Killer Whales and Vessel Activity in Robson Bight from 1991 to 1994

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Summary

During the summers of 1991 to 1994 (July 1 - August 31), the movements of vessels and killer whales (*Orcinus orca*) were monitored during daylight hours in the Robson Bight - Michael Bigg Ecological Reserve, in Johnstone Strait, British Columbia.

Numbers of whales using the Ecological Reserve increased through the month of July, peaking in early to mid August, and dropping thereafter. Diurnally, increases occurred from morning to mid-afternoon in numbers of whales and the amount of time spent within the Reserve. Whales spent an average of 12% of their time resting in the Ecological Reserve, 25% rubbing and 63% engaged in other activities. They travelled through all four zones of the Reserve with equal frequency, but spent significantly more time in the rubbing beach zone than in any of the other three zones.

Over 75% of the vessels that entered the Ecological Reserve were commercial fishing vessels. Fishing activity rose sharply through the last week of July, peaking in early August. This was followed by a smaller peak in commercial activity during the last week of August. Low numbers of recreational vessels entered the Reserve throughout the summer with a small peak in activity during the last week of July. Vessel activity was highest at the western end of the Reserve and lowest at the eastern end (at the rubbing beaches).

Considerable variability was observed in abundance and activity levels of whales and vessels from day to day, and from hour to hour. This meant that although general trends could be described from the large number of observations, it was not possible to accurately predict either boat or whale activity for a given day or time.

Vessel activity does not appear to have marked effects on the presence of whales in the Ecological Reserve. However, the movement of whales within the Ecological Reserve does appear to be affected by vessels. Whales were more likely to move to a different zone or to leave the Reserve entirely when vessels were present, and were more likely to leave the rubbing beach zone than any other zone of the Reserve.

Continued research on the effects of vessel activity on killer whales in the Ecological Reserve is recommended and should include: continued analysis of existing data; posing well defined questions to guide research design; collecting detailed information on whale behaviours, vessel numbers and vessel activities; and rigorously collecting data on whales and vessels from the waters immediately adjacent to the Ecological Reserve.

Introduction

Robson Bight, located at the northern end of Vancouver Island (Fig. 1), is considered by many to be the best place in the world to view killer whales (*Orcinus orca*) in the wild. It is also considered by many to be one of the best places to fish for salmon.

Killer whales frequent Robson Bight during the summer months to feed on salmon and to rub their bodies on its pebble beaches. People also frequent the Bight each summer aboard their recreational vessels, commercial fish boats and whale watching charter vessels.

Many of the 25,000 people who visit the Johnstone Strait area each year encounter the killer whales of Robson Bight (1993 census data, Ford *et al.* 1994; Duffus and Dearden 1993). These whales belong to a population that ranges from Vancouver Island to southeast Alaska. It numbers only 200 individuals (Ford *et al.* 1994). Whether the whales that frequent Robson Bight can tolerate the levels of commercial fishing activity and the increasing demands of the tourism and whale watching industry in this region is not known.

In 1982 the Robson Bight - Michael Bigg Ecological Reserve was established by BC Parks to protect the rubbing beaches and the killer whales that use them. 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, sail and anchor in the Reserve at any time.

A visitor management program was conducted in 1987, 1989 and 1990 to direct vessel traffic (on a voluntary basis) away from the Ecological Reserve and to monitor its use by whales, visitors and researchers (Taylor 1988a,b; Taylor and Parsons 1989). The program was expanded between 1991 and 1994 to develop an education program and to monitor the movements of whales and vessel activity during daylight hours (Wong *et al.* 1993). Analysis of some of these data collected from 1991 to 1993 was presented by Trites and Hochachka (1994). Since this time, an additional year of data was collected (1994) and additional observations made between 1991 and 1993 were keypunched for analysis. The following therefore replaces the earlier analyses and report by Trites and Hochachka (1994).

The goal of our study was to summarize the activities of whales and vessels in the Ecological Reserve from 1991 to 1994, and to determine from the existing data whether vessels have an effect on the presence and distribution of whales.

We begin by briefly reviewing the biology of the northern resident killer whales and describing the methods used to collect and analyze the data. The types of activities (resting, rubbing, *etc.*) and their frequency of occurrence are contrasted from one year to the next, as are the activity levels of different types of vessels (recreational and commercial). Finally we consider the interaction of whales and boats, and make recommendations for future research.

Killer Whale Biology

Two forms of killer whales in British Columbia, *residents* and *transients*, are socially and genetically isolated (Bigg *et al.* 1990). Residents eat predominately fish while transients prefer marine mammal prey. The transients travel in small, unstable groups typically consisting of a mother and two or three offspring. They do not use the rubbing beaches of Robson Bight. Residents do use the beaches and tend to live in stable groups (pods) comprised of several related females and their offspring.

In British Columbia there are northern and southern resident killer whales. The northern residents range 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 congregate in 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 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. In 1993, there were 16 northern resident pods consisting of 35 subpods and 200 whales (Ford *et al.* 1994).

Methods

Study Site

For the purpose of the study, western Johnstone Strait was divided into six zones (Fig. 1), of which one bounded the Ecological Reserve (Zone 2) and four were within the Reserve (Zones 3-6). Zone 1 included Blackney Passage and Blackfish Sound to the west of Zone 2. Whale and vessel activity in Zones 2-6 were monitored from a cliff on West Cracroft Island across from the Ecological Reserve (Fig. 2). Observations of Zone 1 could not be made from the cliff. Zone boundaries were determined using a vessel equipped with a LORAN positioning device.

Data Collection

As reported in Wong *et al.* (1994), observations were made from July 1 to August 31 in 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.

Table 1. Types of data collected from 1991 to 1994. The asterix indicates data that were collected but not entered into a computer data base, or were not in a form that can be keypunched. Note that all data are not necessarily comparable among years.

	Year of Study			
	1991	1992	1993	1994
Vessels				
Number	yes	yes	yes	yes
Activity	some*	some*	no	some
Time Entered Zone	yes	yes	yes	yes
Time Exited Zone	no	yes	no	yes
Direction of Travel	yes	yes	yes	yes
Hourly Counts	yes	yes	yes	some
Whales				
Numbers	yes	yes	yes	yes
Pod ID	yes	yes	yes	yes
Time Activity Started	yes*	yes	yes	yes
Time Entered Zone	yes	yes	yes	yes
Time Exited Zone	yes	yes	yes	yes
Direction of Movement	yes*	yes*	yes*	yes
Cumulative Time Resting	yes*	yes	yes	no
Cumulative Time Rubbing	yes*	yes	yes	yes
Whale/Vessel Interactions				
	no	no	no	some

Observations were recorded on data sheets and compiled in binders. Some information about vessels was not collected in all years, while some data collected on whale and vessel behaviours were not entered into a computer data base (Table 1). No data were collected in Zone 1, while data from Zone 2 were considered unreliable (E. Gregr and M. Wong, Bion Research, pers. comm.). Thus we only analyzed whale and vessel data within the Ecological Reserve (Zones 3, 4, 5 and 6).

Killer whales that entered the Ecological Reserve were visually identified from their dorsal fins and saddle patches. Occasionally, acoustic cues were used to identify the pod. Observers noted the numbers of whales present in each Zone and identified them as members of a particular pod or subpod. In 1993 however, identities of individual whales were sometimes recorded. Times that groups entered and left each zone in the Reserve were recorded in all years, but behaviour of the group (rubbing, resting or other) could only be analyzed for 1992 and 1993. *Rubbing* was assumed to occur when the whales were in Zone 6 and within 50 m of shore. *Resting* was noted when the whales were observed in a resting line (Ford 1984). Observers noted the total time spent rubbing or resting, and the time of occurrence. Behaviours such as travelling, feeding and socializing were grouped as *other* because they could not be readily differentiated.

Ten types of vessels were observed: kayaks, sail boats, power boats, cruise ships, commercial fish boats, commercial whale watching boats, government patrol boats, research boats, tugs and others (*e.g.* float planes). Observers recorded the type of vessel present, and the time it entered a zone. Exit times were not recorded consistently, nor were vessel activities consistently noted (*i.e.* whether vessels were moving, stationary, fishing, approaching whales, or otherwise potentially interacting with whales). Furthermore, only vessels that were moving into the Ecological Reserve were recorded; stationary vessels or vessels that had been stationary at the start of observation but left during the period of observation were not reported. Numbers of vessels that were in the Ecological Reserve were counted every 30 minutes in 1991, every 60 minutes in 1992 and 1993, and three times per day in 1994.

Data Analysis

We made no assumptions about the presence or absence of whales and vessels on bad weather days when observations could not be made. Data for these days were treated as missing values. In addition, we combined data from recreational power and sail vessels.

The amount of time whales were present in the Reserve can be summarized at the individual level (*whale hours*) or at the group level (*group hours*). Cumulative times of individual whale activities are referred to as *whale hours* (*i.e.* length of time whale 1 was present + length of time whale 2 was present); *group hours* is the amount of time the pod or subpod spent in a given activity (*i.e.* length of time whales 1 and 2 were present together). *Whale hours* reflect changes in numbers of whales present and/or changes in the amount of time spent by each whale in a given activity. However the two cannot be distinguished from this single statistic. Given that such a distinction is important in a management context and because killer whales typically travel in social groups rather than individually, we felt it was more reasonable to use groups as our unit of study. Hence, we examined numbers of whales and *group hours* of whale activity (note however that *whale hours* can be approximated by multiplying numbers of whales by *group hours*).

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 specific behaviours (*i.e.* resting and rubbing).

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 re-ran the analyses, including only those variables that were potentially statistically significant ($P<0.15$). 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.

Results & Discussion

Vessel Activity

The only measure of vessel activity in the Ecological Reserve is *vessel visits* - the number of times that vessels crossed zone boundaries. This statistic showed high variability in daily zone visits (ranging from 1 to 128 times a day) with an overall mean of 17.3 visits per day[1] (Fig. 3). Most of the *vessel visits* were by commercial fish boats (76-87% of the total). In contrast to commercial fishing vessels, recreational power and sailing vessels were infrequent visitors to the Ecological Reserve (9-17% of all vessel visits; Table 2).

The 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. 4). This suggests that much of the variation in vessel activity within the Ecological Reserve is driven by the schedule of short-term fishing openings (Fig. 4).

No relationship was found between the movements of recreational vessels and commercial fishing vessels within the Reserve (Fig. 3). Thus there is no indication from the data that recreational vessels were drawn into the Ecological Reserve when commercial fishing boats were present. The lack of a relationship between commercial and recreational vessel movements might reflect the efforts of the warden program to reduce recreational traffic in the Reserve.

Seasonal Variation

We tested whether the number of times that vessels entered zones in the Ecological Reserve was affected by *day, year* or *zone* using analysis of covariance. We added day^2 to the analysis 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.

[1] these values represent all vessel types combined and all zones summed within a day.

Table 2. 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

Considerable variation was noted in the number of times vessels moved across zone boundaries in the Ecological Reserve (Fig. 5; Tables A1 - A3). 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, the low number of 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. 6).

Frequency of visits to the Reserve differed among years (P<0.05 for the *year* 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 (*i.e. vessel visits* in Zone 3 + *vessel visits* in Zone 4 + ...) by week shows the underlying seasonal rise in vessel activity in the Ecological Reserve as a whole (Fig. 7).

Vessel activity was highly variable among years, particularly during the month of August and may reflect differences in the size of salmon runs sought by the commercial vessels. Note however, that as in previous figures for vessels, the amount of vessel movement is not necessarily the same as the total number of vessels in the area.

Daily Variation

Analysis of covariance was used to test whether changes in vessel activity within the Ecological Reserve were related to the *hour* of the day, the *year, day* or *zone* (nos. 3 - 6). $Hour^2$ was entered to check for diurnal activity patterns (*e.g.* if movement of recreational vessels increased as the day progressed, and dropped off as nightfall approached). Additionally, 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 within the season to control for the significant seasonal variation previously noted (Tables A1-A3).

