fishing activity and catch in Johnstone Strait. Finally, we would like to thank A. Blachford and L. Bailey at the UBC Zoology Computing Unit for their assistance, and D. Briggs, J. Ford, E. Gregr and R. Taylor for useful comments and suggestions on earlier drafts of this manuscript. The manuscript was improved by fruitful discussions with members of the Whalewatching Subcommittee of the International Whaling Commission at its 58th annual meeting of the Scientific Committee in St Kitts (May/June 2006).

Literature Cited

BAIRD, R. W., and H. WHITEHEAD. 2000. Social organization of mammal-eating killer whales: group stability and dispersal patterns. Canadian Journal of Zoology 78:2096-2105.

BAKER, C. S., and L. H. HERMAN. 1982. The impact of vessel traffic on the behaviour of humpback whales in southeast Alaska. Unpubl. Rep. (available from Nat. Mar. Mamm. Lab., NMFS, Seattle WA), Contract 81-ABC-00114, 39 pp.

BIGG, M. A., P. F. OLESIUK, G. M. ELLIS and K. C. BALCOMB. 1990. Social organization and genealogy of resident killer whales (*Orcinus orca*) in the coastal waters of British Columbia and Washington State. Reports of the International Whaling Commission (special issue) 12:383-405.

BRIGGS, D. A. 1991. Impact of human activities on killer whales at the rubbing beaches in the Robson Bight Ecological Reserve and adjacent waters during the summers of 1987 and 1989. Report to BC Ministry of Environment, Land and Parks., pp.

BRIGGS, D. A. 1993. Activities of killer whales and humans in the Robson Bight Ecological Reserve and adjacent waters, in the summer of 1990. Report to BC Ministry of Environment, Lands and Parks, pp.

CONSTANTINE, R., D. H. BRUNTON and T. DENNIS. 2004. Dolphin-watching tour boats change bottlenose dolphin (*Tursiops truncatus*) behaviour. Biological Conservation 117:299-307.

DUFFUS, D. A., and P. DEARDEN. 1993. Recreational use, valuation, and management of killer whales (*Orcinus orca*) on Canada's Pacific coast. Environmental Conservation 20:149-156.

FORD, J. K. B. 1989. Acoustic behaviour of resident killer whales (*Orcinus orca*) off Vancouver Island, British Columbia. Canadian Journal of Zoology 67:727-745.

FORD, J. K. B., G. M. ELLIS and K. C. BALCOMB. 2000. Killer whales: the natural history and genealogy of *Orcinus orca* in British Columbia and Washington. 2nd ed., University of British Columbia Press, Vancouver.

FORD, J. K. B., G. M. ELLIS, L. G. BARRETT-LENNARD, A. B. MORTON, R. S. PALM and K. C. BALCOMB III. 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. 1990. Sympatrie des deux categories d'orques dans le detroit de Johnstone, Columbie Britannique. Revue d'Ecologie 45:25-34.

HEIMLICH-BORAN, J. R. 1986. Fishery correlations with the occurrence of killer whales in greater Puget Sound. Pages 113-131 *in* B. Kirkevold and J. S. Lockard, eds. Behavioural biology of killer whales. Alan R. Liss, Inc., New York.

HEIMLICH-BORAN, J. R. 1988. Behavioral ecology of killer whales *(Orcinus orc*a) in the Pacific Northwest. Canadian Journal of Zoology 66: 565-578.

JAHODA, M., C. L. LAFORTUNA, N. BIASSONI, C. ALMIRANTE, A. AZZELLINO, S. PANIGADA, M. ZANARDELLI and G. NOTARBARTOLO DI SCIARA. 2003. Mediterranean fin whale's (*Balaenoptera physalus*) response to small vessel and biopsy sampling assessed through passive tracking and timing of respiration. Marine Mammal Science 19:96–110.

KRUSE, S. 1991. The interactions between killer whales and boats in Johnstone Strait, British Columbia. Pages 149-159 *in* K. Pryor and K. S. Norris, eds. Dolphin societies: discoveries and puzzles. University of California Press, Berkeley.

LUSSEAU, D. 2005. Residency pattern of bottlenose dolphins *Tursiops* spp. in Milford Sound, New Zealand, is related to boat traffic. Marine Ecology Progress Series 295:265-272.

