Killer Whales and Vessel Activity in Robson Bight from 1991 to 1993

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Summary

During the summers of 1991, 1992 and 1993, the movements of vessels and killer whales (*Orcinus orca*) were monitored during daylight hours in the Robson Bight - Michael Bigg Ecological Reserve. Analyses of these data showed numbers of whales using the Ecological Reserve increased through the summer season (July 1 to August 31), but did not change with the time of day or among years. In contrast, the lengths of time groups of whales (pods and subpods) spent in the Reserve tended to be higher in the morning than in the afternoon, and varied over the season, and among years.

Vessel activity in the Reserve (recreational and commercial fishing) also increased as the summer progressed and varied among years. More commercial fishing vessels entered the Ecological Reserve than any other class of vessel; their presence apparently being driven by commercial fishing openings in Johnstone Strait. General trends in abundance and activity levels of whales and vessels were surrounded by considerable variability such that neither boat nor whale activity could be accurately predicted for a given day or time.

Variation in whale activity among days was not strongly correlated with daily levels of vessel activity. However, vessels entering the Reserve during the morning or late afternoon appeared to cause whales to move to other parts of the Reserve. But vessel activity did not appear to have any noticeable effect on the whales during the early afternoon. 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 at certain times of the day. In particular, it appears that whales are more likely to move to a different area of the Reserve when vessels are present than when they are absent.

Future research on the effects of vessel activity on killer whales in the Ecological Reserve is recommended and should include: further 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 is considered by many to be the best place in the world to view killer whales (*Orcinus orca*) in the wild. But the relative ease of approaching killer whales at sea and the increasing numbers of people who want to see them is raising concern for the whales' well being. Recreational vessels frequent the areas used by killer whales in summer, as do commercial fish boats and whale watching charter vessels. Many of the 25,000 people who visit the Johnstone Strait area each year come to see the whales (1993 census data, Ford *et al.* 1994).

In contrast to the thousands of visitors, the number of killer whales ranging from Vancouver Island to Southeast Alaska is only 200 (Ford *et al.* 1994). This northern community of resident killer whales congregates in western Johnstone Strait and Queen Charlotte Strait to intercept migrating salmon from June to October. Many of the whales in Johnstone Strait can be found feeding or rubbing on the beaches of Robson Bight.

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. A visitor management program was conducted in 1987, 1989 and 1990 to direct vessel traffic 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 1993 to develop an education program and to monitor the movements of whales and vessel activity during daylight hours (Wong *et al.* 1993).

The primary goal of our study was to determine from the existing data whether vessels and commercial fishing openings have an effect on the presence and distribution of whales in the Ecological Reserve. A secondary goal was to summarize the activities of whales and vessels in the Reserve.

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 vessels and commercial vessels). Finally we consider the interaction of whales and boats, and make recommendations for future research.

Killer Whale Biology

The 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. The whales remain until the last of the migrating salmon have passed. It is rare to have more than 50 whales present in one place at one time in 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 total (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 east 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. In 1991, all observations were made between 0800h to 2000h, but times varied from day to day. In 1992 and 1993, observations alternated between 0800-1800h and 1000-2000h. Observations were not made during foul weather because the Zones and whales could not be clearly seen.

Observations were recorded on data sheets and compiled in binders. Some information about vessels were not collected in all years, while some data collected on whale and vessel behaviours

Table 1. Types of data collected from 1991 to 1993. The asterix indicates data that were collected but not entered into a computer data base. Note that all data is not readily comparable or in a form that can be keypunched.

	Year of Study		
	1991	1992	1993
Vessels			
Number	no	no	no
Activity	some*	some*	no
Time Entered Zone	yes*	yes	yes
Time Exited Zone	no	yes*	no
Whales			
Numbers	yes	yes	yes
Pod ID	yes	yes	yes
Time Activity Started	yes*	yes*	yes*
Time Entered Zone	yes	yes	yes
Time Exited Zone	yes	yes	yes
Direction of Movement	yes*	yes*	yes*
Cumulative Time Resting	yes*	yes*	yes
Cumulative Time Rubbing	yes*	yes*	yes

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 (M. Wong, Bion Research, pers. comm.). Thus we only analyzed whale and vessel activity in 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 recordings 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 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, but the time of occurrence was not entered into the computer data base. Behaviours such as travelling, feeding and socializing were grouped as *other* because they could not be readily distinguished.

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). In 1991 however, recreational power vessels and recreational sailing vessels were grouped into a single class: recreational vessels. Observers only recorded the type of vessel present, and the time it entered a zone. Exit times were not recorded (except in 1992), nor were their 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. Hence, the actual numbers of vessels that were in the Ecological Reserve is unknown.

All that is known about vessel activity from the computer data base is the number of times they entered a zone of the Reserve (*vessel visits*). In 1991, vessels were counted each time they entered a zone, but the actual number of different vessels present was never noted. Thus a single boat entering more than one zone cannot be distinguished from many boats entering a single zone. Entrance times could only be analyzed for 1992 and 1993 (Table 1).

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 in 1992 and 1993 to maintain consistency among years with the 1991 data. Finally, we restricted our analysis to days when both vessels and whales were seen.

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 these two together).

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 tested for statistically using analysis of covariance. We were not able to test for inter-annual variations in specific behaviours (*i.e.* resting and rubbing) because data were only available for one year, 1993.

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 statistically significant ($P<0.05$), to calculate coefficients for 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 the number of times that vessels crossed zone boundaries (*vessel visits*). This statistic showed high variability in daily zone visits (ranging from 0 to 181 times a day), but a rather low overall mean ($\bar{x} = 23.2$ visits per day)[1]. Most of the *vessel visits* were by commercial fish boats (75-85% of the total, Table 2, Fig. 3a), with the combined recreational power and sailing vessels ranking a distant second (9-15%).

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 (Fig. 4). These data suggest that much of the variation in vessel activity within the Ecological Reserve is driven by the schedule of short-term openings of fishing seasons (Fig. 4).

No relationship was found between the movements of recreational vessels and commercial fishing vessels (Fig. 3b). Thus there is no indication from the data that recreational vessels were drawn into the Ecological Reserve when commercial fishing boats were present.

Seasonal Variation

There was considerable variation in the number of times vessels moved across zone boundaries in the Ecological Reserve (Fig. 5). The general tendency however, was for *vessel visits* to be highly skewed with a relatively low overall daily mean between July 1 and August 31.

Using analysis of covariance to test for seasonal changes in vessel activity in the Ecological Reserve, we tested whether the number of times vessels entered zones was affected by *Day, Year* or *Zone*. We also added Day^2 to the analysis in case the relationship between day and vessel activity was nonlinear. Finally, because vessels may not have used all zones of the Reserve equally over the summer months, we added the interactions *Zone*Day* and $Zone*Day^2$.

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

Vessels do not appear to favour the use of one area over any other within the Reserve based on how many times each Zone was entered (*Zone* term:Tables A1, A2 and A3). However, the number of times that recreational and commercial fishing vessels entered the Reserve did change with time. Most notably there was a nonlinear increase in the number of vessels entering the Reserve over the summer months (P=0.001 for the Day^2 term). The frequency of visits differed among years (P<0.001 for the *Year* term), but there was no trend in the number of vessel visits recorded from 1991 to 1993..

The seasonal changes in activity levels of vessels within each zone were slight compared to the high variability that surrounded them (Fig. 5). These large differences from one day to the next can not be explained by seasonal differences in average vessel activity. On average, relatively few vessels entered any given zone of the Ecological Reserve on a single day.

Plotting the total number of times vessels crossed zone boundaries (*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. 6). Vessel activity was highly variable among years, particularly in the latter half of the season (the last 3 weeks of August). This variability in activity 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

As with seasonal variation in vessel activity, there was a great deal of variation in the number of vessels that entered a zone in a given hour of the day in 1992 and 1993 (Fig. 7). At most times of the day, few vessels entered a zone in a given hour, but occasionally the number of *vessel visits* was large.

The presence or absence of a daily pattern of vessel activity within the Ecological Reserve was determined using analysis of covariance (Tables A4, A5 and A6). We tested whether changes in vessel activity 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* 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.

The total number of times the combined vessels entered a zone varied through the day (Table A4) due to changes in recreational vessel activity (Table A5) rather than to changes in commercial fishing activity (Table A6). The probability of a diurnal pattern underlying the activities of commercial fishing vessels is less than 30% (a level that is not statistically significant). In contrast

Table 2. Number of times that vessels entered one or more zones of the Ecological Reserve in 1992 and 1993. 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. Number of days of observation were 57 and 59 in 1992 and 1993, respectively.

Type of Vessel	Year of Study			
	1992		1993	
Commercial Fishing Vessel	1,448	(75.7)	1,937	(85.5)
Recreational Power Vessel	189	(9.9)	125	(5.5)
Recreational Sailing Vessel	108	(5.6)	75	(3.3)
Recreational Kayak Group	65	(3.4)	52	(2.3)
Government Patrol Vessel	46	(2.4)	44	(1.9)
Commercial Charter Vessel	23	(1.2)	9	(0.4)
Commercial Ocean Liner	13	(0.7)	3	(0.1)
Tugboat	11	(0.6)	0	(0.0)
Photographer Research Vessel	8	(0.4)	8	(0.4)
Other	2	(0.2)	13	(0.6)
TOTAL	1,913		2,266	

to the constant activity of commercial fishing boats, *vessel visits* by recreational power and sail boats showed a distinct diurnal pattern. They increased through the morning, peaked at midday and dropped through the afternoon ($P < 0.001$ for the *Hour* and *Hour*^{2} terms).

Fitting locally weighted regressions to the hourly data (Fig. 8) confirms the decline in recreational vessel activity through the late afternoon, but suggests an increase in activity by commercial fishing vessels throughout the day. Again, average commercial vessel activity exceeded that of recreational vessels.

As with seasonal changes, hourly changes in activity levels of vessels within each zone was slight compared to the high variability that surrounded them (Fig. 7). The variability could not be explained by daily differences in average vessel activity. On average, relatively few vessels entered zones in the Ecological Reserve at any one time of day.

Whale Activity

Fourteen of the 16 northern resident pods were seen in the Ecological Reserve at least once during the three years of study (Table 3). Of these, 5 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 80-94% of the days observed). The number of times each pod was seen varied from year to year (Table 3). Similarly, use by the 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. No temporal trend in usage patterns were apparent from the three years of data.

The amount of time spent resting, rubbing or engaged in other activities depended upon which zone of seen in the Ecological Reserve the whales were in (Table 5). In 1993, the only year for which such data were available, the whales were in Zone 6 (the rubbing beaches) three times longer than in Zone 3 and twice as long as in Zones 4 and 5. In general, killer whales spent an average of 21% of their time resting in Zones 3, 4 and 5; and 79% of their time engaged in other activities. This is in sharp contrast to Zone 6 where whales spent 72% of their time rubbing, but only 3% resting and 25% in other activities (Table 5).

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. We therefore assumed in our analyses that there were no significant behavioural differences among pods within a season or from year to year.