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 (Figs. 8 and 9). The small number of visits by recreational vessels tended to peak slightly at 1200 h and dropped off through the rest of the day (from Table A5); while commercial vessel activity was highest in the early morning and late afternoon - early evening (Table A6: $P < 0.001$ for the *Hour* and $Hour^2$ terms). No diurnal movement patterns were detected, however, when commercial, recreational and other vessel types were pooled together (Table A4).

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 (Fig. 8) 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 3). Of these, five pods (A1, A4, A5, C1 and I11) used the Reserve more frequently than others, with the A1s being the pod most consistently sighted (*i.e.* they were present on 39-82% of the days observed). The number of times each pod was seen varied from year to year (Table 3). Similarly, use by subpods (units of the pod) also varied annually (Table 4). On some occasions, subpods arrived together with other members of their pod, while at other times they came alone. Over an average of 66 days of observation each summer, the whales spent an average of 193 subpod days in the ecological reserve from 1991 to 1993, but only 100 subpod days in 1994 (Table 4 - weighted means).

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 5). 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).

Table 3. Number of days that 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

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 behaviours of the individual pods given the available data, and therefore assumed that no significant behavioural differences existed among pods within a season or from year to year.

Seasonal Variation

Numbers of whales and the amount of time that groups[2] of whales spent in the Reserve (*group hours*) varied considerably between June 29 and September 5 (Fig. 10). In general, their numbers and the amount of time they spent (*group hours*) rose through the month of July, peaked in early to mid August, and declined slightly thereafter (Fig. 10). *Whale hours* (numbers of whales x hours present) also showed the same seasonal increase and decrease in time spent in the Reserve (Fig. 11).

Interannual variability in number of whales present and the amount of time they spent within the Reserve was also considerable (Tables A7 and A8). Most striking was the drop in numbers of pods sighted in 1994 (Tables 3 and 4), when whales left at the end of July and did not return for the

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[2]Groups contained entire pods and subpods of whales, combinations of subpods, or a fraction of a single subpod.

Table 4. 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)
R1	R5	1 (1.6)	1 (1.5)	(0.0)	(0.0)
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 5. 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

remainder of the season (Fig. 11). Killer whales travelled in all parts of the Reserve and were seen with equal frequency in all zones (Table A7, Fig. 12a). However, they spent significantly more time in Zone 6 at the rubbing beaches than anywhere else in the Reserve (Table A8, Fig. 12b).

Amounts of time that groups of whales spent resting and rubbing[3] did not vary systematically through the season (Tables A9, A10 and A11), but did vary by year. There was also a slight effect of time of day (Table A12). 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 (Table A12).

Seasonal movements of resident killer whales have been related to the inshore distribution and abundance of salmon in Juan de Fuca Strait (Heimlich-Boran 1986) and in Johnstone Strait (Guinet 1990, Nichol and Shackleton 1996). We therefore compared total whale numbers and group hours of activity in Zones 3-6 with pink, chum, sockeye, chinook and total salmon catches (gill net and troll combined) in DFO Statistical Area 12 of Johnstone Strait.

The number of salmon caught in Johnstone Strait from one year to the next (Figs. 13 and 14) do not appear to explain changes in the numbers of whales observed in the Bight. In 1994 for example, killer whales left the Johnstone Strait area much earlier than normal (Fig. 11) despite the apparent high abundance of salmon (Figs. 13 and 14). No correlation was observed with whale numbers or group hours and the catch of any individual species of salmon, or with the total catch of all salmon species in the area. This may mean that killer whale use of the Reserve is independent of the amounts of salmon caught, or that catch statistics are not a good index of salmon abundance.

[3] rubbing includes data from 1994 (see Table 2).

Daily Variation

As with numbers of whales counted throughout the season, the numbers counted throughout the day varied considerably, ranging from 0 to 51 per hour (Fig. 15). The effect of *hour* on numbers of whales and length of time in the Reserve (Fig. 15) was tested using analysis of covariance. Additional factors included in the model were *zone*, *year*, *day*, day^2, and $hour^3$. The interaction between *zone* and $hour^2$ was included to uncover possible linear and/or quadratic interactions with *zone*. The cubic term ($hour^3$) was used to verify the bimodal peaks of whale activity shown in Fig. 5 of Wong *et al.* (1993) at about 1300h and 1800h. A cubic regression, hence the $hour^3$ term, is the simplest way to generate a curve with 2 peaks.

Numbers of whales and time spent in the Ecological Reserve varied with the hour of the day. Numbers increased in all zones from morning to evening (Tables A13-A15, Fig. 15). Numbers of whales visiting each zone of the reserve varied little throughout the day (Table A13). However, whales spent more time as a group in Zone 6 (the rubbing beaches) than in any of the other three zones (Fig. 15, Tables A14 and A15). Time spent in Zone 6 increased through the day while use of 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 innate daily and seasonal changes in their numbers and activities. However, as noted, average changes in the numbers and activities of whales and vessels is far smaller than the range of variation seen within a given hour or day. Thus, average or systematic variations in numbers and activities over the season are unlikely to affect analyses of interaction between vessels and whales.

Effect of Boats on Numbers of Whales

There were many days when whales or boats were alone in the Reserve as well as many days when they were present together (Fig. 16). However, there is little evidence that activities of vessels are related to either numbers of whales or *group hours* of whale activity (Fig. 16). This was tested statistically using weighted regressions to account for the decreasing variation in number of whales with the rise in vessel visits (Fig. 16). We analyzed data from each zone separately to control for possible differences among zones, and ignored the slight differences in whale activity among years and days. We also 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).

The likelihood of obtaining a statistically significant result will increase with the number of statistical tests carried out, even when no biological basis exists for finding differences. Hence, we employed Bonferroni corrections for each set of 4 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 $P<0.05$.

The concomitant rise and fall in seasonal numbers of vessels and whales entering the Ecological Reserve (Figs. 6 and 10) may reflect the local abundance of salmon that both are seeking (Fig. 13). However, correlations were not found between numbers of whales and number of salmon commercially caught. This may mean that commercial catches are not a good index of fish availability, or that commercial fisheries and whales do not target the same species with the same intensity.

Variation in boat activity does not appear to be associated with variation in numbers of whales using the Ecological Reserve (Tables A16 and A17). Only 1 of the 12 regressions of whale numbers was statistically significant, suggesting 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* were 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 potentially biologically unimportant.

Effect of Boats on Activities of Whales

Even though vessel activity does not appear to affect the numbers of whales using the Ecological Reserve, there may be subtler, less apparent effects of vessels on the activity of whales. For example, vessels entering a zone may cause whales to leave it prematurely. We therefore used the available data to test whether vessels entering a zone affected the likelihood of whales leaving it.

Our approach was to estimate the probability that whales would leave a zone within a given amount of time when vessels were present and when they were absent. We chose an arbitrary 15 minute time block in the belief 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*, $hour^3$, number of whales in the zone, and the cumulative amount of time that whales had already been in the zone. 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". This dichotomy of choices is more appropriately analyzed by logistic regression than by analysis of covariance. Thus we applied logistic regression to estimate the probability that groups of whales would leave a zone when vessels entered.

The general conclusion from the logistic regressions is that whales are more likely to leave a zone of the Reserve when vessels enter it than if the vessels stayed out, and that the probability of a whale leaving rises as the number of vessels entering the zone increases (Table A18, Fig. 17). 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). It has been previously suggested that whales may be more sensitive in Zone 6 to human disturbance than in any other zone (Briggs 1993). They may also have a higher probability of leaving Zone 6 because of its relatively small size (Fig. 2) and their propensity for increasing their swimming speed in the presence of boats (Kruse 1984).

Effects of vessels on whale activity were more pronounced in the morning than later in the day (Fig. 17). For example, at 800 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 2000h, however, numbers of vessels appear to have little or no effect on the likelihood of whales leaving a zone.

Conclusions

Whales & Boats

Our primary goal was to determine if vessels affected the activity of killer whales in the Ecological Reserve. What we found were some potentially negative effects of boats on whales.

Numbers of whales and the activity levels 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 which may reflect the abundance of salmon in the Reserve. However, general patterns were surrounded by such high variability that neither boat nor whale activity can be accurately predicted for a given date or time.

The total amount of time that groups of whales spent within the Ecological Reserve (all zones combined) was not correlated with daily levels of vessel activity (Table A17, Fig. 16). 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 (Table A18, Fig. 17).

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 actual 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.The whales are also more likely to leave Zone 6 than any other Zone in the Reserve. Commercial fishing openings account for most of the whale-boat interactions. Over 75% of the vessel movements within the Reserve were associated with commercial fishing.

Commercial fishing 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 and the increasing demands of the tourism and whale watching industry, consideration should be given to restricting human activity in Robson Bight, particularly near the rubbing beaches. Our results show that killer whales favour use of the rubbing beaches in Zone 6 and are more sensitive to human disturbance here than anywhere else in the Reserve. It would seem to be a small concession for fishers to concede the small Zone 6 to the whales and concentrate their activities at the other end of the Ecological Reserve if they must remain in it.

Although our analyses indicate that vessels affect whale activities, we do not know what the effects are, or their exact cause. 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 the durations of activities such as resting or rubbing affected by the presence of vessels (*c.f.* Briggs 1993)? (5) Are the magnitude of the effects of vessels on whales biologically significant? Such questions need to be answered before firmer conclusions can be drawn about the impact of vessel activity on whales in the Ecological Reserve.

Future Research

To date, studies of killer whales and vessel activity in the Robson Bight - Michael Bigg Ecological Reserve have answered some questions. More remain to be answered.

Data collected from 1991 to 1994 as well as in previous years of study still contain potentially useful information for further analysis. For example, whale identities (subpod and/or individual animals) were noted for all whale observations and could be used to test whether different pods or individuals used the Ecological Reserve in different manners (*i.e.* whether they spent different proportions of time resting and rubbing, or whether they preferred one zone of the Reserve over another). The data might also be used to determine whether some pods were more sensitive to the presence of vessels than others, or whether some activities (*i.e.* resting and/or rubbing) were more likely to be disturbed by vessels than others. Similarly the effects of tidal cycles on whale abundance and activities could be examined.

Based on the data collected from 1991 to 1994, a general recommendation for future field studies of whale/vessel interactions in the Ecological Reserve is that specific objectives be defined. The goals of the 1991-1994 study were relatively general, and yielded data that could only address some relatively general questions. Detailed information is needed on whale behaviour. Our analysis shows that vessels may have relatively subtle effects on whale activity; effects that are not easily detected when the question asked is whether the average activity of vessels in the Reserve affects the numbers of whales or duration of their activity over a day. Additional information about vessels is also needed. Recording only the number of times vessels crossed the zone boundaries of the Ecological Reserve left us assuming vessel activity was a reasonable index of the actual number of vessels in the area. This should be substantiated by collecting data on both vessel numbers and their activity such that the effects of moving and stationary boats on the activity of whales can be differentiated. Finally, information should be gathered about movements, or at least about numbers, of whales and vessels in Zone 2 given that most of the whale-oriented vessel activity occurs here Such information would provide insight into whether whale activity in the Ecological Reserve was related to the total number of whales visiting the area, or whether only some of the pods in Johnstone Strait made heavy use of the Reserve itself. Additionally, information on vessel activity inside and outside the Reserve could be used to demonstrate whether public education programs are effective in deterring vessels from entering the Reserve during their passage through the Strait.

We are pleased to note that many of these shortcomings have been addressed already in a new killer whale - vessel interaction study that was designed and implemented in Robson Bight in 1995 and 1996. Additional research is clearly needed to understand the full effects of vessels on killer whales in the Robson Bight - Michael Bigg Ecological Reserve. Our results indicate a subtle effect of vessels on the behaviour of whales in the Reserve, but no effect on their numbers. Only with additional research can the possible long term effects of vessels on whales be ascertained.