LUSSEAU, D., WILLIAMS, R., WILSON, B., GRELLIER, K., BARTON, T., HAMMOND, P.S., and THOMPSON, P.M. 2004. Parallel influence of climate on the behaviour of Pacific killer whales and Atlantic bottlenose dolphins. *Ecology Letters* **7:**1068.

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

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

NOTARBARTOLO DI SCIARA, G., M. JAHODA, N. BIASSONI and C. LAFORTUNA. 1996. Reactions of fin whales to approaching vessels assessed by means of a laser range finder. the tenth annual meeting of the European Cetacean Society, Lisbon, 11-13 March 1996. Page 6.

RICHARDSON, W. J., M. S. FRAKER, B. WÜRSIG and R. S. WELLS. 1985. Behavior of bowhead whales summering in the Beaufort Sea: reactions to industrial activities. Biological Conservation 32:196-280.

SCHEIDAT, M., C. CASTRO, J. GONZALEZ and R. WILLIAMS. 2004. Behavioural responses of humpback whales (*Megaptera novaeangliae*) to whalewatching boats near Isla de la Plata, Machalilla National Park, Ecuador. Journal of Cetacean Research and Management 6:63-68.

TAYLOR, R. E. 1988. The use of a marine mammal reserve by researchers and photographers. unpub. rep., Natural Resource Management Program, Simon Fraser University, 41 pp.

TAYLOR, R. E., and H. J. PARSONS. 1989. Report on 1989 Robson Bight visitor program. BC Ministry of Land, Parks and Housing, 22 pp.

WEINRICH, M. T., R. H. LAMBERTSON, C. R. BELT, M. R. SCHILLING, H. J. IKEN and W. E. SYRIALA. 1992. Behavioral reactions of humpback whales *Megaptera novaeangliae* to biopsy procedures. Fishery Bulletin 90:558-598.

WILLIAMS, R., D. E. BAIN, J. K. B. FORD and A. W. TRITES. 2002a. Behavioural responses of male killer whales to a 'leapfrogging' vessel. Journal of Cetacean Research and Management 4:305-310.

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

WILLIAMS, R. M. 1999. Behavioural responses of killer whales to whale-watching: opportunistic observations and experimental approaches. M.Sc. dissertation. University of British Columbia. 61 pp.

WONG, M. L., W. E. EASTON and J. J. VANDERLEELIE. 1993. Robson Bight - Michael Bigg Ecological Reserve visitor management program (1991-93). BC Ministry of Environment, Lands and Parks, pp.

WONG, M. L. and WILLIAMS, R. 1998. Robson Bight - Michael Bigg Ecological Reserve Visitor Management Program - 1998 Season Report. Parksville, BC, B.C. Ministry of Lands and Parks**,** 26 pages.

Table 1. Number of times that vessels entered one or more zones of the Ecological Reserve. Numbers of entries by each vessel type are shown in brackets as a percentage of all visits. Note that numbers of kayaks represent groups and not individual kayaks, and that numbers of commercial fishing vessel visits are slightly underestimated because groups of boats were occasionally treated as a unit without designating their number.

Type of Vessel	**Year of Study**			
	1991	1992	1993	1994
Commercial Fishing Vessel	2,514 (78.7)	3,397 (75.9)	3,780 (87.0)	1,623 (81.0)
Recreational Power Vessel	307 (9.6)	462 (10.3)	220 (5.1)	207 (10.3)
Recreational Sailing Vessel	165 (5.2)	289 (6.5)	160 (3.7)	60 (3.0)
Recreational Kayak Group	83 (2.6)	106 (2.4)	64 (1.5)	40 (2.0)
Government Patrol Vessel	79 (2.5)	100 (2.2)	65 (1.5)	19 (0.9)
Commercial Charter Vessel	23 (0.7)	35 (0.8)	0 (0.0)	31 (1.5)
Commercial Ocean Liner	12 (0.4)	42 (0.9)	6 (0.1)	21 (1.0)
Tugboat	10 (0.3)	33 (0.7)	12 (0.3)	2 (0.1)
Photographer / Research Vessel	1 (0.0)	10 (0.2)	11 (0.3)	0 (0.0)
Other	0 (0.0)	1 (0.0)	28 (0.6)	0 (0.0)
TOTAL	3,194	4,475	4,436	2,003
number of days of observation	62	64	56	68

Table 2. Number of days that pods (and portions of pods) of killer whales were seen in the Ecological Reserve. Observers watched for 61 days in 1991, 66 in 1992, 56 in 1993, and 66 in 1994. Bracketed numbers show the frequency of pod sightings in the Reserve (%).