Seasonal Variation

Numbers of whales and the amount of time, in hours or fractions thereof, that groups[2] of whales spent in given activities (*group hours*) varied considerably between July 1 and August 31 (Fig. 9). Overall, however, the day to day pattern indicates that the whales consistently used the Reserve despite high variance in numbers and group activity.

Analysis of covariance revealed statistical differences in numbers and *group hours* of whales observed through the field seasons (Tables A7 and A8). In addition, the total amount of time spent by groups in the Reserve varied among years, but usage of each zone was consistent from one year to the next (Table A8). Numbers of whales present in the Ecological Reserve rose through the month of July, peaking in mid August and declining slightly thereafter (Fig. 9). *Whale hours*

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

Table 3. Number of days that pods of killer whales were seen in the Ecological Reserve. Observers watched for 48 days in 1991, 49 in 1992, and 45 in 1993. Bracketed numbers show the frequency of pod sightings in the Reserve (%).

Pod	1991	1992	1993
A1	38 (79.2)	46 (93.9)	41 (91.1)
A4	20 (41.7)	14 (28.6)	17 (37.8)
C1	14 (29.2)	11 (22.4)	24 (53.3)
A5	11 (22.9)	4 (8.2)	30 (66.7)
I11	9 (18.8)	19 (38.8)	9 (20.0)
B1	7 (14.6)	2 (4.1)	7 (15.6)
H1	5 (10.4)	4 (8.2)	1 (2.2)
I31	4 (8.3)	(0.0)	1 (2.2)
R1	1 (2.1)	1 (2.0)	11 (24.4)
D1	(0.0)	3 (6.1)	(0.0)
I2	(0.0)	1 (2.0)	3 (6.7)
I27	(0.0)	1 (2.0)	(0.0)
G1	(0.0)	(0.0)	1 (2.2)
G12	(0.0)	(0.0)	1 (2.2)
Other	(0.0)	4 (8.2)	2 (4.4)

(numbers of whales x hours present) also revealed the seasonal increase and decrease in how whales used the Reserve (Fig. 10).

The seasonal rise and fall in numbers and *group hours* indicated by the fitted curves in Fig. 9 is relatively slight compared to the range of variation actually observed. In other words, considerable variation surrounds the small changes in average whale activity through the season (or among years, when group hours are examined). Furthermore, there was considerable variability from year to year (Fig. 10).

Amounts of time that groups of whales spent resting and rubbing in 1993 did not vary systematically through the season (Tables A9 and A10). Again, despite considerable variation from one day to the next, average activity levels were low throughout the season.

Table 4. Number of days that subpods of killer whales were seen in the Ecological Reserve. Observers watched for 48 days in 1991, 49 in 1992, and 45 in 1993. Bracketed numbers show the frequency of subpod sightings in the Reserve (%).

Pod	Sub	1991	1992	1993
A1	A30	27 (56.3)	39 (79.6)	31 (68.9)
A1	A12	26 (54.2)	25 (51.0)	22 (48.9)
A1	A36	10 (20.8)	8 (16.3)	19 (42.2)
A4	A11	19 (39.6)	14 (28.6)	17 (37.8)
A4	A24	2 (4.2)	11 (22.4)	7 (15.6)
C1	C5	10 (20.8)	9 (18.4)	24 (53.3)
C1	C6	9 (18.8)	4 (8.2)	6 (13.3)
A5	A25	9 (18.8)	1 (2.0)	2 (4.4)
A5	A8	8 (16.7)	3 (6.1)	21 (46.7)
A5	A23	7 (14.6)	2 (4.1)	26 (57.8)
A5	A5	1 (2.1)	(0.0)	21 (46.7)
I11	I15	9 (18.8)	19 (38.8)	9 (20.0)
B1	B1	7 (14.6)	2 (4.1)	7 (15.6)
H1	H1	5 (10.4)	4 (8.2)	1 (2.2)
I31	I31	4 (8.3)	(0.0)	1 (2.2)
R1	R5	1 (2.1)	1 (2.0)	(0.0)
R1	R2	(0.0)	1 (2.0)	9 (20.0)
R1	R9	(0.0)	(0.0)	3 (6.7)
D1	D7	(0.0)	3 (6.1)	(0.0)
I2	I22	(0.0)	1 (2.0)	(0.0)
I2	I2	(0.0)	(0.0)	3 (6.7)
I27	I22	(0.0)	1 (2.0)	(0.0)
G1	G17	(0.0)	(0.0)	1 (2.2)
G1	G4	(0.0)	(0.0)	1 (2.2)
G12	G8	(0.0)	(0.0)	1 (2.2)
other	other	(0.0)	4 (8.2)	2 (4.4)

Table 5. Percent time groups of whales spent resting rubbing and engaged in other activities in Zones 3-6 during 1993. Percentages are calculated from *group hours*. Whales were seen for a total of 355.7 hours out of a total of 477.5 hours of observations.

	Zone 3	Zone 4	Zone 5	Zone 6
% Time Resting	16.4	21.4	24.8	2.9
% Time Rubbing	0.0	0.0	0.0	72.0
% Time Other Activity	83.6	78.6	75.2	25.1
Total Group Hours	56.9	73.9	75.6	149.3

Daily Variation

As with numbers of whales counted throughout the season, the numbers counted throughout the day varied considerably (Fig. 11). Variability in hourly whale activity within each of the zones was also high.

The lack of any apparent effect of *hour* on numbers of whales and length of time in the Reserve (Fig. 11) was tested using analysis of covariance. Additional factors included in the model were *zone*, *year*, *day*, $hour^2$, and $hour^3$. 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.

Results of the statistical analysis confirmed that the number of whales in a zone did not vary with the hour of the day (Table A11). However, the duration of activity (*group hours*) showed a statistically significant drop through the day (Table A12). As with previous analyses though, the change in average activity of whales was far smaller than the range of variation seen within any single hour of the day.

Whale - Boat Interactions

The apparent concomitant rise 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. 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 we have demonstrated, 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 is little visual evidence that activities of vessels are related to either numbers of whales or *group hours* of whale activity (Fig. 12). This was tested statistically using weighted regression to account for the decreasing variation in number of whales with the rise in vessel visits (Fig. 12a). We were not able to simultaneously control for the effects of year, season, or zone. 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 $P<0.05$.

Variation in boat activity does not appear to be associated with variation in whale use of the Ecological Reserve (Tables A13 and A14). Only 1 of the 12 regressions of whale numbers was statistically significant, suggesting a decrease of 0.1 whales each time a recreational vessel (sail or power) entered Zone 6. Similarly only 2 of the 12 regressions of vessel activity against *group hours* were statistically significant. In Zone 5, whale activity was reduced by 0.01 hours for each additional commercial fishing vessel that entered the zone. Not surprisingly, the regression using total vessels was also significant due to the large proportion of commercial fishing vessels that make up total vessels. Thus the magnitudes of the statistically significant effects of additional boats on whale numbers and *group hours* was 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*^{2}, 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, except at mid-day (Table A15, Fig. 13). The regressions also showed that whales were more likely to spontaneously leave a zone in the middle of the day than at any other time (whales moved more frequently in the middle of the day), and that the whales were more likely to leave Zone 6 (the rubbing beaches) than any other zone of the Ecological Reserve. Whales may be more sensitive in Zone 6 to human disturbance than in any other Zone (Briggs 1993). It is also possible that whales increase their swimming speed in the presence of boats (Kruse 1984) and are therefore more likely to leave Zone 6 than other zones because of its relatively small size (Fig. 1).

The likelihood of whales leaving a zone rose dramatically in the morning and late afternoon as increasing numbers of vessels entered a zone. For example,whales in Zone 3 at 0800 h had a 21% probability of leaving the zone when no boats were present. However, when 1 boat entered, the probability that a whale would leave the zone within the next 15 minutes rose to 33%. With 2 boats

it rose to 48%, and with 3 boats to 63%. The effects of vessels on whale activity was relatively large in the morning and late afternoon; the appearance of even 2 vessels entering a zone of the Ecological Reserve could more than double the probability that whales would leave the area (Fig. 13).

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.

Variation in whale activity among days was not strongly correlated with daily levels of vessel activity (Table A14, Fig. 12). However, when we considered whale activity on a much finer scale, we found that whales had a high probability of leaving individual zones shortly after boats arrived in the morning and late in the afternoon (Table A15, Fig. 13).

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 move around more when vessels are present than when they are absent.

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)? Such questions need to be answered before conclusions can be drawn about the impact of vessel activity on whales in the Ecological Reserve.

Commercial fishing openings affected the behaviour of whales in that they accounted for increased vessel activity in the Reserve. Commercial fishing activity, as indexed by aerial counts of numbers of fishing vessels in the region encompassing the Ecological Reserve, was closely related to the number of *vessel visits* into the Ecological Reserve over the same time periods (Fig. 4). Commercial fishing openings in the area would appear to drive much of the variation in the level of whale/boat interactions in Robson Bight.

Our secondary goal was to describe how whales and vessels use the Ecological Reserve. We found that the numbers of whales and the activity levels of whales and vessels varied systematically among years, days, and hour of day. Numbers of whales in the Ecological Reserve did not vary among years (Table A7), unlike the amount of time groups of whales spent there (Table A8). Of the three years studied, the amount of time groups spent in the Reserve was highest in 1993 and lowest in 1992. Similarly, activity of commercial and recreational vessels also varied among years (Tables A1 and A2) and was highest in 1992 and lowest in 1991. Both whales and boats showed a general increase in activity as the summer progressed (Figs. 6 and 10) which may reflect the abundance of salmon in the Reserve that both groups are seeking. Within any given day, however, whale activity tended to decrease from morning to evening (Fig. 11), whereas recreational vessels were most active in the middle of the day (Fig. 7). However, as previously noted, the general patterns were surrounded by such high variability that neither boat nor whale activity can be accurately predicted for a given date or time.

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 1993 as well as in previous years of study still contain 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 could 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. (Note: we did not conduct these additional analyses because the data were either available in the original field records but not in computer files, or the original computer files required labour intensive modifications before analyses could be performed.)

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 previous three years' work were relatively general, and yielded data that could only address some relatively general questions. By defining specific questions, the amount of information required to statistically detect effects (*e.g.* number of hours, days, or whale/vessel encounters to be observed) can be determined using power analysis (see Zar 1984, Cohen 1988, Nemac 1991). In this way the amount of effort required to answer the questions can be determined and the feasibility of doing so can be assessed. A second advantage of asking specific questions is to ensure that the most appropriate data are collected and that these data are gathered in a form that simplifies their analysis.

A more specific recommendation is that more detailed information be collected on whale behaviour. Our analysis of the 1991-93 data 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. We suggest that attention be paid to specific behaviours of individual whales that may change in response to vessel activity. For example, are (1) bouts of rubbing shorter when vessels are active in the vicinity, or (2) is the duration of a bout of resting affected by nearby vessel activity, or (3) is the direction that whales are travelling affected by movements of vessels?

Additional information should also be collected about vessels. 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. However, this assumption should be substantiated by collecting data on both vessel numbers and their activity. In this way the effects of moving and stationary boats on the activity of whales could be differentiated.