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Appendix: Statistical Tables

Table A1. The effects of zone, year and day on commercial fishing vessel visits in the Ecological Reserve (Zones 3-6). *Year* and *Zone* were treated as categorical variables, and *Day* and *Day*^{2} treated as continuous variables in the analysis of covariance. However, *Day* and *Day*^{2} failed to fit the data properly and were dropped from further analysis. The resulting analysis of variance (and regression) showed commercial fishing vessel activity varied significantly between Zones (Zone 3 > Zone 4 > Zone 5 > Zone 6) and among years (1993 > 1992 > 1991 > 1994).

Analysis of Variance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	3396.481	3	1132.160	2.87	0.036
Zone	4020.169	3	1340.056	3.39	0.018
Year*Zone	1523.282	9	169.254	0.43	0.920
Error	312854.952	792	395.019		

*The equation predicting the number of commercial fishing vessel visits is:

vessel_visits = 7.56 + year_constant + zone_constant

where: year_constant is 1.96 (1991), 2.50 (1992), 5.90 (1993), and 0.00 (1994)
zone_constant is 6.63 (Zone 3), 4.55 (Zone 4), 3.01 (Zone 5), and 0.00 (Zone 6)

Table A2. The effects of zone, year and day on visits by recreational power and sail vessels in the Ecological Reserve (Zones 3-6). *Year* and *Zone* were treated as categorical variables, and *Day* and *Day*^{2} were treated as continuous variables in the analysis of covariance. The results show recreational vessel activity varied significantly over the season (June 29 to September 1), among years (1991 to 1994) and between zones (Zone 3 > Zone 4 > Zone 5 > Zone 6).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	243.080	3	81.027	18.91	<0.001
Zone	108.460	3	36.153	8.44	<0.001
Day	34.909	1	34.909	8.15	0.004
Day^2	19.210	1	19.210	4.48	0.034
Error	3423.981	799	4.285		

*The equation predicting the number of recreational vessel visits is:

vessel_visits = 2.12 - 0.095*Day + 0.002*Day^2 + year_constant + zone_constant

where: Days are June 29-30 (-1, 0), July 1-31 (1- 31), Aug 1-31 (32 - 62), and Sept 1 (63)
year_constant is 0.62 (1991), 1.20 (1992), -0.11 (1993), and 0.00 (1994)
zone_constant is 1.02 (Zone 3), 0.55 (Zone 4), 0.37 (Zone 5), and 0.00 (Zone 6)

Table A3. The effects of zone, year and day on visits by all vessels (commercial fishing + recreational + other) in the Ecological Reserve (Zones 3-6). *Year* and *Zone* were treated as categorical variables, and *Day* and *Day*^{2} were treated as continuous variables in the analysis of covariance. The results show the activity of all vessels combined varied significantly over the season (June 29 to September 1), among years (1991 to 1994) and between zones (3-6).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	2990.454	3	996.818	2.31	0.075
Zone	8154.769	3	2718.256	6.30	<0.001
Day	2574.425	1	2574.425	5.97	0.015
Day^2	2533.029	1	2533.029	5.87	0.016
Error	344715.665	799	431.433		

*The equation predicting the number of visits by all vessels combined is:

$$vessel\_visits = 4.76 + 0.82*Day - 0.02*Day^2 + year\_constant + zone\_constant$$

where: Days are June 29-30 (-1, 0), July 1-31 (1- 31), Aug 1-31 (32 - 62), and Sept 1 (63)
year_constant is 2.71 (1991), 4.08 (1992), 5.63 (1993), and 0.00 (1994)
zone_constant is 8.83 (Zone 3), 5.45 (Zone 4), 3.57 (Zone 5), and 0.00 (Zone 6)

Table A4. The effects of zone, year, day and hour on the total vessel activity (commercial fishing + recreational + other vessels) in the Ecological Reserve (Zones 3-6). *Year* and *Zone* were treated as categorical variables, and *Day*, *Day²*, *Hour* and *Hour²* were treated as continuous variables in the analysis of covariance. The results show that total activity varied significantly over the season (June 29 to September 1) and among years (1991 to 1994), but did not change with time of day (800 h to 1900h) .

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	449.559	3	149.853	23.41	<0.001
Zone	43.355	3	14.452	2.26	0.080
Day	325.441	1	325.441	50.84	<0.001
Day^2	357.866	1	357.866	55.91	<0.001
Hour	3.038	1	3.038	0.47	0.491
$Hour^2$	5.257	1	5.257	0.82	0.365
Zone*Hour	37.404	3	12.468	1.95	0.120
Zone*$Hour^2$	38.902	3	12.967	2.03	0.108
ERROR	35563.907	5556	6.401		

*The equation predicting the number of total vessel visits is:

$$vessel\_visits = 1.40 + 0.11*Day - 0.004*Day^2 + year\_constant + zone\_constant$$

where: Days are June 29-30 (-1, 0), July 1-31 (1- 31), Aug 1-31 (32 - 62), and Sept 1 (63)
year_constant is -0.01 (1991), 0.06 (1992), 0.67 (1993), and 0.00 (1994)
zone_constant is 0.53 (Zone 3), 0.43 (Zone 4), 0.26 (Zone 5), and 0.00 (Zone 6)

Table A5. The effects of zone, year, day and hour on the activity of recreational vessels in the Ecological Reserve (Zones 3-6). *Year* and *Zone* were treated as categorical variables, and *Day*, Day^2, *Hour* and $Hour^3$ were treated as continuous variables in the analysis of covariance. The results show the number of recreational vessels varied significantly through the day (800 h to 1900h), over the season (June 29 to September 1), and among years (1991 and 1994).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	15.156	3	5.052	11.60	<0.001
Zone	0.041	3	0.014	0.03	0.992
Day	6.975	1	6.975	16.02	<0.001
Day^2	3.758	1	3.758	8.63	0.003
Hour	22.679	1	22.679	52.10	<0.001
$Hour^2$	30.058	1	30.058	69.05	<0.001
Zone*Hour	0.041	3	0.014	0.03	0.993
Zone*$Hour^2$	0.048	3	0.016	0.04	0.990
Error	2418.706	5556	0.435		

*The equation predicting the number of recreational vessel visits per zone is:

$$\text{vessel\_visits} = -0.58 - 0.02 \cdot \text{Day} + 0.0004 \cdot \text{Day}^2 + 0.19 \cdot \text{Hour} - 0.008 \cdot \text{Hour}^2 + \text{year\_constant}$$

where: Days are June 29-30 (-1, 0), July 1-31 (1- 31), Aug 1-31 (32 - 62), and Sept 1 (63)
year_constant is 0.04 (1991), 0.07 (1992), -0.06 (1993), and 0.00 (1994)

Table A6. The effects of zone, year, day and hour on the number of commercial fishing vessels in the Ecological Reserve (Zones 3-6). *Year* and *Zone* were treated as categorical variables, and *Day*, *Day*^{2}, *Hour* and *Hour*^{3} were treated as continuous variables in the analysis of covariance. The results show the number of commercial fishing vessels varied significantly through the day (800h to 1900h), over the season (June 29 to September 1) and among years (1991 and 1994).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	653.966	3	217.989	28.21	<0.001
Zone	54.902	3	18.301	2.37	0.069
Day	433.795	1	433.795	56.13	<0.001
Day^2	430.260	1	430.260	55.67	<0.001
Hour	51.846	1	51.846	6.71	0.010
Hour^2	68.663	1	68.663	8.88	0.003
Zone*Hour	51.959	3	17.320	2.24	0.081
Zone*Hour^2	54.204	3	18.068	2.34	0.072
Error	42937.913	5556	7.728		

*The equation predicting the number of commercial fishing vessel visits per zone is:

$$\text{vessel\_visits} = 2.72 + 0.13\text{*Day} - 0.004\text{*Day}^2 - 0.30\text{*Hour} + 0.01\text{*Hour}^2 + \text{year\_constant}$$

where: Days are June 29-30 (-1, 0), July 1-31 (1- 31), Aug 1-31 (32 - 62), and Sept 1 (63)
year_constant is -0.05 (1991), -0.05 (1992), 0.75 (1993), and 0.00 (1994)

Table A7. Seasonal variation in numbers of whales using the four zones of the Ecological Reserve. *Year* and *Zone* were treated as categorical variables, and *Day* and *Day*^{2} were treated as continuous variables in the analysis of covariance. The results show the number of whales varied significantly over the season (June 28 to September 5) and among years (1991 and 1994), but not between zones. Removing the interaction terms from the model does not change these conclusions.

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	5520.188	3	1840.063	14.54	<0.001
Zone	39.778	3	13.259	0.10	0.957
Day	6420.639	1	6420.639	50.73	<0.001
Day 2	4419.239	1	4419.239	34.92	<0.001
Zone*Day	62.760	3	20.920	0.17	0.920
Zone*Day^2	73.546	3	24.515	0.19	0.901
Zone*Year	386.341	9	42.927	0.34	0.962
Error	123518.885	976	126.556		

*The equation predicting number of whales visiting a single zone is:

$$\text{whale\_number} = -2.05 + 0.51*\text{Day} - 0.006*\text{Day}^2 + \text{year\_constant}$$

where: Days are June 28-30 (-2, 0), July 1-31 (1- 31), Aug 1-31 (32 - 62), and Sept 1-5 (63-67)
year_constant is 5.16 (1991), 6.04 (1992), 6.42 (1993), and 0.00 (1994)

Table A8. Seasonal variation in number of hours groups of whales used the four zones of the Ecological Reserve. *Year* and *Zone* were treated as categorical variables, and *Day* and *Day²* were treated as continuous variables in the analysis of covariance. The interaction between *Day* and *Zone*, and between *Day²* and *Zone* were tested and removed because they are correlates with *Zone* and masked the effect of *Zone* on whale activity. The results show that group hours varied significantly over the season (June 28 to September 5), among years (1991 to 1994) and between zones (3-6). The whales spent more time in the rubbing beach area (Zone 6) than in any other zone.

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	*P*
Year	65.373	3	21.791	5.84	0.001
Zone	95.448	3	31.816	8.53	<0.001
Day	70.468	1	70.468	18.89	<0.001
Day^2	59.541	1	59.541	15.96	<0.001
Error	3696.945	991	3.731		

*The equation predicting group hours of activity in a single zone is:

$$group\_hours = 0.684 + 0.055*Day - 0.001*Day^2 + year\_constant + zone\_constant$$

where: Days are June 28-30 (-2, 0), July 1-31 (1- 31), Aug 1-31 (32 - 62), and Sept 1-5 (63-67)
year_constant is 0.40 (1991), 0.51 (1992), 0.69 (1993), and 0.00 (1994)
zone_constant is -0.80 (zone 3), -0.58 (zone 4), -0.68 (zone 5), and 0.00 (zone 6)

Table A9. Seasonal variation in the number of hours groups of whales rested in the four zones of the Ecological Reserve. *Zone* was treated as a categorical variable, and *Day* and *Day²* were treated as continuous variables in the analysis of covariance. Group hours of resting varied only by year. Data were only available for 1992 and 1993.

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	3.604	1	3.604	6.60	0.011
Zone	0.624	3	0.208	0.38	0.767
Day	0.559	1	0.559	1.02	0.312
Day^2	0.759	1	0.759	1.39	0.239
Zone*Day	0.180	3	0.060	0.11	0.954
Zone*Day^2	0.687	3	0.229	0.42	0.739
Error	209.251	383	0.546		

*The equation predicting the group hours of resting per zone is:

group_hours_resting = 0.11 + year_constant

where: year_constant is 0.19 in 1992, and 0.00 in 1993

Table A10. The effects of zone, year, day and hour on the number of hours groups of whales rested in the four zones of the Ecological Reserve. *Zone* was treated as a categorical variable, and *Day* and *Day*^{2} were treated as continuous variables in the analysis of covariance. Group hours of resting varied only among years. Data were only available for 1992 and 1993.