Pod	1991	1992	1993	1994
A1	40 (65.6)	54 (81.8)	35 (62.5)	26 (39.4)
A4	22 (36.1)	13 (19.7)	15 (26.8)	13 (19.7)
C1	14 (23.0)	15 (22.7)	18 (32.1)	16 (24.2)
A5	11 (18.0)	9 (13.6)	26 (46.4)	8 (12.1)
I11	9 (14.8)	21 (31.8)	7 (12.5)	7 (10.6)
B1	7 (11.5)	2 (3.0)	4 (7.1)	6 (9.1)
H1	5 (8.2)	3 (4.5)	0 (0.0)	0 (0.0)
I31	4 (6.6)	1 (1.5)	0 (0.0)	1 (1.5)
R1	1 (1.6)	1 (1.5)	6 (10.7)	0 (0.0)
D1	0 (0.0)	3 (4.5)	0 (0.0)	0 (0.0)
I2	0 (0.0)	1 (1.5)	2 (3.6)	0 (0.0)
Total	113	123	113	77

Table 3. Number of days that subpods of killer whales were seen in the Ecological Reserve. Observers watched for 61 days in 1991, 66 in 1992, 56 in 1993, and 66 in 1994. Bracketed numbers show the frequency of subpod sightings in the Reserve (%).

Pod	Sub	1991	1992	1993	1994
A1	A12	28 (45.9)	31 (47.0)	12 (21.4)	11 (16.7)
A1	A30	27 (44.3)	40 (60.6)	27 (48.2)	6 (9.1)
A4	A11	21 (34.4)	15 (22.7)	15 (26.8)	10 (15.2)
A4	A24	18 (29.5)	15 (22.7)	13 (23.2)	11 (16.7)
A1	A36	11 (18.0)	14 (21.2)	12 (21.4)	20 (30.3)
C1	C5	10 (16.4)	13 (19.7)	16 (28.6)	16 (24.2)
A5	A8	10 (16.4)	6 (9.1)	12 (21.4)	8 (12.1)
A5	A25	10 (16.4)	2 (3.0)	2 (3.6)	1 (1.5)
A5	A23	10 (16.4)	2 (3.0)	19 (33.9)	1 (1.5)
I11	I15	9 (14.8)	21 (31.8)	7 (12.5)	7 (10.6)
C1	C6	9 (14.8)	5 (7.6)	4 (7.1)	(0.0)
B1	B7	7 (11.5)	2 (3.0)	4 (7.1)	6 (9.1)
H1	H6	5 (8.2)	3 (4.5)	(0.0)	(0.0)
I31	I31	4 (6.6)	1 (1.5)	(0.0)	1 (1.5)
A5	A9	1 (1.6)	4 (6.1)	20 (35.7)	2 (3.0)
R1	R9	(0.0)	(0.0)	1 (1.8)	(0.0)
R1	R2	(0.0)	1 (1.5)	6 (10.7)	(0.0)
I2	I22	(0.0)	1 (1.5)	(0.0)	(0.0)
I2	I2	(0.0)	(0.0)	2 (3.6)	(0.0)
D1	D7	(0.0)	3 (4.5)	(0.0)	(0.0)
Total		181	180	172	100

Table 4. Percent time groups of whales spent resting, rubbing and engaged in other activities in Zones 3-6 during 1992 and 1993. Percentages are calculated from *group hours.*

	Zone 3	Zone 4	Zone 5	Zone 6	All Zones
% Time Resting	25.2	12.1	10.4	6.1	11.9
% Time Rubbing	0.0	0.0	0.0	66.6	25.1
% Time Other Activity	74.8	87.9	89.6	27.3	63.0
Total Group Hours	132.8	161.5	150.2	268.5	713.0