Finally, we did not analyze activities of whales and vessels in the area immediately adjacent to the Ecological Reserve (the area designated as Zone 2) because these data were not considered reliable. However, useful information should be gathered about movements or at least about numbers of whales and vessels in Zone 2. 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 were effective in deterring vessels from entering the Reserve during their passage through the Strait.

Clearly, additional research is 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. The results show commercial fishing vessel activity varied significantly over the season (July 1 to August 31) and among years (1991 to 1993).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	34130.788	2	17065.394	85.354	<0.001
Zone	81.626	3	27.209	0.136	0.938
Day	5114.109	1	5114.109	25.579	<0.001
Day^2	1937.135	1	1937.135	9.689	0.002
Zone*Day	73.231	3	24.410	0.122	0.947
Zone*Day^2	7.237	3	2.412	0.012	0.998
Error	96369.831	482	199.937		

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

$$vessel\_visits = -4.94 + 0.76*Day - 0.007*Day^2 + year\_constant$$

where: July 1 - 31 are Day 1 - 31, and August 1 - 31 are Day 32 - 62
year_constant is -10.47 in 1991, 0.60 in 1992, and 0.00 in 1993

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 (July 1 to August 31) and among years (1991 to 1993).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	725.937	2	362.968	122.569	0.000
Zone	2.484	3	0.828	0.280	0.840
Day	31.716	1	31.716	10.710	0.001
Day^2	34.692	1	34.692	11.715	0.001
Zone*Day	4.661	3	1.554	0.525	0.666
Zone*Day^2	3.675	3	1.225	0.414	0.743
Error	1427.361	482	2.961		

*The equation predicting number of recreational vessel visits is:

$$vessel\_visits(RV) = 0.87 + 0.06*Day - - 0.001*Day^2 + year\_constant$$

where: July 1 - 31 are Day 1 - 31, and August 1 - 31 are Day 32 - 62
year_constant is -1.54 in 1991, 1.34 in 1992, and 0.00 in 1993

Table A3. The effects of zone, year and day on visits by all vessels in the Ecological Reserve (Zones 3-6). *Year* and *Zone* were treated as categorical variables, and *Day* and *Day²* were treated as continuous variables in the analysis of covariance. The results show the activity of all vessels combined varied significantly over the season (July 1 to August 31) and among years (1991 to 1993).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	46741.485	2	23370.742	104.698	<0.001
Zone	113.100	3	37.700	0.169	0.917
Day²	6102.284	1	6102.284	27.338	<0.001
Day²	2558.604	1	2558.604	11.462	0.001
Zone*Day²	132.455	3	44.152	0.198	0.898
Zone*Day²	13.676	3	4.559	0.020	0.996
Error	107592.027	482	223.220		

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

$$\text{vessel\_visits(Total)} = -4.19 + 0.78*\text{Day} - 0.008*\text{Day}^2 + \text{year\_constant}$$

where: July 1 - 31 are Day 1 - 31, and August 1 - 31 are Day 32 - 62
year_constant is -10.87 in 1991, 3.93 in 1992, and 0.00 in 1993

Table A4. The effects of zone, year, day and hour on the total vessel activity in the Ecological Reserve (Zones 3-6). *Year* and *Zone* were treated as categorical variables, and *Day*, *Day*^{2}, *Hour* and *Hour*^{2} were treated as continuous variables in the analysis of covariance. The results show that total activity (recreational + commercial vessels) varied significantly over the season (July 1 to August 31), through the day (800 h to 1900h) and among years (1992 to 1993).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	357.585	1	357.585	43.490	0.000
Zone	20.936	3	6.979	0.849	0.467
Day	1314.799	1	1314.799	159.909	0.000
Day^2	751.510	1	751.510	91.401	0.000
Hour	79.039	1	79.039	9.613	0.002
Hour^2	93.013	1	93.013	11.312	0.001
Zone*Hour	24.029	3	8.010	0.974	0.404
Zone*Hour^2	23.428	3	7.809	0.950	0.416
ERROR	19864.734	2416	8.222		

*The equation predicting number of total vessel visits is:

$$vessel\_visits = -3.49 + 0.18*Day - 0.002*Day^2 + 0.575*Hour - 0.023*Hour^2 + year\_constant$$

where: July 1 - 31 are Day 1 - 31, and August 1 - 31 are Day 32 - 62
year_constant is -0.39 in 1992, and 0.00 in 1993

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*^{2} were treated as continuous variables in the analysis of covariance. The results show the number of recreational vessels varied significantly over the season (July 1 to August 31), through the day (800 h to 1900h) and among years (1992 and 1993).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	16.171	1	16.171	33.285	0.000
Zone	0.519	3	0.173	0.356	0.785
Day	2.570	1	2.570	5.290	0.022
Day^2	0.065	1	0.065	0.134	0.714
Hour	16.362	1	16.362	33.677	0.000
Hour^2	21.266	1	21.266	43.772	0.000
Zone*Hour	0.574	3	0.191	0.394	0.757
Zone*Hour^2	0.506	3	0.169	0.347	0.791
Error	1173.787	2416	0.486		

*The equation predicting number of recreational vessels per zone is:

$$\text{vessel\_visits} = -0.907 - 0.005*\text{Day} + 0.26*\text{Hour} - 0.011*\text{Hour}^2 + \text{year\_constant}$$

where: July 1 - 31 are Day 1 - 31, and August 1 - 31 are Day 32 - 62
year_constant is 0.095 in 1992, and 0.00 in 1993

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*^{2} were treated as continuous variables in the analysis of covariance. The results show the number of recreational vessels varied significantly over the season (July 1 to August 31), through the day (800 h to 1900h) and among years (1992 and 1993).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	584.570	1	584.570	75.885	0.000
Zone	14.298	3	4.766	0.619	0.603
Day	1408.224	1	1408.224	182.806	0.000
Day^2	736.480	1	736.480	95.605	0.000
Hour	6.094	1	6.094	0.791	0.374
Hour^2	7.455	1	7.455	0.968	0.325
Zone*Hour	13.391	3	4.464	0.579	0.628
Zone*Hour^2	13.777	3	4.592	0.596	0.618
Error	18611.333	2416	7.703		

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 (July 1 to August 31) and among years (1992 and 1993).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	82.552	2	41.276	0.362	0.696
Zone	25.381	3	8.460	0.074	0.974
Day	4947.511	1	4947.511	43.409	0.000
Day^2	3372.777	1	3372.777	29.592	0.000
Zone*Day	88.826	3	29.609	0.260	0.854
Zone*Day^2	59.807	3	19.936	0.175	0.913
Error	54935.537	482	113.974		

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

$$\text{whale\_number} = 5.12 + 0.75*\text{Day} - 0.009*\text{Day}^2$$

where: July 1 - 31 are Day 1 - 31, and August 1 - 31 are Day 32 - 62

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 *Day*^{2} were treated as continuous variables in the analysis of covariance. The results show that group hours varied significantly over the season (July 1 to August 31).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	*P*
Year	29.392	2	14.696	3.077	0.047
Zone	2.667	3	0.889	0.186	0.906
Day	41.196	1	41.196	8.624	0.003
Day^2	37.663	1	37.663	7.885	0.005
Zone*Day	14.996	3	4.999	1.046	0.372
Zone*Day^2	14.198	3	4.733	0.991	0.397
Error	2302.378	482	4.777		

*The equation predicting average number of whale hours use of a single zone is:

$$\text{whale\_hours} = 1.11 + 0.067*\text{Day} - 0.001*\text{Day}^2 + \text{year\_constant}$$

where: July 1 - 31 are Day 1 - 31, and August 1 - 31 are Day 32 - 62
year_constant is -0.16 in 1991, -0.19 in 1992, and 0.00 in 1993

Table A9. Seasonal variation in 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. No significant effects were found. Data were only available for 1993.

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Zone	0.072	3	0.024	0.020	0.996
Day	2.698	1	2.698	2.283	0.133
Day^2	2.156	1	2.156	1.824	0.179
Zone*Day	0.397	3	0.132	0.112	0.953
Zone*Day^2	0.381	3	0.127	0.108	0.956
Error	186.690	158	1.182		

Table A10. Seasonal variation in number of hours groups of whales were rubbing in the Ecological Reserve. A multiple regression was conducted using *Day* and *Day*^{2} as continuous variables. Whales used Zone 6 exclusively for rubbing and data were only available in 1993.

Multiple Regression

Variable	Coefficient	Std Error	Std Coef	Tolerance	*t*	*P* (2 tail)
Constant	2.689	1.809	0.000	.	1.487	0.145
Day	0.066	0.122	0.376	0.052	0.541	0.591
Day^2	-0.001	0.002	-0.579	0.052	-0.834	0.409

Table A11. The effects of zone, year, day and hour on the number of killer whales 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 results show significant differences in numbers of killer whales from day to day, and from zone to zone, but no change in numbers with time of day (800 h to 1900h).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	88.578	2	44.289	0.706	0.494
Zone	2665.092	3	888.364	14.163	0.000
Day	5210.507	1	5210.507	83.069	0.000
Day^2	4522.955	1	4522.955	72.108	0.000
Hour	8.625	1	8.625	0.138	0.711
Hour^3	0.204	1	0.204	0.003	0.955
Error	90073.210	1436	62.725		

Table A12. 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 results show significant differences in numbers of killer whales from day to day, from zone to zone, and with time of day (800 h to 1900h).

Analysis of Covariance

Source	Sum of Squares	df	Mean Square	*F*-Ratio	P
Year	18.458	2	9.229	16.476	0.000
Zone	83.869	3	27.956	49.908	0.000
Day	6.175	1	6.175	11.024	0.001
Day^2	8.548	1	8.548	15.261	0.000
Hour	1.642	1	1.642	2.931	0.087
Hour^3	3.699	1	3.699	6.604	0.010
Error	804.374	1436	0.560		

*The equation predicting killer whale activity within a single zone is:

$$\text{group\_hours} = 0.98 + 0.0008*\text{Day} - 0.000001*\text{Day}^2 - 0.05*\text{Hour} + 0.00013*\text{Hour}^3 + \text{Zone\_constant} + \text{Year\_constant}$$

where: July 1 - 31 are Day 1 - 31, and August 1 - 31 are Day 32 - 62
Hour is on a 24 hour clock varying from 8 to 19
Year_constant is -0.111 in 1991, -0.051 in 1992, and 0.00 in 1993
Zone_constant is -0.217 for Zone 3, -0.118 for Zone 4, -0.088 for Zone 5, and 0.00 for Zone 6

Table A13. 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). 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	14.8	0.03	0.38
Total	4	16.1	0.05	0.30
Total	5	16.5	0.08	0.20
Total	6	16.2	0.17	0.10
CFV	3	14.9	0.03	0.42
CFV	4	16.2	0.05	0.28
CFV	5	16.4	0.10	0.13
CFV	6	16.1	0.25	0.03
RV	3	15.1	0.10	0.79
RV	4	16.7	0.07	0.87
RV	5	18.3	-0.61	0.11
RV	6	18.6	-0.10	0.005

Table A14. Daily whale use (group hours) of the Ecological Reserve each day as a function of vessel activity (CFV - commercial fishing vessels, RV - recreational vessel, Total = CFV + RV). 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	1.44	-0.004	0.19
Total	4	1.78	-0.003	0.61
Total	5	1.99	-0.015	0.01
Total	6	3.00	0.025	0.58
CFV	3	1.40	-0.001	0.13
CFV	4	1.80	-0.001	0.31
CFV	5	1.84	-0.001	0.005
CFV	6	3.17	0.001	0.60
RV	3	1.13	0.080	0.09
RV	4	1.56	0.037	0.58
RV	5	1.64	-0.031	0.56
RV	6	3.83	-0.327	0.08

Table A15. 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* and *Hour*^{2} were treated as continuous variables in the logistic regression.