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	0.478	1	0.478	7.91	0.005
Zone	0.134	3	0.045	0.74	0.528
Day	0.078	1	0.078	1.28	0.258
Day^2	0.145	1	0.145	2.39	0.122
Hour	0.026	1	0.026	0.44	0.508
Hour^3	0.006	1	0.006	0.10	0.752
Zone*Hour^2	0.104	4	0.026	0.43	0.788
Error	60.387	999	0.060		

Table A11. Seasonal variation in number of hours groups of whales rubbed in the Ecological Reserve. *Day* and *Day*^{2} were treated as continuous variables in the analysis of covariance. Whales rubbed almost exclusively in Zone 6. The results show that group hours of rubbing varied only among years. Data were only available for years 1992-1994.

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	51.620	2	25.810	5.68	0.004
Day	8.399	1	8.399	1.85	0.176
Day^2	10.155	1	10.155	2.24	0.137
Error	613.029	135	4.541		

*The equation predicting group hours of rubbing is:

group_hours_rubbing = 0.97 + year_constant

where: year_constant is 0.32 in 1992, 1.46 in 1993, and 0.00 in 1994

Table A12. The effects of year, day and hour on the number of hours groups of whales rubbed in the Ecological Reserve. *Year* was treated as a categorical variable, and *Day*, Day^2, *Hour* and $Hour^3$ were treated as continuous variables in the analysis of covariance. The results show group hours of rubbing varied significantly only among years (1992 and 1993), however a slight effect by time of day (800h to 1900h) was indicated.

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	10.286	1	10.286	10.35	0.002
Day	1.679	1	1.679	1.69	0.195
Day^2	2.178	1	2.178	2.19	0.140
Hour	2.690	1	2.690	2.71	0.101
$Hour^3$	0.547	1	0.547	0.55	0.459
Error	221.683	223	0.994		

*The equation predicting group hours rubbing is:

group_hours_rubbing = -0.31 + 0.09*Hour + year_constant

where: Time is on a 24 hour clock from 800h to 1900h
year_constant is -0.42 in 1992, and 0.00 in 1993

Table A13. The effects of zone, year, day and hour on the number of killer whales in the Ecological Reserve through the day. *Year* was treated as a categorical variable, and *Day*, Day^2, *Hour*, $Hour^2$, and $Hour^3$ were treated as continuous variables. The results show significant differences in numbers of killer whales with time of day (800 h to 1900h), through the season (June 28 - September 5), and among years (1991-1994).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	777.909	3	259.303	6.97	<0.001
Zone	51.231	3	17.077	0.46	0.711
Day	630.920	1	630.920	16.97	<0.001
Day^2	409.178	1	409.178	11.00	0.001
Hour	253.613	1	253.613	6.82	0.009
$Hour^3$	479.775	1	479.775	12.90	<0.001
Zone*$Hour^2$	452.747	4	113.187	3.04	0.016
Error	335013.514	9009	37.187		

*The equation predicting number of killer whales per zone is:

$$whale\_number = 9.68 + 0.06*Day - 0.0007*Day^2 - 2.87*Hour - 0.007*Hour^3 + zone\_constant*Hour^2 + year\_constant$$

where: Days are June 28-30 (-2, 0), July 1-31 (1- 31), Aug 1-31 (32 - 62), and Sept 1-5 (63-67)
year_constant is 0.78 (1991), 0.63 (1992), 0.30 (1993), and 0.00 (1994)
zone_constant is 0.267 (Zone 3), 0.268 (Zone 4), 0.267 (Zone 5), and 0.268 (Zone 6)

Table A14. The effects of zone, year, day and hour on killer whale activity (measured in whale hours) in the Ecological Reserve through the day. *Year* and *Zone* were treated as categorical variables, and *Day*, *Day*^{2}, *Hour* and *Hour*^{3} were treated as continuous variables. The interaction between *Hour* and *Zone*, and between *Hour*^{2} and *Zone* were tested and removed because they are correlates with *Zone* and masked the effect of *Zone* on whale hours. The results show significant differences in whale hours of killer whale activity with time of day (800h to 1900h), through the season (June 28 - September 5), and among zones and years (1991-1994)

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	158.101	3	52.700	6.71	<0.001
Zone	549.931	3	183.310	23.32	<0.001
Day	110.279	1	110.279	14.03	<0.001
Day^2	76.764	1	76.764	9.76	0.002
Hour	174.780	1	174.780	22.23	<0.001
Hour^3	80.589	1	80.589	10.25	0.001
Error	72241.451	9013	7.861		

*The equation predicting whale hours of activity within a zone is:

$$\text{whale\_hours} = -1.182 + 0.02*\text{Day} - 0.0003*\text{Day}^2 + 0.19*\text{Hour} - 0.0002*\text{Hour}^3 + + \text{year\_constant} + \text{zone\_constant}$$

where: Days are June 28-30 (-2, 0), July 1-31 (1- 31), Aug 1-31 (32 - 62), and Sept 1-5 (63-67)
year_constant is 0.38 (1991), 0.26 (1992), 0.18 (1993), and 0.00 (1994)
zone_constant is -0.63 (Zone 3), -0.48 (Zone 4), -0.55 (Zone 5), and 0.00 (Zone 6)

Table A15. The effects of zone, year, day and hour on group hours of killer whale activity in the four zones of the Ecological Reserve. *Year* and *Zone* were treated as categorical variables, and *Day*, *Day*^{2}, *Hour*, and *Hour*^{3} were treated as continuous variables. The interaction between *Hour* and *Zone*, and between *Hour*^{2} and *Zone* were tested and removed because they are correlates with *Zone* and masked the effect of *Zone* on group hours. The results show significant differences in group hours of activity with time of day (800 h to 1900h), through the season (June 28 - September 5), and among years and zones.

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	2.820	3	0.940	4.85	0.002
Zone	10.560	3	3.520	18.52	<0.001
Day	1.794	1	1.794	9.25	0.002
Day^2	1.936	1	1.936	9.98	0.002
Hour	4.588	1	4.588	23.66	<0.001
Hour^3	2.040	1	2.040	10.52	0.001
Error	1747.712	9013	0.194		

*The equation predicting group hours of activity within a zone is:

$$\text{group\_hours} = -0.17 + 0.003*\text{Day} - 0.00005*\text{Day}^2 + 0.03*\text{Hour} - .00003*\text{Hour}^3 + \text{year\_constant} + \text{zone\_constant}$$

where: Days are June 28-30 (-2, 0), July 1-31 (1- 31), Aug 1-31 (32 - 62), and Sept 1-5 (63-67)
year_constant is 0.02 (1991), 0.02 (1992), 0.05 (1993), and 0.00 (1994)
zone_constant is -0.89 (Zone 3), -0.64 (Zone 4), -0.76 (Zone 5), and 0.000 (Zone 6)

Table A16. Number of whales using the Ecological Reserve each day as a function of vessel activity (CFV - commercial fishing vessels, RV - recreational vessel, Total = CFV + RV + Other). Separate weighted linear regressions were conducted for each boat type and Zone of the Ecological Reserve. Note that results should only be considered statistically significant if $P < 0.0125$ (see text for explanation).

Linear Regression

Vessel Type	Zone	Intercept	Slope	*P*
Total	3	14.9	0.03	0.48
Total	4	16.4	-0.01	0.66
Total	5	18.1	-0.12	<0.001
Total	6	14.9	0.14	0.15
CFV	3	14.9	0.05	0.25
CFV	4	16.4	-0.02	0.64
CFV	5	16.6	-0.005	0.92
CFV	6	15.3	0.13	0.13
RV	3	14.7	0.32	0.30
RV	4	14.5	0.67	0.20
RV	5	17.3	-0.22	0.65
RV	6	17.8	-0.77	0.20

Table A17. Daily whale use (group hours) of the Ecological Reserve each day as a function of vessel activity (CFV - commercial fishing vessels, RV - recreational vessels, Total = CFV + RV +Other). Separate weighted linear regressions were conducted for each boat type and zone of the Ecological Reserve. Note that results should only be considered statistically significant if $P < 0.0125$ (see text for explanation).

Weighted Linear Regression

Vessel Type	Zone	Intercept	Slope	*P*
Total	3	1.55	-0.005	0.23
Total	4	1.88	-0.007	0.15
Total	5	1.86	-0.007	0.0101
Total	6	2.72	0.022	0.43
CFV	3	1.51	-0.005	0.25
CFV	4	1.88	-0.009	0.10
CFV	5	1.76	-0.001	0.94
CFV	6	2.75	0.022	0.38
RV	3	1.38	0.020	0.57
RV	4	1.68	-0.003	0.96
RV	5	1.86	-0.046	0.57
RV	6	3.11	-0.101	0.56

Table A18. The Probability of whales leaving a zone of the Ecological Reserve (Zones 3-6). *Year* and *Zone* were treated as categorical variables, and *Day*, *Day*^{2}, *Hour*, *Hour*^{2} and *Hour*^{3} were treated as continuous variables in the logistic regression.

Logistic Regression

Effect	Parameter	Estimate	Error	$\chi 2$	*P*
Intercept	1	0.0235	0.4322	0.00	0.9566
Year 1991	2	0.0670	0.0539	1.55	0.2135
Year 1992	3	-0.0583	0.0516	1.28	0.2579
Year 1993	4	0.0481	0.0533	0.81	0.3669
Zone 3	5	-0.4089	0.0558	53.75	0.0000
Zone 4	6	-0.2112	0.0516	16.78	0.0000
Zone 5	7	-0.3205	0.0527	36.92	0.0000
Day	8	0.00884	0.00736	1.44	0.2296
Day^2	9	-0.00008	0.00011	0.50	0.4796
Hour	10	-0.0296	0.0456	0.42	0.5157
Hour^3	11	0.000107	0.000075	2.02	0.1557
Whales	12	-0.00860	0.00891	0.93	0.3344
Group_hours	13	0.2819	0.0640	19.41	0.0000
Vessel_visits	14	0.2275	0.1255	3.28	0.0700
Hour^2 *Vessel_visits	15	-0.00062	0.000454	1.87	0.1716
Whales*Vessel_visits	16	-0.00735	0.00889	0.68	0.4084

*Regression equation predicting probability of whales leaving is given by the equation:

$$\text{probability\_of\_departure} = e^{B} / (1 + e^{B})$$

where:

e is base of the natural logarithms

$$B = -0.10 + 0.00005{*}\text{Hour}^3 + 0.30{*}\text{Group\_hours} + 0.16{*}\text{Vessel\_visits} - 0.0004{*}\text{Hour}^2{*}\text{Vessel\_visits} + \text{zone\_constant}$$

zone_constant is -0.42 (Zone 3), -0.21 (Zone 4), -0.31 (Zone 5),and 0.94 (Zone 6)