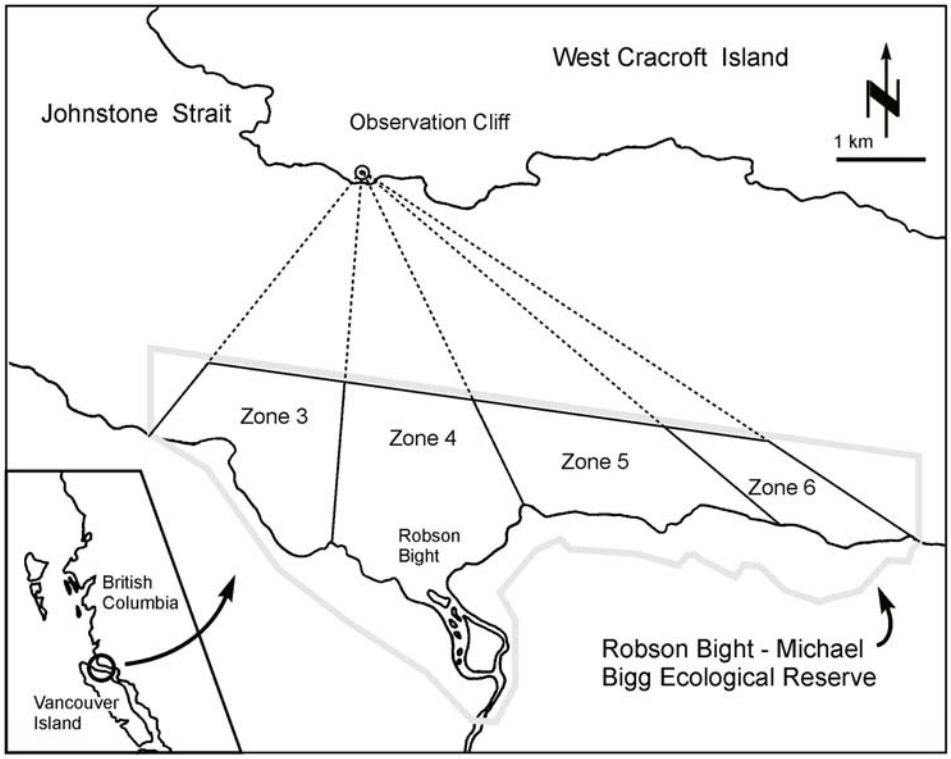

Figure 1. Western Johnstone Strait showing the Robson Bight - Michael Bigg Ecological Reserve (Zones 3-6) and the location of the observation cliff.