Logistic Regression

Effect	Parameter	Estimate	Error	$\chi 2$	*P*
Intercept	1	-5.6665	1.4237	15.84	0.0001
Year	2	0.00408	0.0464	0.01	0.9299
Hour	3	0.8177	0.1954	17.52	0.0000
Hour^2	4	-0.0283	0.00662	18.27	0.0000
Day	5	0.0115	0.0112	1.06	0.3040
Day^2	6	-0.00015	0.000174	0.79	0.3745
Whales	7	-0.0248	0.0165	2.27	0.1322
Zone 3	8	-0.4139	0.0833	24.69	0.0000
Zone 4	9	-0.2746	0.0769	12.74	0.0004
Zone 5	10	-0.3375	0.0788	18.37	0.0000
Time_in	11	0.0626	0.0986	0.40	0.5254
Vessel_visits	12	3.2488	1.3874	5.48	0.0192
Hour*Vessel_visits	13	-0.4556	0.1978	5.30	0.0213
Hour^2*Vessel_visits	14	0.0159	0.00697	5.21	0.0225
Whales*Vessel_visits	15	-0.00047	0.0124	0.00	0.9700

*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

$$B = -5.38 + 0.78*\text{Hour} - 0.027*\text{Hour}^2 + 3.22*\text{Vessel\_visits} - 0.455*\text{Hour}*\text{Vessel\_visits} + 0.016*\text{Hour}^2*\text{Vessel\_visits} + \text{Zone\_Constant}$$

Zone_Constant is -0.43 for Zone 3, -0.28 for Zone 4, -0.34 for Zone 5,and 1.05 for Zone 6

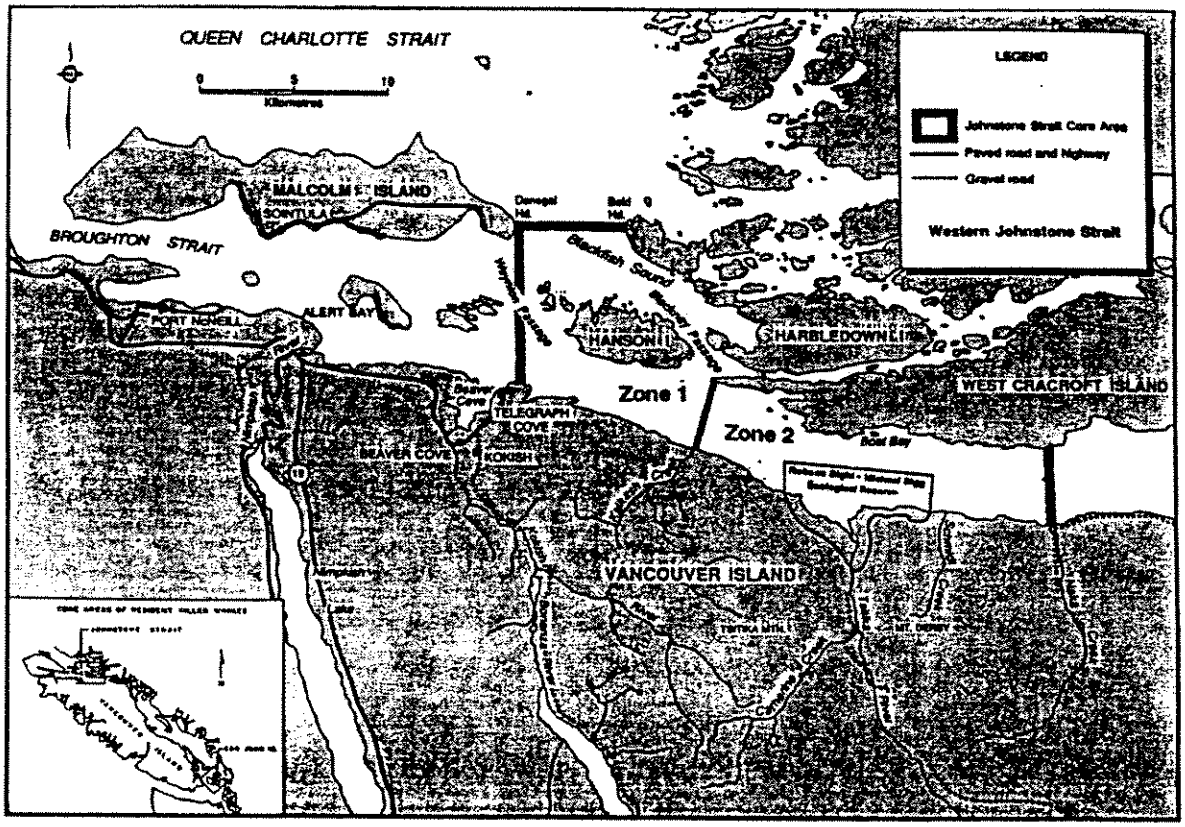

Figure 1. Western Johnstone Strait showing showing Zones 1 and 2, and the Robson Bight - Michael Bigg Ecological Reserve (Zones 3-6). From Wong *et al.* (1993).

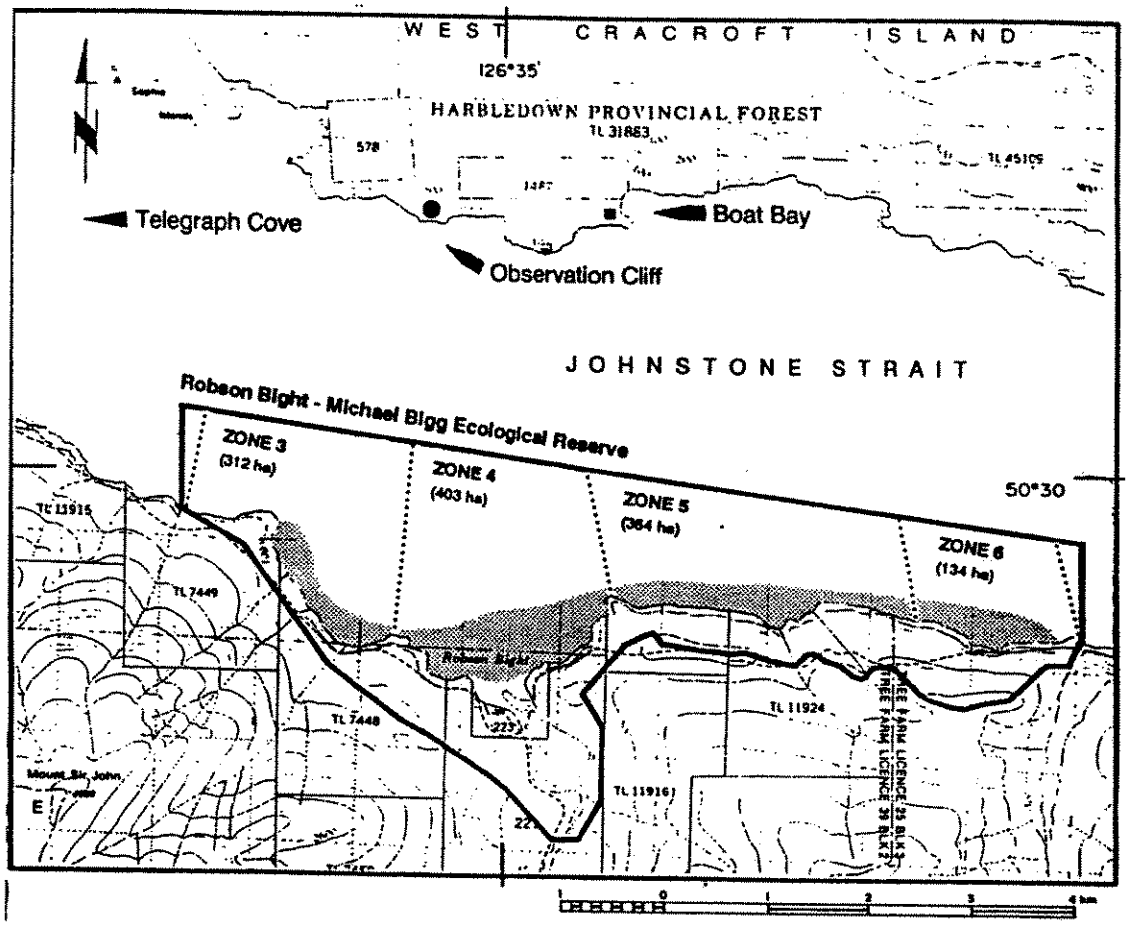

Figure 2. Location of the observation cliff and Zones 3 - 6 (the Robson Bight - Michael Bigg Ecological Reserve). From Wong *et al.* (1993).