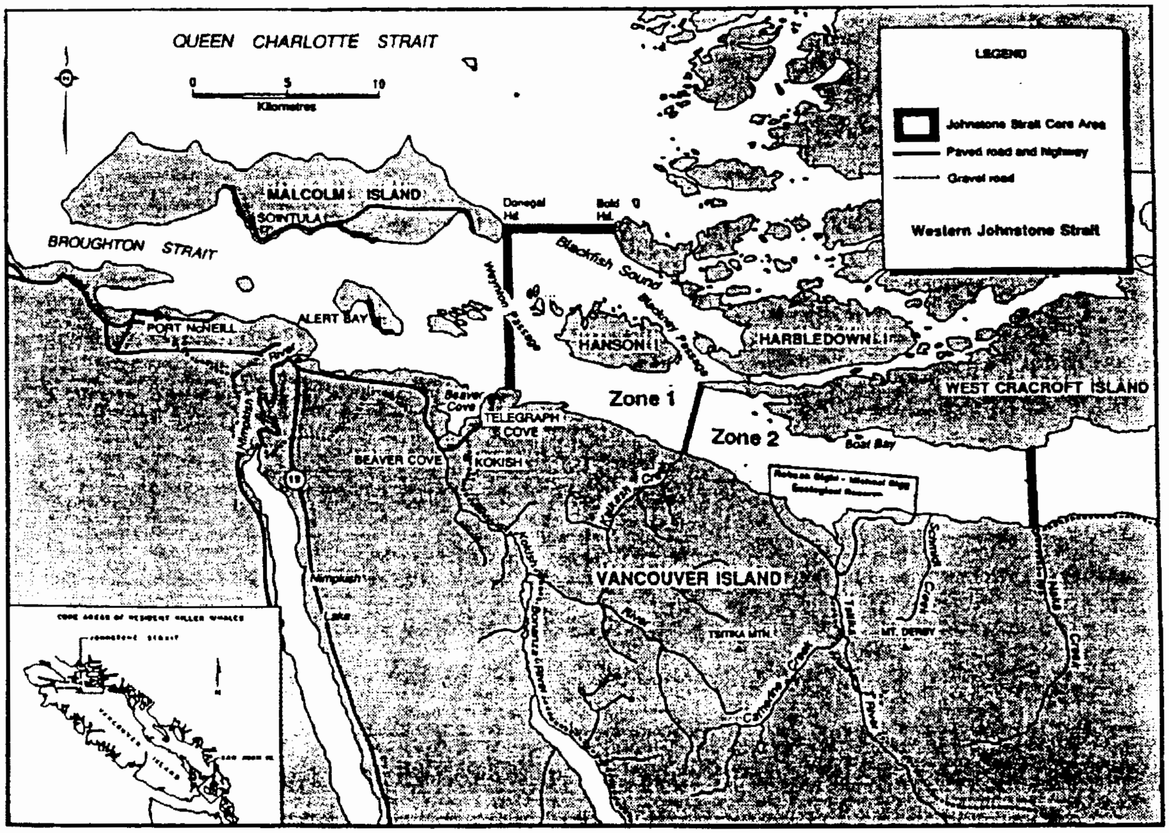

Figure 1. Western Johnstone Strait showing showing Zones 1 and 2, and the Robson Bight - Michael Bigg Ecological Reserve (Zones 3-6). From Wong *et al.* (1993).

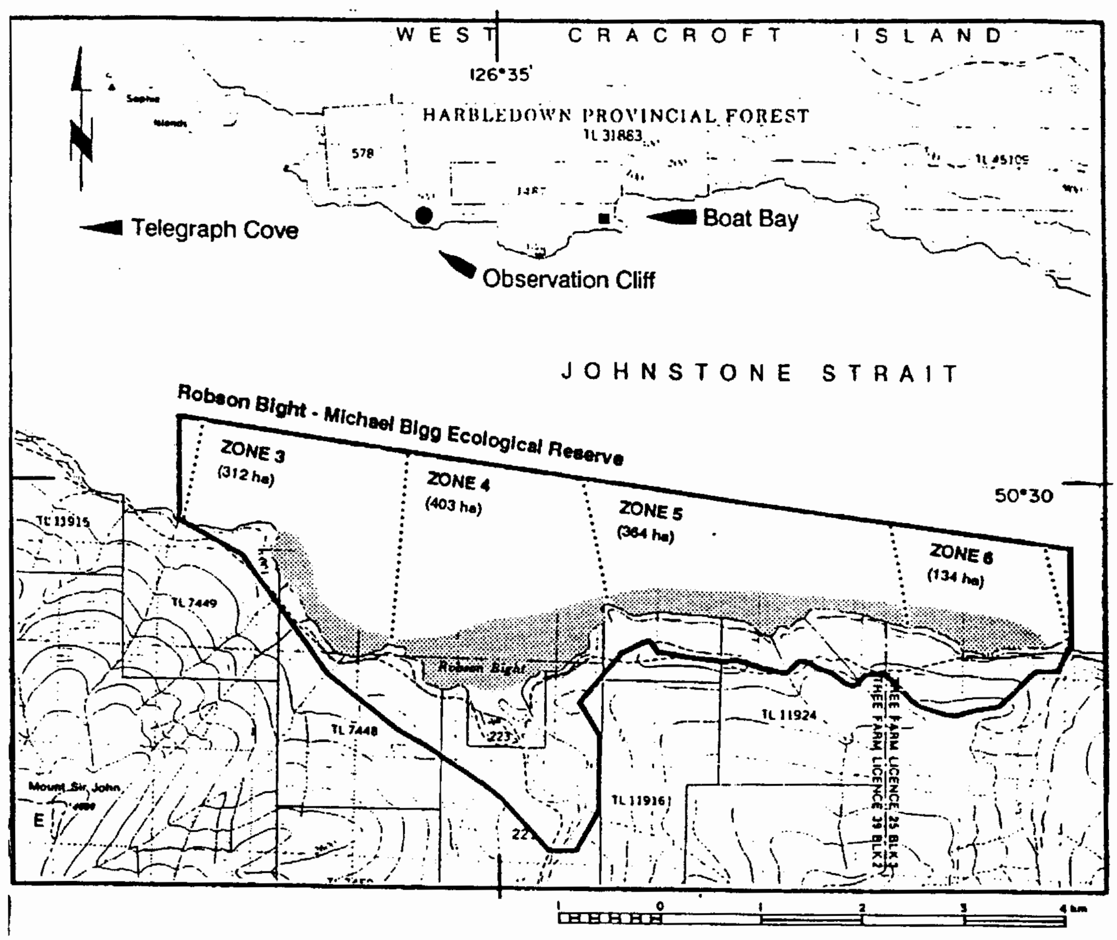

Figure 2. Location of the observation cliff and Zones 3 - 6 (the Robson Bight - Michael Bigg Ecological Reserve). From Wong *et al.* (1993).

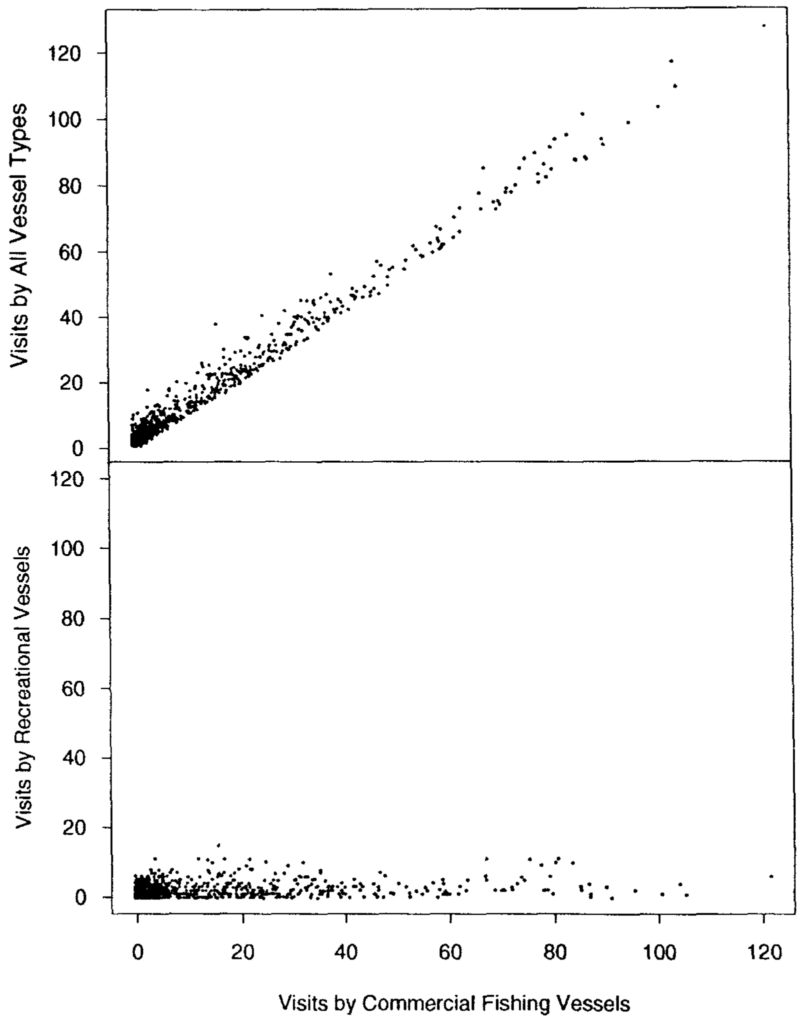

Figure 3. Levels of activity of commercial fishing vessels in relation to that of recreational and total vessels (commercial + recreational + kayak + charter + ...). Each data point is the daily number of *vessel visits* for one zone (nos. 3-6) in one year (1991-94). The data were jittered by adding a small amount of random variation to reveal overlapping points. The tight relationship between total vessel activity and commercial fishing vessel activity shows the dominance of commercial vessels in the Ecological Reserve (top panel). No significant relationship occurred between commercial vessel visits and the low levels of activity observed for recreational vessels (bottom panel).

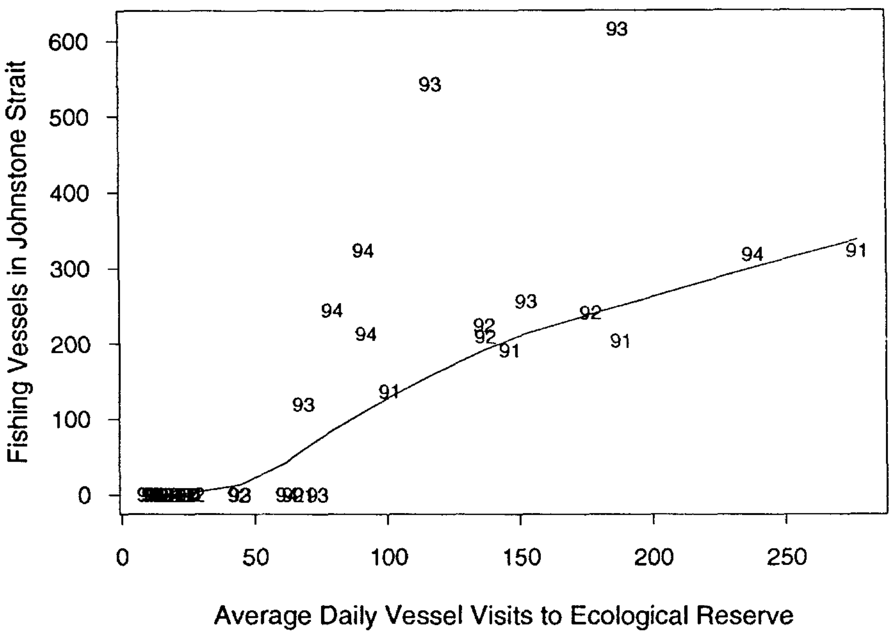

Figure 4. Weekly commercial fishing activity in Johnstone Strait (DFO statistical Area 12) in relation to average daily *vessel visits* within the Ecological Reserve from 1991 to 1994. Numbers of fishing vessels in western Johnstone Strait were estimated from aerial and visual surveys (Paul Ryall, Pacific Biological Station, Nanaimo, pers. comm.) and reflect commercial fishing openings (when numbers in aerial survey exceeded 0). Total *vessel visits* to the Ecological Reserve (Zones 3-6 combined) were calculated from daily values averaged over the same weekly periods. A locally weighted regression (*lowess*) suggests vessel activity within the Ecological Reserve was related to overall numbers of commercial fishing vessels in the region (r=0.74).