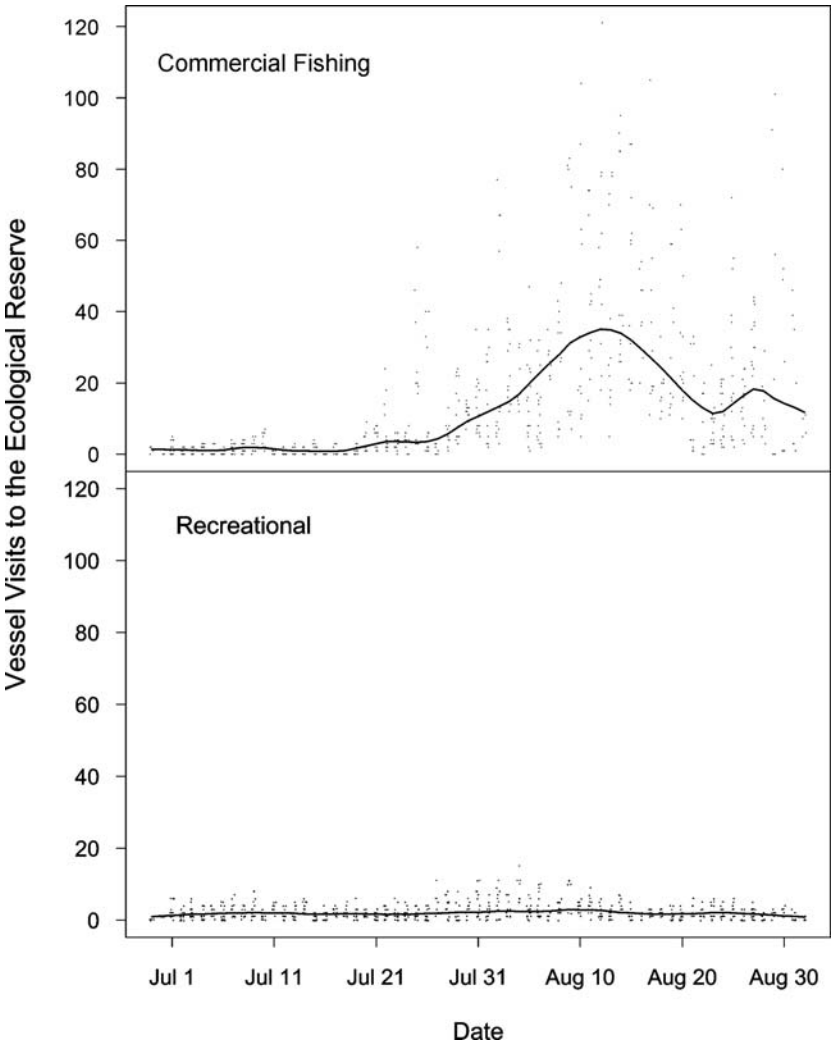

Figure 2. *Vessel visits* by commercial and recreational vessels from Jun 29 to Sep 1, 1991-1994. Each point represent daily vessel visits in a single zone of the Ecological Reserve. Each panel contains data from all zones and years, which were jittered by adding a small amount of random variation to reveal overlapping points. They indicate a tendency for commercial fishing activity to increase in the month of August (top panel), unlike recreational *vessel visits*, which showed little change through the season (bottom panel).

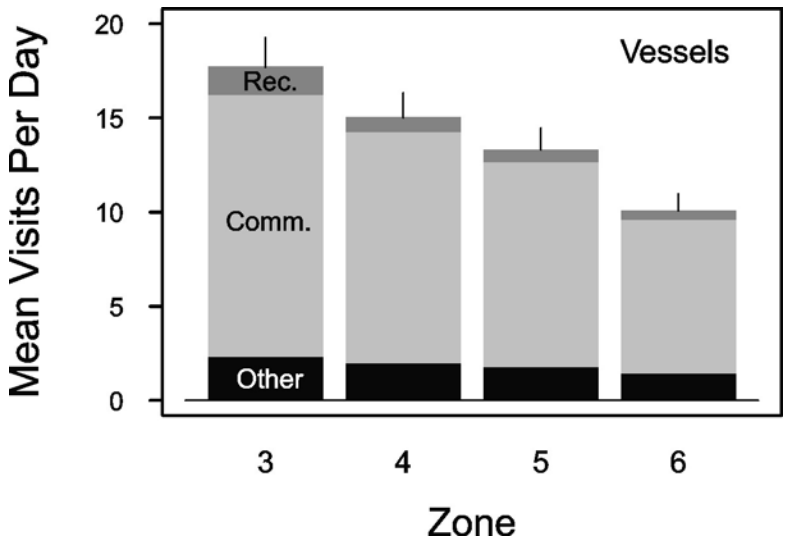

Figure 3. Mean number of *Vessel visits* by commercial fishing, recreational and other vessels over 250 days of observations (Jun 29 to Sep 1, 1991-1994). The vertical bars show standard errors of the estimate of total vessel visits per zone.