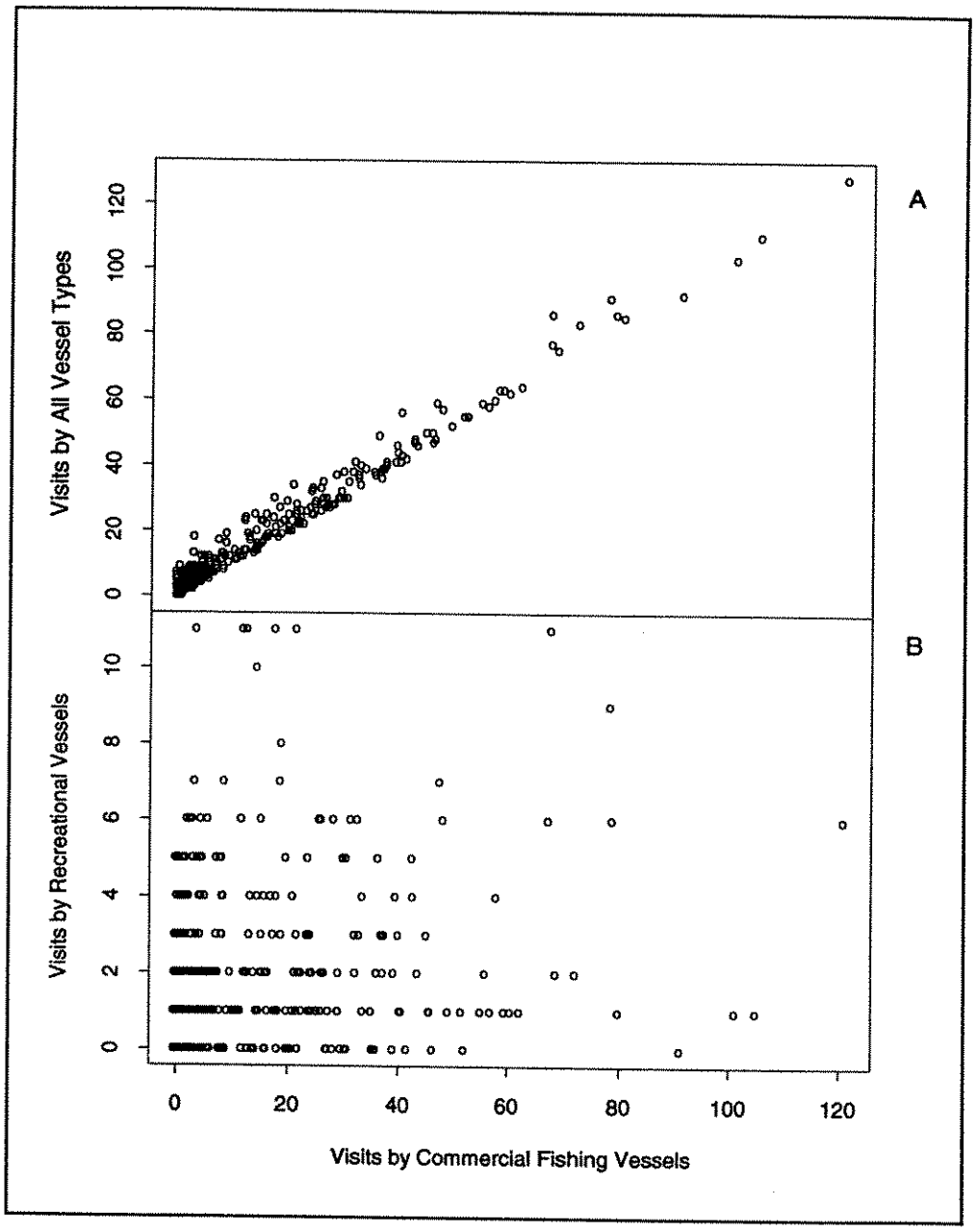

Figure 3. Levels of activity of commercial fishing vessels in relation to that of recreational and total vessels (commercial + recreational + kayak + charter + ...). Each data point is the daily number of *vessel visits* for one zone (nos. 3-6) in one year (1991-93). The data were jittered by adding 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).

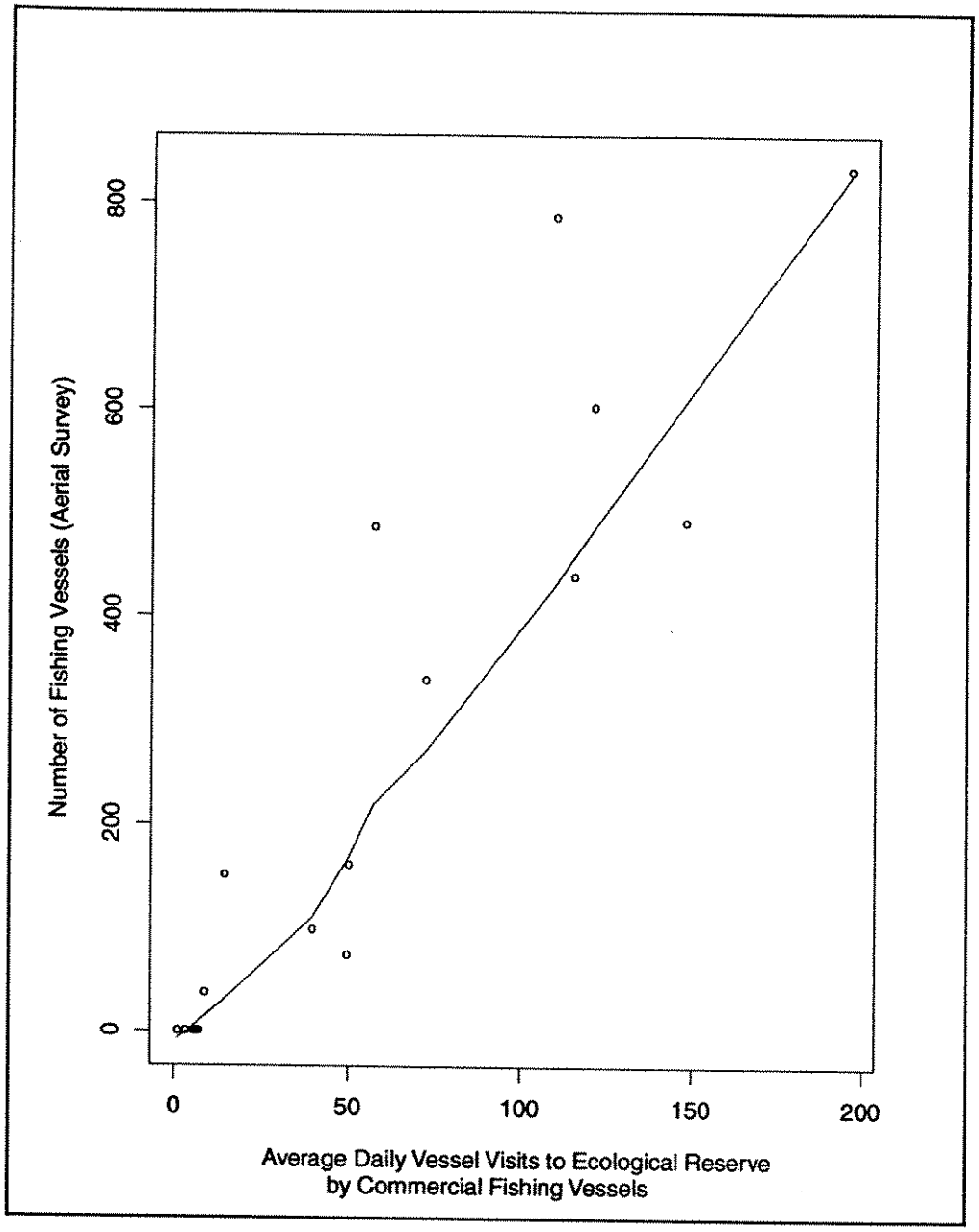

Figure 4. Weekly commercial fishing activity in Johnstone Strait in relation to average weekly *vessel visits* within the Ecological Reserve from 1991 to 1993. Numbers of fishing vessels in western Johnstone Strait were estimated from weekly aerial surveys (Ed Lochbaum, Pacific Biological Station, Nanaimo, 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 closely related to overall numbers of commercial fishing vessels in the region.

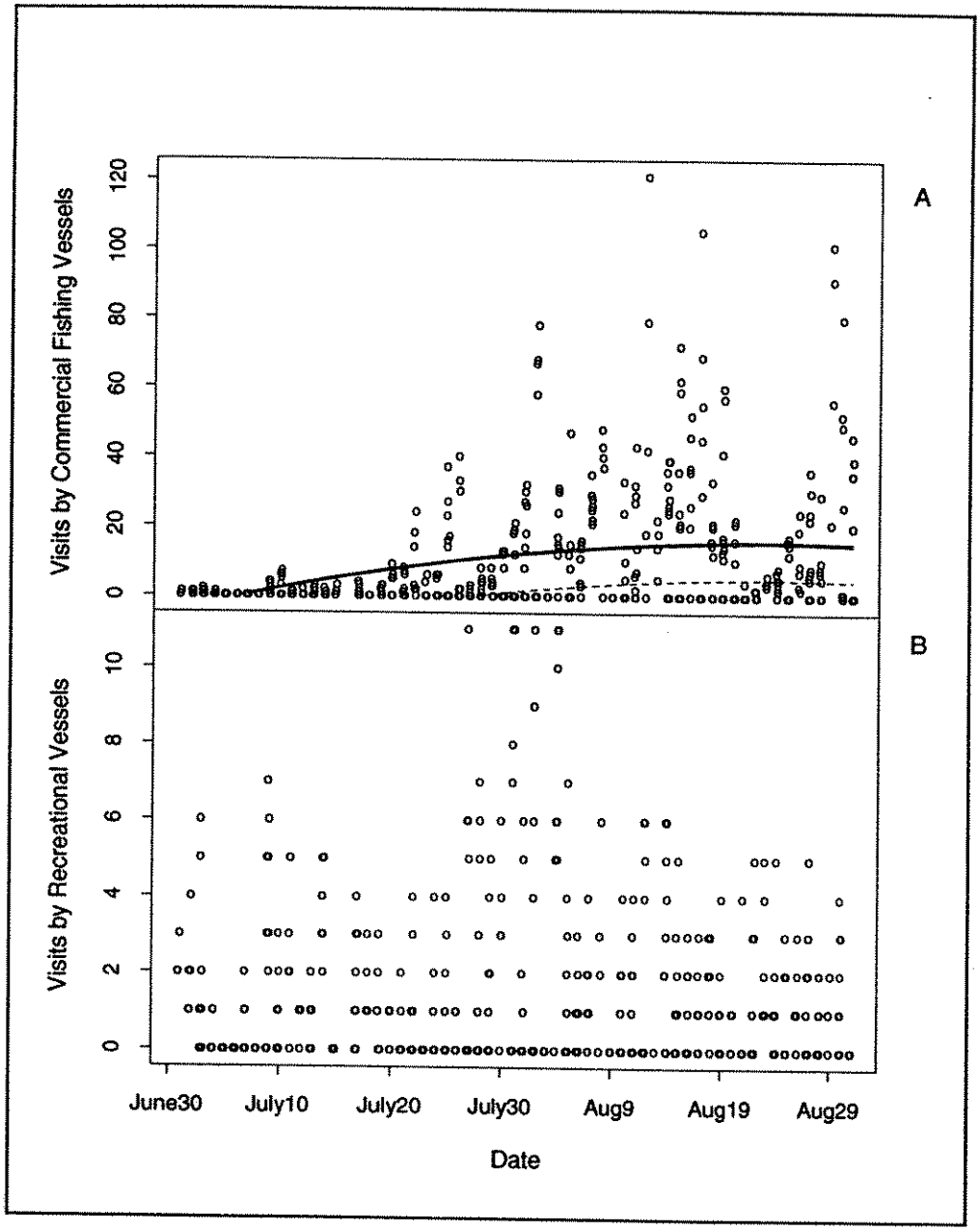

Figure 5. *Vessel visits* by commercial and recreational vessels from Jul. 1 to Aug. 31, 1991-93. Each panel contains data from all zones and years, and were jittered by adding a small amount of random variation to reveal overlapping points. They indicate a tendency for commercial fishing activity to increase throughout the summer (top panel), unlike recreational *vessel visits* which showed no apparent change through the season (bottom panel). Activity levels of commercial fishing vessels differed among years and were lowest in 1991 (dashed line).