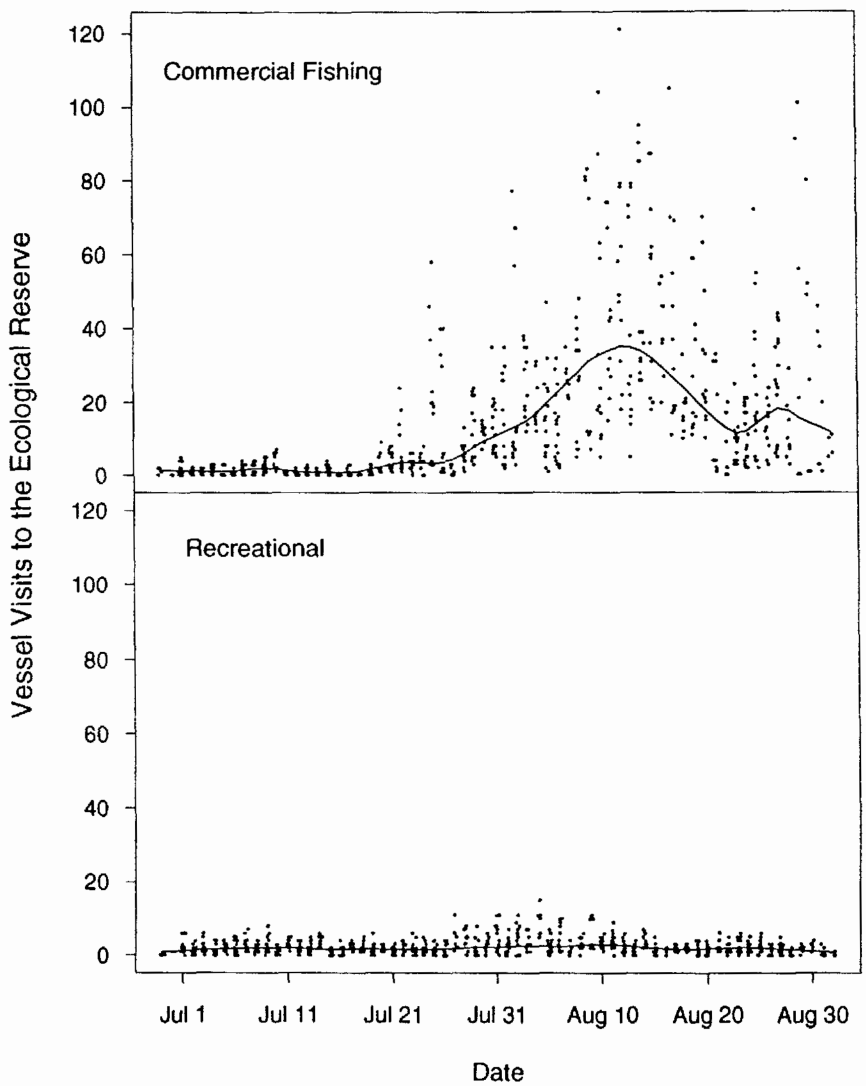

Figure 5. *Vessel visits* by commercial and recreational vessels from Jun 29 to Sep 1, 1991-1994. Each point represent daily vessel visits in a single zone of the Ecological Reserve. Each panel contains data from all zones and years, and were jittered by adding a small amount of random variation to reveal 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).

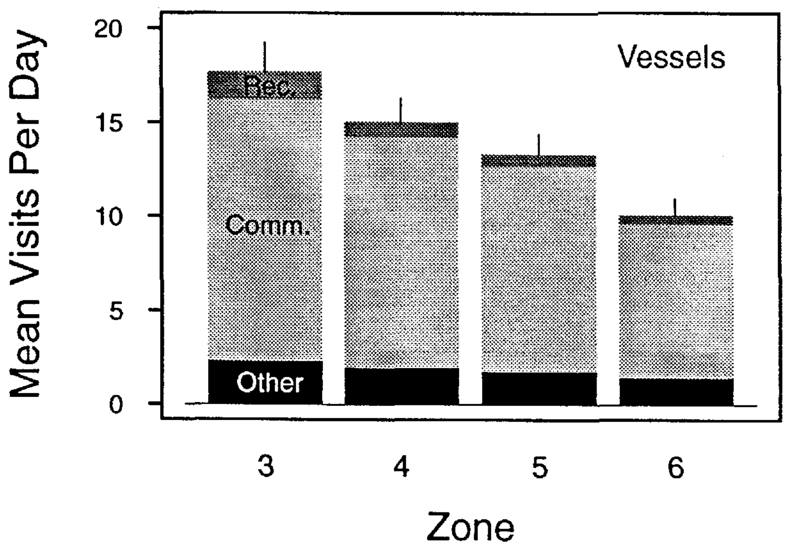

Figure 6. Mean number of *Vessel visits* by commercial, recreational and other vessels from over 250 days of observation (Jun 29 to Sep 1, 1991-1994). Standard errors of the estimate of total vessel visits per zone are shown by the vertical bars.

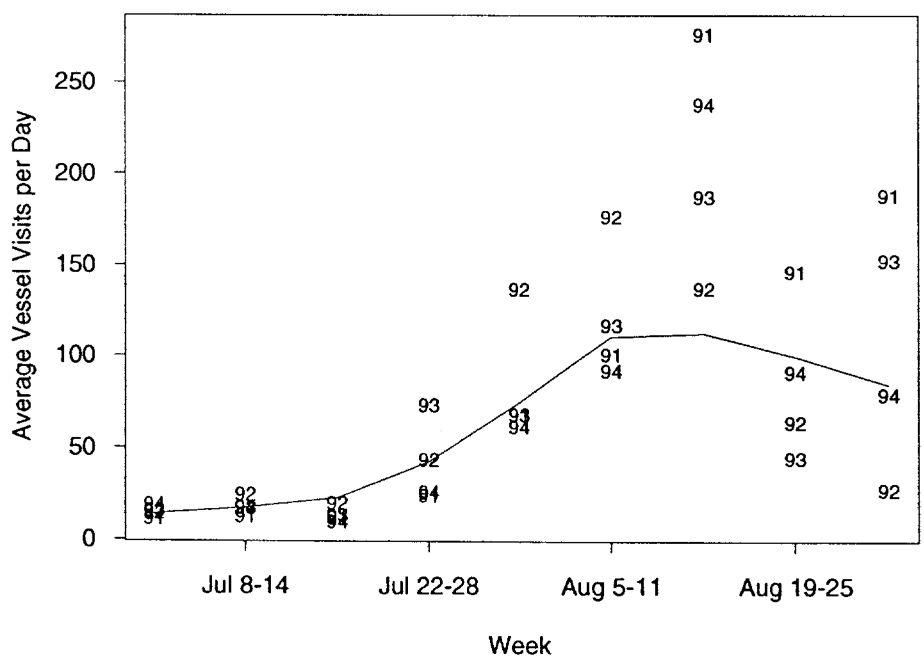

Figure 7. Weekly variation in total vessel activity within the Ecological Reserve (all Zones added together). Symbols indicate year and plot the average number of times in a day that vessels crossed zone boundaries during a given week. The locally weighted regression (*lowess*) shows overall vessel activity peaked in mid August and decreased thereafter.

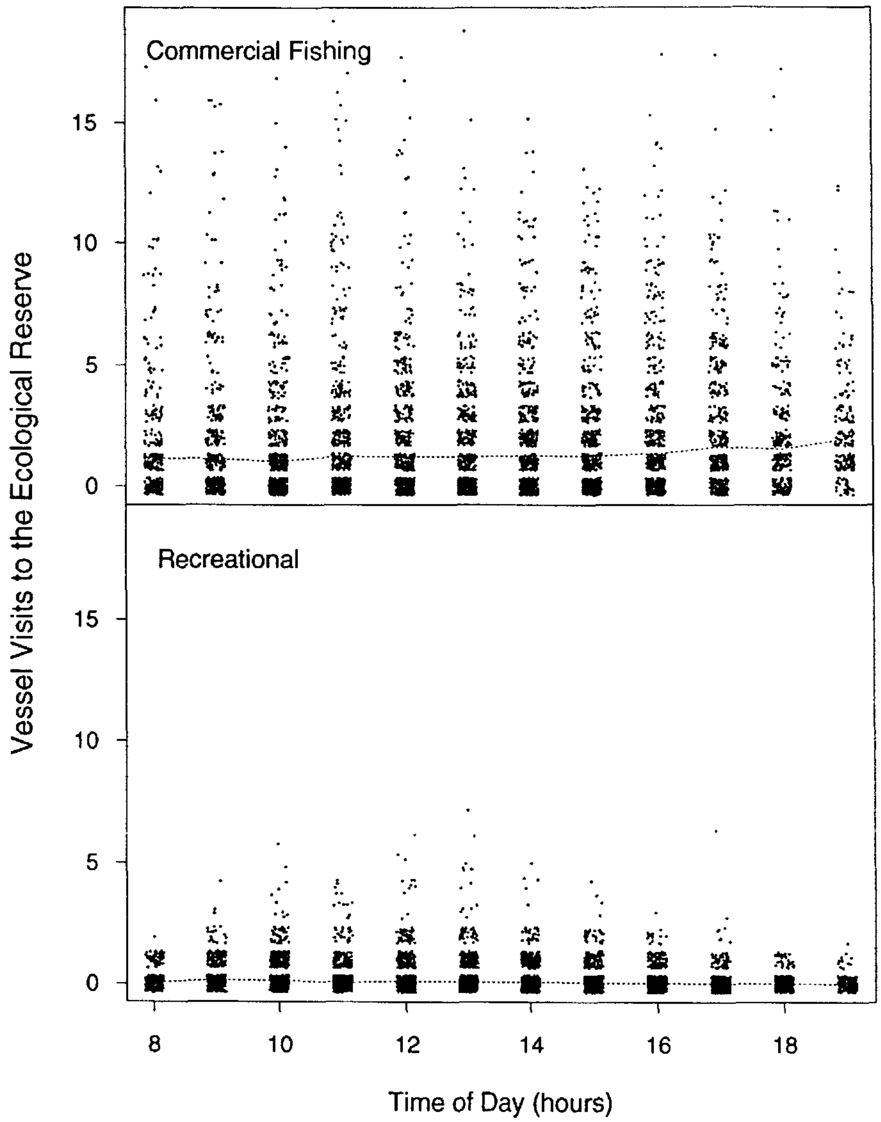

Figure 8. *Vessel visits* by commercial and recreational vessels through the daily period of observation (0800 h to 1900h). Each data point represents the level of activity in one of four zones during a one hour interval (starting at the time noted on the x-axis). A small amount of random variation was added to each data point to reduce visual overlap. Locally weighted regressions (*lowess*) show an increase in commercial fishing vessel activity through the day (top panel), and a slight decrease in recreational vessel activity (bottom panel).

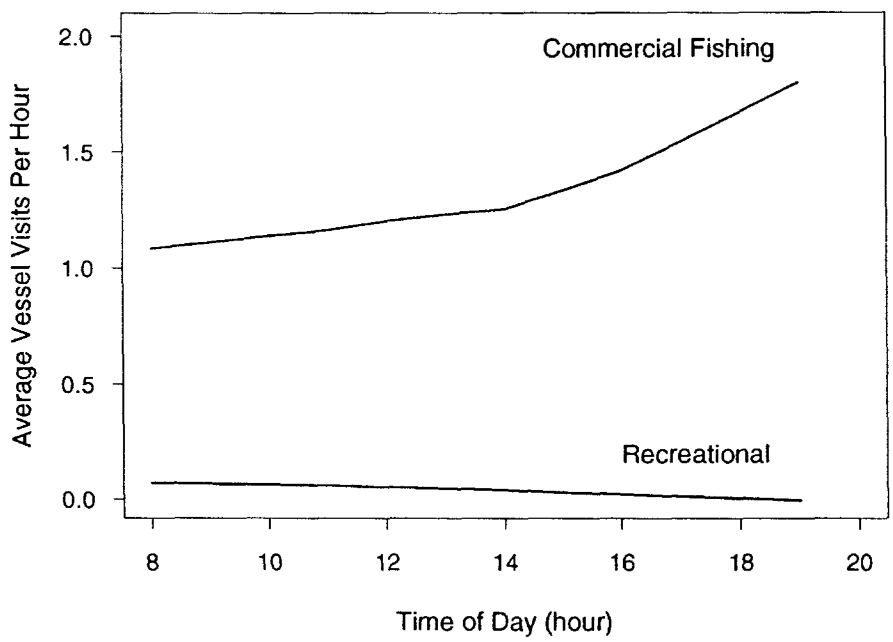

Figure 9. Locally weighted regressions (*lowess*) of recreational and commercial fishing vessel activity through the day (from Fig. 7). Note the low mean number of times vessels crossed zone boundaries and the apparent tendency for activities of commercial fishing vessels to increase while recreational fishing vessels decrease throughout the day. It should be recognized however that the *lowess* lines are essentially moving averages and do not necessarily represent statistically significant patterns in the data.