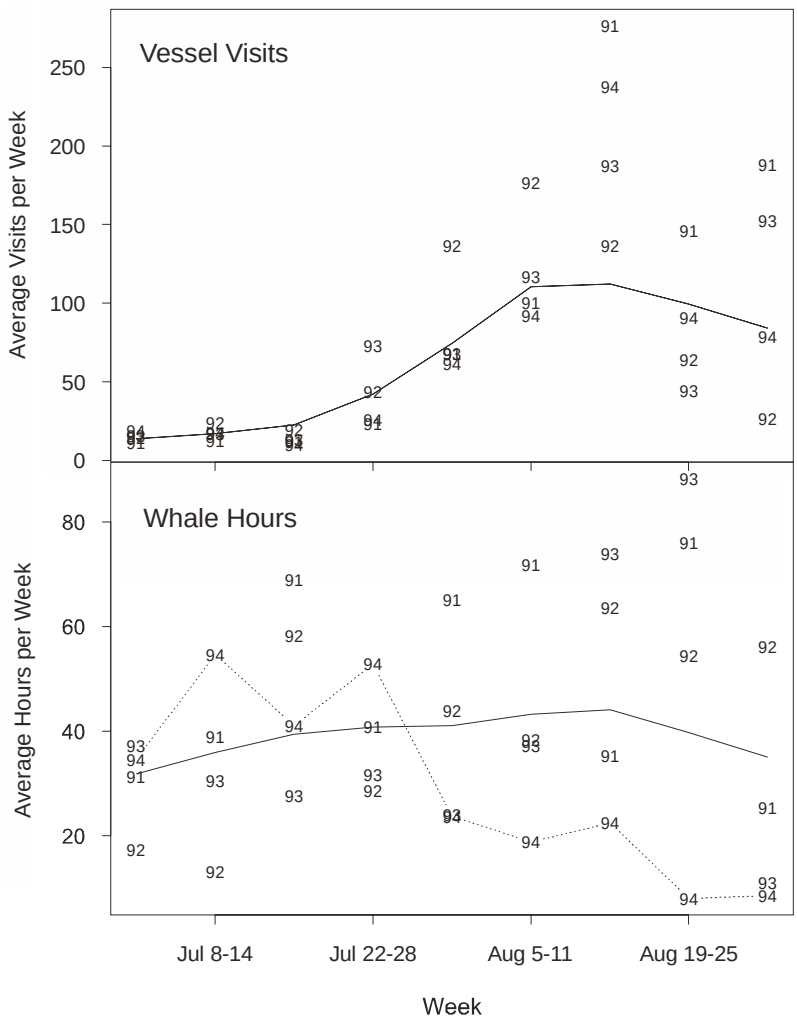

Figure 4. Weekly variation in total vessel activity and time spent by killer whales within the Ecological Reserve (all Zones added together). Symbols indicate year and plot (A) the average number of times in a day that vessels crossed zone boundaries during a given week, and (B) the average number of *whale hours* observed in a day during a given week. The locally weighted regression (*lowess*) shows overall vessel activity peaked in mid August and decreased thereafter. Whale activity increased through the season, peaking in mid August and dropping thereafter (solid line). Note the high variability in average weekly activity from one year to the next, and the relative absence of whales in August of 1994 (dashed line).