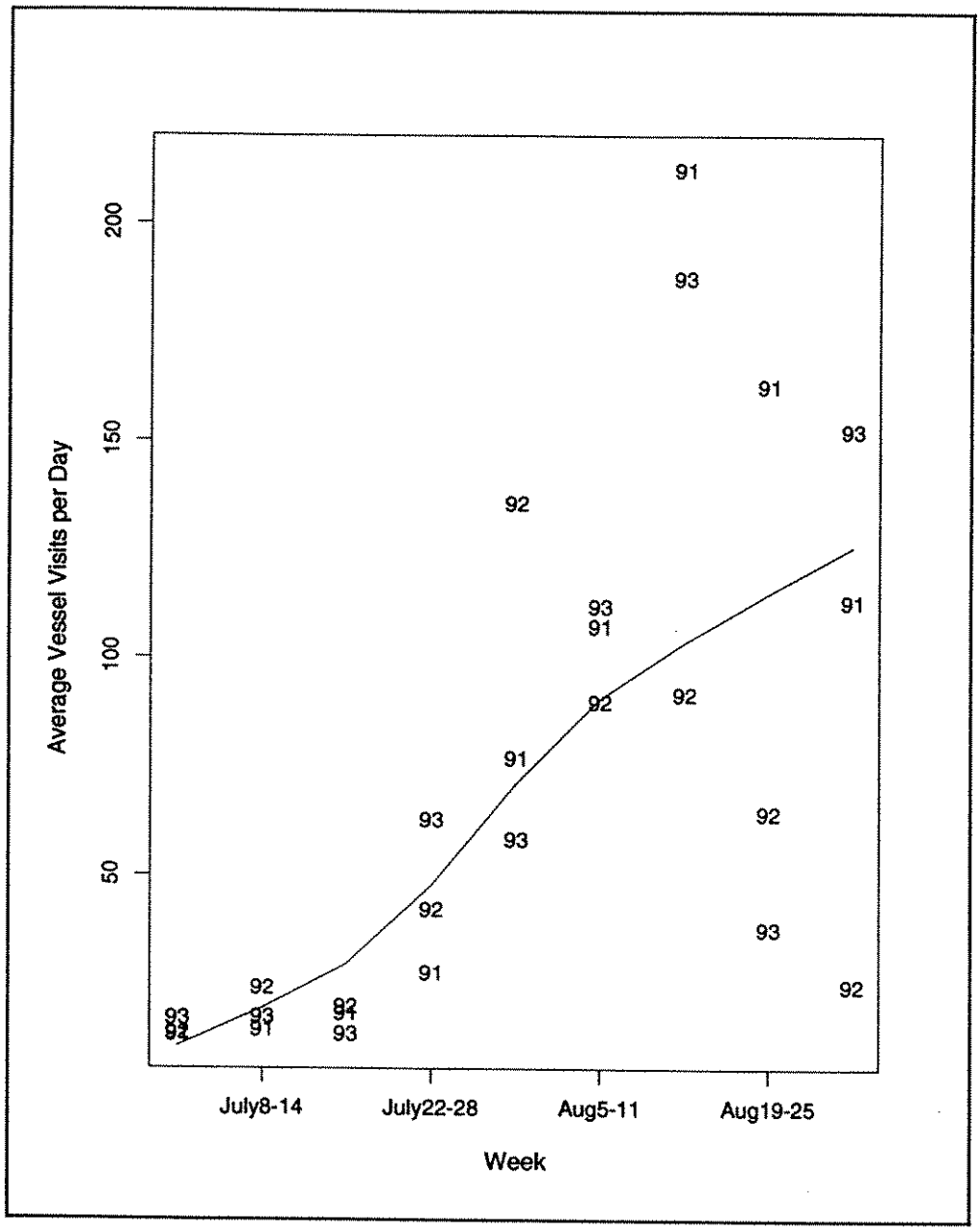

Figure 6. Weekly variation in total vessel activity within the Ecological Reserve (all Zones added together). Symbols indicate year and plot the average number of times in a day that vessels crossed zone boundaries during a given week. The locally weighted regression (*lowess*) shows overall vessel activity increased through the season, although vessel activity did vary greatly among years in the later weeks of August.

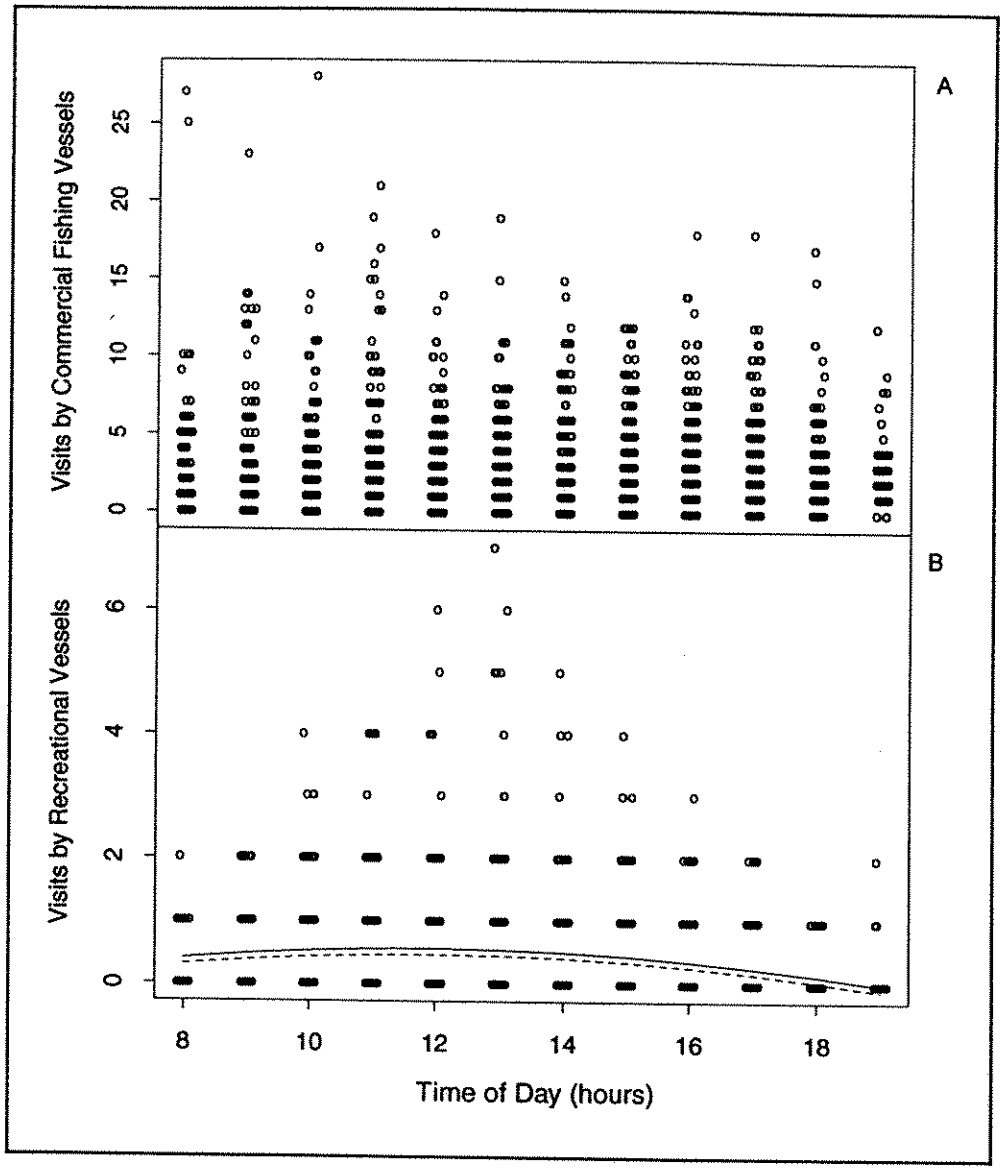

Figure 7. *Vessel visits* by commercial and recreational vessels through the daily period of observation (0800 h to 2000h). Each data point represents the level of activity occurring in 1992 or 1993 in one of four zones during a one hour interval (starting at the time noted on the x-axis). Hourly data were not collected in 1991. A small amount of random variation was added to each data point to reduce visual overlap. There was no systematic change in commercial fishing vessel activity through the day (top panel), unlike the activity of recreational vessels which tended to peak at mid-day (bottom panel). Recreational vessel activity was lower in 1993 (dashed line) than in 1992 (solid line).

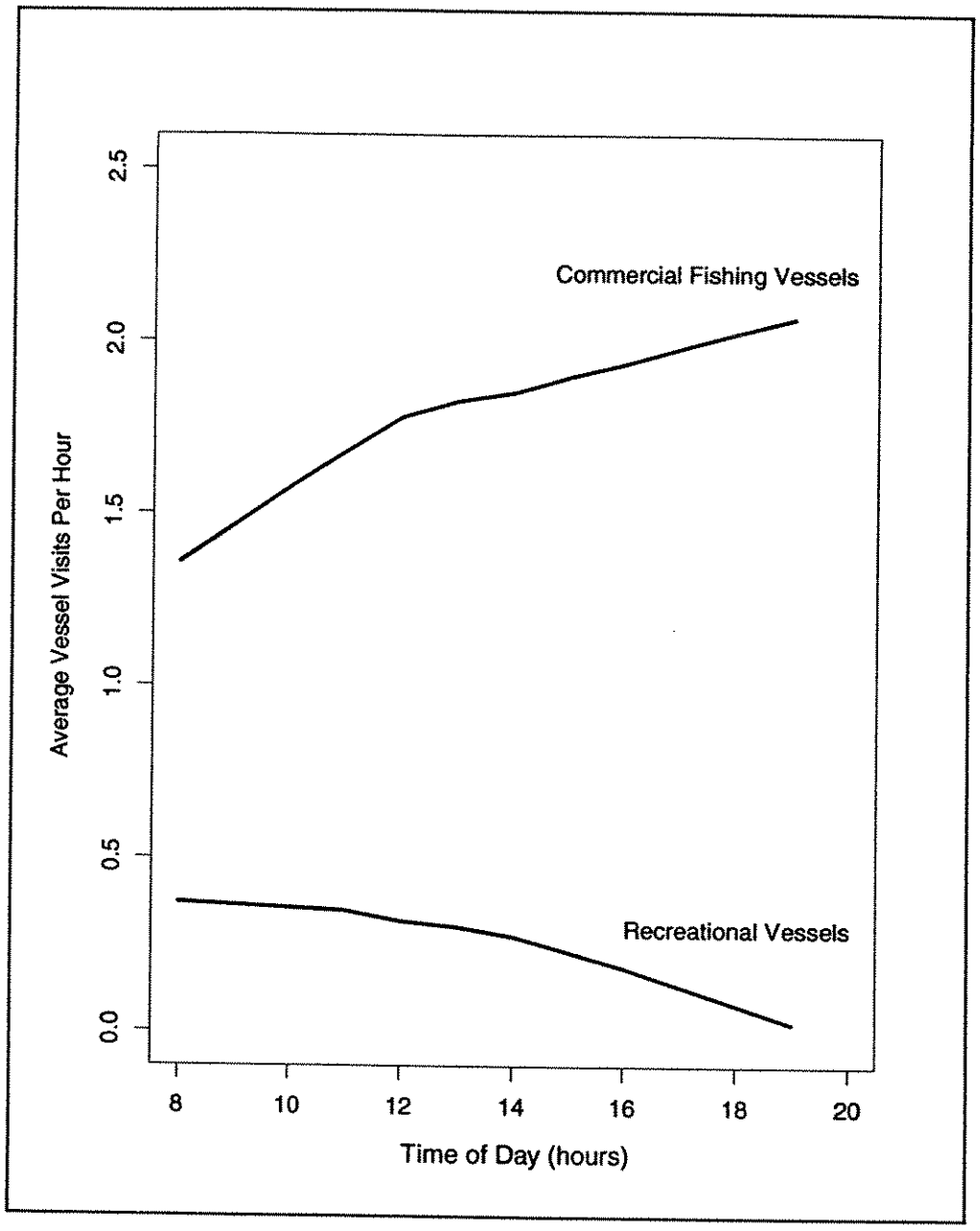

Figure 8. Locally weighted regressions (*lowess*) of recreational and commercial fishing vessel activity through the day. Note the low mean number of times vessels crossed zone boundaries and the apparent tendency for activities of commercial fishing vessels to increase while recreational fishing vessels 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.