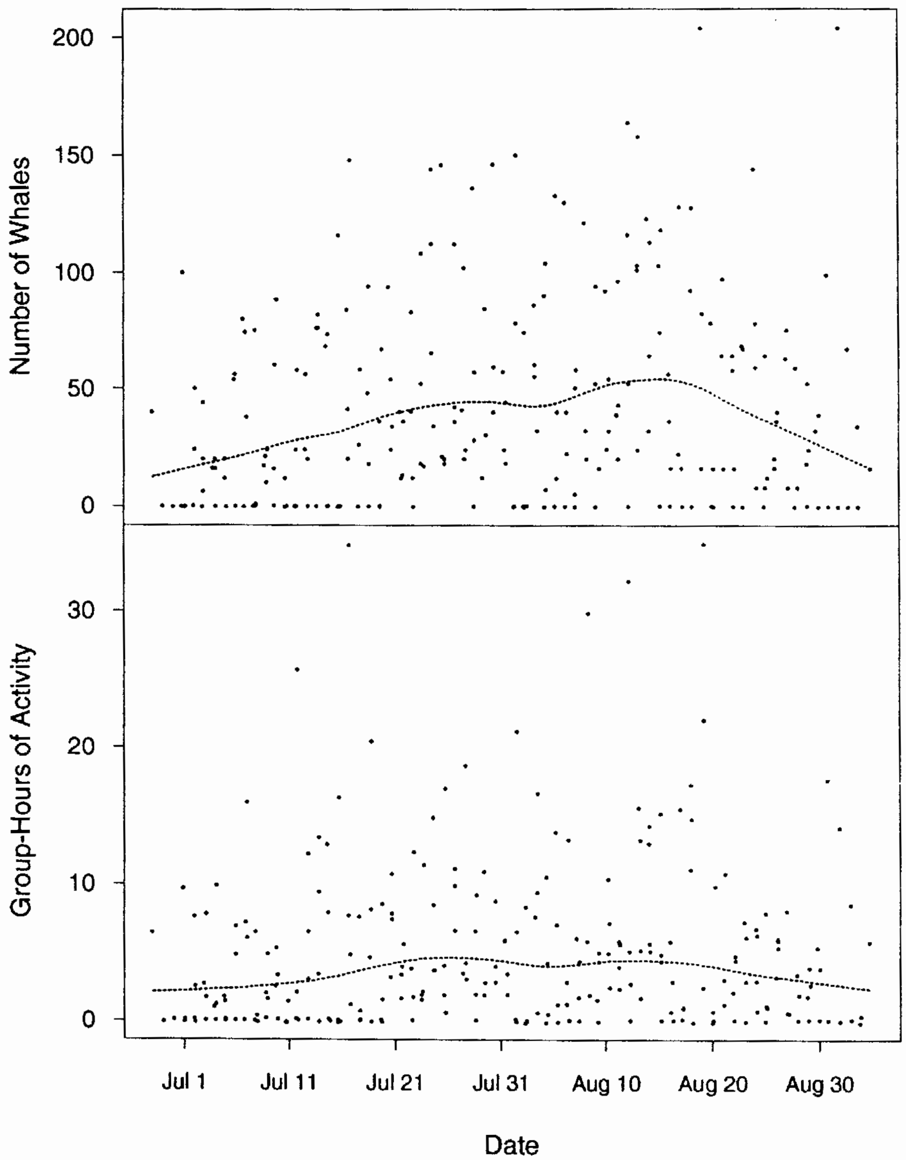

Figure 10. Seasonal variation in whale activity from Jun 28 to Sep 5 in Zones 3, 4, 5 and 6. Both numbers of whales (top panel) and group hours of activity (bottom panel) tended to peak towards the middle of the summer as shown by the *lowess* curves. The jittered data represent all available information from all years and zones of the Ecological Reserve combined.

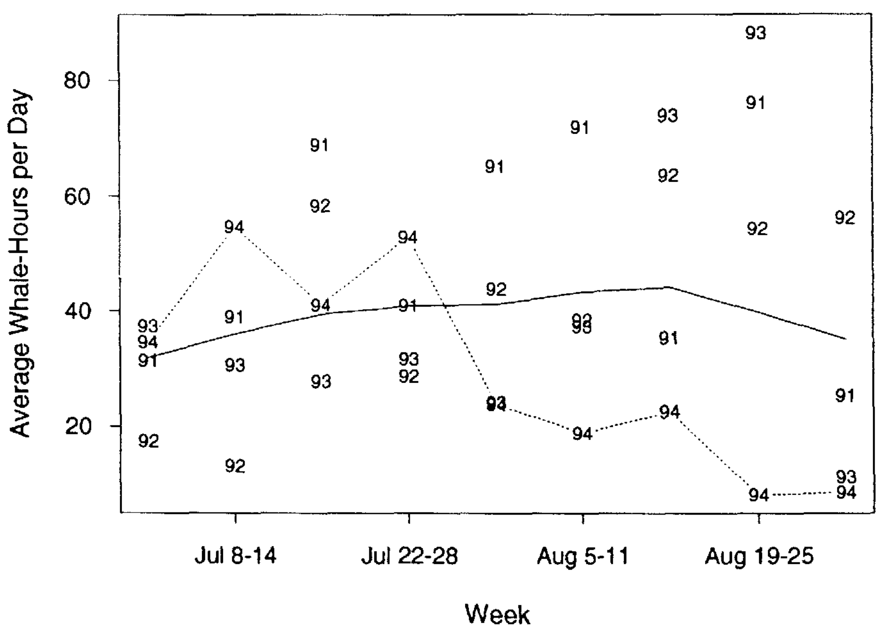

Figure 11. Weekly variation in whale activity within the Ecological Reserve (all Zones summed). Symbols indicate year and plot the average number of *whale hours* observed in a day during a given week. The locally weighted regression (*lowess*) shows overall whale activity increased through the season, 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).

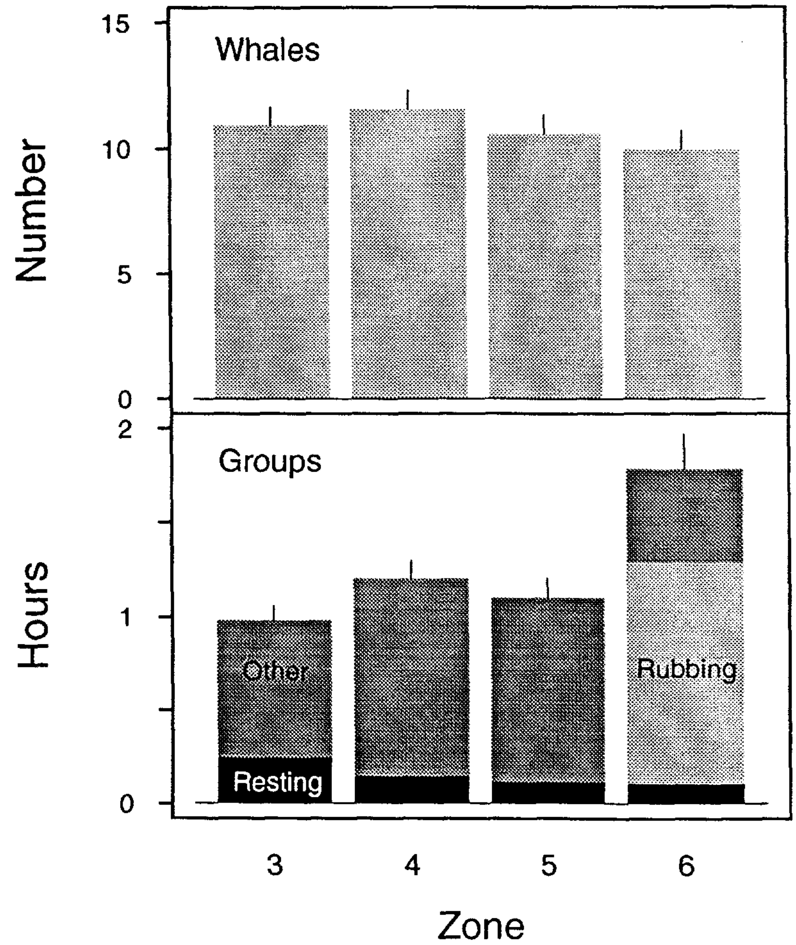

Figure 12. Mean number of whales counted each day and the amount of time (*group hours*) spent resting, rubbing and engaged in other activities in each zone over 250 days of observation (Jun 29 to Sep 1, 1991-1994). Standard errors of the estimates are shown by the vertical bars.

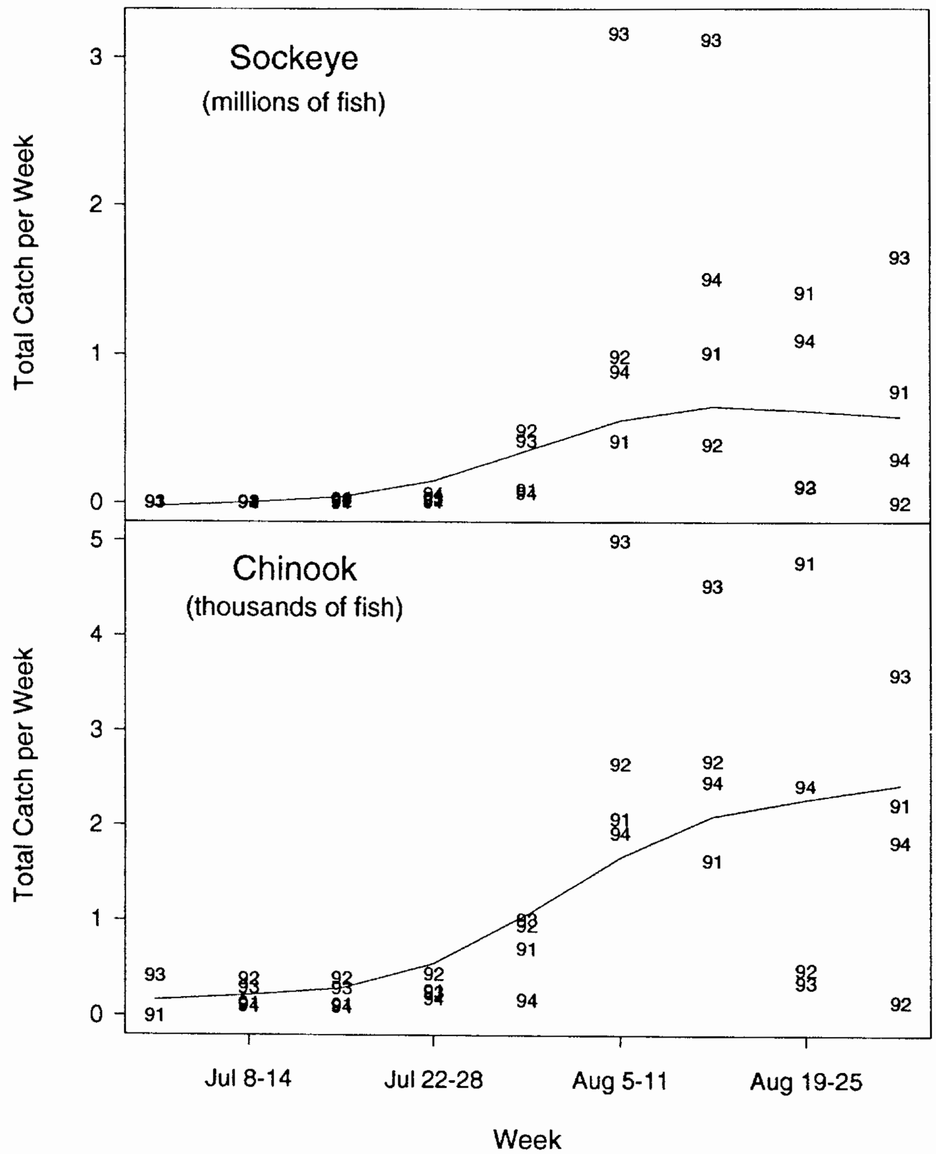

Figure 13. Numbers of sockeye and chinook salmon caught each week in DFO statistical Area 12 (Johnstone Strait) from 1991 to 1994 (Paul Ryall, Pacific Biological Station, Nanaimo, pers. comm.).