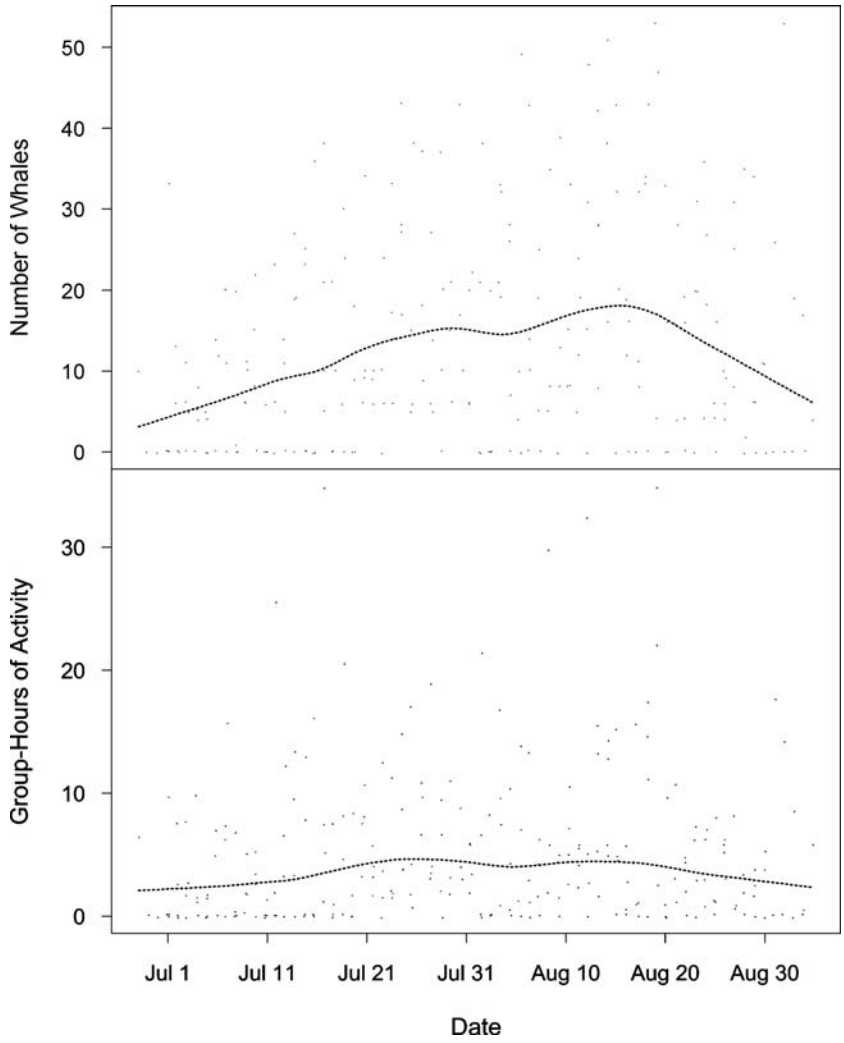

Figure 5. Intra-seasonal variation in whale activity from Jun 28 to Sep 5 in Zones 3, 4, 5 and 6. Both numbers of whales (top panel) and group hours of activity (bottom panel) tended to peak towards the middle of the summer as shown by the *lowess* curves. The jittered data represent all available information from all years and zones of the Ecological Reserve combined.

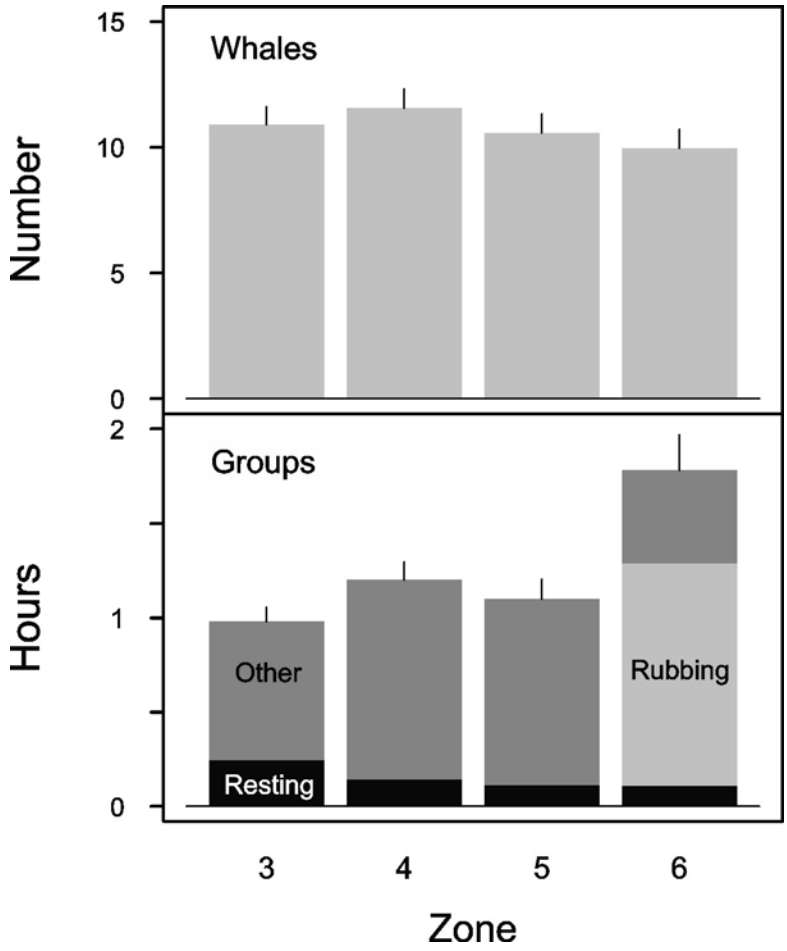

Figure 6. Mean number of whales counted each day and the amount of time (*group hours*) spent resting, rubbing and engaged in other activities in each zone over 250 days of observation (Jun 29 to Sep 1, 1991-1994). The vertical bars show standard errors of the estimates.