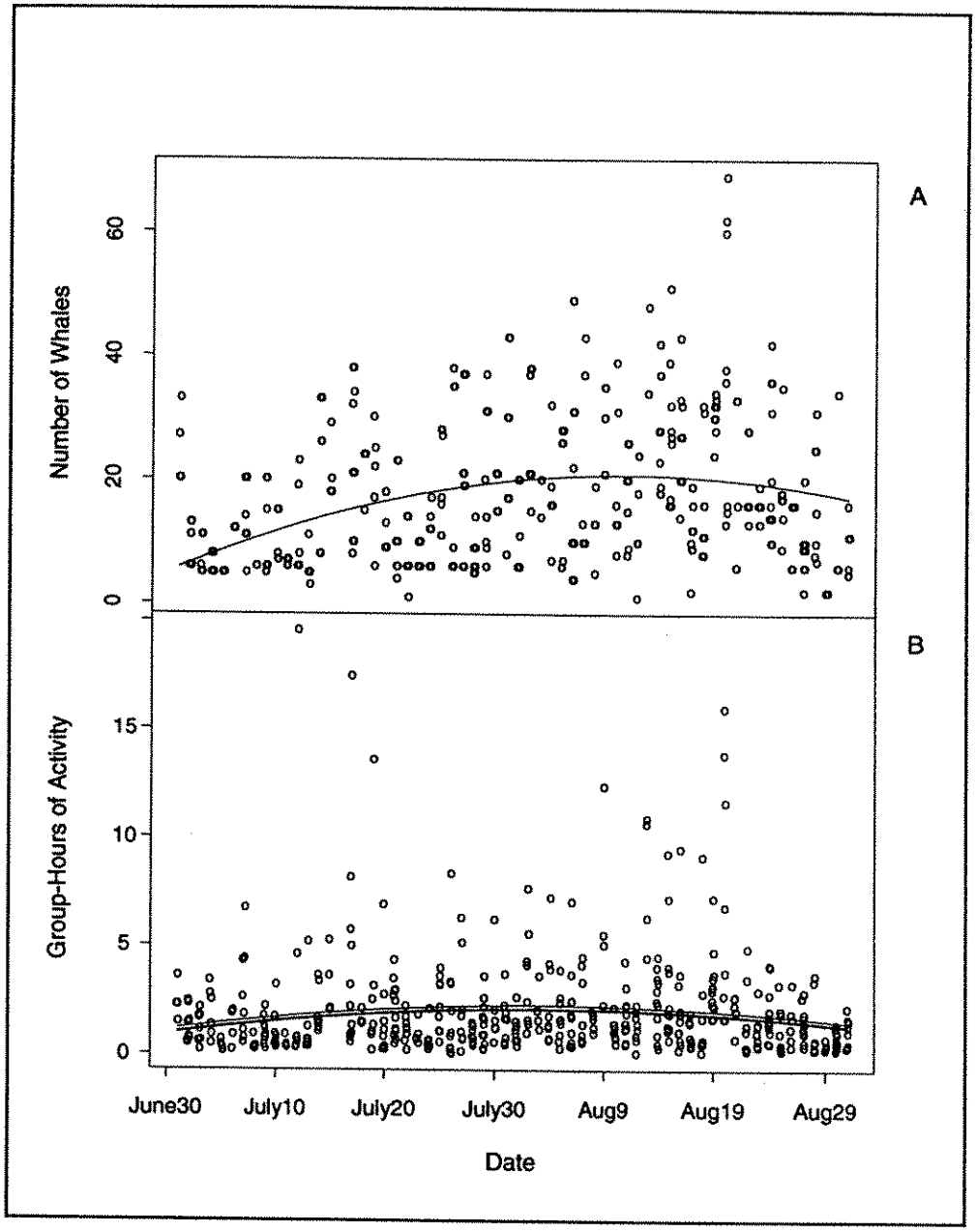

Figure 9. Seasonal variation in whale activity from July 1 to August 31 in Zones 3, 4, 5 and 6. Both numbers of whales (top panel) and group hours of activity (bottom panel) tended to peak towards the middle of the summer. Trends in number of whales present from one year to the next were consistent, but group hours of activity varied among years. Regression lines show the predicted average variation in whale activity, and are separated by year in the bottom panel. The jittered data represent all available information from all years and zones of the Ecological Reserve combined.

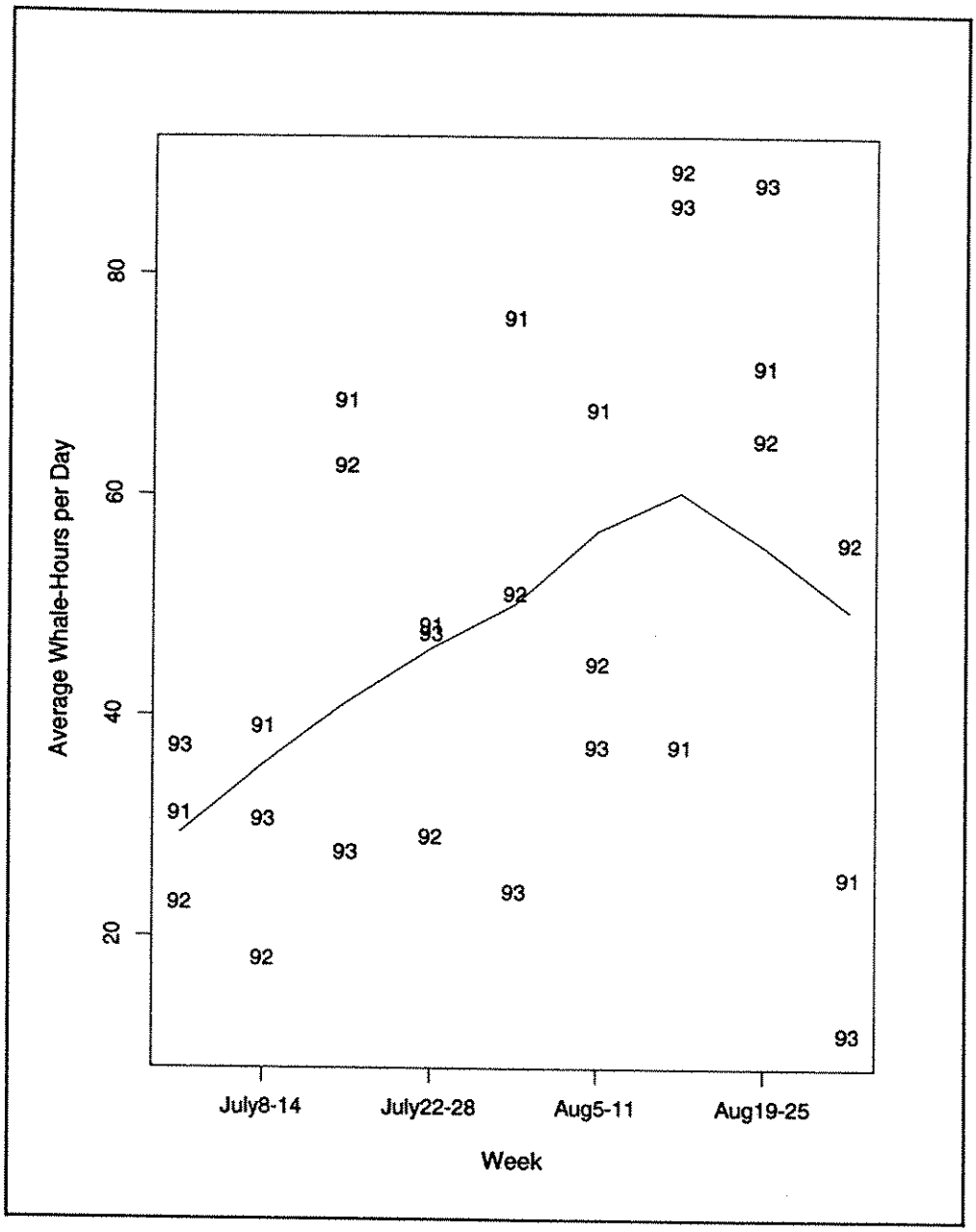

Figure 10. Weekly variation in whale activity within the Ecological Reserve (all Zones added together). Symbols indicate year and plot the average number of *whale hours* observed in a day during a given week. The locally weighted regression (*lowess*) shows overall whale activity increased through the season, peaking in mid August and dropping thereafter. Note the high variability in average weekly activity from one year to the next.