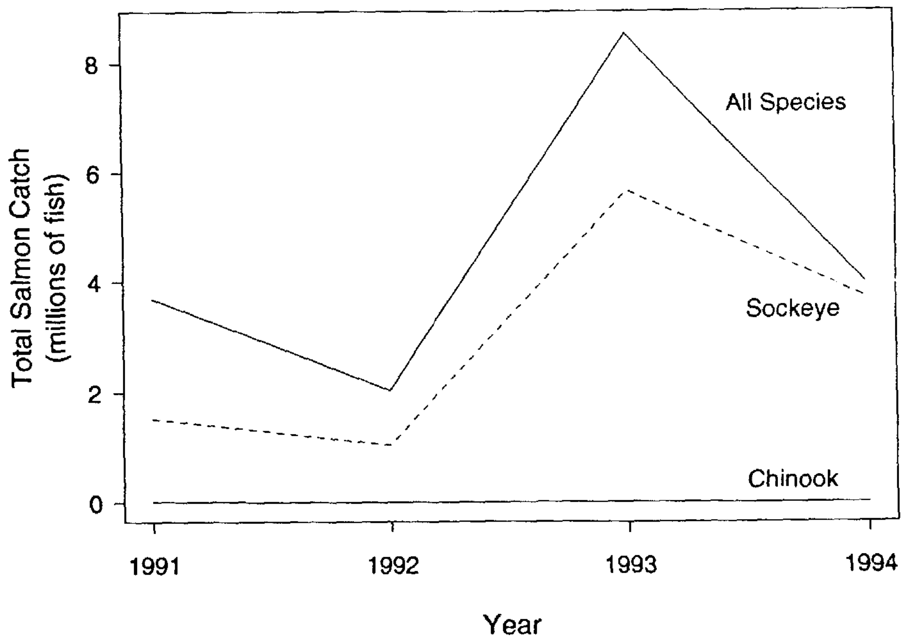

Figure 14. Total numbers of salmon caught in DFO statistical Area 12 (Johnstone Strait) from 1991 to 1994. Weekly troll and gill net catches of each salmon species (Chinook, Sockeye, coho, pink and chum) were summed for the period July 1 - Sep 5 (Paul Ryall, Pacific Biological Station, Nanaimo, pers. comm.). Chinook catches were low through all years.

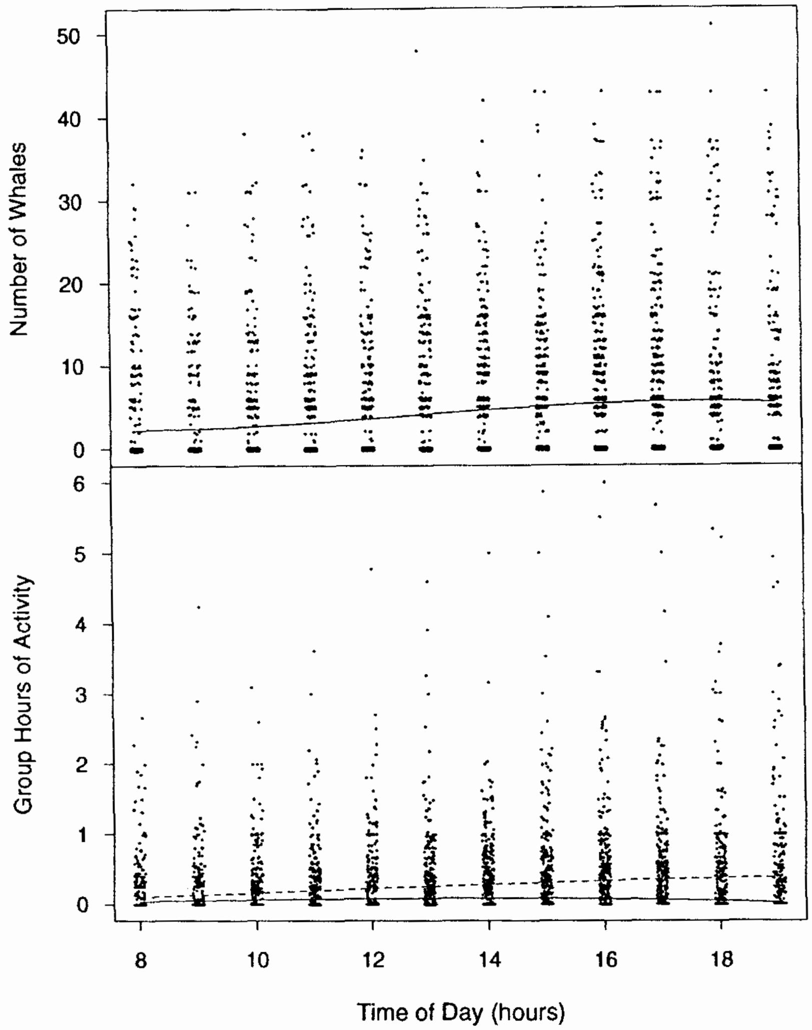

Figure 15. Numbers of whales and hours of group activity by hour of day. Each data point shows the number of whales or *group hours* of activity recorded during a one hour period in a single zone (starting at the time noted on the x-axis). A small amount of random variation was added to each data point to reduce visual overlap. The regression in the upper panel predicts an increase through the day in numbers of whales present in each zone (from Table A13). The regressions shown in the lower panel for August 1 (from Table A15), predict an increase through the day in the length of time groups of whales spent in Zone 6 (dashed line) and a decline in total time spent in the other 3 zones (solid line).

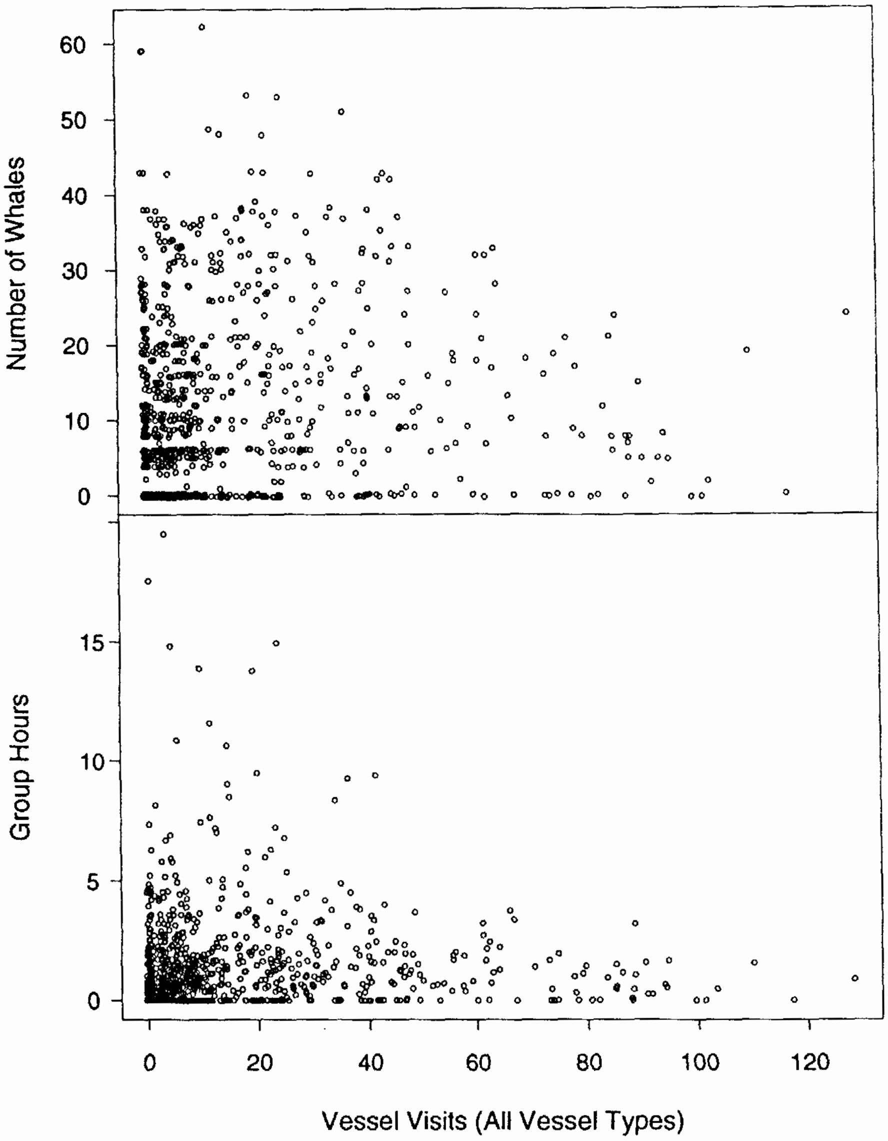

Figure 16. Number of whales and group hours of activity as a function of vessel activity in Zones 3-6. No relationship is seen between the number of whales in a zone on a particular day and the number of times vessels crossed the zone boundary (top panel). Similarly there is no apparent relation between 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.

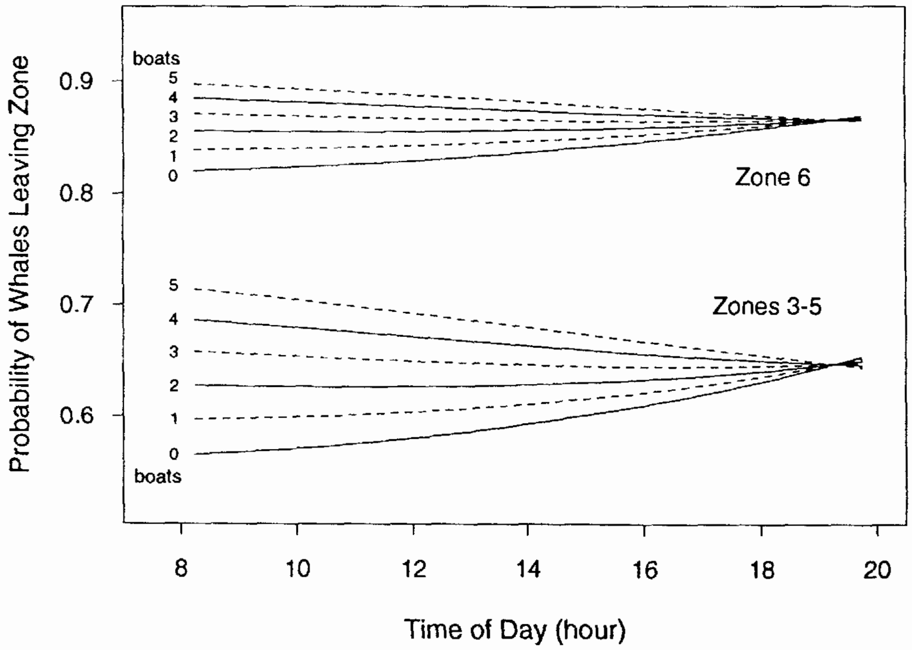

Figure 17. Probabilities of whales leaving any given Zones of the Ecological Reserve within 15 minutes of vessels arriving. Whales have a higher probability of leaving Zone 6 (the rubbing beaches) than they do of leaving any of the other three Reserve zones. Probabilities of whales leaving Zones 3, 4 or 5 did not differ significantly from one another. Increasing the number of vessels that enter a zone increases the probability that whales will move to another zone or leave the Ecological Reserve entirely.