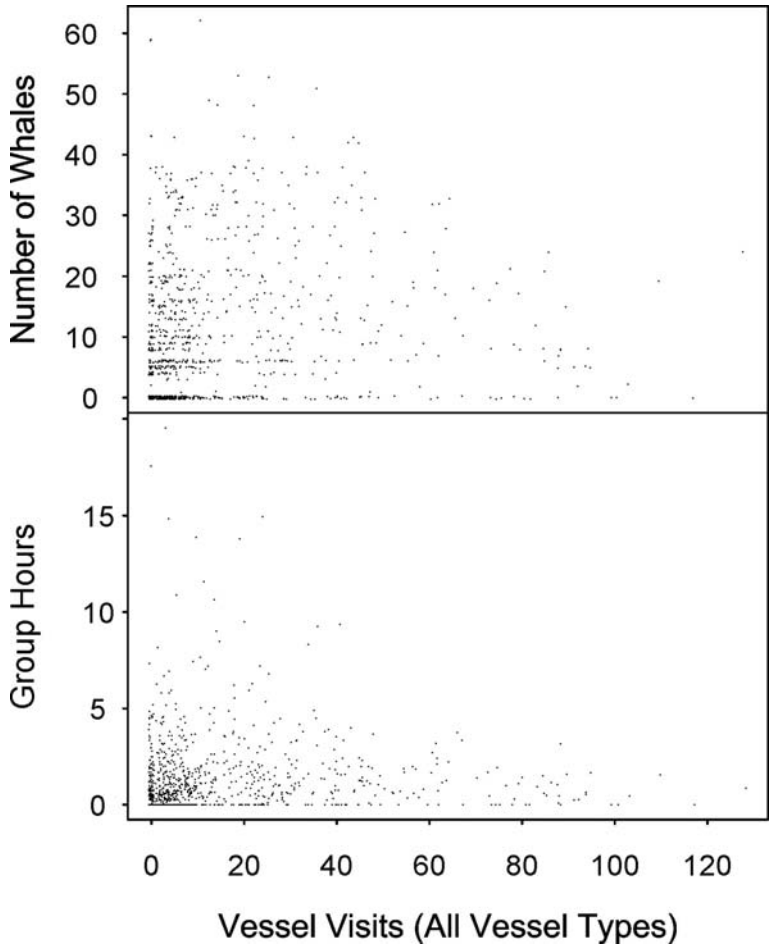

Figure 7. Number of whales and group hours of activity as a function of vessel activity in Zones 3-6. No relationship was seen between the number of whales in a zone on a particular day and the number of times vessels crossed the zone boundary (top panel). Similarly there was no apparent relation between whale activity (measured as group hours) and vessel activity. As in other figures, a small amount of random variation was added to the plotted data.

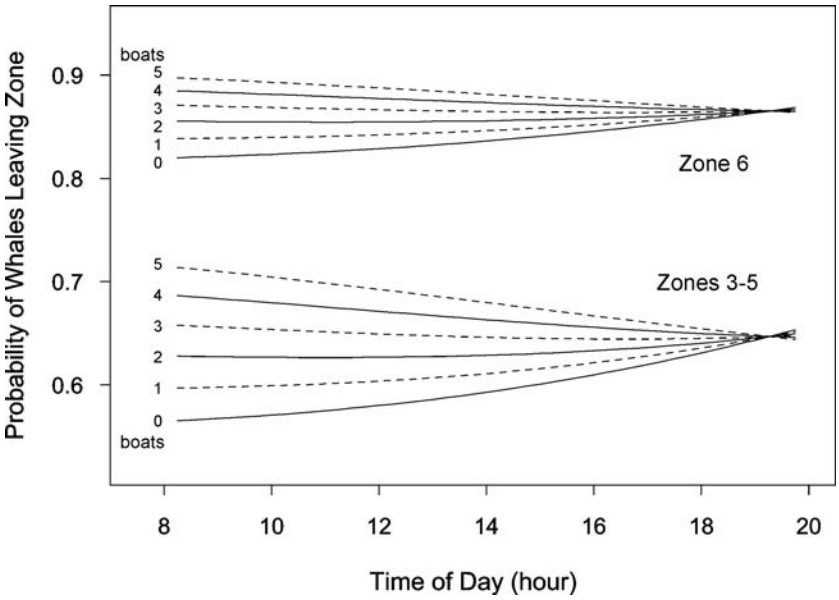

Figure 8. Probabilities of whales leaving any given Zones of the Ecological Reserve within 15 minutes of vessels arriving. Whales had a higher probability of leaving Zone 6 (the rubbing beaches) than they did of leaving any of the other three Reserve zones. Probabilities of whales leaving Zones 3, 4 or 5 did not differ significantly from one another. Increasing the number of vessels that entered a zone increased the probability that whales would move to another zone or leave the Ecological Reserve entirely.