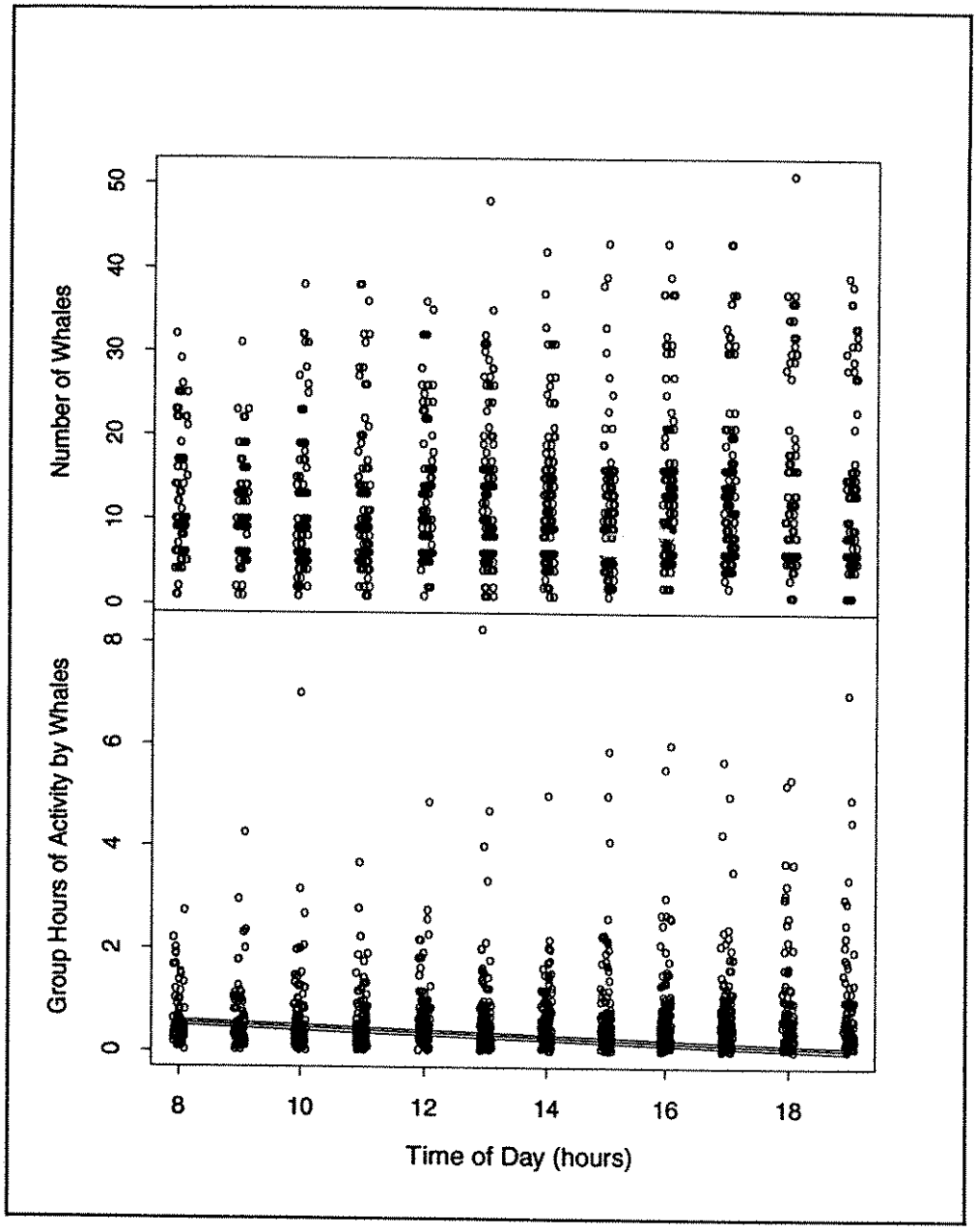

Figure 11. Numbers of whales and hours of group activity by hour of day. Data are from all zones and years combined in one hour intervals (starting at the time noted on the x-axis). A small amount of random variation was added to each data point to reduce visual overlap. There was no statistically detectable variation in the average number of whales using the Ecological Reserve throughout the day, but overall average hours of use did decrease. The three regression lines in the lower panel (for each year of study) predict the relationship between group hours of activity and time of day on August 1.

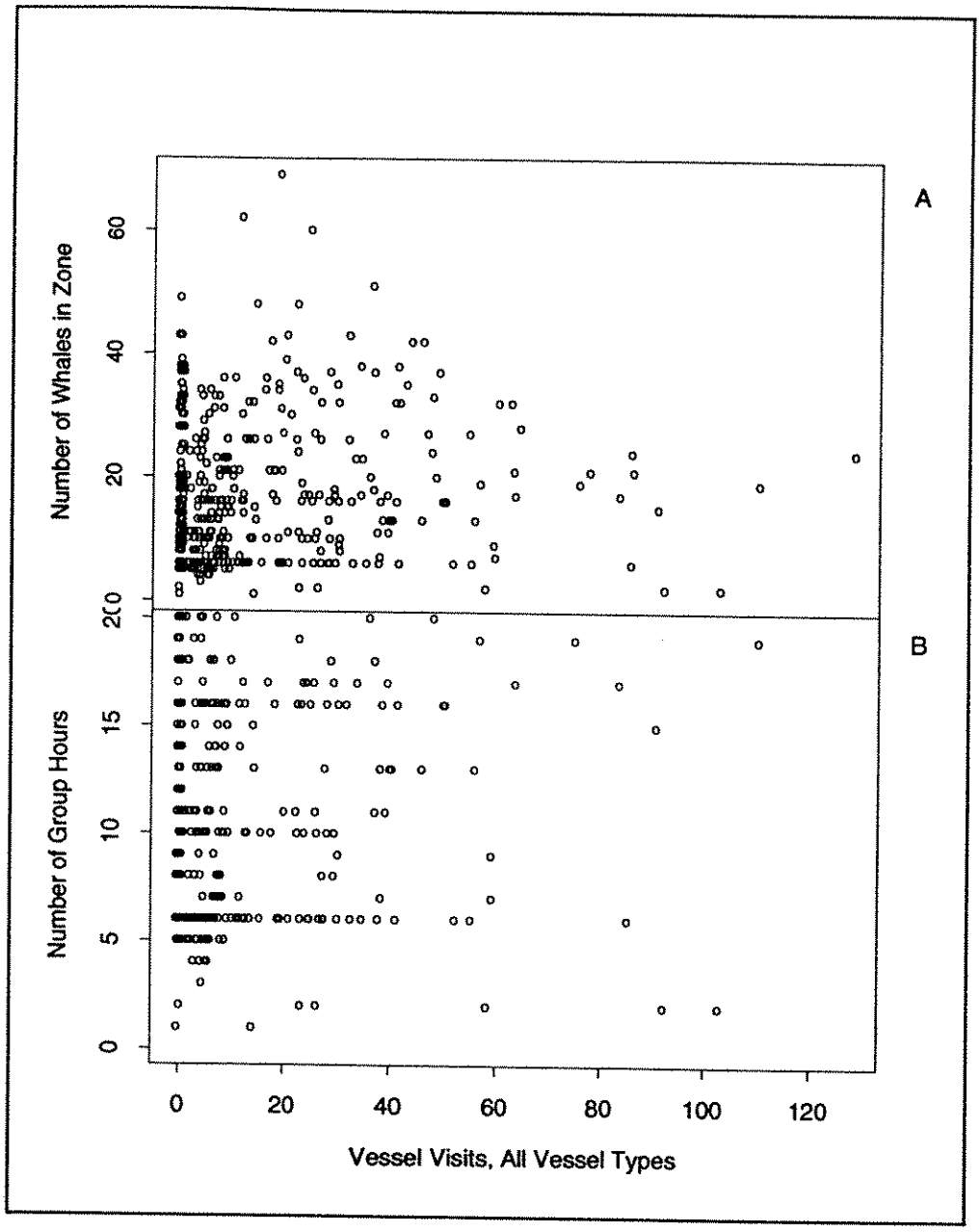

Figure 12. Number of whales and group hours of activity as a function of vessel activity in Zones 3-6. No relationship is seen between the number of whales in a zone on a particular day and the number of times vessels crossed the zone boundary (top panel). Similarly there is no apparent relation between whale activity (measured as group hours) and vessel activity. As in other figures, a small amount of random was added to the plotted data.

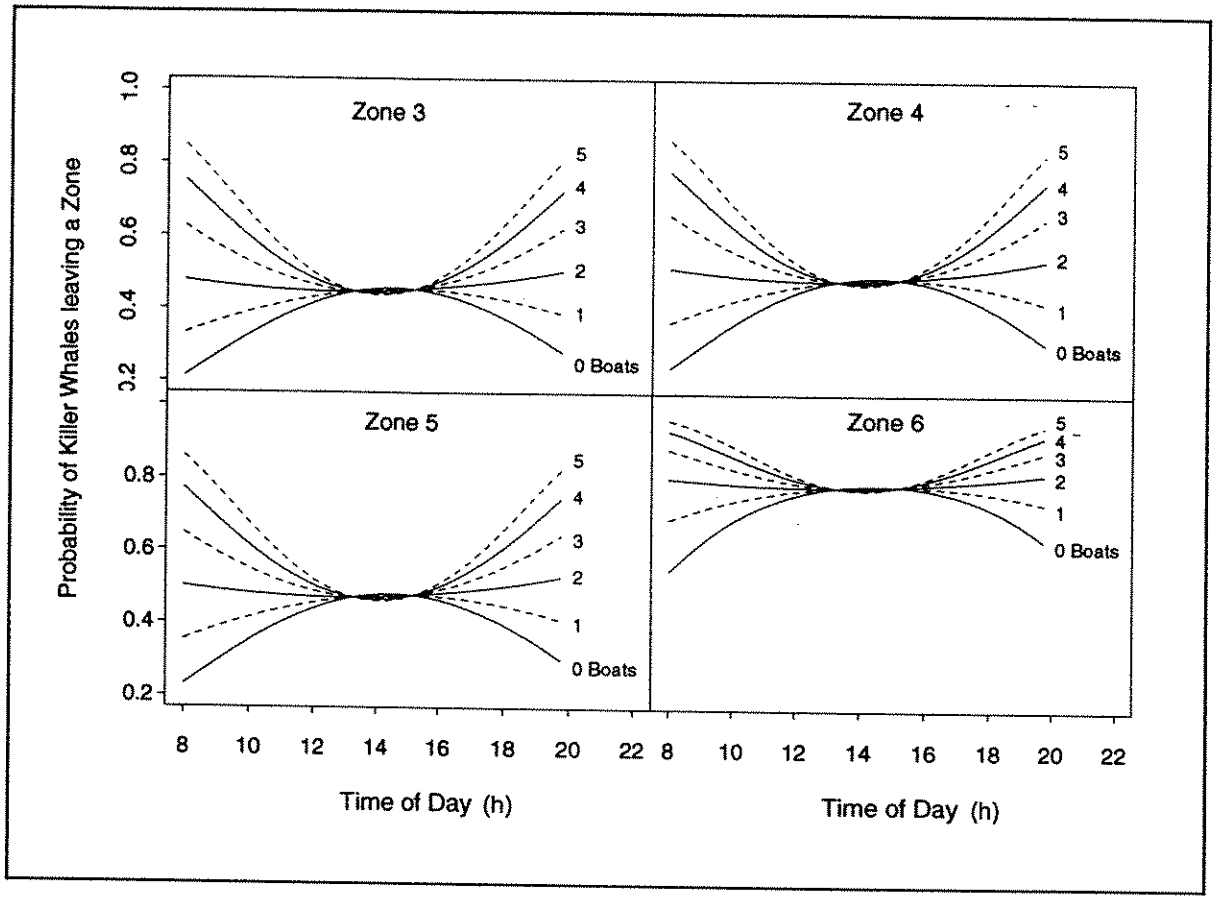

Figure 13. Probabilities of whales leaving Zones 3, 4, 5 and 6. The data show whales are more likely to leave a zone in the middle of the day than at any other time. They also show that whales have a higher probability of leaving Zone 6 (the rubbing beaches) than they do of leaving any of the other three Reserve zones. Increasing the number of vessels that enter a zone in the morning or late afternoon, dramatically increases the probability that whales will move to another zone. However, whales do not appear to be sensitive to vessel movements at mid-day (12:30 - 3:30 pm).